Introduction to Engineering

Embry-Riddle Aeronautical University
EGR 101

9^{th} Edition

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Preface

"Introduction to Engineering" is about making our students at Embry-Riddle Aeronautical University successful in academia and responsible engineering professionals. The collective knowledge of several authors representing all departments within the College of Engineering went into its making. Topics were chosen especially for students in the engineering programs at ERAU to specifically address their needs and tailored to assure their success.

Your path to a career in engineering begins now. Whether you succeed or not, is up to you. One of the most important philosophies that you can adopt that will make you successful in your academic years and professional career is to take responsibility for your own learning.

Knowledge is expanding rapidly. Learning must be a lifelong goal of all in the engineering profession. The hard work and dedication of the authors of this text is for naught if it is not read. If this book helps you to achieve your goal of becoming an engineer, then that will be the greatest reward you can give the authors.

Chapter 1
Transition from High School to College

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After years of hard work (or maybe not) you are finally in college and out of your parents' house. All your hard work now seems well worth it. The decisions you make during the next couple of months may have a long lasting effect in your future. These decisions fall into a number of categories such as life style, academics, health, etc. Embry-Riddle Aeronautical University (ERAU) provides a variety of services which you can use in order to help you with these decisions. As part of your orientation activities and during the course of this semester, you will be introduced to a number of services. We suggest you take advantage of them and if you have any questions, please contact one of your advisors, instructors, or mentors in order to find answers to your questions. The concept is simple; the services are provided to you as part of your tuition fees. You have already paid for them, so why not take advantage of them? <u>It is like going to a car dealership, paying $40,000 for a fully loaded vehicle, only to get a plain factory model instead. Wouldn't you ask where all the extras you paid for went?</u> Likewise, take advantage of all the services available to you. Trust us, you will not regret it. The additional services that you find at ERAU are some of the many differences between high school and college. The remainder of this chapter discusses some of these differences.

In general, high school is a TEACHING ENVIRONMENT where you acquire facts and skills, which you will use to solve simple problems. College is a LEARNING ENVIRONMENT in which you take responsibility for thinking through and applying what you have learned throughout your education. This means that you will need to demonstrate mastery in all the skills you learned from elementary school all the way up to the university level in order to solve complex problems. As you get closer to your graduation, these problems will become more complex, and you will be expected to solve more difficult problems with less direction. For example, it is not unusual to get a simple, yet vague, problem statement at the beginning of your senior design project requiring you to solve the problem for the rest of the semester or two with almost minimal guidance from your instructor. The main reason behind this is that we are preparing you for the job you hope to acquire post-graduation and that is how it works out there. For example, no one would hire an engineer right out of the college with his/her bachelor degree and pay them a fifty or sixty thousand dollar salary knowing they will have to spend a lot of time teaching them how to solve a problem. It is expected that you can find a logical, working solution on your own. Don't get scared. This does not mean from here on out you are on your own. What it means is that in order to get you ready for your job, or graduate work, we have to teach you differently when compared to what you have become used to in high school. Understanding some of these important differences between high school and college may help you achieve a smoother transition, and make you more successful at the university level. But, always remember, as we mentioned earlier, there are plenty of services that are available for you, for which you have already paid, so make sure you take advantage of them!

Point-by-Point Comparison between High School and College[1]

Table 1.1a Personal Freedom in High School vs. Personal Freedom in College	
High school is mandatory & free (unless you choose other options).	College is voluntary and expensive.
Your time is usually structured by others.	You manage your own time.
You are not responsible for knowing what it takes to graduate.	Graduation requirements are complex, and differ from year to year. You are expected to know those that apply to you.
You will usually be told what to do and corrected if your behavior is out of line.	You are expected to take responsibility for what you do and don't do, as well as for the consequences of your decisions
You can count on parents and teachers to remind you of your responsibilities and to guide you in setting priorities.	You're old enough to take responsibility for what you do and don't do, as well as for the consequences of your decisions. You will face moral and ethical decisions you have never faced before.
Students' values are often strongly influenced by parents, teachers, peers and the community.	Students have opportunities to question previously held values and to develop their own perspectives, opinions, and values.
Since a student's environment is often controlled by parents and teachers, distractions and choices are usually kept in check.	More choices are available to students and the students control whether or not these choices become distractions. Managing time and setting priorities are left completely to the individual student.
Most of your classes are arranged for you.	You arrange your own schedule in consultation with your advisor. Schedules tend to look lighter than they really are.
Each day you proceed from one class directly to another, spending 6 hours each day--30 hours a week--in class.	You often have hours between classes; class times vary throughout the day and evening and you spend only 12 to 16 hours each week in class
You need permission to participate in extracurricular activities	You decide whether or not to participate in extracurricular activities.
You need money for special purchases or events.	You need money to meet basic necessities
Motivation to complete work and succeed often comes from teachers and parents.	Students must find motivation within themselves to become involved in the university life and to excel academically.

Table 1.1b High School Classes vs. University Classes	
The school year is 36 weeks long; some classes extend over both semesters and some don't	The academic year is divided into two separate 15-week semesters, plus a week after each semester for exams
Classes generally have no more than 35 students.	Classes may number 100 students or more (although rare at ERAU)
You may study outside class as little as 0 to 2 hours a week, and this may be mostly last-minute test preparation.	You need to study <u>at least 2 to 3 hours outside of class for each hour in class</u>.
You seldom need to read anything more than once, and sometimes listening in class is enough.	You need to review class notes and text material regularly.
You are expected to read short assignments that are then discussed, and often re-taught, in class.	You are assigned substantial amounts of reading and writing which may not all be directly addressed in class, but on which you will still be tested.
You will usually be told in class what you need to learn from assigned readings.	It's up to you to read and understand the assigned material; lectures and assignments proceed from the assumption that you've already done so.

Table 1.1c High School Teachers vs. College Professors	
Teachers check your completed homework.	Professors may not always check completed homework, but they will assume you can perform the same tasks on tests.
Teachers remind you of your incomplete work.	Professors may not remind you of incomplete work.
Teachers approach you if they believe you need assistance.	Professors are usually open and helpful, but most expect you to initiate contact if you need assistance.
Teachers are often available for conversation before, during or after class.	Professors expect and want you to attend their scheduled office hours.
Teachers have been trained in teaching methods to assist in imparting knowledge to students.	Professors have been trained as experts in their profession and/or particular areas of research, but not necessarily trained in education.
Teachers carefully monitor class attendance.	Professors may not formally take roll, but they are still likely to know whether or not you attended.
High school is a teaching environment in which you acquire facts and skills.	College is a learning environment in which you take responsibility for thinking through and applying what you have learned. Higher level thought is required.
Teachers provide you with information you missed when you were absent.	Professors expect you to check the course webpage for information and to get any notes you missed from classmates.
Teachers present material to help you understand the material in the textbook.	Professors may not follow the textbook. Instead, to amplify the text, they may give illustrations, provide background information, or discuss research about the topic you are studying. Or, they may expect you to relate the classes to the textbook readings.
Teachers often write information on the board to be copied in your notes	Professors may lecture nonstop, expecting you to identify the important points in your notes. When professors write on the board, it may be to amplify the lecture, not to summarize it. Good notes are a must.
Teachers impart knowledge and facts, sometimes drawing direct connections and leading you through the thinking process.	Professors expect you to think about and synthesize seemingly unrelated topics.
Teachers often take time to remind you of assignments and due dates.	Professors expect you to read, save, and consult the course syllabus; the syllabus spells out exactly what is expected of you, when it is due, and how you will be graded. Many will expect you to check your email and the course webpage for information pertaining to class assignments, exams, etc.

Table 1.1d Tests in High School vs. Tests in College	
Testing is frequent and covers small amounts of material.	Testing is usually infrequent and may be cumulative, covering large amounts of material. You, not the Professor, need to organize the material to prepare for the test. A particular course may have only 2 or 3 tests in a semester.
Makeup tests are often available.	Makeup tests are seldom an option; if they are, you need to request them.
Teachers frequently rearrange test dates to avoid conflict with school events.	Professors in different courses usually schedule tests without regard to the demands of other courses or outside activities.
Teachers frequently conduct review sessions, pointing out the most important concepts.	Professors rarely offer review sessions, and when they do, they expect you to be an active participant, one who comes prepared with questions.
Mastery is usually seen as the ability to reproduce what you were taught in the form in which it was presented to you, or to solve the kinds of problems you were shown how to solve.	Mastery is often seen as the ability to apply what you've learned to new situations or to solve new kinds of problems, or solving a problem using a combination of techniques.

Table 1.1e Grades in High School vs. Grades in College	
Grades are given for most assigned work	Grades may not be provided for all assigned work.
Consistently good homework grades may help raise your overall grade when test grades are low.	Grades on tests and major papers usually provide most of the course grade.
Initial test grades, especially when they are low, may not have an adverse effect on your final grade.	Watch out for your first tests. These are usually "wake-up calls" to let you know what is expected-but they also may account for a substantial part of your course grade. You may be shocked when you get your grades.
You may graduate as long as you have passed all required courses with a grade of D or higher.	You may graduate only if your average in classes meets the departmental standard-typically a 2.0 or C.
"Effort counts." Courses are usually structured to reward a "good-faith effort."	"Results count." Though "good-faith effort" is important in regard to the professor's willingness to help you achieve good results, it will not substitute for results in the grading process.
Extra credit projects are often available to help you raise your grade.	Extra credit projects cannot, generally speaking, be used to raise a grade in a college course.

After completing high school, you have a choice to go to college or just start working. The fact that you chose to go to college, indicates that you are hoping to gain the education you need to reach one of your goals, and understand that post-secondary education is very different from K-12 education. In addition to the above, there are some more issues that need to be discussed which hopefully will help with this transition.

Class Syllabus

The first day of class, you received a course syllabus which is, in essence, your road map for the course. Use the syllabus to plan your semester, note important dates (exam and paper due dates) on your personal calendar. By doing so -- you may find that you have several items due in each of your classes in a single week, or even worse in a single day. This means that you will need to plan ahead to complete them on time.

Think with a Positive Attitude

Over the next four years, you will have some good days and some bad days. Always keep a positive attitude; remind yourself that you must be good enough to have already gotten to where you are. On the days that you feel bad, remind yourself that you can do better, by making good decisions, and asking help from your support group (family, friends, mentors, instructors, etc). And on the days you are doing very well, don’t lose your concentration, and don’t forget about your goals.

Maintain a sense of balance

Your studies are important but they shouldn't make your life miserable! In order to be an effective student, you need a healthy, balanced lifestyle. To do this, you need to be aware of your different needs. For example, make sure that your diet contains enough fresh, healthy foods (fruit and vegetables in particular) without too many fast foods and coffee or energy drinks. Stay away from alcohol, tobacco, or recreational drugs. Also, it is important to exercise regularly in order to ensure that you maintain a healthy body. Even 30 minutes of alternating between a light jog and walk is good for your circulation and your general health, and it also helps to combat lethargy and depression. Make sure you get enough sleep and maintain an organized schedule, which does not require you to cram all night in order to prepare for an exam or an assignment. Finally, program some relaxation into your daily and weekly routine. This is crucial. Make time to do something you enjoy doing to help you to unwind. Look forward to pleasant events in your life!

Dorms & Roommates

Many of you will start your college experience living in a dorm where you are assigned a roommate. This is a new experience and challenge. Take some time and get to know your new roommate. Try to identify your expectations from each other in this new living arrangement and set some ground rules. Remain flexible and approach any problems honestly and directly.

To sum it up, you are starting a new chapter of your life which could shape the rest of your life. Be wise, make the right decisions, look for help from your support group, and enjoy your time at the college. You will never get these years back; make the most of them by taking the right approach and you won't find yourself saying "I wish I would have done it differently." Finally, we (the EGR 101 Instructors and peer mentors) are here to help you to make this transition as smooth as possible, so if you are in need of anything, please contact one of us.

Exercises

1. List 5 differences between high school and college with respect to class and learning expectations.
2. What document do you receive the first day in each of your classes (in college) that is essentially the course road-map?
3. How many hours outside of class should be dedicated to study/homework time for each hour in class?
4. List your professors, their office locations and office hours in a table format. Make a photocopy and turn it in. Even if your professors give their office hours on their syllabi, go to their office and get the hours posted outside their office door; many times these are the most up-to-date office hours.

References

[1] Created by Old Dominion University with funding from the Virginia Department of Education. Revised by the Southern Methodist University with collaboration with colleagues in the Dedman College Advising Center and faculty from the Provost's Commission on Teaching and Learning and the English Department's First-YearWriting Program. Further adaptations made by Office of Academic Support Programs, Baylor University and the Engineering Fundamentals Department at Embry-Riddle Aeronautical University.

Chapter 2
Time Management

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Introduction

Time cannot be saved or stopped; the only thing we can do to maximize our time is to budget and plan the way we spend our time. We each have 168 hours a week to get all the things done that we need to get done. The primary goal of this chapter is to discuss the importance of time management as it applies to freshmen students studying Engineering. In addition, we will produce a preliminary weekly plan for the semester; and provide you with some tools and techniques to managing your time and commitments.

Time Management

Time management is a crucial skill to all professionals. Having a firm grip on what you can accomplish in a given amount of time is a skill that can only be obtained by planning what needs to be done, tracking your time, and comparing your measured results to your initial plan. "Management … I thought I was studying Engineering," right? Yes, you are – but it's amazing how much easier and less stressful life can be as an engineer if you learn and practice a few management skills: planning, budgeting, prioritizing, tracking, and making changes when the results are not matching the plan.

Why are we talking about time management? Quite simply you are coming into a completely new environment and you are going to have to take responsibility for getting the following things done:

- wake up on time
- get to class on time
- finish your homework on time
- read and study 2-3 hours out of class for each hour in class
- make it to meetings on time
- eating regularly
- get proper sleep
- keep yourself healthy
- manage your extra time and personal activities

You are going to need multiple tools to help you track your time:

Weekly schedule:	identify class times, meeting times, work times
Calendar:	mark tests, major project due dates and milestones
Daily schedule:	to do lists, appointments, homework assignments
Time logs:	tracking where you spend your time
Phone book:	record phone numbers and email addresses of friends and classmates

Each of you should have received an ERAU planner. If not, you should immediately go to the bookstore and purchase one. It has each of the tools listed above and will get you on the right track immediately.

<u>Planning</u>

There is a famous management cycle called the Shewhart Process [1] shown in Fig. 2.1.

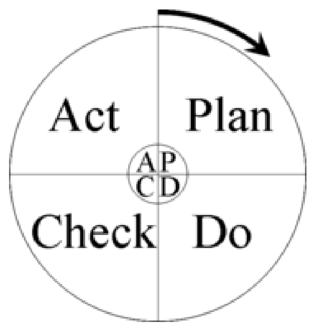

Figure 2.1 Shewhart Cycle Diagram

This process can be used to manage any type of resource or project. Quite simply it says: make a plan, do the work, check the work against the plan, and then act on discrepancies between the planned time and the actual time the work took. If the process continues, then repeat the process. We will use this process for looking at time management.

Planning is the first step in the process. In this step you identify what tasks need to be accomplished and what your resources are, and then develop a schedule for when the tasks are to be accomplished. In the planning step we will develop a time budget and a weekly schedule for time spending our time.

<u>Budget</u>

Time is a fixed resource. We have 168 hours per week. We must budget and allocate our time. Below we will create your initial time budget. Using the questions below as a guide, list all the recurring tasks you must accomplish each week. Then provide an estimate for the number of hours each task will take to accomplish per week.

- How many courses are you taking?
- How many study/homework hours are you planning? (General rule of thumb is 2-3 hours out of class for each hour in class.)
- How many hours of sleep do you require per night?
- How long will it take you to walk from course to course or travel between where you are and where you need to be? (Do you live off campus? Eat off campus? Travel between courses?)
- When will you eat? How long might it take to travel to the cafeteria, choose your food, consume it, and get back to class/library, etc.?

- What other weekly commitments do you already have? ROTC – need to plan for time to do PFT and weekly meetings.
- Do you have to work? How many hours are you planning?
- Will you be playing sports here at ERAU? Or perhaps playing intramural sports?
- Do you plan on joining any engineering or recreational clubs?

Fill in the following spreadsheet:

Task	Task Description	Estimated Hours Per Week	% of the Week (Divide previous column by 168 and then x 100)
1	Class Hours		
2	Study Hours		
3	Sleep Hours		
4	Travel time		
5	Meal time		
6	Other Obligations (ROTC)		
7	Clubs		
8	Sports		
9	Work		
10	Leisure		
	Total	168	100

Putting this into Microsoft Excel might look like that given in Figure 2.2 below:

Hours Per Week	168	
Weekly Activities	Hours	% of Time
Class Hours	15	8.9
Study Hours	45	26.8
Sleep Hours	56	33.3
Travel time	3.75	2.2
Meal time	21	12.5
Clubs	3	1.8
Sports	3	1.8
Work	10	6.0
Free time	11.25	6.7

Figure 2.2 Weekly time data organized into an Excel worksheet.

A pie graph helps (Fig. 2.3) visualize what our time budget looks like.

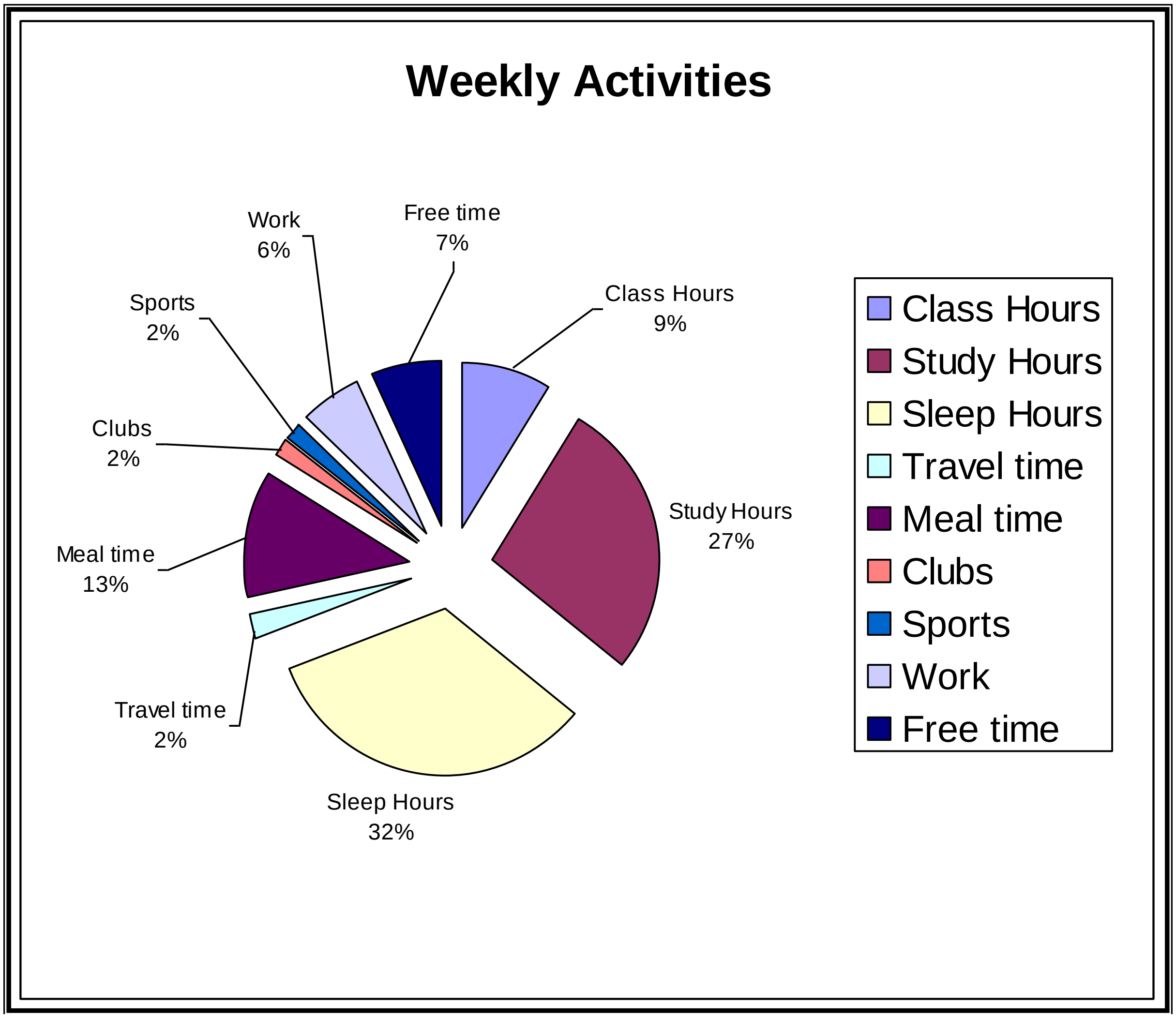

Figure 2.3 Pie graph representing time breakdown of a typical student's week.

Looking at our time budget it should quickly become evident why we are talking about time management; you do not have as much free time as you would think. When you get your college schedule it looks like you have tons of free time; even from this diagram, if you are taking 15 credit hours of classes your class time is only 9% of your week, but when you add study time (27%), sleep time (32%), and meal time (~13%), you see you only have about 19% of your time left. You need to start making some decisions, and hopefully you immediately see the importance of spending your time wisely.

Prioritizing

Since we have so little free time in college, being able to prioritize one activity over another is a very important time management skill. You will be bombarded with opportunities; therefore, you will need to choose on which activities you will spend your free time. You do not want to neglect managing your time only to have to sacrifice sleep or study time. This is unfortunately an easy mistake to make since they are the large spans of time from which it is tempting to steal time. Be careful, many of you are on scholarship or trying to get scholarships; trimming time from either of these two areas could have seriously adverse effects. Remember, you are here to earn an education; not master your favorite x-box game or watch syndicated marathons of Breaking Bad.

Stephen Covey, author of First Things First, [2] produces a graph of where activities lie with respect to their importance and their urgency (see Fig. 2.4). This graph has four quadrants: going counter clockwise: important and urgent, not important and urgent, not important and not urgent, important and not urgent.

Not Important, Urgent	Important, Urgent
Not Important, Not Urgent	Important, Not Urgent

Figure 2.4 Prioritizing activities according to importance and urgency.

Being disciplined to focus on topics that are important to you is the general thought that is trying to be conveyed. Focus on the things that are important: class, study, sleep, eat, and exercise. Avoid the things that are not important (whether urgent or not). For example, your suitemate coming over and telling you that they're getting ready to watch a movie. This may be an *urgent* opportunity, but is the movie truly *important* to you? Is it more important than getting your homework completed, or studying a difficult concept in physics? Email and text messages are additional examples that have that "urgency" feeling, but likely are not important to address immediately. Just because someone emails you does not mean you have to reply immediately (it's probably not really important and not really all that urgent when you step back and look at it). Try to check your email only 2 times a day, and limit that to 10 minutes each time. Do you really have more than 20 minutes a day to devote to email? Go back to your budget and be honest. You could probably text on your way to class, but perhaps you could also review your notes.

If you find that ALL of your tasks fall into the Important and Urgent category, and you find yourself beginning to struggle to meet your deadlines, you may be doing way too much. Living your life such that you are hurriedly finishing task after task, always under pressure, will quickly wear you down. Consider cutting back on the number of clubs in which you participate, or perhaps take a less rigorous course schedule next semester. It is true that the majority of your tasks should be important, but all of them shouldn't be urgent as well.

Watch out for the unplanned activities, aka "Time Bandits"

- Email, Texting, Phone
- TV, Gaming
- Friends popping over

Weekly Schedule

Once the budget is prioritized and worked out, next we develop a weekly schedule to show when the budgeted tasks will get accomplished. The weekly schedule provides a one week view of when you will work on all of the tasks. Since you are a student, we will start with the premise that class is your most important priority. Schedule your class time first. Using your course schedule and your daily planner and fill in your course hours.

Below is a typical first year student's class schedule:
EGR 101: M/W 10:30 – 11:30 T 5:15-6:15
EGR 120: T/R 1:00 – 3:00
MA241: M/W/F 9:15-10:15 R 2:00-3:00
PS150: M/W/F 3:30 – 4:30
HU120: T/R 11:00-12:15
** R = Thursday

These are fixed times or scheduled times, and they are pretty easy to fill into your weekly schedule. The next part will be the discretionary times, those that are not rigidly scheduled but still must get done (i.e. you need to eat, but when does it fit in?). Fill in your courses and your expected eating and sleeping times and see how this starts to look (see Fig 2.5).

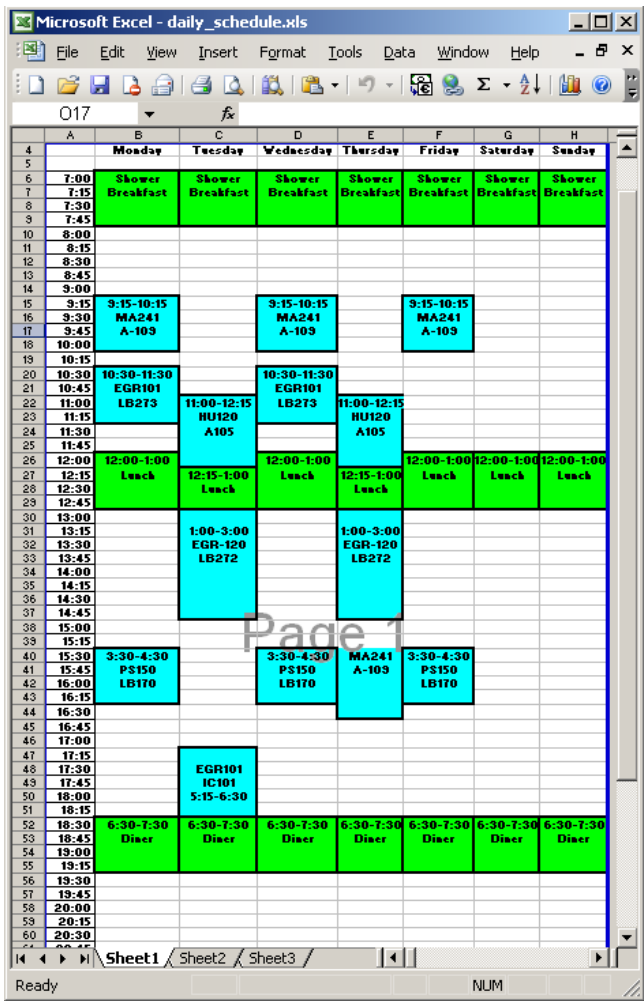

Figure 2.5 Sample Excel Spreadsheet illustrating a typical course schedule.

Add to your weekly schedule the other items from your budget list. You have the flexibility to schedule most of these items at your discretion; however, these items will be more difficult to manage since they are up to your discretion. Try not to forget that they ***need*** to get done – especially the studying and homework. You are spending considerable money on your education; get the most out of your money; put the time in that is required to earn the grades you want. Later if you feel you have over allocated time to studying out of class, you can adjust your schedule, but remember the courses will get tougher as the semester progresses and comes to an end.

A roommate of mine from college treated college as a job. Every day he woke up at 7:00 AM, showered, had breakfast and went to the library. He would return home at 6:30 every night. His uncle had told him that this was the best way to deal with college. He planned and scheduled to get all his work done by 6:30 every night; and he did. Chris always seemed to have free time in the evenings, but that is because he got all of his work done during the day; he did not waste time in between classes. He was rarely stressed, had excellent grades, and was free to enjoy his evenings; he always got eight hours of sleep. Chris learned quickly that to be successful, he had to put aside what he wanted right now for what he really wanted later.

The Doing Phase and the Daily Schedule

Congratulations, you have now finished the planning phase; and you are off to the doing phase in the Shewhart Cycle. You will use your weekly schedule to determine when you can schedule in team meetings, sports activities, and other spontaneous events. In addition, you will utilize your daily planner and time logs while carrying out your daily activities. The daily schedule is a list of things that you need to get done on a day by day basis. Basically it's a daily calendar and you mark down all the things you need to do that day. Be sure to keep your calendar with you at all times and record when homework is due, scheduled quizzes, scheduled tests, meetings etc.

Time Logs and Tracking Your Performance

While in the doing phase, we need to record some vital information about how we actually spend our time. We keep track of our time in the form of time logs, which look like that given in Fig. 2.6.

Date	Task ID	Start Time	Stop Time	Hours	Comments

Figure 2.6 Example time log.

Utilize the time log to record time spent for each item listed in your time budget. Record other items not on your budget that take more than 15 minutes. By the time you go to bed each night, fill in your spreadsheet of the day's date, the start time and stop time of each activity, the task (cross reference this to your budgeted tasks), the total hours spent, and any comments. For the best accuracy, it is best to keep track of time at the actual time you spend it, but if you have to wait until the day's end, that is better than nothing. Do not wait longer than one day; the accuracy will diminish greatly. Time is like money, if you do not track where you spend it, you will wonder where it all went.

It takes a very disciplined engineer to track how they spend their time[3]. It is not always easy to do, but it is vital to making the necessary changes to your daily routine. Without the data you will always look at your plan optimistically and say: "I'm doing all right." You need the time log data to compare your plan to your actual performance.

Checking Your Progress

You have completed your initial plan, and you have recorded your time for one week; now we enter the check phase. On Sunday night, add up the task times from your daily time logs and compare your budget allocations to your actual time usage.

Compute the percent difference in your budgeted times where percent difference = (budgeted time – actual time) / budgeted time) * 100 %.

Questions to ask yourself about your time budget versus reality:
- Have I recorded my time accurately?
- Did I make it to all my classes this week?
- Did I get all my homework completed and submitted on time?
- How are my grades so far?
- Am I getting enough sleep?
- Where did I spend the most time and was it important?

Making the change

The last step of the time management process is to suggest changes that need to occur in your daily routine to make you more productive. Once you have compared your budget to your actual performance, it will become apparent on where you thought you would spend time and where you actually spent time. This is meant to be an eye opening experience. It will take several cycles for you to establish a solid routine. Make some small changes to your budget and your schedule, set some goals, and reward yourself for achieving the goals.

For example, if you only spent ten hours studying and planned to study 25 (60% error, which is not uncommon), then set a goal to spend 30 more minutes a day studying. Thirty minutes is two of the fifteen minute breaks between classes. By the end of the week, you will have 3.5 more hours of studying in, and you will have made significant improvement in your hours studying. The next week try to get another 15 minutes a day and so on. Your goal is to establish good habits and a daily/weekly routine. By establishing a routine, you will be able to build yourself up for the four year journey ahead.

Continue to monitor your performance. The only way you can make the change is to have the data in front of you. Without adequate data you are going to say I did ok, and next week you will do the exact same thing. You have to physically see where the resource went, before it sinks in that you have to make some changes (i.e. not playing video games for 6 hours a week). It is ok to reward yourself, but move the reward to the end of the week or the end of the day after you have completed the necessary tasks.

After analyzing your data, you really need to share them with someone. You need a coach to help you get on track, spot some of your deficiencies, and encourage you through the process. Good candidates for coaches are your RA or your EGR 101 peer mentor; these are older students and have likely experienced the same things you have recently.

Phone Book

The last important time management tool we want to discuss is your phone book. In the back of your scheduler is a phone book. In each class, write down the name, phone number, and email address of two to three people in each class. There will be times when you have to miss class, and you are going to need to get the notes from someone. Most professors expect, or even demand, you get material from missed classes from your class mates. Class was scheduled and conducted on a prior date and time, and it was your responsibility to be there. Since you missed it, it is your responsibility to get the notes from someone else.

Miscellaneous Thoughts

- Be careful about adding too many commitments to your schedule, especially if you’re an ROTC cadet or on athletic scholarship. The number one reason why you are here is to obtain a four year degree. Manage your commitments with respect to your work load and schedule. Prior to making a new commitment (i.e. a job, new club, etc.) check your schedule to ensure you will have time for this new obligation.
- Early in the semester, there will be extra free time. Less homework is given, tests and projects are far out in the future. However, as the weeks pass, the progression of material accelerates. Be prepared to adapt your schedule!
- Your final exams are already scheduled. Determine these dates and times and include them on your calendar. In general, ERAU professors are NOT willing to reschedule final exams; when making your travel arrangements for the end of the semester, do not assume you can take your finals early.
- Planning to pledge a fraternity or sorority? It’s a great idea and a great way to meet people, but just like ROTC or athletics, it requires a tremendous amount of time. It would be wise to wait one semester and learn the college routine prior to taking on the time commitment of pledging. This will easily consume 4-6 hours a week, and more as the semester progresses.
- Dealing with crisis. If a crisis comes your way, there are plenty of help resources on campus:
    - extremely sick: contact health services and the Dean of Students
    - death of family member: contact the Dean of Students
    - home sickness: contact your RA, contact the Counseling/Wellness center
    - room mate issues: see your RA, and the Housing Office

    - test anxiety or learning disability – contact Disability Support Services
- Tests are not optional in college. You must take them. If you feel sick and don't take the exam, you will get a 0. If you happen to be sick, go take the exam anyway. At a minimum, contact your professor as soon as possible BEFORE the exam. If they happen to allow make-ups, they may allow you to reschedule the exam. Most professors do NOT reschedule an exam if you show up AFTER the exam with an excuse, valid or not.
- Learn to be realistic on your commitments and to prioritize activities.
- Learn to say no. Unfortunately, you simply can not do everything. It is ok to say: "I appreciate the offer, but I'm not going to be able to do that. Thank you for asking".
- Some time in any given semester, it is possible to have four exams in one day. Be prepared for this by staying on top of homework and studying so "cramming" the night before the exams is not necessary (it doesn't work anyway).
- If you find yourself getting way behind, it is possible you are taking too many classes this semester. Be aware that you can audit one or more of your classes. You still attend, but you do not have to submit the work; and you do not get credit. This can lighten your load and help you maintain a solid GPA. Dropping a class is similar, but you drop the whole class altogether and do not attend. You do not get your money back in either case, but it could help you if you're in over your head. Do not drop below 12 credits, as it can affect your financial aid.

Exercises

1. Submit a photocopy of your weekly time budget.
2. Submit a photocopy of your weekly schedule.
3. Write one or two paragraphs about your concerns and give it to your peer mentor.
4. Track the time spent on your budget items for the second week of school. Submit your time log to your EGR101 peer mentor.

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Chapter 3
<u>Communication Skills</u>

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Communication

One of the most important traits an employer looks for in a prospective employee is the ability to communicate. Employers know that if you hold an engineering degree, you are likely pretty smart and able to think critically. What they do not know is whether you can clearly communicate your ideas and intentions. <u>The primary reason for a job interview is to determine whether you possess this ability.</u> In the engineering world, for any design or solution to be successfully implemented, it must be fully understood by those reviewing the design documentation, fabricating the product and ultimately using it. This can only be accomplished if the engineers can appropriately communicate their ideas, both in written form and verbally.

Technical Communication

The type of communication engineers commonly use is called technical communication, which is the focus of this chapter. Unlike literature and poetry, technical communication is not preoccupied with flowery descriptions and the portrayal of emotions. Rather, technical communication is characterized by a detailed but succinct, clear presentation of information. The purpose of technical communication is to effectively transfer information with the intent of explanation and justification. Personal reflections and emotional interpretations should not be included in a technical report or presentation. Not only are they unnecessary, but they often distract the reader/audience from the essential information. There are some common conventions that should be used in technical communication; these are discussed below.

<u>Written Communication</u>

When writing a technical report, it is imperative that your report be concise. Reports that are verbose (overly-wordy) are not only difficult to read, but are annoying to readers. Always include all pertinent information, documentation and supporting analysis of your choices (such as calculations); avoid the temptation of including unrelated information that you just consider interesting. The purpose of a technical *design* report is to document the results of the design process by supplying all the elements pertinent to and supportive of those results. BUT be careful not to get into step-by-step mundane details as to how you actually did it. For example, there should not be sentences in your report like: "…then we plugged that number into the equation and got…". The calculations and three line format (discussed in detail below) will demonstrate how you performed the calculations; there is no need to reiterate them with sentences.

What you *should* include are descriptions of why you chose a particular number, or what the implications are for a particular result. For example, if you were designing a barstool, would you choose to give it three legs or four legs? The number of legs is important to specify, but just as important is WHY you chose that number and the calculations that show: 1) it is acceptable and will not fail, and 2) it is the best choice compared to other alternatives. Just listing the values you choose is not good enough, and simply showing the calculations that support your choices is also not good enough. The report should fully EXPLAIN the analysis you've done and WHY you chose what you chose. This is how you adequately communicate your design.

Below is a suggested style for formatting and writing a technical report. This is the formatting and style you should use when writing the technical reports for this class. These suggestions come from your faculty who have worked in the industry and have written technical reports. Take heed of these suggestions as you will surely be writing reports as an engineer.

Style and Content Instructions

1. Use a report cover like folder that will allow the report to lie flat when open. **Do not use over-sized three ring binders or clear sheet covers.**

2. All reports MUST be neat and legible. **Text must be typed, except as noted in 2.1.** These are working reports. It is your objective to display and explain your calculations in sufficient detail such that the reader can check their correctness. This may require greater detail than you are accustomed to providing. The text of the report explains what was done to accomplish the final results, how and why you did it, and what the results mean. Reports **MAY NOT BE** simply a spreadsheet printout. It is impossible to make a spreadsheet with correct subscript notation, and is very difficult to get a spreadsheet arranged in an orderly sequence that readers can follow. Any spreadsheets included must be **in addition** to sample calculations provided in the report (see sections 2.1, 2.2 and 4.3 below) and be included as an appendix ONLY.

   2.1 Lengthy calculations may be done by hand but must be neat and orderly. Hand written explanatory text must be lettered in vertical upper case letters (capitals) no less than 3/16 of an inch high, a government drafting specification.

   2.2 Typed calculations usually come out looking unfamiliar and very hard to read unless they are done with a good equation editor. Specifically, DO NOT type equations in all-on-one-line computer coding format (for example, $v_0 = R_E (g_0/(R_E+h))$^1/2), which makes the equations too difficult to recognize and check. Also, do not create notations for variables that your word processor can't type correctly. Use an equation editor such as Equation 3.0 in Word, or Mathtype for typing your calculations.

   2.3 Liberal use of sketches and diagrams in analysis reports makes them both understandable and professional looking. Get into the habit of including them.

3. Spelling and grammar count in grades, as required by guidelines of the Accrediting Board for Engineering and Technology (ABET). Misspelled words and incorrect homonyms give the impression of a careless engineer at best, or an uneducated one at worst. Proofread your work!!!

4. The contents of the technical report should be: 1) A separate title page. 2) An introduction. 3) The analysis. 4) The conclusion. Each of these elements is described in further detail below:

   4.1 Table of contents (page i): The table of contents (TOC) should, at a minimum, provide the sections of the report (introduction, analysis, conclusion, etc.) and their corresponding page numbers. If you have sub-sections in the report, these can also be listed in the TOC. The TOC itself should not be listed in the TOC. Appendices should also be listed in the TOC if they are used in the report. Look at any textbook as a reference for the contents and sample formats of TOCs.

   4.2 Section Introduction: This should be a brief introduction describing the design objectives, requirements and constraints for the system you are describing. This should usually be only one or two paragraphs.

   The objectives should be stated both from a project perspective and from a team perspective. This means to state the objectives of the project (i.e. what is the purpose of the design once it is complete? What will it do?) and also state the team's objectives for the design (i.e. do you plan on producing a design that is cost effective, superior quality, cutting-edge technologically, safe, easy to maintain or a combination of these?). Keep in mind, we can't always meet ALL of these objectives (it is difficult to be both cutting-edge <u>*and*</u> cost effective), though we'd like to, so you must prioritize them and list the main ones in your introduction.

   The requirements and constraints are more detailed than the objectives. These are specific characteristics or values that must be met and can oftentimes be customer driven. For example, one of the projects you may participate in (in this course) is the satellite system project. The <u>***objective***</u> of that project is to design a military-grade reconnaissance satellite for low earth orbit. Your team may choose to design for high quality pictures and the ability to upgrade as the technology of charge-coupled devices improves. The <u>***requirements***</u> for the system are that it must produce visible pictures of reasonable quality and it must have renewable power sources so that it can remain in orbit indefinitely. The <u>***constraints***</u> for the system include a minimum size for the pictures taken by the satellite, a minimum resolution, and a space envelope within which the satellite must fit for launch. Any actual values for requirements and constraints should be provided in the introduction.

   4.3 Analysis: Your goal is to explain your calculations in sufficient detail for readers to check them for correctness. **You are not simply summarizing the results. Integrate explanatory notes into the calculations**. Though most professional reports will not include every calculation, for EGR101, you will. For each calculation, you should specify the following: what is the calculation used for, what are the assumptions you have made, what do the variables represent and how did you determine the numbers that you are substituting into the equation (is the number a requirement, design choice, or a previously calculated number?), and what do your results mean (do they meet the requirements and do they seem reasonable?). As mentioned in the beginning of this chapter, if any of your inputs are design choices, explain *WHY* you made that choice and justify *HOW* it's acceptable. Be neat and proceed according to the order you followed in actually performing the calculations **(not necessarily the order presented in the project documentation, as sometimes those are given out of sequence)**. Use equation numbers (not necessarily the same as those in the project documentation) for each equation you use and reference those numbers in your explanations.

If any alternatives were considered (which, frankly, is essential for one to claim they have the best design), the different alternatives should be summarized and compared. A table is a nice way to compare and contrast alternatives. Use the comparisons to demonstrate and justify why the final design was chosen over the alternatives considered. If results forced you to make changes or consider other alternatives, explain them.

For the sake of clarity and convention, **each calculation is to be written out the first time it is done using the 3-Line format:** 1) write out the equation with all variables shown, 2) write it out again with the values and units substituted into it, and 3) give the final answer – including UNITS!! An example of the 3 line format is given below:

Below is the sample calculation for determining the orbital speed of a satellite in a circular orbit at a given orbit height of 900,000 ft.

$$V_o = R_E \sqrt{\frac{g_o}{(R_E + h)}} \qquad \text{line 1}$$

$$V_o = 2.0925x10^7\ ft \sqrt{\frac{32.174\,\frac{ft}{s^2}}{(2.0925x10^7\ ft + 9.00x10^5\ ft)}} \qquad \text{line 2}$$

$$V_o = 25{,}400\,\frac{ft}{s} \qquad \text{line 3}$$

Again, state where you got all values you use for variables (this is not shown for the above example). If the same equation is calculated multiple times for several values, summarize those iterations in a table or plot. If you write your own computer program or use a commercial software package (including spreadsheets) for any part of the calculations, you must show sample calculations done by hand to verify the program's correctness. Previous experiences have repeatedly shown that Excel can give incorrect answers --- it is common to accidentally set up equations for something not originally intended. IT IS IMPERATIVE that you hand check ALL computer produced calculations, and demonstrate these hand checks in the report. You can include your computer generated results as an appendix, but the three line format should be used for every sample calculation performed. Every different type of value calculated should have at least one sample calculation.

Include drawings in the analysis section if you have any. These are working drawings, **so be sure they are large enough to see.**

4.4 Conclusion: A technical conclusion should reiterate the major design points and specifications of your design. Comment on whether or not all of your calculations give results which are consistent with your intended configurations. At a minimum, the major attributes and dimensions of the final design should be reiterated in the conclusion. Reiterating the requirements, constraints and objectives mentioned in the introduction and demonstrating how your design meets or exceeds them should also be included in the conclusion.

5. Physical layout format for the Title page is given below. The Title page information should be centered on the page and include the following:

Project Title
(double space)
Date
(triple space)
Course and section number
Team Name
Team leader’s name with title of Leader shown to identify him/her
Team members' names
(double space)
Submitted to:
Instructor’s name

Oral Communication

Oral communication is the spoken interaction between two or more people. Your ability to give effective oral presentations and to participate actively in discussion is one of the major factors determining the level of your success. In this section, we provide some information on how to develop essential skills for making an effective oral presentation. In our discussion, we focus on formal presentation, i.e., the type of presentation that involves a preset time, date and a certain amount of preparation. However, most information is also valid for informal presentations.

Before the Presentation

Needless to say, preparation is the key to a successful presentation. Although you may be very familiar with the topic you will present, organizing your knowledge and opinions in a clear and informative way often requires much preparation.

First, identifying the purpose and audience of the presentation is always important[1]. It helps you stay focused, clear and concise. For example, is the presentation to inform, train, persuade, or demonstrate? Being clear about the purpose also helps you decide what information to include or omit, and approaches and structure that are most appropriate. For example, will you include role play, a PowerPoint presentation, or a video demonstration?

Second, you need to create the presentation material with maximal audience impact. Whether you will be using PowerPoint or handing out printed copy of materials, the organization and structure of the material is essential to any effective presentation. Here are some useful suggestions:

1. Limit the presentation to three to five major points. Keep in mind that the amount of information the audience retains is much more important than how much is presented. In the case of a multiple-subsystem project, each presenter in your team should limit themselves to 2-3 major points.
2. A sample outline of a presentation on engineering topics can be as follows:
   a) Introduction: who you are, and why you are making this presentation.
   b) Summary: outline of the whole presentation.
   c) Need and solution: why your proposed method/design is useful, what it is, and what you have done to confirm its usefulness (do not bore your audience with calculations; present your methods and approaches – not the step by step analysis).
   d) Advantages and limitations of your method/design compared to others.
   e) Conclusion, future improvement and the allowance for questions and answers
3. Use the power of repetition: "Tell them what you are going to tell them, tell them, then tell them what you told them".
4. Present only one central idea per slide. The slides should be as brief as possible. Use large fonts. Use graphs, charts and high contrast colors. It is important that you verify everything is visible from the audience *before* the presentation. If possible, practice your presentation at the actual locale with your PowerPoint presentation and view each slide on the projection screen. In many scenarios, what looks great on the computer screen does not look as good on the projector screen.
5. Make every effort to have your presentation materials ready a couple of days in advance. This allows practice time and final improvements. Also, being finished well in advance of the presentation helps to reduce stress and builds confidence during the presentation.
6. Rehearsing your presentation serves to assess timekeeping, body language, pace of speech and logical order of content. If possible, have your friends as the audience during rehearsal and obtain their feedback for improvement.

Delivering the presentation

Establishing eye contact and rapport with the audience at the beginning of the presentation is critical. Often, asking a general question is very useful in inspiring interest and making a connection.

During the presentation, your body language and movement should be relaxed but animated to show familiarity and confidence with the content. Also, monitor the audience's response and make proper adjustment if they look confused or bored. Make sure everybody can hear your speech, and maintain an even pace that is comfortable to listen to. As a rule of thumb, speak for approximately one minute per slide. This can also help to control your time.

At the end of your talk, let the audience know you are finished and give them the opportunity to raise questions. In fact, for most occasions the audience should be encouraged to interact with the speaker throughout the presentation, so they are kept engaged.

If you are nervous, here are some techniques to help[2]:

1. Take three deep breaths before you start;
2. Well ahead of time, visualize yourself successfully giving the presentation;
3. Tell the audience a joke or something interesting that is related to your presentation;
4. Use props, because it gives your hands something to do.
5. Realize that others feel nervous too; you are not alone.
6. Practice, practice, practice!
7. Use notecards – put only keywords on the notecards to serve as reminders
8. Look at the back of the room (just above the heads of the last row of people), if looking at individuals makes you nervous.

After the presentation

Most people prefer to forget about the presentation they make once it is over. However, it is to your benefit to learn from past experience and improve your skills in the future. Here are some items to evaluate after your presentation:

1. What went well?
2. Did the audience seem interested, bored or frustrated at certain points, and why?
3. Was there any point when you felt particularly nervous or not sure how to proceed?
4. Was there anything you planned to mention or emphasize, but failed to?
5. Did you have the right amount of time for the presentation, and what improvement you can make in planning future presentations?

If possible, always ask someone in the audience to provide feedback. Based on all the assessment information you gather, make a list of actions to take for improvement next time.

Exercises

1. What makes technical communication different from literature or the Performing Arts?
2. What sections should be included in a technical report?
3. What should be included in the Introduction?
4. What should be included in the Analysis section?
5. What should be included in the Conclusion?
6. What is the three line format?
7. During a presentation, about how many points should be covered overall?
8. How many ideas should be presented per slide?
9. List and explain three useful tips detailed in the Oral Communication section of the chapter that you expect to incorporate into your next presentation.
10. What should you do after you give your presentation?

References

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Chapter 4
Critical Thinking and Problem Solving

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Critical Thinking

What undergraduate degree do you think is most common among the Chief Executive Officers (the top bosses) of the 500 largest corporations in the U.S.? In a recently published, very detailed statistical analysis of the backgrounds of the CEOs of the Standard and Poor's top 500 companies, the highest percentage for any one field of study was 20%, with second place at 15%. Understandably, most people would probably guess the answer is business management since we are talking about managing successful businesses. And they are totally surprised to find that the most common bachelor's degree among these big bosses in major corporations is actually engineering. "Why engineering?" you are probably asking yourself. There are many possible reasons, but one that is often mentioned is that engineering education emphasizes and practices critical thinking skills. The efficiency and productivity of almost any work scenario is improved when its leader has a well-developed ability to clearly define problems and organize a logical series of steps that need to be taken to solve the problem.

Critical thinking simply means organizing one's thoughts into a pattern that will ultimately lead to a correct interpretation of the meaning of the information presented. It is not limited to scientific thought. You probably learned how to write critical essays in your high school writing classes. You have no doubt seen movie critics or music critics on TV or online. These are all examples of critical thinking. In this context critical doesn't necessarily imply saying uncomplimentary things, which is often what critical means in everyday conversation. In our context it means that you are making an organized, logical effort to determine what something actually means or is actually telling you.

There are formal rules of logical analysis to determine whether or not a hypothesis is true. And those rules are surprisingly similar to the commutative, distributive, and associative laws that you learned in algebra. But you probably don't need anything quite that formal at this stage of your education. Instead, try thinking about the way most science fair projects are organized (or at least how they were *supposed* to be organized). Developing critical thinking skills is one of the reasons that science fairs exist. What did you do? First, you came up with a hypothesis, a problem statement that clearly defined some piece of information that was of interest to you. Then you planned an experiment or data gathering process which would generate information that would either prove or disprove your hypothesis. And finally you drew conclusions about whether your data did or did not prove your hypothesis. This sequence of thought, often described as the scientific method, is an example of critical thinking. You can use it to help yourself solve almost any type of problem.

An often-quoted and useful approach to figuring out the cause of a problem is called the "Five Whys." It is frequently used as a tool of Root Cause Analysis. It is not the only tool, but its simplicity makes it an attractive tool for quickly brainstorming possible root causes for a problem. The concept is that the root cause of almost any problem can be arrived at by five iterations of the process: stating a symptom of the problem and asking yourself why that symptom exists and to come up with a logical, possible answer. A famous example is the deterioration of the stone structure in one of the government monuments in Washington, D.C. The smooth granite blocks and columns in the monument were beginning to get visibly rough on the surface and the managers of the monument, of course, wanted to know why so that they could take corrective action.

Why #1. Why are the stones deteriorating? Answer: the cleaning solution that they were using on the monument was beginning to eat into the surfaces of the stones because they were cleaning the stone surfaces too often.
Why #2. Why do we clean the surfaces so often? Answer: because of bird droppings being deposited on the stones.

Why #3. Why are the birds here? Answer: the birds came to this monument to feed on the ample supply of spiders which inhabited the monument.
Why #4. Why are there so many spiders here? Answer: the spiders were there because they fed on gnats which gathered at the monument in unusually large numbers.
Why #5. Why are there so many gnats around the monument? Answer: because the monument was always lighted up at night and the lights attracted the gnats.

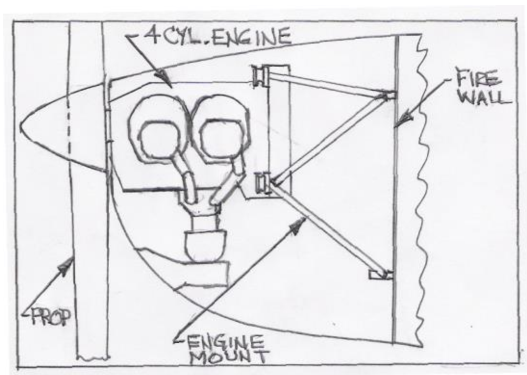
So they turned off the lights and the stone deterioration problem stopped. It is amusing to picture the reaction of disbelief that would have been given to a custodian suggesting this solution at the very beginning, before the "Five Whys" critical thinking process was exercised: we can save the stones by turning off the lights at night.

As mentioned previously, the Five Whys is only one of the tools used in Root Cause Analysis. For more on the topic, the pro-active student is encouraged to look into any of the online resources available. One such webpage that is available at the time of this writing is: http://www.des.wa.gov/services/Risk/AboutRM/enterpriseRiskManagement/Pages/rootCauseAnalysis.aspx.

The Fine Art of Making Educated Guesses

This will sound a little surprising at first, but bear with me for a minute. Engineering education lost a valuable skill when we stopped using slide rules and switched over to calculators. For most people that was probably late 1960s to early 1970s. Yeah, I know, ancient history. But the issue is that a slide rule is a wooden or plastic device which is literally a graphical means of adding and subtracting logarithms. It can tell you the digits in the numerical result of a math problem, but cannot tell you where the decimal point belongs. You have to be able to do a quick, rough calculation in your head to tell you where the decimal point belongs. Now calculators do that for you and you no longer have to think about it. That's too bad. The ability to do quick, ballpark estimates in your head is a valuable engineering skill. If you don't have it you should practice it. It is often referred to as making sanity checks or reality checks. Specifically, whenever you solve a problem you should ask yourself, "Does this answer make sense?" Or another related question might be, "Is this answer consistent with some simple physical reality that I am sure is correct?"

For example, a number of years ago in the senior aircraft design class a student turned in a multi-page computer printout giving the results of the structural analysis of an engine mount for his team's aircraft. The engine mount was a truss made of welded steel tubes as big around as your fingers, typical of what is found in most general aviation aircraft. The engine mount was about 15 inches long, also typical of small real airplanes. And the computer program calculated the deflection of bolt locations at the front of the engine mount that attach the truss to the back of the engine. But the deflection of the front of the engine mount was printed out as about 10^5 inches, which the student turned in to be graded without comment or question. OK, here's the spot for a sanity check. As entering first year students you have probably not yet learned anything about structural design and analysis. But just think about physical reality. 10^5 inches is about 1.5 miles. Does it make any sense at all that a 15-inch long engine mount could have deflected 1.5 miles under the weight of the engine attached to it? Of course not! Anyone can see that. You just need to think about it for a few seconds. Something obviously went wrong with the calculations performed by the software (or likely the values inputted and assumptions used by the user). You will learn equations in your second year that would allow you to make a hand calculation in a few minutes to use as a more accurate sanity check, but any engine mount deflection bigger than a quarter inch or a half inch just doesn't make sense. It will be to your benefit as an engineering student and ultimately as a working engineer to get into the habit of checking your solutions against common sense and reason.



A closely-related concept is: don't ever believe the answer from a computer program until the program output has been checked against a hand-solved sample problem. A piece of commercial software has likely been checked carefully if it was developed by a reputable developer. But if you write your own code for any of your assignments, be very careful to check it the first time you use it. It would be rare indeed for a new piece of code to be completely correct the first time it runs. Getting a code to run all the way through the computing process and produce an answer is a big step in the right direction, but until its accuracy is verified, it is still incomplete. Accuracy verification is a huge part of the software development process. And to bring this back to the sanity check context, when a new piece of software has an undetected flaw the resulting output is often so far off that it is easy to spot as long as the user is looking for sanity checks. Even if you are using professionally developed code, you still want to verify your analysis by a hand-solved ballpark method, as even perfectly functioning codes still rely on inputted information, which the user (you) may have accidentally entered incorrectly. If you don't check, you will never know!

And another helpful thought in checking problems on tests or in homework is whether the units on both sides of the equation match. The formal name of the concept is dimensional homogeneity. If an equation does not have the same units on both sides of the equal sign then it cannot possibly be correct. Many students have already developed the habit of checking units but just don't know there is a fancy name for it. It's a good habit.

The plan of attack in problem solving

Here are the critical thinking questions to ask yourself when you start solving a problem:

What do I know?
What do I need to find?
What is happening in the problem?
What law of physics or scientific principle provides an equation that relates what I know to what I need to find?
Are there any realistic assumptions or simplifications that can I make to the problem?

Some teachers actually require that you write out these headings on your sheet of paper. It's a useful habit to get into, whether required or not.

Given:
Find:
Assumptions:
Solution:

Always work in pencil---everyone makes mistakes. And mistakes should be cleanly erased. Cross-outs are really sloppy and unprofessional looking, and you are stuck with them if you work in pen. Many engineers don't even own a pen. You were often required to use a pen in writing class or other classes, but it's a bad habit for engineering classes.

Show all the steps in the solution process. Most instructors will not give you full credit unless you show your work. An answer without any work written down strongly suggests that the answer was copied from someone else. Few people, no matter how brilliant they may be, can go directly from a problem statement to the answer without any intermediate steps. And even if you aren't concerned about getting grading credit, writing out the intermediate steps is usually an essential assist in the process of finding and correcting the inevitable mistakes. It is important to recognize as well that writing out a solution isn't only for your own benefit, but also for anyone else who must check your work. In industry, a prototype is not built until all analysis has been verified and approved in writing (also known as "signed off") by at least three different people. And how can someone verify your calculations if the calculations are not shown and explained in full detail? Extending this thought leads us into a discussion about technical report writing, which is presented in Chapter 3.

Box the answer. It is often useful to the grader, and anyone trying to understand your work, to know that you think you have arrived at the answer and did not simply stop working. Some of you may have the habit of writing "Q.E.D." next to the answer, which in some regions is a common format for teaching math. QED is the initials for the Latin phrase quod erat demonstrandum, which means literally "it has been demonstrated." In more modern slang, one might translate it as "There it is, Dude." Drawing a box around the answer is a neat way of delivering the same message.

Exercises

Critical Thinking

1. Use the 5 Whys method to generate a reason why it is so hard to find a parking space on campus.
2. Use the 5 Whys method to explain why the price of gasoline is so high. (There should be some really inventive answers to this one. It should be interesting to compare answers arrived at by students from different cultures and/or parts of the world.)
3. Research Root Cause Analysis and describe one of the other tools (besides the Five Whys method) used in the process.

The Fine Art of Making Educated Guesses

1. If water weighs about 62 pounds per cubic foot, estimate the weight of a typical concrete block which is 8x8x16 inches and is cast with air cavities that make 60 % of the volume hollow. Show your work and list your assumptions.
2. An Olympic marathon runner runs the 26.2 mile race in just over 2 hours. Based on this information, estimate how many days it would take for a cyclist to ride coast-to-coast across the U.S. Mileage, of course, varies depending upon the route chosen so assume 2700 miles for the total distance. Show your work and list your assumptions.
3. A good sprinter runs 100 meters in a little under 10 seconds. An athlete who is not specifically a sprinter is more likely to take 13 or 14 seconds. Estimate how fast a dog can run a kilometer. Show your work and list your assumptions.
4. How many times would an airline airplane have to stop for fuel on a trip around the world? Show your work and list your assumptions.
5. If you searched the world and found an 8-foot tall basketball player, how much would he/she probably weigh? Show your work and list your assumptions.
6. What is the approximate volume, in gallons, of your EGR101 classroom? Show your work and list your assumptions.

Chapter 5
Math Essentials

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Introduction

The purpose of this chapter is to provide a reference for review and future use. EGR101 is NOT a math course and is not meant to teach you mathematics. However, your professor may assign you problems from this chapter for review. He/she might assign you problems as mastery of those concepts will be needed for the projects or simply because he/she feels those concepts are important for you to review (perhaps for concepts used in EGR115). If you have never seen some of these concepts before, or you are having a difficult time recalling the concepts, do not despair. Successful completion of EGR101 does not hinge upon your ability to solve these math problems. However, as engineering is a math-intense course of study, you will need to master algebra, trigonometry, vector manipulation (and eventually calculus) very soon. So if you struggle with this chapter, be sure to seek help in your math courses and begin to really work hard on your mathematics studies. Engineers are not mathematicians, but we use mathematics as a tool regularly!

The sections of this chapter include Algebra, Trigonometry, Statistics and Vectors. Exercises for all four sections are given at the end of the chapter. There is also an appendix with some additional miscellaneous concepts that your EGR115 professors use often and with which they would like you to be familiar. These concepts are given in Appendix 4.

Algebra

<u>Three algebraic laws</u> (applicable to both real and complex numbers):

1. Commutative Law: $a + b = b + a;\ ab=ba$
2. Distributive Law: $a(b + c) = ab + ac$
3. Associative Law: $a + (b + c) = (a + b) + c;\ a(bc) = (ab)c$

<u>Quadratic formula</u>

The roots of the quadratic equation $ax^2 + bx + c = 0$ are:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

If $b^2<4ac$, the roots are a pair of complex numbers conjugate to each other.

The binomial theorem

$(a + b)^2 = a^2 + 2ab + b^2$
$(a + b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$

In general, the binomial theorem states that[1]:

$$(a+b)^k = a^k + ka^{k-1}b + \frac{k(k-1)}{1\cdot 2}a^{k-2}b^2 + \frac{k(k-1)(k-2)}{1\cdot 2\cdot 3}a^{k-3}b^3 + \cdots$$
$$\cdots + \frac{k(k-1)\cdots(k-n+1)}{1\cdot 2\cdot 3\cdot\cdots\cdot n}a^{k-n}b^n + \cdots + kab^{k-1} + b^k$$

Exponents

Let x and y be positive numbers and let and a and b be any rational numbers. Then

$x^a x^b = x^{a+b}$
$x^a/x^b = x^{a-b}$
$(x^a)^b = x^{ab}$
$(xy)^a = x^a y^a$
$(x/y)^a = x^a/y^a$

Logarithms

If $x^a = y$, then $a = log_x y$. Most engineering applications involve logs that have bases 2, 10 or e (e = 2.7183…). The log function with base e is named *natural log* and is written as *ln*.

Here are some useful identities (using the natural log function for illustration):

$ln\ x^a = a\ ln\ x$
$ln\ (xy) = ln\ x + ln\ y$
$ln\ (x/y) = ln\ x - ln\ y$
$ln\ 1 = 0$, this rule is true for all log functions with any positive base
$ln\ e^a = a$
$(ln\ a)/(ln\ b) = log_b a$, this formula is called *change of base*

Complex numbers (optional)

Define $i = \sqrt{-1}$, then $i^2 = -1$. The standard form of a complex number is $x + iy$, where x is called the real part, and y is called the imaginary part. Complex numbers are very useful in many applications. For example, many quadratic equations have complex-valued roots. In Electrical Engineering, we use complex numbers to represent AC (Alternating Current) voltages and currents.

The standard form of the complex number, also known as the rectangular form, is convenient for operations like addition and subtraction. For multiplication and division, the polar form is often preferred. The polar form is expressed as:

$$re^{i\theta} = x + iy\,.$$

Where r is called the magnitude and θ is called the phase.

The relations between the polar form and the rectangular form can be easily obtained by Euler's Identity:

$$e^{i\theta} = \cos\theta + i\sin\theta\,.$$

Based on the above equation, we can perform transformation between the rectangular form and the polar form:

$$x = r\cos\theta\,,\quad y = r\sin\theta\,,\quad r = \sqrt{x^2 + y^2}\quad \text{and}\quad \tan\theta = \frac{y}{x}$$

If we want to perform multiplication or division between two complex numbers, it is often convenient to express them in polar form, because it is easy to multiply or divide two exponential numbers.

Another important operation on complex numbers is *complex conjugation.* The definition is:

$$\overline{x + iy} = x - iy \quad \text{and} \quad \overline{re^{i\theta}} = re^{-i\theta}$$

In many engineering applications, it is useful to plot a complex number $z = x + iy$ in a coordinate system, with the real part denoted by the horizontal coordinate and the imaginary part by the vertical coordinate. The magnitude and phase can also be explicitly specified in the coordinate system as follows:

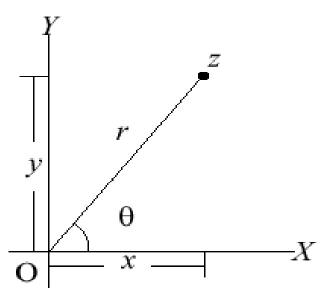


Figure 5.1. The diagram showing the two related ways of representing an imaginary number. The figure is analogous to the relationship between Cartesian and Polar representations of ordered pair coordinates and vectors.

Examples of algebra problems

Example 1: Solve the equation $5x^2 + 3x - 3 = 0$

Solution: $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \dfrac{-3 \pm \sqrt{3^2 - 4 \times 5 \times (-3)}}{2 \times 5} = \dfrac{-3 \pm \sqrt{69}}{10}$

In this case, the roots are two different real numbers, because b^2-$4ac>0$.

Example 2: Expand $(x-2)^5$

Solution: Using the binomial theorem with $a = x$, $b = -2$, $k = 5$, we have

$$(x-2)^5 = x^5 + 5x^4(-2) + \frac{5 \cdot 4}{1 \cdot 2}x^3(-2)^2 + \frac{5 \cdot 4 \cdot 3}{1 \cdot 2 \cdot 3}x^2(-2)^3 + 5x(-2)^4 + (-2)^5$$

$$= x^5 - 10x^4 + 40x^3 - 80x^2 + 80x - 32$$

Example 3: Given the voltage response of a transient circuit: $v(t) = 100 - 100e^{-0.02t}$ V, how much time is it required for the voltage to drop to 80V?

Solution: Let $v(t)=80$, we have:

$80 = 100 - 100e^{-0.02t}$
$0.2 = e^{-0.02t}$
$\ln 0.2 = \ln e^{-0.02t}$
$-1.6094 = -0.02t$
$t = 80.47$ *seconds*

Example 4: Compute the following calculations involving complex numbers:

1. $(-4 + i7) + (5 - i4)$
2. $(4 + i12) - (3 - i15)$
3. $(1 + i1)(2 + i2)$
4. $\dfrac{\sqrt{3} + i}{1 + i\sqrt{3}}$

Solutions:
1. $(-4 + i7) + (5 - i4) = 1 + i3$
2. $(4 + i12) - (3 - i15) = 1 + i27$
3. $(1 + i1)(2 + i2) = \sqrt{2}e^{i\pi/4} \times 2\sqrt{2}e^{i\pi/4} = 4e^{i\pi/2} = i4$
4. $\dfrac{\sqrt{3} + i}{1 + i\sqrt{3}} = \dfrac{2e^{i\pi/6}}{2e^{i\pi/3}} = e^{-i\pi/6} = \dfrac{\sqrt{3} - i}{2}$

Trigonometry

Trigonometry will prove to be an extremely important tool in your mathematics toolbox. In particular, you will notice its importance in manipulating and using vectors. For example, trigonometry is helpful for resolving vectors into their components, determining the angular direction of a resultant vector from the addition, subtraction or even multiplication of vectors, and numerous other applications. For this reason, a brief review of trigonometry is prudent.

Trigonometry is simply the study of triangles, the angles within them and the relationships between the angles and sides. Here we will discuss the most common trigonometric tools that you will be using, especially when manipulating vectors. They are sine, cosine, tangent, arcsine, arccosine and arctangent. The laws that will also be covered include the Law of Sines, Law of Cosines and Pythagorean's Theorem. There is, of course, much more to the study of trigonometry, but as previously mentioned, this is to serve as a review on how to use those tools immediately required of you.

Triangles

As you may recall, there are three different categories of triangles: equilateral, isosceles and scalene (see figure 5.1 below). Within the Isosceles or Scalene categories, triangles can be further defined by the types of angles they contain. If all of the angles are less than 90 degrees, the triangle is said to be *acute*. If one angle is greater than 90 degrees, the triangle is an *obtuse* triangle. Finally, if one angle is precisely 90 degrees the triangle is called a *right* triangle. Besides being great material for a Jeopardy question, knowing the type of triangle is important for determining the quickest way to relate the angles and sides of that triangle.

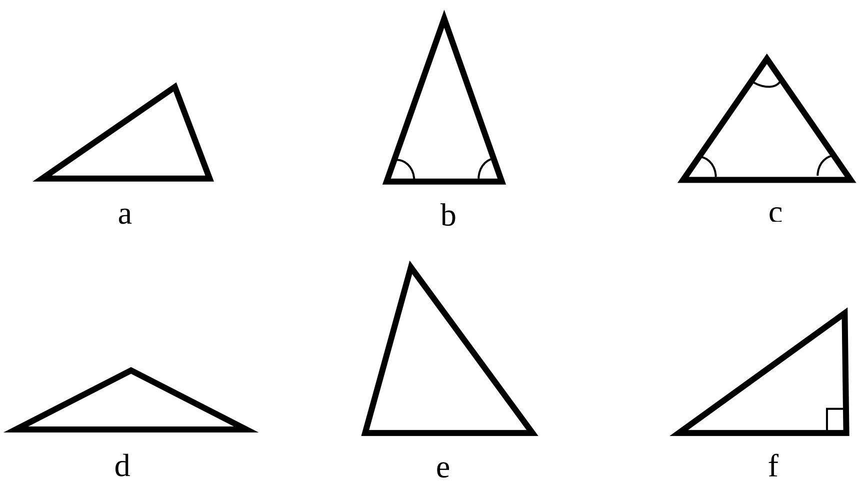


Figure 5.1 Types of Triangles. Shown from left to right: Top row: a) Scalene (no angles or sides are equal), b) Isosceles (two angles and sides are equal) and c) Equilateral (all angles and sides are equal). Bottom row: d) Obtuse (one angle greater than 90 deg.), e) Acute (all angles less than 90 deg.) and f) Right (one angle exactly 90 deg.).

Although you can always use the Laws of Cosines and Sines to determine an unknown angle or side length, when you have a certain type of triangle you can use Pythagorean's

Theorem, which is a simplified form of the Law of Cosines. Can you recall the special type of triangle for which Pythagorean's Theorem applies? A *right* triangle! As you will see in the vectors section of this chapter, resolving vectors into their components always involves a right triangle (so long as your coordinate system is *orthogonal*).

<u>Sine, Cosine and Tangent</u>

As a tool for relating the angles and sides of a triangle, let us review sine, cosine and tangent of an angle. Although their use is not restricted to the application of triangles, the sine, cosine and tangent functions are commonly associated with triangles, specifically right triangles. It is important to note that alternate, and more general, definitions of sine and cosine exist. However, for simplicity, we will define them in terms of a right triangle. The mathematically curious reader should refer to their advanced mathematics textbooks, such as Calculus by James Stewart, for these more general definitions.

For a given right triangle, the sine of any angle is simply the ratio of the length of the triangle side opposite of the angle to the length of the *hypotenuse* (see fig. 5.2 below). Remember, the hypotenuse is the longest side of a right triangle and is opposite the 90 degree angle. The definition is given in mathematical terms for angle α as:

$$\sin\alpha = \frac{A}{C} \qquad \text{Eqn. 5.1}$$

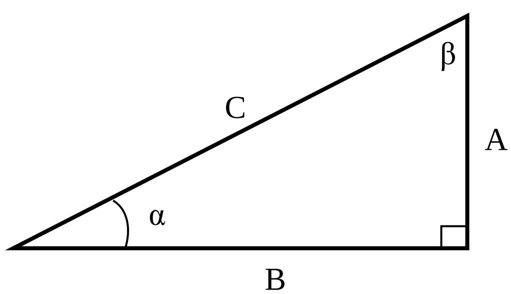


Figure 5.2 The corresponding sides of a right triangle for computing the sine or cosine of an angle. This is also the diagram for label definition for the Pythagorean Theorem. Note that only the hypotenuse can be labeled C for use of the Pythagorean Theorem.

For the same triangle and angle, the cosine of the angle is equal to the length of the triangle side *adjacent* (directly next to) to the angle to the length of the hypotenuse (refer back to fig. 5.2). This is also given as a mathematical definition below for the angle α:

$$\cos\alpha = \frac{B}{C} \qquad \text{Eqn 5.2}$$

Finally, the tangent of a given angle is defined as the sine divided by the cosine of that angle. From this definition, it should be easy to see that the tangent is equal to the ratio of the length of the side opposite of the angle to the length of the side adjacent to the angle. This proof is shown below:

$$\tan\alpha = \frac{\sin\alpha}{\cos\alpha}$$ Eqn 5.3

Substituting in Eqn. 5.1for sin α and Eqn. 5.2 for cos α, tan α becomes:

$$\tan\alpha = \frac{\left(\frac{A}{C}\right)}{\left(\frac{B}{C}\right)}$$ In this equation, the C's cancel and we are left with:

$$\tan\alpha = \frac{A}{B}$$ Eqn. 5.4

It should be noted that abbreviations are typically used when referring to the sine, cosine and tangent of an angle. These abbreviations are: sin, cos and tan. A quick and easy way to remember the correct sides for computing the sine, cosine and tangent is SOH CAH TOA. The O stands for opposite, the A for adjacent and H for hypotenuse. It doesn't spell anything familiar, but after saying it a few times, it is easy to remember.

Finding the sine and cosine of an angle is useful, but many times you will find that you need the angle for which the sine or cosine is given. In this case, you want to find the arcsine or arccosine. The arc functions are simply the inverse functions of a given trigonometric function. If you are given the sine of an angle as 0.5 and you are asked to find what the angle must be, you would want to use the inverse function on your calculator to find the angle. You will notice in some text books and on some calculators, the notation $\sin^{-1}$ or $\cos^{-1}$ is employed for the inverse or arc functions. This is important to note; $\sin^{-1}$ does NOT mean the reciprocal of the sine, it represents the inverse function. In other words, $\sin^{-1} 0.5 =?$ is asking you to find what angle for which the sine is 0.5. If you take the sine of 0.5 (while in degrees mode) and then take the reciprocal of the answer, you get 114.6. Clearly, this is NOT the correct answer. The angle for which the sine is 0.5 is 30 degrees, or π/6 radians. Another detail that may help you to remember that the $^{-1}$ notation represents the inverse function is that when you take the sine or cosine of an angle, the answer is a ratio, not an angle. So if you are looking for an angle, you should not be taking the sine or cosine of a number, but rather the inverse.

You might remember the reciprocal of sine and cosine as having some importance as well, and so it is helpful to review secant (sec), cosecant (csc) and cotangent (cot). These are the reciprocal functions. The secant is equal to the reciprocal of the cosine, the cosecant is equal to the reciprocal of the sine and the cotangent is the reciprocal of the tangent. The mathematical notation for secant would be $\sec\theta = (\cos\theta)^{-1}$. So if the parentheses are left out, the superscript of $^{-1}$ refers to the inverse, not the reciprocal.

It is important to remind you at this point, that when you are using the trigonometric functions on your calculator, you must be aware of whether your calculator is in radians or degrees mode. You can use either, but you must ensure the information you are inputting corresponds with the mode. Radians, like degrees, are a unit of measure of angles. However, one radian is defined as being equal to the angle spanned by a circular arc, with an arc length equal to the radius of that arc. In a perfect circle, there are 6.283185307.... radians (6.283185307 is the same as 2π), or in other words you have to line up 6.283185307 radii end to end to make up the length of the circumference . This means the circumference of a circle is 6.283185307.....times the radius, or $C = 2\pi r$ or $C = \pi d$. This definition should be familiar to you. The fact that the diameter of a circle could always be laid end to end 3.141592654... times within the circumference, regardless of the size of the circle was discovered by the Babylonians[2] circa 2000 B.C. Hence, the value of pi is defined by this relationship, C/d. On the other hand, there are 360 degrees in one circle. The conversion between these units is:

π radians = 180 degrees

The Law of Cosines, Law of Sines and the Pythagorean Theorem

The Law of Cosines, Sines and the Pythagorean Theorem are extremely useful laws that allow you to relate the angles and lengths of sides of a triangle. The Law of Cosines and Sines are always valid for any triangle; the Pythagorean Theorem is the Law of Cosines simplified for a right triangle, and so is only valid for right triangles. These laws are given below; please refer to the corresponding diagram (figure 5.2 for the Pythagorean Theorem and figure 5.3 for the Law of Cosines and Sines) for variable (label) clarification. The sides of the triangle will be labeled with the English capital letters A, B, and C. The angles will be labeled with lower case Greek letters α, β and γ. The angle α is always opposite the side labeled A, the angle β is always opposite the side labeled B, and the angle γ is always opposite the side labeled C. Any restrictions on these labels, as required by the pertinent law or theorem, are given in the caption of the corresponding figure.

Law of Cosines

$$C^2 = A^2 + B^2 - 2AB\cos\gamma \qquad \text{Eqn. 5.5}$$

Law of Sines

$$\frac{\sin\alpha}{A} = \frac{\sin\beta}{B} = \frac{\sin\gamma}{C} \qquad \text{Eqn. 5.6}$$

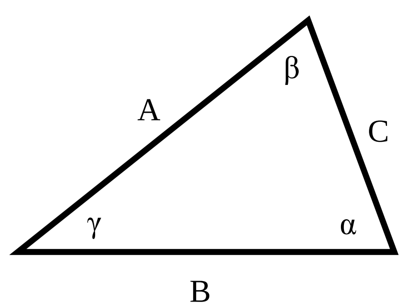


Figure 5.3 Diagram defining the sides and angles involved in the Law of Cosines and Law of Sines. Note that ANY side can be labeled A, B or C. The angle must be labeled to correspond with their "opposing" side, as described above.

Pythagorean Theorem

$$C^2 = A^2 + B^2 \qquad \text{Eqn. 5.7}$$

As mentioned in Figure 5.2, only the hypotenuse can be labeled C, and by default, γ corresponds to the 90 degree angle. When using these laws, it is also helpful to remember that the three angles of a triangle must equal 180 degrees, or π radians. That is:

$$\alpha + \beta + \gamma = 180 \text{ degrees (or } \pi \text{ radians)} \qquad \text{Eqn. 5.8}$$

Statistics

This section reviews the very basic terms that are often associated with statistical analysis. You likely learned these terms in middle school, but unless you took a statistics course in high school, you might not have used them since; thus a review is most certainly in order. The definitions of the terms are given below with a very simple example provided.

1. **Mean** is another term for average. To find the Mean of a set of values, you add all of the values together and then divide by the number of values in the summation.
2. **Median** is the value in the very middle of the set of values, when they are arranged in either ascending or descending order. If you have an even number of values, the Median is the average of the two middle values.
3. **Mode** is the value which appears the most. If no value appears more than once, then there is no Mode. It is possible to have more than one Mode as well.
4. **Range** is the difference between the largest and smallest values in the set.
5. **Standard Deviation** (represented by σ) measures the average amount by which the values in the set differ (or deviate) from the Mean value; thus a set with a very small standard deviation is a set of numbers that are very close in value. It is calculated by taking the square root of the average of the squared differences between each value and the Mean. This is shown below in equation form:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - Mean)^2}{n}} \qquad \text{Eqn. 5.9}$$

(if you are not familiar with the summation notation, please refer to Appendix 4, item 1.)

Examples

Examples of each given the following set of values (for ease, the set has already been put into ascending order):

X = {3, 10, 11, 11, 14, 19, 24, 24} - there are 8 values in this set

<u>Mean</u>

$$Mean = \frac{\sum_{i=1}^{n} x_i}{n}$$ where n = 8 for the above set

$$Mean = \frac{3+10+11+11+14+19+24+24}{8}$$

$$Mean = 14.5$$

<u>Median</u>

Median = average of 11 and 14 (as there is an even number of values and 11 and 14 are in the middle)

Median = 12.5

<u>Mode</u>

The most frequent values each appear two times: both 11 and 24. Thus,

Modes = 11 and 24

<u>Range</u>

Range = Hi – Lo
Range = 24-3
Range = 21

<u>Standard Deviation</u>

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - Mean)^2}{n}}$$

$$\sigma = \sqrt{\frac{132.25 + 20.25 + 12.25 + 12.25 + 0.25 + 20.25 + 90.25 + 90.25}{8}}$$

$$\sigma = 6.87$$

Vectors

Vector and Vector Algebra are two of the most essential concepts you must master as an engineering student. Although you are taught about vectors in both your mathematics and physics classes, you will likely be provided reviews on vector mathematics in several of your fundamental engineering mechanics courses. Why do you think you are taught about vectors in so many of your classes? Yes, because they are *ubiquitous* (everywhere) throughout engineering, and understanding their meaning and the ability to use them in your analyses is critical to your success as an engineer.

So what exactly *IS* a vector? It is simply a way to represent not only a *value* (or *magnitude*) of a variable, but also its *direction* when it is important. When is direction important? Please consider the following situation:

You're told that a block of metal, weighing 25 lbs sits atop a level table. A force of 50 lbs is applied to the block. The table on which the block is sitting is made from the same metal as the block itself, and so you know from physics what the kinetic and static coefficients of friction are between two pieces of this particular metal. This will allow you to determine the frictional force acting on the block as follows: static frictional force is less than or equal to the normal force multiplied by the static coefficient of friction if the piece is stationary ($F_f \leq \mu_s N$); kinetic frictional force is equal to the normal force multiplied by the kinetic coefficient of friction if the piece is sliding($F_f = \mu_k N$). You are then asked to give the acceleration that the block would experience under this applied force of 50 lbs. Can you solve this problem?

Your answer should be NO - not without knowing which way the applied force is acting!! Consider some of the possible directions of the applied force, and the corresponding results:

1) If the force is applied straight down, the block will experience no acceleration, it will simply be pushed against the table (unless, of course, the table breaks!). The frictional force will be zero since there is no tangential force (parallel to the table) acting on the block. The normal force acting on the block will be equal and opposite of the sum of the block's weight and the applied force (see fig. 5.4)

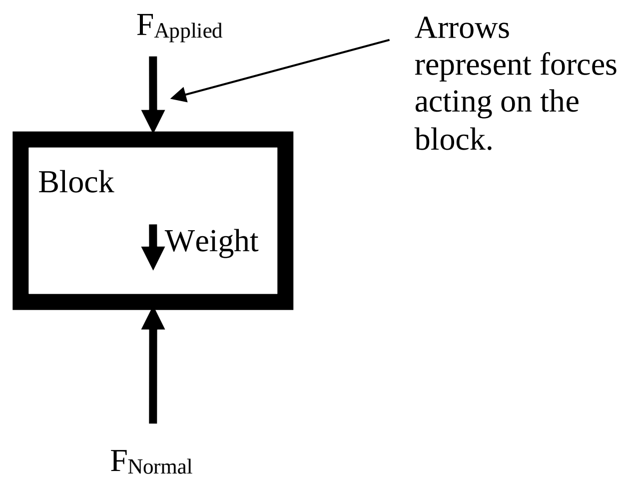


Figure 5.4 Free-Body Diagram for applied force straight down.

2) If the force is acting straight up, again the frictional force will be zero, but the acceleration will now be non-zero and equal to 32.2 ft/s^2 upward. The weight is still acting down, but the applied force is acting up; the net force is 25 lbs up (see fig. 5.5). We know $\Sigma F=ma$, and so acceleration =32.2 ft/s^2 (try finding the answer yourself!).

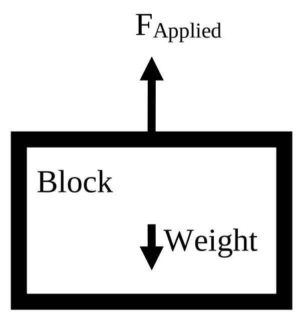


Figure 5.5 Free-Body Diagram for applied force straight up.

3) If the force is acting to the left (or the right), the frictional force is now non-zero. It could either be equal to the kinetic coefficient of friction multiplied by the normal force from the surface (if it slides), or it could be lesser than or equal to the static coefficient of friction times the normal force (if the force is not large enough to make it slide); this analysis has to be done to verify which situation applies. Once the appropriate frictional force is determined, $\Sigma F=ma$ can then be used to determine the acceleration (which would be to the left or right-the same as the direction of the force-or zero, if the applied force is not large enough to overcome the static frictional force). See fig. 5.6 for a schematic of the forces.

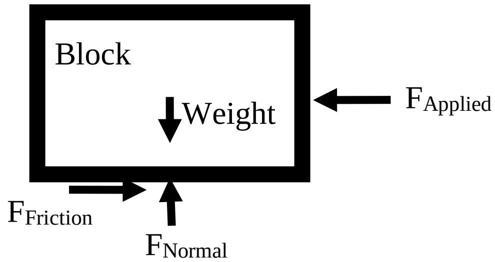


Figure 5.6 Free-Body Diagram for applied force to the left.

4) If the force is down and to the left (or right), the analysis is similar to the above analysis, but now the applied force must be broken down into components - the downward component and the leftward component (see fig. 5.7). The downward component of the force doesn't produce acceleration (like in possibility #1), but it does affect the resulting leftward acceleration through the normal force, and hence the frictional force.

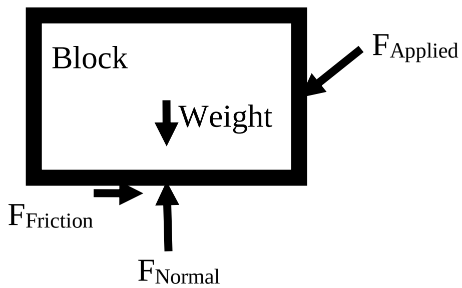


Figure 5.7 Free-Body Diagram for applied force down and to the left

There are, of course, an infinite number of variations in addition to the four explained above, but you should get the point from just those four. The point is that the direction of the applied force greatly affects the result! In order to analyze the situation, we must have a way to recognize and include the direction of the applied and resulting forces. This is what vectors do for us!! A vector is any quantity that requires not only a value (i.e. 50 lbs), but also a direction (i.e. down, up, left, etc.) in order to be completely defined. A scalar, on the other hand is any quantity that is defined completely by its magnitude. Some examples of other common vectors and scalars are listed below.

Vectors: Force, Velocity, Acceleration, Displacement, Momentum, Angular Velocity
Scalars: Temperature, Mass, Speed (the magnitude of velocity), Time, Energy, Work

Representation of Vectors

When working with vectors, choosing a coordinate system and sign convention is essential. Many times, the existing or expected motion of the object you're analyzing defines the most appropriate coordinate system. For example, if the motion of the object you're analyzing is circular in nature, polar or cylindrical coordinates are best suited for the analysis. If the motion is predominantly straight-lined (referred to as rectilinear), Cartesian coordinates are the best suited for the analysis. There are other coordinate systems, especially for analyzing motion in all three dimensions, but polar and Cartesian are the primary two for two-dimensional motion.

Cartesian Coordinates

In the Cartesian coordinate system, the two axes you are familiar with are labeled as x and y. But because we also use x and y as variables for the magnitude, we need to use a different variable to describe the direction of the vector. For indicating a direction parallel to the x axis, we give the direction as $\hat{\imath}$. For a direction parallel to the y axis, we give the direction as $\hat{\jmath}$. The $\hat{\imath}$ and $\hat{\jmath}$ represent unit vectors, so they do not affect the magnitude of the vector you are trying to express; they simply indicate the direction. The final vector is expressed as x $\hat{\imath}$ + y $\hat{\jmath}$. As an example, if the acceleration of the block in the earlier example was to the right at a rate of 5 ft/s^2, we would express the acceleration vector as $\vec{a}$ = 5 ft/s^2 $\hat{\imath}$. The value was kept positive as "up" and "to the right" are generally taken as the positive directions in the Cartesian coordinate system. If the force had been at an angle, let's say up and to the left, making the resulting acceleration up at a rate of 3 ft/s^2 and to the left at a rate of 4 ft/s^2 , we would express the acceleration vector as: $\vec{a}$ = - 4 ft/s^2 $\hat{\imath}$ + 3 ft/s^2 $\hat{\jmath}$. We refer to the components as a_x = -4 ft/s^2 and a_y = 3 ft/s^2. This is shown graphically in figure 5.8. The unit vectors $\hat{\imath}$ and $\hat{\jmath}$ can be seen in figure 5.9. This is the most common way of expressing a vector. You might learn in your Calculus classes other conventions, such as using angle brackets and listing the components (in order of x, y, then z components), separating them with commas (i.e. $\vec{a}$ = <-4, 3> ft/s^2). This convention is commonly used in programming. For the remainder of this text, however, the former example of vector notation will be used. Notice in both examples the half arrow over the answer variable (in this case a, for acceleration). This should always be included as it indicates to the reader that this answer is for a vector.

Polar Coordinates

The information transferred when using polar coordinates seems vastly different from Cartesian coordinates, but really is not. When expressing information about a vector in polar coordinates, the length of the vector is given, followed by the angle at which it is oriented with respect to the positive x axis. You can think of this as giving the radial component first and then the transverse component second, similar to the second format discussed for Cartesian coordinates. Polar information is generally expressed in parentheses as (R, θ). For example, the acceleration vector described at the end of the preceding section would be expressed in polar coordinates as: $\vec{a}$ = (5 ft/s^2, 143.13°). The angle specified is measured counter clockwise from the positive x-axis. This is also shown graphically in figure 5.8.

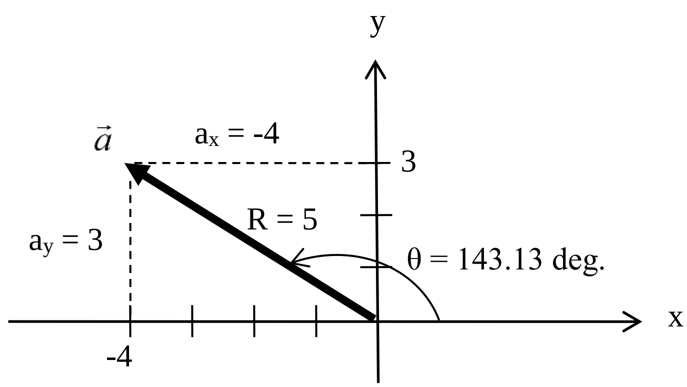


Figure 5.8 Graphical demonstration of an example acceleration vector. Example illustrates the same vector in both Cartesian and polar coordinates.

You might notice that although the information given was in polar coordinates, the vector was graphed using a Cartesian axis pair (x and y). This is common as you still need a frame of reference from which to measure the angle and the length of the vector. The only difference in the coordinates is the format of the vector expression.

<u>Vector Resolution</u>

As you may have guessed, you will often need to "convert" between these two formats of vector representation. This procedure is not difficult once you realize that the x and y components of the Cartesian system are simply the two legs that make up a right triangle with the vector itself as the hypotenuse! The R is the length of the hypotenuse and the θ is the angle between the hypotenuse and the x-axis (see fig. 5.9). Converting a vector from polar to Cartesian coordinates is often referred to vector resolution; this is because you are "resolving" the vector from a given length into usable "components" that can be manipulated when adding, subtracting or multiplying vectors. If necessary, you may want to go back and review the Trigonometry section of this chapter before moving forward; when resolving vectors, you want to be comfortable and confident with your trigonometric functions.

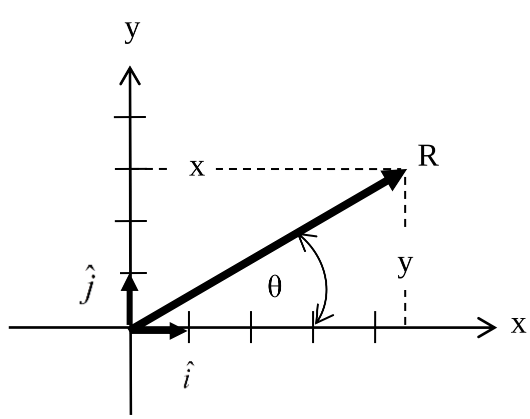


Figure 5.9 General diagram of a vector defining x, y, R, and θ.

To convert from polar to Cartesian, use the following relationships:

Find:

Cartesian information: $x\hat{i} + y\hat{j}$ given Polar information: (R, θ)

Equations:

$x\hat{i} = R\cos\theta$ Eqn. 5.10

$y\hat{j} = R\sin\theta$ Eqn. 5.11

To convert from Cartesian to Polar, use the following relationships:

Find:

Polar information: (R, θ) given Cartesian information: $x\hat{i} + y\hat{j}$

Equations:

$$R = \sqrt{x^2 + y^2}$$ Eqn. 5.12

$$\theta = \arctan\left(\frac{y}{x}\right)$$ Eqn. 5.13

Let's use the previous example to verify that the components were resolved correctly.

Example:

Given: The vector was given as: $\vec{a}$ = (5 ft/s^2, 143.13°). This means the vector length is 5 and the angle is 143.13°.

Find: Cartesian components.

Relevant information: Although you may have seen the definition of sine and cosine given in terms of an acute angle, it is not necessary to find the corresponding acute angle associated with the given angle. In fact, if the angle is given properly (measured counterclockwise from the x-axis), the sign of the component will automatically be determined by the trigonometric functions!

Solution:

$a_y = R\sin\theta$

$a_y = 5\sin(143.13)$

$a_y = 3.000007$ ft/s^2

Paying attention to the significant digits, and expressing the answers in the correct format:

$\vec{a} = (-4\hat{i} + 3\hat{j})$ ft/s^2

This checks out with the original information given, including the correct sign!

Vector Mathematics

Now that we are familiar with vector representation, we can begin to learn how to manipulate vectors, both graphically and mathematically. We will learn how to add, subtract and multiply vectors in the following section.

Addition

When adding two or more vectors, you simply add the similar components together. All of the $\hat{i}$ values are added together to determine the $\hat{i}$ component of the resulting vector. Likewise, all of the $\hat{j}$ components are added together to determine the $\hat{j}$ component of the resulting vector. An example is given below:

Example 1:

Let us define vector $\vec{A}$ as: $\vec{A} = 3\hat{i} + 6\hat{j}$

and let us define vector $\vec{B}$ as: $\vec{B} = 5\hat{i} - 4\hat{j}$

To add $\vec{A}$ and $\vec{B}$, we simply add like components:

$$\begin{array}{lr} \vec{A} + \vec{B} = & 3\hat{i} + 6\hat{j} \\ & \underline{+\ 5\hat{i} - 4\hat{j}} \\ \boxed{\vec{A} + \vec{B} = \quad 8\hat{i} + 2\hat{j}} & \end{array}$$

If you wanted to add three or more vectors together, the procedure is identical; simply add all values of the $\hat{i}$ components together and then add all the values for the $\hat{j}$ components together. Another example follows:

Example 2:

Let us define vector $\vec{A}$ as: $\vec{A} = 12\hat{i}$

vector $\vec{B}$ as: $\vec{B} = 3\hat{i} + 7\hat{j}$

and vector $\vec{C}$ as: $\vec{C} = -3\hat{j}$

Adding all three vectors together gives us:

$$\begin{array}{lr} \vec{A} + \vec{B} + \vec{C} = & 12\hat{i} + 0\hat{j} \\ & 3\hat{i} + 7\hat{j} \\ & \underline{+\ 0\hat{i} - 3\hat{j}} \end{array}$$

$$\vec{A} + \vec{B} + \vec{C} = 15\hat{i} + 4\hat{j}$$

We can also perform vector addition graphically, which often is a useful method of analysis. To add (or subtract) vectors graphically, you arrange the vectors so that they are drawn tip to tail. This means that the beginning of the first vector can remain at the origin of the axes (although it need not be), and the next vector, which you are adding to the first vector, should be drawn so that the beginning (tip) is placed at the end (tail) of the first vector. As long as you do not change the length or angle of a vector, you can move it around anywhere on the graphing plane without affecting it. Once the vectors are arranged for addition, the resultant vector is drawn from the tip of the first vector to the tail of the last vector. Graphical addition of vectors is illustrated below in figures 5.10 – 5.12. For the example given in the figures below, the three vectors defined in Example 2, above, will be employed.

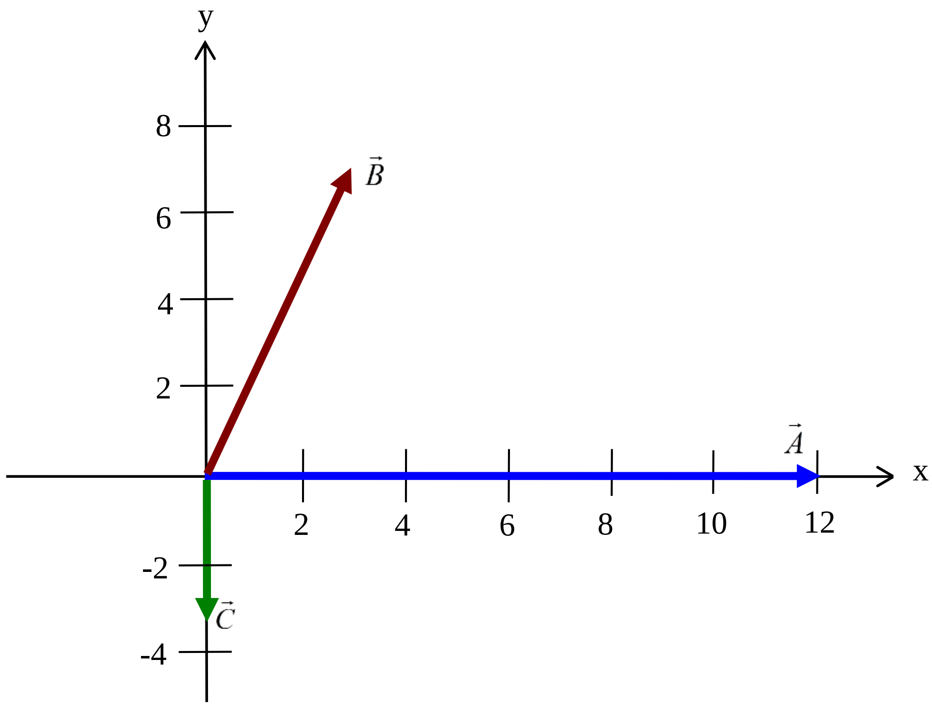


Figure 5.10 Vectors $\vec{A}$, $\vec{B}$, and $\vec{C}$ (as defined in Example 2) given on the same graph.

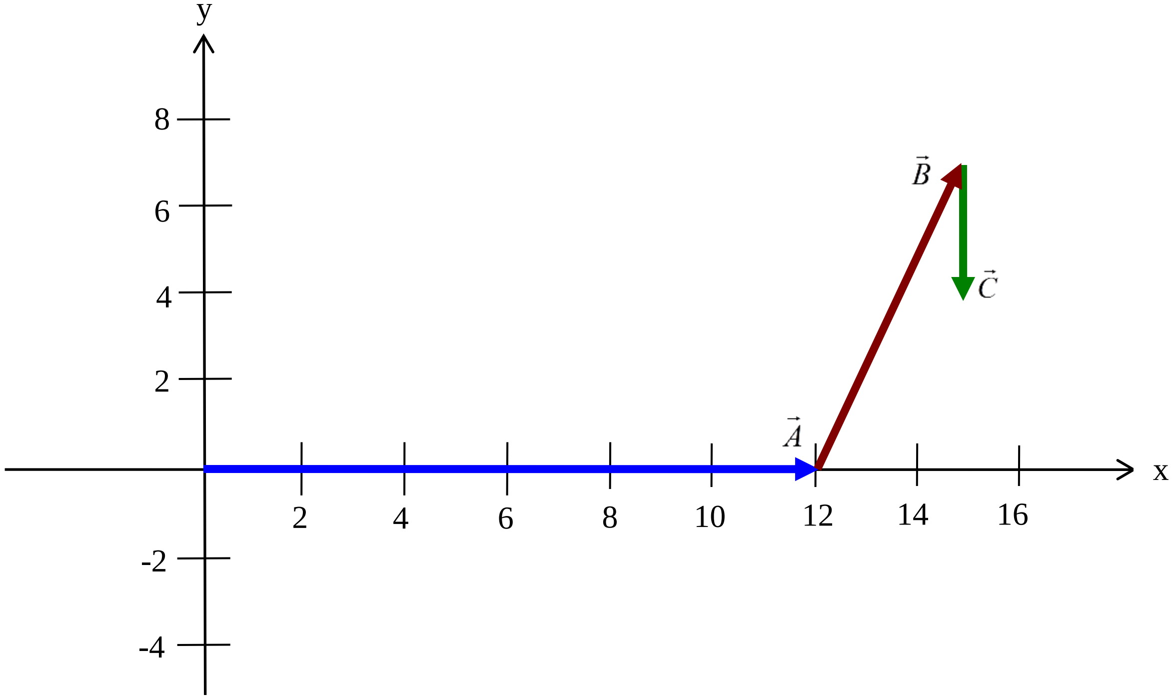


Figure 5.11 Arrangement of vectors for addition (tip to tail).

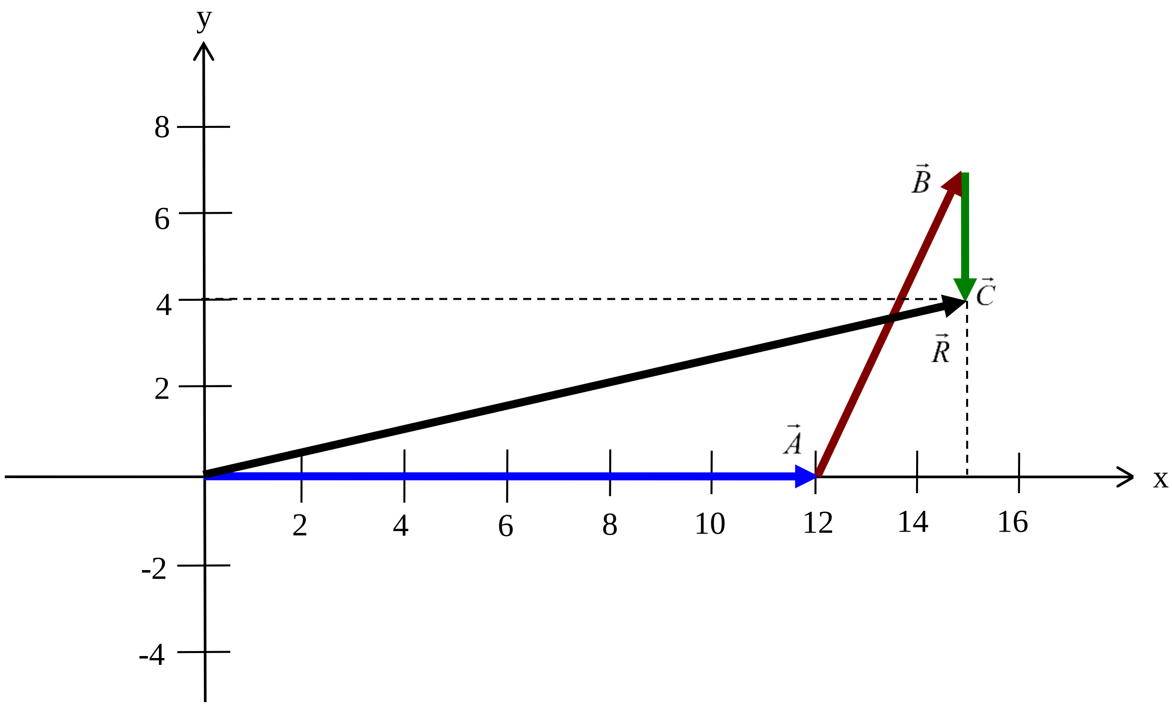


Figure 5.12 Drawing of the resultant vector, $\vec{R}$.

Notice the resultant vector in the graph above is the same as the result we found in Example 2, as it should be! Just as we added three vectors in the above example, you can add as many vectors as you want, just be sure to draw them in a chain, tip to tail each time.

Subtraction

Subtraction of a vector from another can be viewed simply as the addition of the *negative* of that vector. For example, consider the two vectors shown below in Example 3.

Example 3:

Let us define vector $\vec{A}$ as: $\vec{A} = 3\hat{i} + 6\hat{j}$

and let us define vector $\vec{B}$ as: $\vec{B} = -7\hat{i} + 4\hat{j}$

To subtract $\vec{B}$ from $\vec{A}$, we simply subtract the like component of $\vec{B}$ from $\vec{A}$:

$$\vec{A} - \vec{B} = \quad 3\hat{i} + 6\hat{j}$$

$$\underline{-(-7\hat{i} + 4\hat{j})}$$

$$\boxed{\vec{A} + \vec{B} = \quad 10\hat{i} + 2\hat{j}}$$

This is shown graphically in figure 5.13:

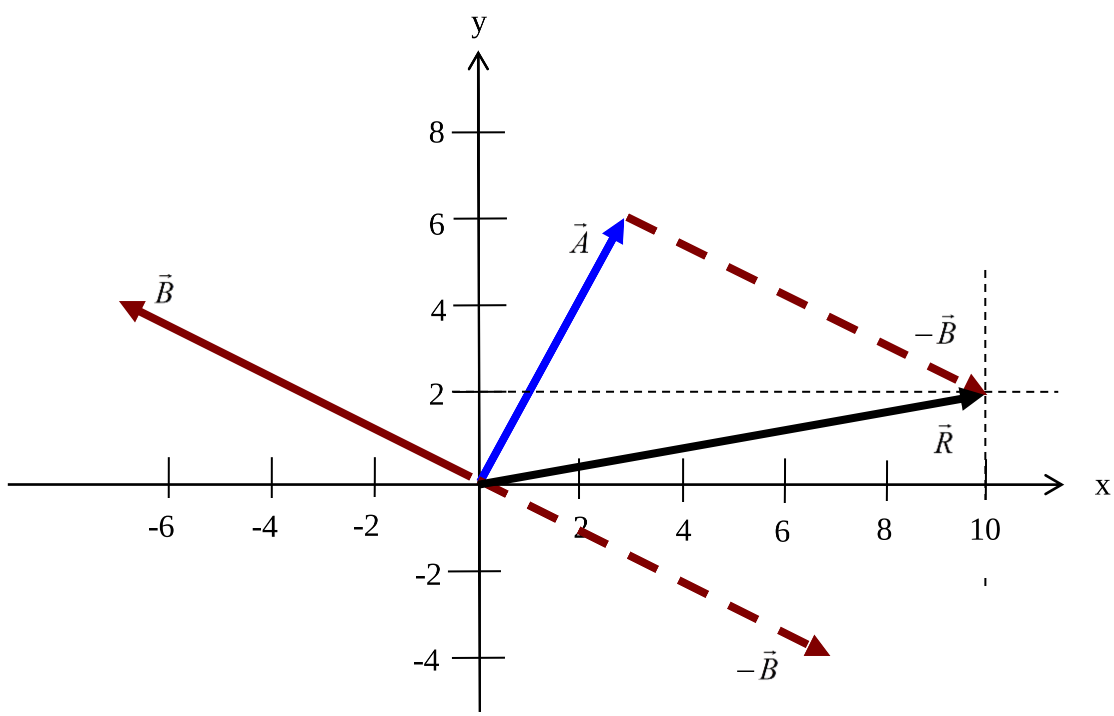


Figure 5.13 Subtraction of two vectors, $\vec{A}$ and $\vec{B}$. The two vectors are defined above in Example 3. Again, notice that the result vector matches the answer given in the mathematical result.

In the same way you can add multiple vectors, you can also subtract and/or add multiple vectors by chaining them together as in the graphical example if figure 5.12. Just remember that if you're subtracting a vector, you need to first "flip" the vector (as shown in figure 5.13) and then draw it tip to tail just as if you're adding it. This is how you simply add the negative of the original vector.

Dot Product

The dot product is one of two ways in which you can multiply two vectors. It is important to note that it is required to specify whether you're *dotting* or *crossing* two vectors. Simply "multiplying" two vectors is not defined; you must either *dot* or *cross* the vectors.

Dot Product Definition for Polar Coordinates

When you are given vectors in polar coordinate form (R, θ), you can easily compute the dot product using that information without transforming to Cartesian coordinates. The following definition is used to compute the dot product. It is important to note that the result of the dot product of two vectors is a scalar, NOT a vector. Given polar information for two vectors, $\vec{A}$ and $\vec{B}$, where $\vec{A}$ = (R_A, θ_A) and $\vec{B}$ = (R_B, θ_B)

$$\vec{A} \bullet \vec{B} = \left\|\vec{A}\right\|\left\|\vec{B}\right\| \cos\theta_{\vec{A},\vec{B}} \qquad \text{Eqn. 5.14}$$

The double lines around vectors $\vec{A}$ and $\vec{B}$ indicate the magnitude only. So $\left\|\vec{A}\right\|\left\|\vec{B}\right\|$ means you simply multiply the *magnitudes* of the two vectors together. Remember, the *magnitude* is the same as the *length* of the vector, or R. So $\left\|\vec{A}\right\|\left\|\vec{B}\right\|$ = $R_A R_B$. The definition is written in the more technical form (using the magnitude symbol) so you become familiar with common symbols and operators of vectors. The $\theta_{\vec{A},\vec{B}}$ indicates the angle between vectors $\vec{A}$ and $\vec{B}$. To compute $\theta_{\vec{A},\vec{B}}$, you need to simply subtract the smaller angle (θ_A or θ_B) from the larger angle given for the two vectors. A numerical example is given below. Figure 5.14 illustrates graphically the two vectors.

Example 4:

Given: $\vec{A} = (6{,}125°)$ $\qquad$ $\vec{B} = (3{,}270°)$

Find: $\vec{A} \bullet \vec{B}$

Solution:

$$\vec{A} \bullet \vec{B} = \left\|\vec{A}\right\|\left\|\vec{B}\right\| \cos\theta_{\vec{A},\vec{B}}$$

$$\vec{A} \bullet \vec{B} = (6)(3)\cos(270°-125°)$$

$$\vec{A} \bullet \vec{B} = -14.745$$

Notice that the answer is simply a number (a scalar quantity); no direction is associated with the result of the dot product. The significant digits given in the result are more than they should be, but it is important that you see that the results are consistent between the different methods of computing the dot product. This will be demonstrated by the following example using Cartesian coordinates.

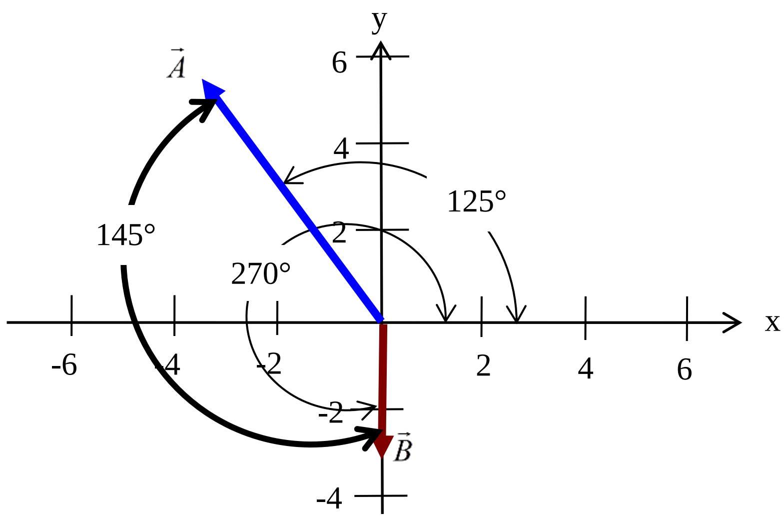


Figure 5.14 Graphical illustration of vectors $\vec{A}$ and $\vec{B}$ from Example 4, and the angle between them.

Dot Product Definition for Cartesian Coordinates

When you are presented with the vectors in Cartesian coordinates (x $\hat{i}$ + y $\hat{j}$), the dot product can be computed using the following definition without transforming to polar coordinates. Vector $\vec{A}$ is defined in general terms as $\vec{A} = A_x\hat{i} + A_y\hat{j}$, and vector $\vec{B}$ as $\vec{B} = B_x\hat{i} + B_y\hat{j}$.

$$\vec{A} \bullet \vec{B} = A_x B_x + A_y B_y \qquad \text{Eqn. 5.15}$$

A numerical example is shown below; the same vectors as given in Example 4 will be used. The transformation to Cartesian coordinates has already been done; this is a good opportunity for you to check your own ability to convert between polar and Cartesian coordinates

Example 5:

Given: $\vec{A} = -3.4415\hat{i} + 4.9149\hat{j}$ $\qquad$ $\vec{B} = 0\hat{i} - 3\hat{j}$

Find: $\vec{A} \bullet \vec{B}$

Solution: $\vec{A} \bullet \vec{B} = A_x B_x + A_y B_y$

$$\vec{A} \bullet \vec{B} = (-3.4415)(0) + (4.9149)(-3)$$
$$\vec{A} \bullet \vec{B} = -14.745$$

Dot Product Physical Significance

The physical significance of the dot product is likely not obvious to you at this point, but it is important to have an idea of what the dot product produces physically. If you consider the definition given in polar coordinates, you might realize that the dot product gives the *projection* of one vector in the direction of the second vector, multiplied by the length of the second vector. The projection can be thought of as the "shadow" cast by the first vector onto the second vector if a light was shone perpendicular to the second vector. Consider the definition again: $\vec{A} \bullet \vec{B} = \|\vec{A}\|\|\vec{B}\|\cos\theta_{\vec{A},\vec{B}}$. The equation can be broken into parts: $\|\vec{A}\|$ and $\|\vec{B}\|\cos\theta_{\vec{A},\vec{B}}$. The latter part is just like vector resolution (R cos θ) – except you're resolving vector $\vec{B}$ **not** along the x or y axes, but in the direction of vector $\vec{A}$; this is accomplished by the fact that you subtract the two angles before taking the cosine. The quantity $\|\vec{B}\|\cos\theta_{\vec{A},\vec{B}}$ gives the length of the "shadow" cast by vector $\vec{B}$ onto vector $\vec{A}$, and then you multiply that quantity by $\|\vec{A}\|$. Figure 5.15 might illustrate the "projection" concept better.

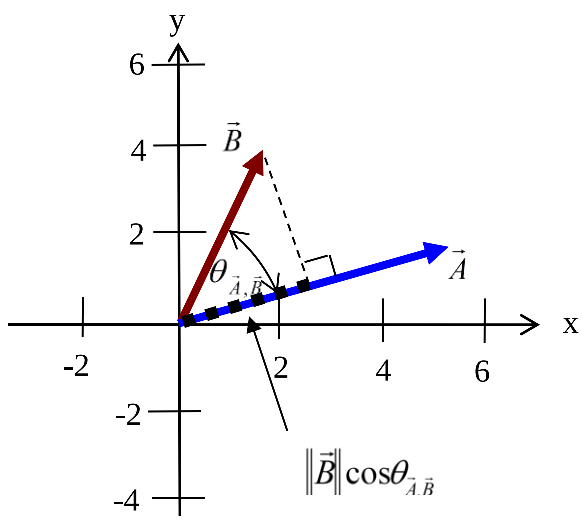


Figure 5.15 Illustration of physical significance of the dot product.

So you may be asking what usefulness is this dot product? Well, consider the definition of *work* you may have encountered in Physics. The definition you may have learned by now is that the work done by a force on an object is the magnitude of the force acting on the object multiplied by the *displacement* (distance moved) of the object as a result of that force. But what other important factor do you have to consider when calculating work? When calculating work, you only want that amount of force that is in the direction of the displacement. What does this mean? Well, consider walking across a level surface with a heavy object. Is gravity doing any work on that object if you keep it at a level height while walking? The answer is no. Since the height above the ground does not change, no work is done on the object by the force of gravity. On the other hand, if you drop the object, there is displacement of that object in the direction of gravity. In this latter case, the work done by the gravitational force is equal to Work = (Weight of the object)x(Distance the object fell). If you consider the dot product, you may notice that it gives us the exact operation we want when computing work. Still not convinced? Consider the metal block on the metal table from the beginning of this section (Figures 5.4- 5.7). For the last situation, when the applied force was exerted down and to the left, how would you compute the work done by that force (if you were given the distance traveled by the block)? Would you multiply the entire force by the distance traveled, or would you multiply only the component of the force parallel to the table? The correct answer is the latter; you would only multiply by the component of the force parallel to the table! The downward component of the force did not result in the displacement of the block, it only served to increase the normal force on the block; thus, it did no work. If you dot the force vector and the displacement vector, what you end up with is the work done by the force vector. There are other applications of the dot product, which you will learn about in such courses as: Calculus, Physics, Dynamics and Fluid Mechanics.

Dot Product Properties

When using the dot product, it is helpful to know the following properties:

Commutative (order):

The dot product IS commutative.

$\vec{A} \bullet \vec{B} = \vec{B} \bullet \vec{A}$ Eqn. 5.16

Associative (grouping):

The dot product IS associative with a scalar

$a(\vec{A} \bullet \vec{B}) = (a\vec{A}) \bullet (\vec{B}) = \vec{A} \bullet (a\vec{B})$ Eqn. 5.17

The dot product is NOT associative with a third vector

$(\vec{A} \bullet \vec{B}) \bullet \vec{C} \neq \vec{A} \bullet (\vec{B} \bullet \vec{C})$

In fact, you cannot dot a third vector with the result from the dot product of two vectors, since the dot product results in a scalar! (You cannot dot a scalar and a vector; it is undefined.)

Distributive (distributing):

The dot product IS distributive

$\vec{A} \bullet (\vec{B} + \vec{C}) = (\vec{A} \bullet \vec{B}) + (\vec{A} \bullet \vec{C})$ Eqn. 5.18

<u>Cross Product</u>

Cross Product Definition for Polar Coordinates

The cross product is the other defined way in which you can multiply two vectors. When you are given vectors in polar coordinates (R, θ), you can easily compute the cross product using that information without transforming to Cartesian coordinates. The following definition is used to compute the cross product. It is important to note that the result of the cross product of two vectors is a VECTOR (remember, the *dot* product results in a scalar). Given polar information for two vectors, $\vec{A}$ and $\vec{B}$, where $\vec{A} = (R_A, \theta_A)$ and $\vec{B} = (R_B, \theta_B)$

$$\vec{A} \times \vec{B} = \|\vec{A}\|\|\vec{B}\| \sin \theta_{\vec{A},\vec{B}} \hat{n}_{\perp \vec{A},\vec{B}} \qquad \text{Eqn. 5.19}$$

Please note the difference between the cross product and the previously defined dot product (see Eqn. 5.13). There are two differences; 1) the definition requires the sine of the angle between the two vectors you are crossing in lieu of the cosine (as in the dot product), and 2) there is now a unit normal vector in the definition ($\hat{n}_{\perp \vec{A},\vec{B}}$). As just mentioned, the cross product results in a vector, so it is necessary to have a direction as part of the definition. By definition, the resulting direction of the cross product is perpendicular to the plane that contains the two vectors you are crossing. *Normal* is another word for perpendicular (*orthogonal* is yet another term), and the ^ is the symbol used to indicate a unit vector (a vector with length equal to one unit so it does not effect the magnitude of the vector, it only assigns the direction). Vectors $\hat{i}$ and $\hat{j}$ are also unit vectors. Notice that they have the ^ symbol over them and not the → symbol.

You may realize that there would always be two unit vectors that are perpendicular to the plane containing vectors $\vec{A}$ and $\vec{B}$, and so how do you know which way is the correct result for your cross product? The best way to determine the answer to this question is the *right-hand rule*[3]. To determine the direction of the cross product result, point your four fingers (of your *right* hand) in the direction of the first vector (in this case $\vec{A}$) and then bend your wrist so your fingers now point in the direction of the second vector (in this case $\vec{B}$); your thumb now points in the resulting direction of the cross product, $\hat{n}_{\perp \vec{A},\vec{B}}$. You may also realize, at this point, that the cross product requires that we work with all three spatial dimensions. When given polar information, you can assume that the vector is 2-D. To properly represent a 3-D vector, spherical coordinates are required (or Cartesian). A numerical example is given below. Figure 5.16 illustrates graphically the cross product for the vectors given in Example 6.

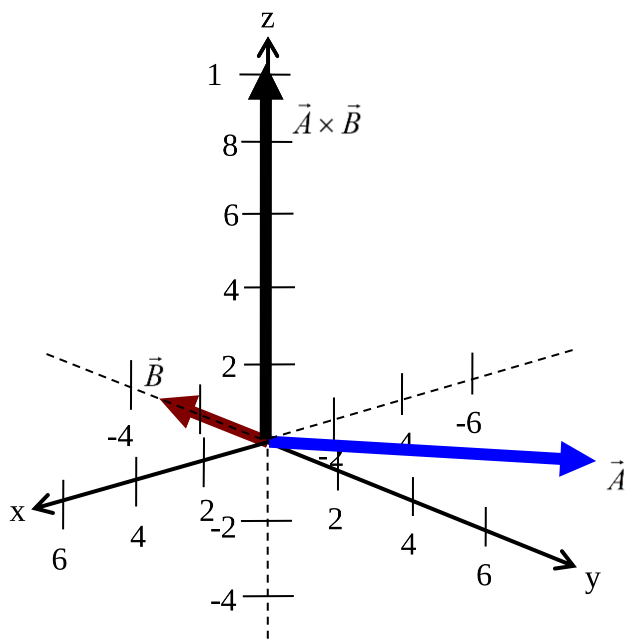


Figure 5.16 Graphical illustration of vectors $\vec{A}$ and $\vec{B}$ from Example 6, and the resulting vector of the cross product.

Example 6:

Given: $\vec{A} = (6{,}125°)$ $\vec{B} = (3{,}270°)$

Assumptions: Angles given are measured from the positive x-axis and vectors are 2-D, confined to the x-y plane.

Find: $\vec{A}\times\vec{B}$

Solution:

$$\vec{A}\times\vec{B} = \left\|\vec{A}\right\|\left\|\vec{B}\right\| \sin\theta_{\vec{A},\vec{B}}\,\hat{n}_{\perp\vec{A},\vec{B}}$$

$$\vec{A}\times\vec{B} = (6)(3)\ \sin\ (270°\text{-}125°)\ \hat{n}_{\perp\vec{A},\vec{B}}$$

$$\vec{A}\times\vec{B}\ = 10.324\,\hat{n}_{\perp\vec{A},\vec{B}}$$

$$\vec{A}\times\vec{B}\ = 10.324\,\hat{k}$$

(where $\hat{k}$ is the unit vector pointing along the positive z axis).

Cross Product Definition for Cartesian Coordinates

When you are presented with the vectors in Cartesian coordinates (x $\hat{i}$ + y $\hat{j}$ + z $\hat{k}$), ($\hat{k}$ is the unit vector associated with the z axis), the cross product can be computed by finding the determinant of order 3 defined by the unit vectors of the Cartesian Coordinate System ($\hat{i}$, $\hat{j}$ and $\hat{k}$), and the components of the vectors you are crossing ($\vec{A}$ and $\vec{B}$)[4]. This procedure is best explained in person by your instructor; you should ask to see it in class. The result of this procedure is given below with vectors $\vec{A}$ and $\vec{B}$ as defined.

Let $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$

And $\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$

Then $\vec{A}\times\vec{B} = (A_yB_z - A_zB_y)\hat{i} + (A_zB_x - A_xB_z)\hat{j} + (A_xB_y - A_yB_x)\hat{k}$ Eqn. 5.20

Two numerical examples are shown below:

<u>Example 7: (using the vectors from Example 6)</u>

<u>Given:</u> $\vec{A} = -3.4414\hat{i} + 4.915\hat{j} + 0\hat{k}$ $\vec{B} = 0\hat{i} - 3\hat{j} + 0\hat{k}$

<u>Find:</u> $\vec{A}\times\vec{B}$

<u>Solution:</u>

$$\vec{A}\times\vec{B} = (A_yB_z - A_zB_y)\hat{i} + (A_zB_x - A_xB_z)\hat{j} + (A_xB_y - A_yB_x)\hat{k}$$
$$\vec{A}\times\vec{B} = [(4.915)(0) - (0)(-3)]\hat{i} + [(0)(0) - (-3.4414)(0)]\hat{j}$$
$$+[(-3.4414)(-3) - (4.915)(0)]\hat{k}$$
$$\vec{A}\times\vec{B} = 10.324\hat{k}$$

(Note: this is the same answer as found in Example 6, as it should be)

<u>Example 8:</u>

<u>Given:</u> $\vec{A} = -5\hat{i} + 3\hat{j} + 2\hat{k}$ $\vec{B} = 0\hat{i} - 3\hat{j} - 3\hat{k}$

<u>Find:</u> $\vec{A}\times\vec{B}$

<u>Solution:</u>

$$\vec{A}\times\vec{B} = (A_yB_z - A_zB_y)\hat{i} + (A_zB_x - A_xB_z)\hat{j} + (A_xB_y - A_yB_x)\hat{k}$$
$$\vec{A}\times\vec{B} = [(3)(-3) - (2)(-3)]\hat{i} + [(2)(0) - (-5)(-3)]\hat{j} + [(-5)(-3) - (3)(0)]\hat{k}$$
$$\vec{A}\times\vec{B} = -3\hat{i} - 15\hat{j} + 15\hat{k}$$

Cross Product Physical Significance

The cross product is useful for computing some very important quantities. When the cross product is computed, the magnitude of the result is equal to the area of the parallelogram enclosed by the vectors $\vec{A}$ and $\vec{B}$. This can be proven by inspection of figure X.17 below. The area of the rectangle is defined as the length of vector $\vec{A}$ multiplied by the length of vector $\vec{B}$ times $\sin\theta_{\vec{A},\vec{B}}$. And as you can see from the diagram, the area of the rectangle and the area of the parallelogram (defined by the two vectors) are equal. Thus, $\|\vec{A}\|\|\vec{B}\|\sin\theta_{\vec{A},\vec{B}}$ equals the area of the parallelogram. It also turns out that quantities such as torque (or *moment*), velocity of an object moving in a circular path, and the vorticity of a flowfield are all computed using the cross product.

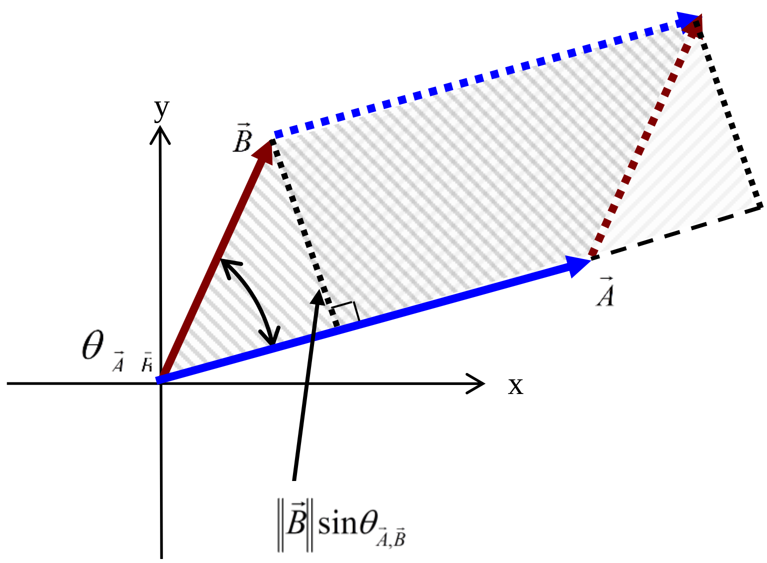


Figure 5.17 Illustration demonstrating the magnitude of the result of the cross product.

Cross Product Properties

When using the cross product, it is helpful to know the following properties:

Commutative (order):

The cross product is NOT commutative.

$\vec{A}\times\vec{B}\neq\vec{B}\times\vec{A}$ [in fact, $\vec{A}\times\vec{B}=-(\vec{B}\times\vec{A})$] Eqn. 5.21

Associative (grouping):

The cross product IS associative with a scalar

$a(\vec{A}\times\vec{B})=(a\vec{A})\times(\vec{B})=\vec{A}\times(a\vec{B})$ Eqn. 5.22

The cross product is NOT associative with a third vector

$$(\vec{A}\times\vec{B})\times\vec{C}\neq\vec{A}\times(\vec{B}\times\vec{C})$$

Although occasionally, you may find it works with the unit vectors.

Distributive (distributing):

The cross product IS distributive

$$\vec{A}\times(\vec{B}+\vec{C})=(\vec{A}\times\vec{B})+(\vec{A}\times\vec{C}) \qquad \text{Eqn. 5.23}$$

Computer Essentials

Please refer to Appendix 3 for a summary of concepts that will be used in your EGR 115 course.

Algebra Exercises

1) Solve the following equations:

a. $x^2 + 9x - 10 = 0$
b. $x^2 - 2x - 7 = 0$
c. $3x^2 + 5x + 1 = 0$

2) Use the Binomial Theorem to expand the expressions:

a. $(x^2 - 1)^4$
b. $(3 + x^2)^5$
c. $(a + b)^6$

3) Simplify the following expressions:

a. $\ln a^4b^{-5}$
b. $64^{-4/3}$
c. $(x^{-5}y^3z^{10})^{-3/5}$

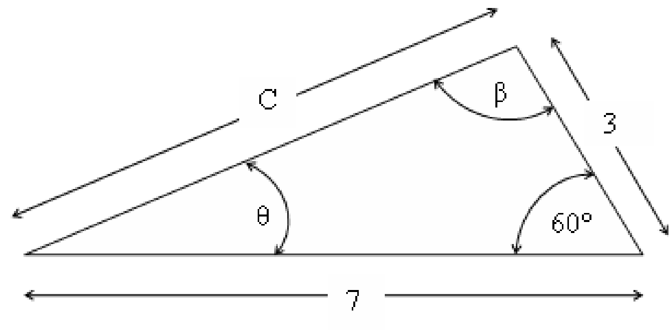
4) Perform operations on complex numbers:

a. $5i - (-9 + i)$
b. $\sqrt{3}e^{i\pi/6} \div 2\sqrt{6}e^{i\pi/4}$
c. What is the polar form of $-5i$?
d. What is the rectangular form of $7e^{i\pi/4}$?

Trigonometry Exercises

1) Find the following trigonometric values using the diagram:

a. C
b. β
c. θ
d. sin β
e. cos θ
f. cot θ
g. csc β



2) Without looking in the chapter, state the Law of Sines, Law of Cosines and Pythagorean Theorem:

a. Law of Sines:
b. Law of Cosines:
c. Pythagorean Theorem:

3) Using a calculator, find the following:

a. sin 45°
b. cos 20°
c. $\sin^{-1}$ (0.5) expressed in degrees
d. The hypotenuse of a right triangle with legs of 3 and 4
e. tan π
f. cos (π/2)
g. sec (π/3)
h. $\cos^{-1}$ (1) expressed in radians

Vector Exercises

1) Determine the validity of the following statements based on the diagram:

T or F a. $\vec{G}+\vec{C}=\vec{H}$

T or F b. $\vec{A}+\vec{C}=\vec{D}$

T or F c. $\vec{B}+\vec{E}+\vec{I}=\vec{0}(zerovector)$

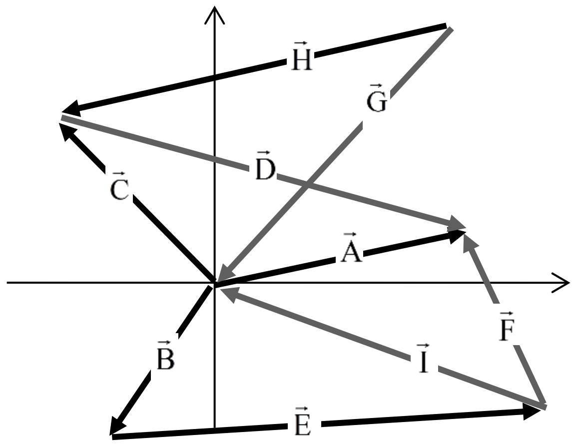
T or F d. $\vec{B}+\vec{E}+\vec{F}=\vec{A}$

T or F e. $\vec{A}-\vec{C}=\vec{D}$

T or F f. $\vec{C}+\vec{D}+\vec{F}+\vec{E}=\vec{B}$

T or F g. $\vec{C}+\vec{I}+\vec{D}=\vec{F}$

T or F h. $\vec{I}-\vec{F}=\vec{A}$



2) <u>Determine the validity of the following statements:</u>

T or F a. $\vec{A}\bullet\vec{B}=|\vec{A}||\vec{B}|\sin\theta_{\vec{A},\vec{B}}$

T or F b. $\vec{A}\bullet\vec{B}=\vec{B}\bullet\vec{A}$

T or F c. $(b\vec{A})\bullet(a\vec{B})=(a\vec{A})\bullet(b\vec{B})$

T or F d. $(\vec{A}\bullet\vec{B})\bullet(\vec{C}\bullet\vec{D})=(\vec{A}\bullet\vec{C})\bullet(\vec{B}\bullet\vec{D})$

T or F e. $\vec{A}\times\vec{B}=|\vec{A}||\vec{B}|\sin\theta_{\vec{A},\vec{B}}$

T or F f. $\left[\vec{A}\times(\vec{B}+\vec{C})\right]\times\vec{E}=\left[(\vec{A}\times\vec{B})\times\vec{E}\right]+\left[(\vec{A}\times\vec{C})\times\vec{E}\right]$

3) <u>Prove the following statements:</u>

a. $\left[\vec{A}\times(\vec{B}+\vec{C})\right]=\left[(\vec{A}\times\vec{B})\right]+\left[(\vec{A}\times\vec{C})\right]$

b. $\vec{A}\times\vec{B}=-(\vec{B}\times\vec{A})$

References

[1] Stewart, J., *Review of Algebra*, available online at: www.stewartcalculus.com/

[2] Beckmann, Petr, *A History of* π, St. Martin's Press, New York, 1971, pg 21

[3] Stewart, J. *Calculus, 2nd edition*, Brooks/Cole Publishing Company, 1991, pg 659

[4] Stewart, J. *Calculus, 2nd edition*, Brooks/Cole Publishing Company, 1991, pg 658

Chapter 6
Excel

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Excel

As an engineering student and as a practicing professional engineer, you will find that certain calculations will have to be performed numerous times. Sometimes this is because you have alternate values you're considering, or because you have to re-iterate through the entire analysis until the final output for a given quantity converges towards the initial estimate. Regardless of the reason, performing the same calculation over and over can be tedious, not to mention time consuming. For this reason, tools such as spreadsheets can be extremely useful and save the engineer valuable time. In this section, the program Excel, as part of the Microsoft Office Suite, will be introduced. It is highly recommended that you borrow from the library, or even purchase, a copy of the program (if you don't already have it on your own computer) and the user manual for the program. The best way to become familiar with all of the functions within Excel is to practice using the program as much as possible. Even if you do not use it much for this course, you will realize its usefulness when you are in your lab classes and senior design classes. By that point in your college career, you do not want to "just" be learning how to use Excel. The current chapter is written with screenshots taken from the 2003 version of Excel. Though this is not the most current version and the "look" may be slightly different, the basic functions shown are still the same.

Data Input and Computing

Microsoft Excel is a spreadsheet program that allows the user to organize data, compute calculations, and graph data[1]. There are several other features to this program, but those will be the primary functions for which you will be using the program, at least initially. The spreadsheet is organized into columns and rows of *cells*, into which data can be inputted and which can be referenced in equations, much like variables. Columns are designated by letters and rows designated by numbers (see fig. 6.1).

For organizing data, Excel is extremely useful. Recall the Time Management chapter where we used Excel to determine the percentage of time per week required for each activity (see Fig. 6.2). To create a similar spreadsheet for yourself, simply follow these instructions: start Excel (Start | Programs | Microsoft Office | Excel), then click in the cell A1 and type in "Weekly Activities". Then hit enter and type in "Class Hours" <enter>, "Study Hours" <enter>, etc., all the way to "Free Time". Next, click on cell B and type in "Hours", and then type in "Percentage" into cell C1. Next click in B2 through B10 (one at a time) and each time type in your quantities for hours for each activity. The last value for Free Time was actually computed.

When you want to compute an equation, you select one of the cells (by clicking on it), type in the equals sign and begin to type in the formula or equation. Each time there is a different variable in the equation, you can choose a different cell to represent that variable and reference it in the equation using its column and row designation. Later, you can plug in different values for those variables by typing in the value into the corresponding cell that you referenced in the equation. As soon as the values are inputted into the cells, the calculation is automatically computed and the result is given in the cell into which you typed the equation! For the current example from the Time Management chapter, click in C10 and type in "= 168 - sum(B2..B9)" then hit <enter>. That says the cell C10 will be computed and assigned the value of 168 – sum of the columns from B2 up to and including B9. A more detailed example which details the process of computing is shown in the sequence of figures 6.3 - 6.8 and begins following Fig. 6.2.

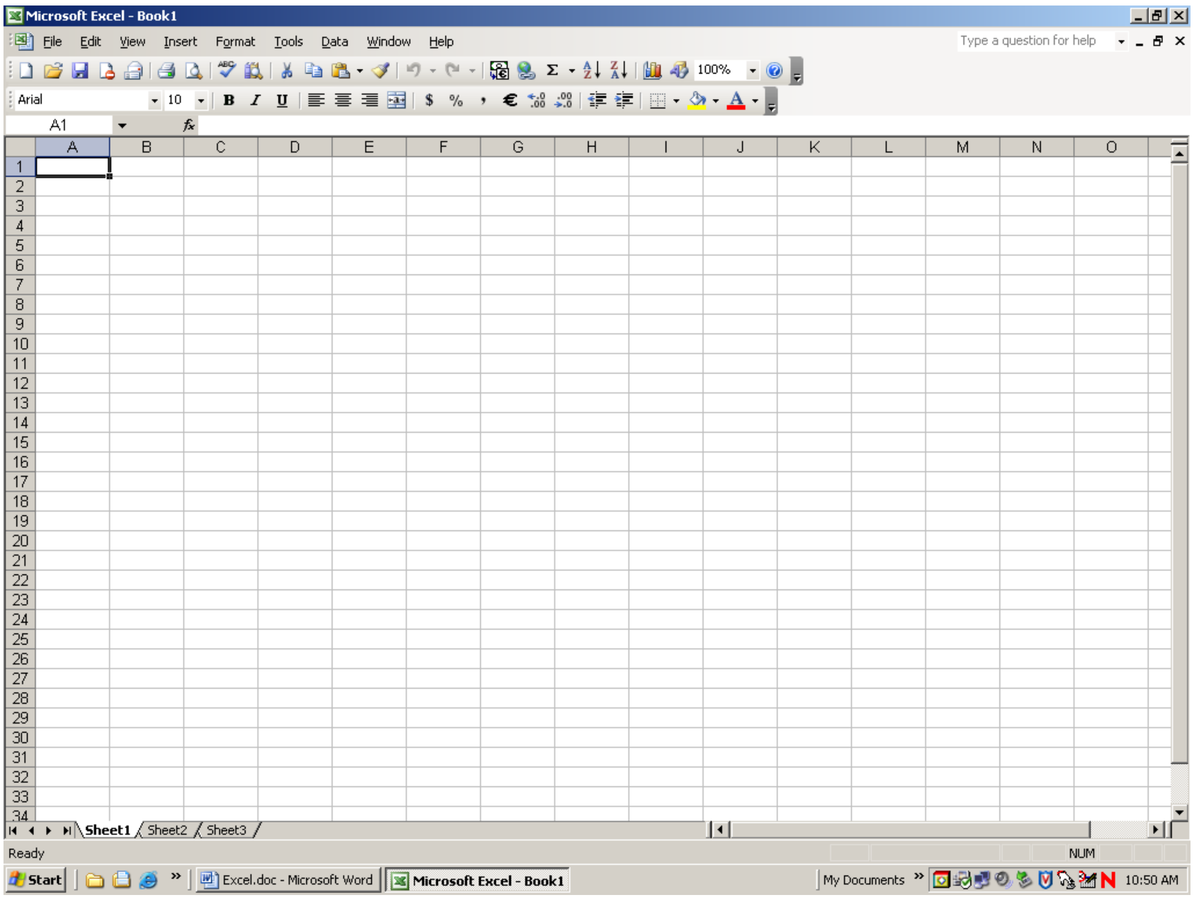
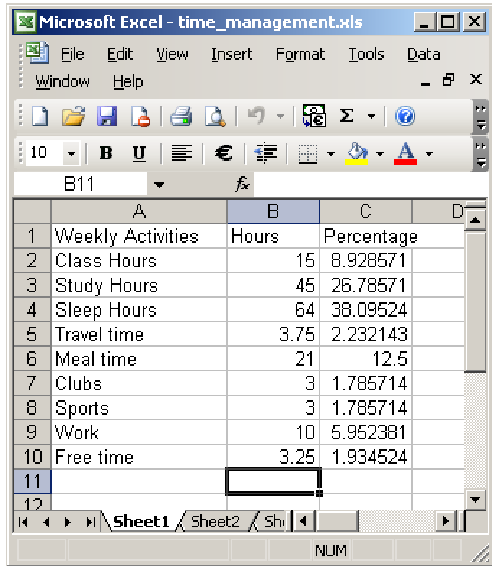


Figure 6.1 Snapshot of a new workbook spreadsheet page.



	A	B	C
1	Weekly Activities	Hours	Percentage
2	Class Hours	15	8.928571
3	Study Hours	45	26.78571
4	Sleep Hours	64	38.09524
5	Travel time	3.75	2.232143
6	Meal time	21	12.5
7	Clubs	3	1.785714
8	Sports	3	1.785714
9	Work	10	5.952381
10	Free time	3.25	1.934524

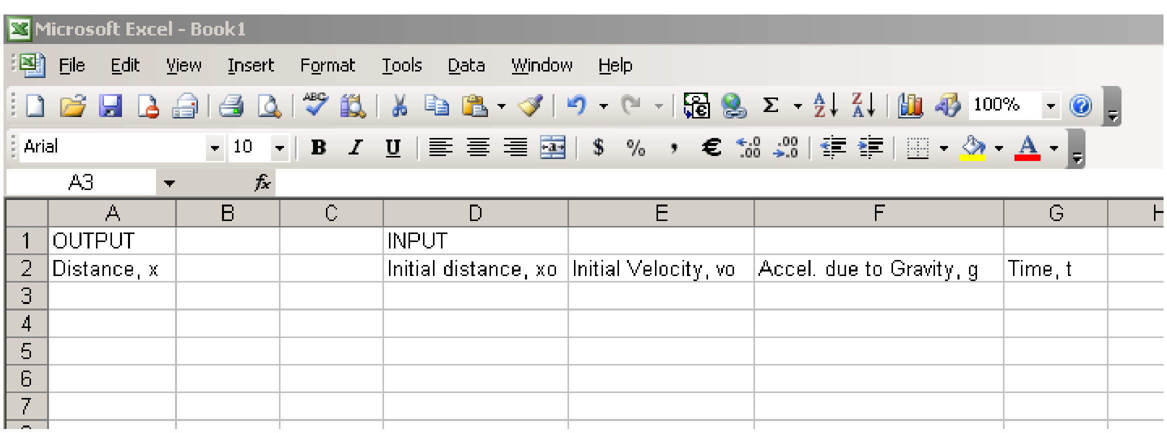
Figure 6.2 Snapshot of Weekly Activities Data Organized in an Excel Spreadsheet.

To demonstrate the process explained above, the distance traveled by a free-falling object will be computed. The equation for this well-defined motion is:

$$x = x_o + V_o t - 0.5gt^2 \qquad \text{Eqn. 6.1}$$

Where x_o is the initial placement at the time of release, V_o is the initial velocity of the object at the time it is released, g is the local acceleration due to gravity acting on the object, t is the time elapsed since the object was released, and x is the final placement of the object at time t. In this example, x_o,V_o, g and t are the input variables and x is the output (or result) variable.

Step 1 is to label your "result" or output cell and all of your input cells, as shown in figure 6.3 below. Notice that the column widths have been increased to accommodate the labels. This is done by moving the cursor on the column line (in between the two letters) to the right of the column you wish to increase. The cursor will turn into an elongated cross with arrows on the horizontal line. As soon as it does, click and hold the left mouse button while dragging the column line to the desired width.



	A	B	C	D	E	F	G
1	OUTPUT			INPUT			
2	Distance, x			Initial distance, xo	Initial Velocity, vo	Accel. due to Gravity, g	Time, t

Figure 6.3 Labeling the output and input cells

Step 2 is to click on the cell under your output label and begin typing in the equation you want to calculate. Instead of typing in the variables, reference the input cells instead. You can do this by either typing in the cell designation (column letter, row number), or by clicking on the cell you want to reference. Excel lets you know which cell you've chosen by highlighting its border in a unique color (see figure 6.4). Reference the cells directly below your labels for each variable input. You will notice the equation appearing in the f_x field directly above the cells. For a list of how to program common mathematical operations, please see Table 6.1 at the end of this chapter.

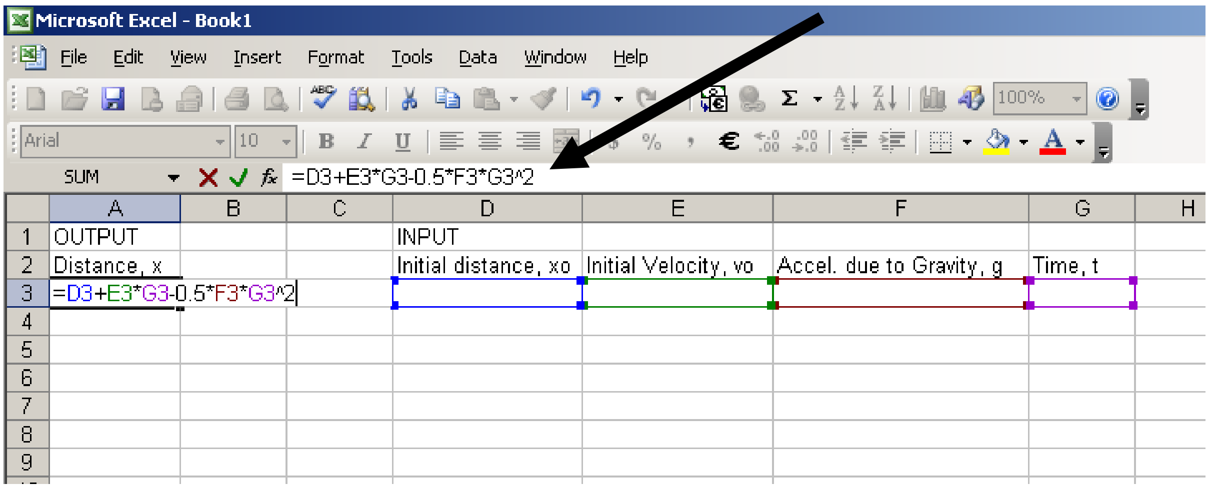


Figure 6.4 Typing in the equation using the cell column and row designation for each input cell in lieu of its original variable name.

Step 3 is initiated once you have finished typing the equation. Click on the green checkmark next to the f_x field into which you were typing the equation. This indicates to Excel that you are finished editing the equation. See figure 6.5 for illustration. If there are any syntax errors in your equation, Excel will notify you immediately after you click the checkmark. It will suggest possible fixes and allow you to either accept its suggestions or fix the equation yourself.

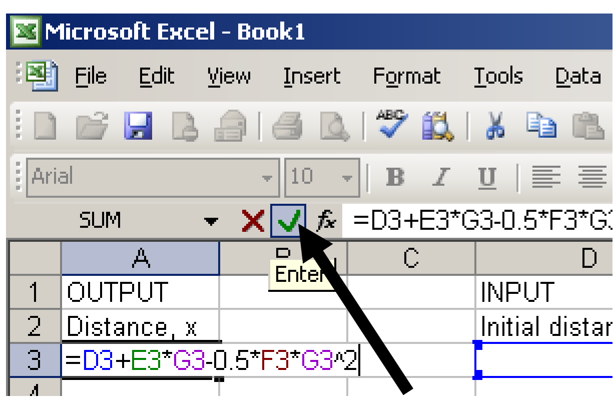


Figure 6.5 Illustration locating the checkmark button for finishing and submitting the equation.

Step 4 is to simply type in the input values for each input variable in your equation. If you followed the directions correctly, you want to type the values into the cells directly below your labels for each input, as these were the actual cells you referenced in the equation. The labels are there to simply serve as indicators for you. Figure 6.6 demonstrates inputting some example values. After you click on the appropriate cell, type in the value and hit <enter>; this submits the value into the equation.

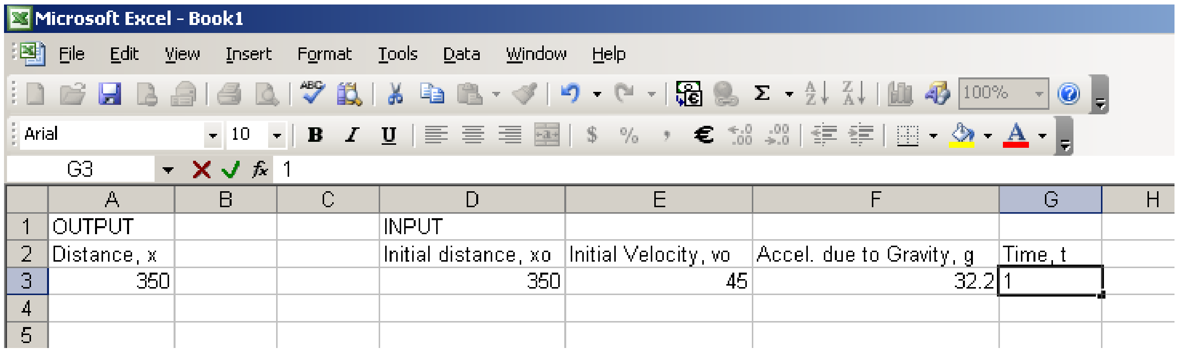


Figure 6.6 Demonstration of inputting values for the variable inputs.

The final step is actually done for you. Once you have all the values inputted, the final result is calculated for you based on those inputted values and displayed in the original "result" cell into which you typed the equation. Actually, the calculation is done even with the cells blank; the calculation is automatically updated every time you update any of the input values (as soon as you hit <enter>, the value is updated and the result re-calculated)! You may begin to realize the power of this tool as you type in different values for t or x_o and the new result for x is automatically re-computed for you! This is illustrated in figures 6.7 and 6.8.

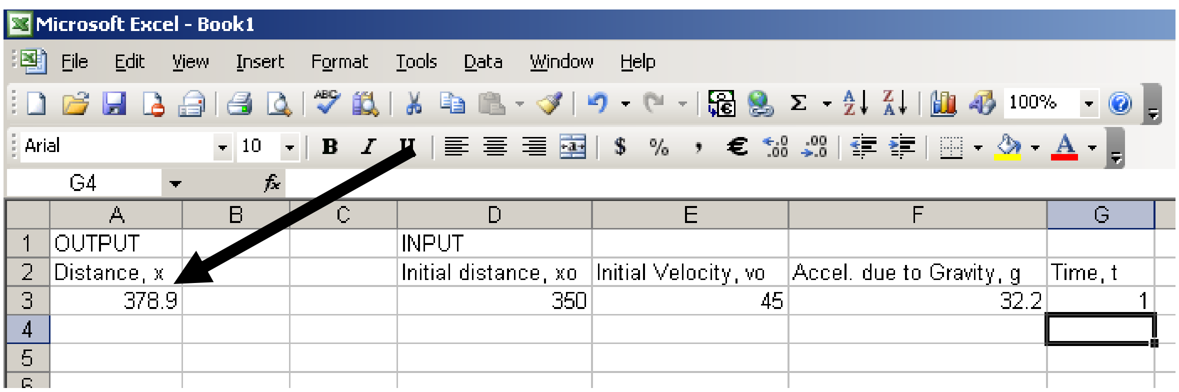


Figure 6.7 Initial result for x displayed with original inputs of x_o=350 ft, V_o = 45 ft/s, g =32.2 ft/s^2 and t = 1 seconds.

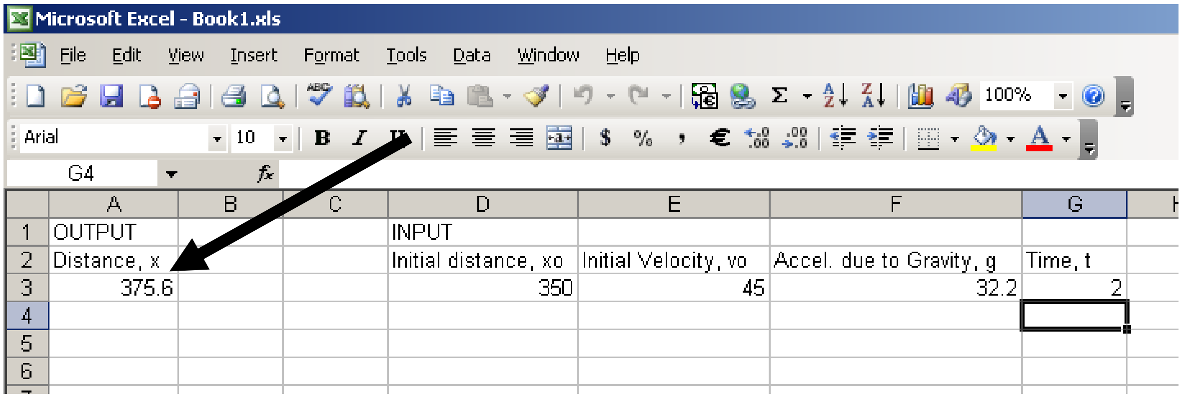


Figure 6.8 Secondary result for x with a value of t = 2 seconds inputted. Result is automatically calculated with no effort required of the user.

Even more powerful is the ability to display multiple calculations at the same time. Let's say you want to plot x as a function of t for some fixed x_o, V_o, and g. You don't want to replace the old result with the new one; instead, you would like to display all of the results for each second from say, t = 0 seconds to t = 6 seconds. How do you do this? You first begin listing all of the input times, starting with 0, listing each successive one under the previous one. This is illustrated in figure 6.8 below. Since the increments between each time value are equal, we can actually input this series of data very quickly. Type in zero into cell G3, then click on cell G4 and input the equation: "=G3+1". Hit the green checkmark (as in Fig.6.5) and then click on the result cell (G4 in this case) and then move your cursor towards the lower right corner of that cell. Hover there until the large cross sign turns into a small black cross sign. As soon as it does, click and drag the mouse down until you've highlighted the number of cells you want (Figures 6.10 and 6.11 illustrate the two different cross signs).

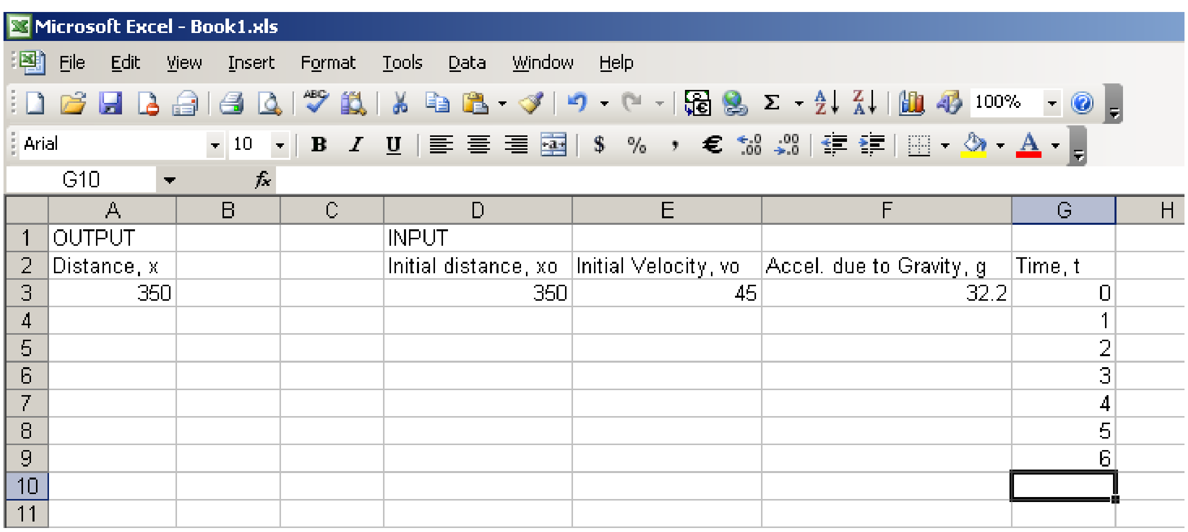


Figure 6.8 Inputting multiple values for a given variable

Since you do not want to change the values for x_o, V_o, and g, you need to fix the original equation to ensure these values do not change. To fix the values, you first need to click on the equation cell (the cell directly below the "Distance, x" label, where you typed in the equation) and then insert a dollar sign, $, in front of the column and row designation for each of the fixed cells. This is demonstrated in figure 6.9. Once finished, click on the green checkmark to indicate you are finished editing the equation.

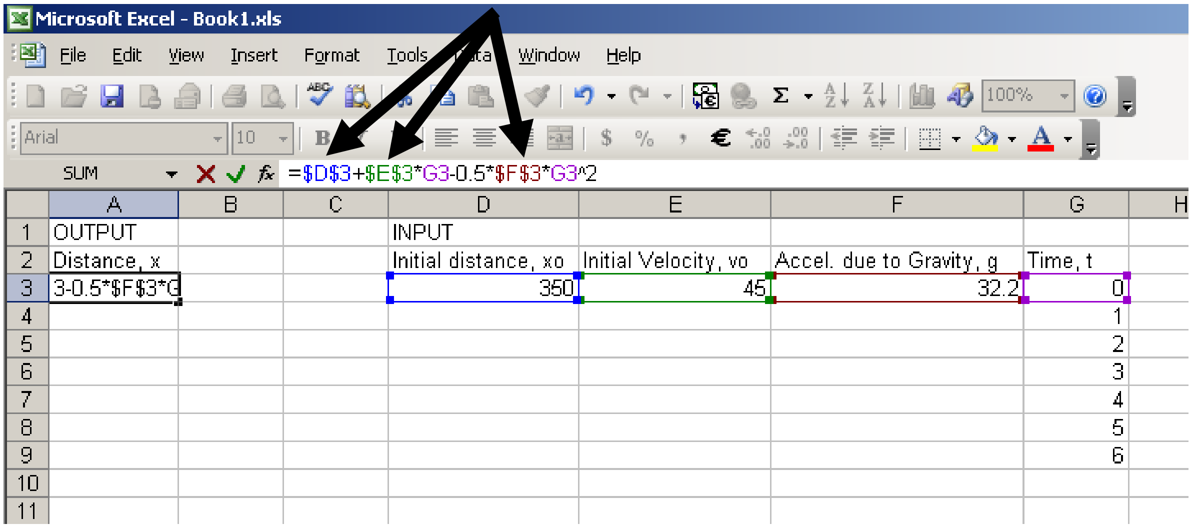


Figure 6.9 Updating original equation to ensure fixed values remain fixed.

Once the above step is completed, you are ready to calculate your multiple results for x. Click on the result cell (A3 in this case) and again move your cursor towards the lower right corner of that cell, and hover there until the large cross sign turns into a small black cross sign (anytime you want to repeat an equation for multiple cells, this is the procedure you use). Once the small cross sign appears, click and drag the mouse down until you've highlighted the same number of cells as the multiple inputs for t. See figures 6.10 below and 6.11.

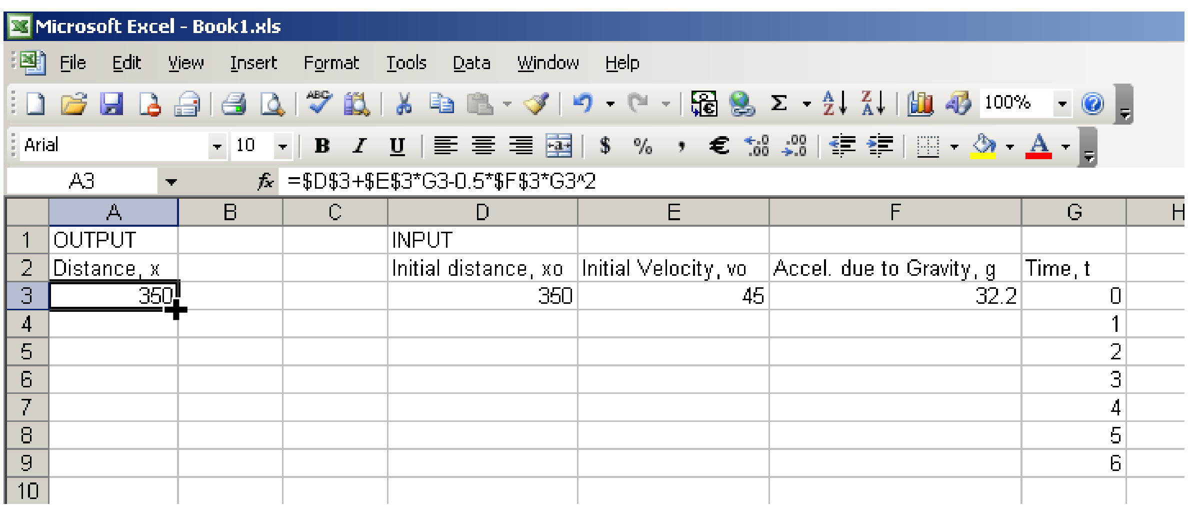


Figure 6.10 Setting up cursor for clicking and dragging

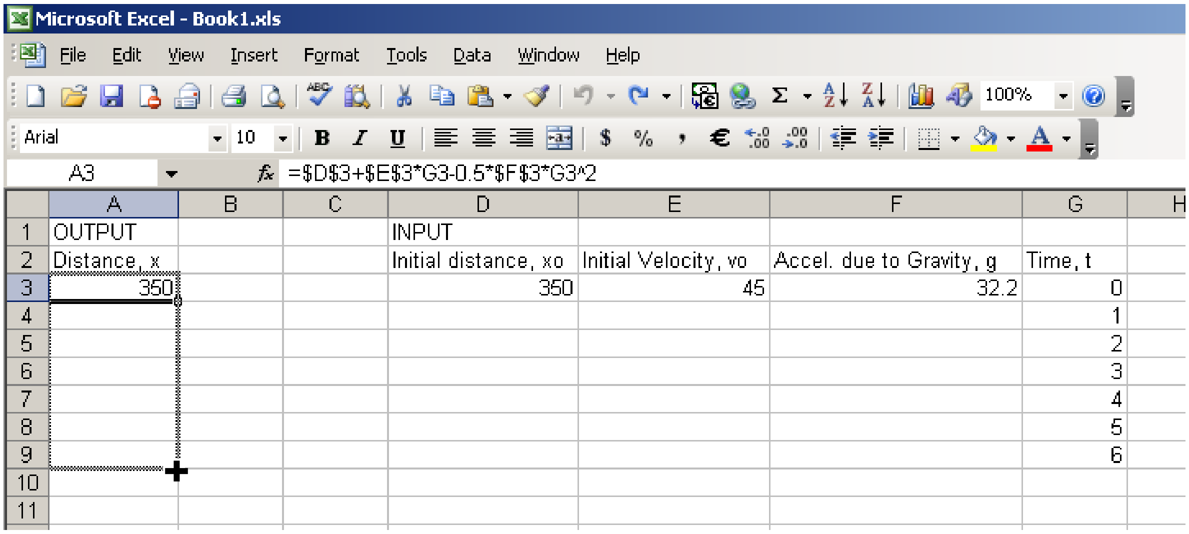


Figure 6.11 Clicking and dragging for multiple calculations of x.

Finally, simply let go of the mouse button and be amazed at the immediate calculation of all those x values (see figure 6.12)!! At this point, you can graph the data values for x and t. This will be left as an exercise at the end of the chapter. However, to get you started with some basic graphing we return to the Time Management example we began earlier.

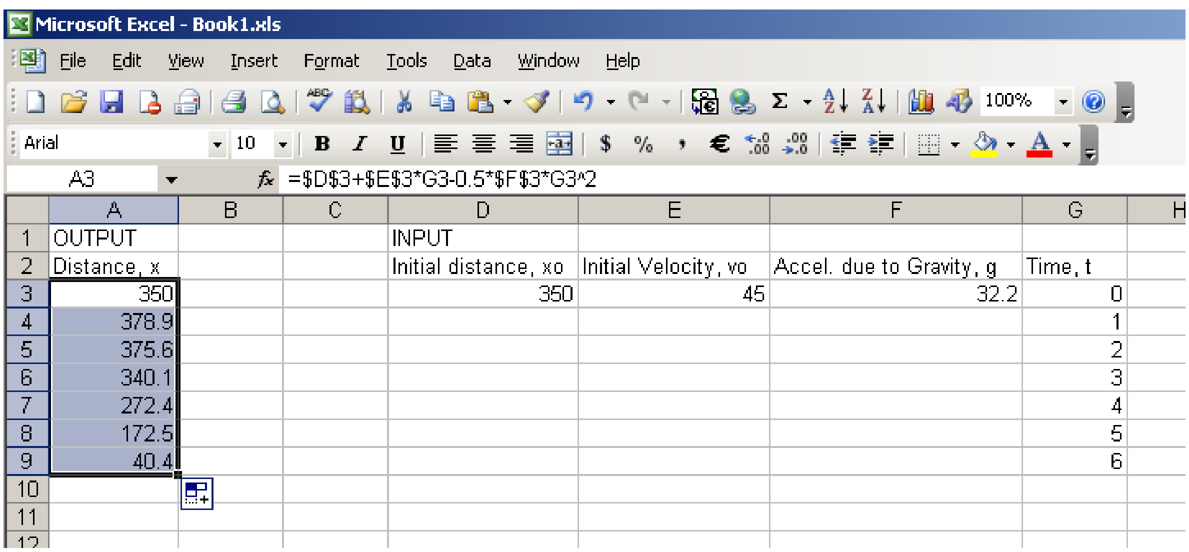


Figure 6.12 Illustration of resulting x values corresponding to the multiple t values.

Returning to the example, first we must calculate the percentage of total available time each of the weekly activities consumes. The formula is: "= (B2 / 168)*100" and is inputted into the C2 cell. Simply "click and drag" as before, and all your percentages are calculated for you. We can also format the percentage to round to 1 decimal place for a cleaner look. Click Column C and it will highlight the whole column (see Fig. 6.13). Then click the "Format" menu item at the top of the screen, choose "cells" while in that menu, then click "Number" in the Category and change the number of decimals to 1 and click OK (Figure 6.14).

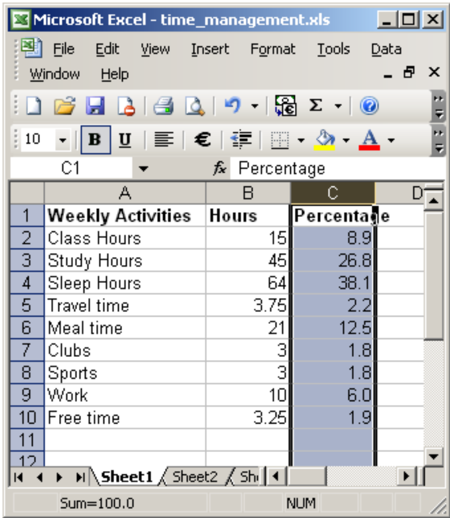


Figure 6.13 Reformatted numbers to show
only one decimal place.

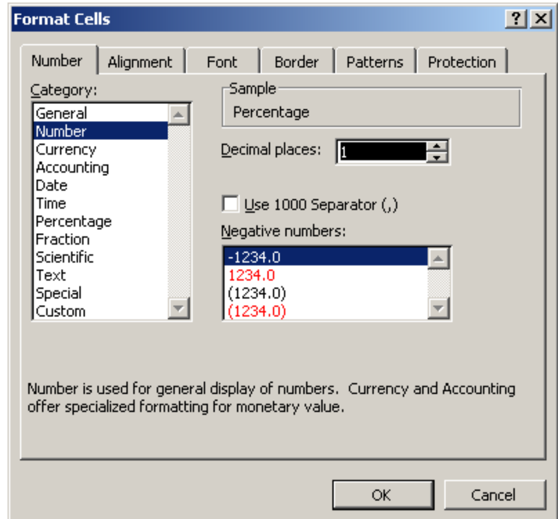


Figure 6.14 Format Cells Menu, showing how to set the number of decimals for a value.

To make the pie chart that was shown in Figure 2.3 in the Time Management chapter, highlight cells A1 through C10 by clicking cell A1 and dragging down and over to C10. While the cells are highlighted, click the "Insert" menu at the top of the screen, and choose "chart" while in that drop-down menu. Click on the "Pie" option in the dialog box that appears and pick the exploded one, finally click "next". Since we've highlighted multiple columns, we have to tell Excel which columns to actually graph. Do this by clicking on the "Series" tab, and delete all the series *except* the ones you want; in this case, we want to keep "Activities" and "Percentage". After clicking "next" one last time, you now can add in a title for your chart. Finally click "finish"; the result is shown below in Figure 6.15.

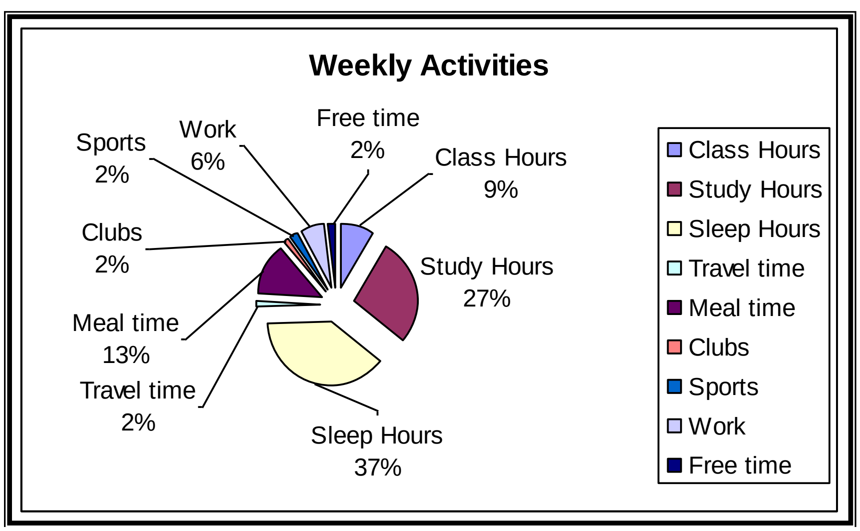


Figure 6.15 Pie graph of Weekly Activities example data.

What's powerful about these charts is that any modifications you make in either the data or even the activity labels will be automatically updated in your chart too; try it!!

Further instruction on graphing will not be covered in this text, but there are many references available that provide instructions on how to use Excel. Also, feel free to inquire with your EGR 101 instructor or peer mentor for tutoring on Excel. As with most software, simply practicing on your own and following the help tutorials within the program itself are often the best ways to learn how to use the program.

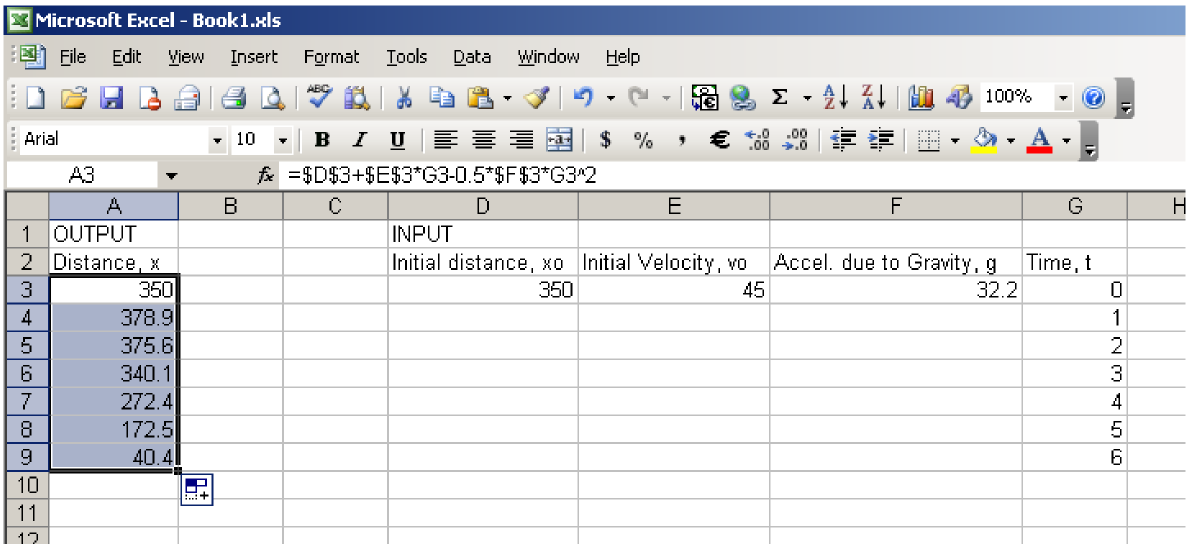


Figure 6.12 Illustration of resulting x values corresponding to the multiple t values.

Table 6.1: Common operators for programming equations into Excel

Mathematical Operation	Typical Symbol	Excel Symbol and Keys
Addition	+	+ (shift , =)
Subtraction	-	- (to the left of the =,+ key)
Multiplication	x	* (shift, 8)
Division	÷	/ (to the left of shift key)
Exponent	x^n	x^n (shift, 6)
Natural Log	ln	LN( )
Square Root	√	x^0.5 (shift, 6)
Cosine, Sine, Tangent	cos, sin, tan	COS ( ), SIN ( ), TAN ( )
Inverse Trig Function	$\cos^{-1}$, $\sin^{-1}$, $\tan^{-1}$	ACOS ( ), ASIN ( ), ATAN ( )

Exercises

1. Create the free-falling object example spreadsheet, but set x_o=500 ft, v_o=60 ft/s, and take t =0 to t =7.5 seconds using 0.5 second increments (instead of 1 second increments as in the example).
2. Try the graphing (chart) function to plot the set of data from exercise 1 (x vs. t). Use the help menu (or the reference listed at the end of this chapter) to learn more about how to create an x-y plot.
3. Using the same example spreadsheet, set t=3 seconds and vary v_o instead of t. Choose an appropriate range for v_o so that x is never negative. You may have to adjust the original equation to reflect the new changing values (see Fig 6.9).
4. Use the "goal seek" function to determine what value of v_o gives x=0 at t=5 seconds (with x_o=500 ft and g=32.2 ft/s^2). Again, use "help" or a reference to learn more about this useful function.
5. Use Excel to create a data set of θ and cosine (θ) for $0<\theta<540°$, with increments of 0.5°. Plot the data (cos θ vs. θ). Keep in mind that Excel expects angle measurements to be in radians.
6. Use Excel to produce a weekly schedule for yourself. An example is shown in Figure 2.5 in the Time Management chapter.

References

[1] Microsoft Office XP Introductory Concepts and Techniques, Course One, Shelly, Cashman and Vermaat, Course Technology - a division of Thomson Learning, 2002, pg E 1.06

Chapter 7
Engineering Measurement

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Dimensions and Units

What is the difference between a dimension and a unit? You've likely heard both terms, and you have probably heard them used interchangeably, but in fact, they are different.
A dimension is commonly thought of as one of the three spatial measurements, such as length, height and width, as in a 3 dimensional or "3-D" movie. However, in terms of scientific measurement, a dimension does not only refer to spatial dimensions. A dimension is any parameter that is measured. Length, width and height are good examples, as are time, force, temperature, speed, energy, etc. The word "dimension" simply refers to what it is we are measuring.

So what is a unit? A unit is the fixed and standardized quantity by which we make our measurements. When we measure length (the dimension), we choose some "unit" length, such as feet or meters, to determine the length. We then count "how many" of those standardized units fit within the length we are trying to determine. When we record the length, we do not simply write the numerical value; it is essential that the unit of measurement also be specified. (There's a big difference between 5 feet and 5 meters, so leaving those units off could result in a major error.)

Below is a table (Table 7.1) of common dimensions and examples of the base units by which those dimensions can be measured. You will notice there are three systems of units provided in the table. The first is the SI system. SI stands for System Internationale and is known as the Metric system. The second listed system is BG, which stands for British Gravitational, sometimes just called the English System. The last is the EE system, which stands for English Engineering.

These are the three most common systems of units you will encounter as an engineering student and later as a professional engineer. As the FAA (Federal Aviation Administration) uses the English System as the standard system, and with most European nations using the Metric System as their standard, it is imperative that you know these systems of units equally well. To be an effective and ethical engineer in today's global market, you must not limit your knowledge and capabilities to one system of units.

In Table 7.1 you will notice that some of the dimensions are primary and others are secondary (or derived) dimensions. Derived dimensions are those which are simply some combination of primary dimensions, for example, speed. Speed is simply length/time. Length and time are both primary dimensions of which speed is comprised. You'll notice mass is marked as a primary dimension, but force is not. In some cases, force is actually taken as the primary dimension and mass is treated as the derived dimension. How can this be? It's simply a matter of how you view the relationship between mass and force, which is of course Newton's Second Law of Motion. You can define the dimensions of force as: mass x length / time^2.

Alternately, you can define the dimensions of mass as: force x time^2 / length. So you see, it's simply a matter of perspective.

Table 7.1: Examples of dimensions and the three systems of units

DIMENSION	SI Unit	BG Unit	EE Unit
Length *	meter	foot	foot
Time *	second	second	second
Mass *	kilogram	slug	pound-mass
Force	Newton	pound	pound-force
Speed	meters/second	feet/second	feet/second
Temperature *	Kelvin (Celsius)	Rankine (Fahrenheit)	Rankine (Fahrenheit)
Acceleration	meters/second^2	feet/second^2	feet/second^2
Work/Energy	Newton-meter (aka Joule)	foot-pound	foot-pound
Volume	meters cubed	feet cubed	feet cubed
Power	Newton-meter/second	foot-pound/second	foot-pound/second

* Primary dimension

If we treat force as the derived dimension, then the standard unit of force is defined by the relationship between mass, length and time as discussed above. It is in these definitions that we can clearly define the three distinct systems of units. The SI system *base* unit of force is the Newton, which is defined as the force required to accelerate a mass of one kilogram at a rate of one meter per second squared. In mathematical form, this is given in equation 7.1 as:

$$1\text{N} = 1\text{kg}\,1\frac{\text{m}}{\text{s}^2} \qquad \text{Eqn. 7.1}$$

Similarly, the *base* unit of force in the BG system is the pound, which is defined as the force required to accelerate a mass of one slug at a rate of one foot per second squared. This is given in equation 7.2 below as:

$$1\text{lb} = 1\text{slug}\,1\frac{\text{ft}}{\text{s}^2} \qquad \text{Eqn. 7.2}$$

You'll notice that the abbreviation for pound is given as lb. This is derived from the Latin word *librae*, for scales. Finally, the base unit of force for the EE system is the pound-force. This unit is also abbreviated using lb, but usually with a subscript of f for force, lb_f, (or sometimes written lbf). Both the pound-force and the pound represent the same amount of force; the subscript is there simply to differentiate the unit of force from the unit of mass in the EE system, which is taken as the pound-mass, lb_m or lbm. You will find in many texts and in many of your future classes, the subscript of f and m will be completely left off. This may seem to be a problem at first glance, but as will be shown below, there really is no need for the subscripts. The definition is as follows: One pound-force is the force required to accelerate one pound-mass at a rate of 32.174 feet per second squared. This is given in equation 7.3 below:

$$1\text{lb}_f = 1\text{lb}_m\, 32.174 \frac{\text{ft}}{\text{s}^2} \qquad \text{Eqn. 7.3}$$

This may not seem particularly interesting at first, but consider the significance of the value of 32.174 ft/s^2. Does this value represent anything? Yes, it represents the acceleration due to gravity on the surface of the Earth! Of course, we know that gravity is not uniform over the surface of the Earth since the Earth is not a perfect sphere, but this value is taken to be the standard value for g in English units just like 9.807 m/s^2 is taken as the standard value for g in metric units. So what does this mean for the relationship given above? It means that for a given mass, the weight in lbf and mass in lbm are numerically equal at the surface of Earth. How is this so? Please consider the example below.

Example:

You walk into a grocery store to buy some ground beef. The label on the styrofoam container says that it contains 2.45 lbs of beef. You want to determine the mass of the beef you're purchasing. So you do a simple calculation; you know that weight = mass x gravity. Your calculation is as given below:

$$W = mg$$
$$2.45\ \text{lb}_f = (m)(32.174\ \text{ft/s}^2)$$
$$m = 0.07615\ \text{lb}_f\,\text{s}^2/\text{ft}$$

Notice the units for the mass were not given as lbm, why? Because unlike the SI and BG systems, you cannot simply replace lbf/(ft/s^2) with lbm, you must use the definition that relates lbf and lbm given in equation 7.3. When doing so, here is the result:

$$1\ \text{lb}_f = 1\text{lb}_m\ 32.174\ \text{ft/s}^2$$

Solving for 1 lb_m gives:

$$1\ \text{lb}_m = 0.0311\ \text{lb}_f\,\text{s}^2/\text{ft}$$

So using this to convert our answer,

$$(0.07615\ \text{lb}_f\,\text{s}^2/\text{ft}) \times \frac{1\text{lb}_m}{0.0311\text{lb}_f\,\text{s}^2/\text{ft}} = 2.45\ \text{lb}_m$$

The value of 0.07615 found in the example above is actually the ground beef's mass in **<u>slugs</u>**. To find the mass in lbm, we could have simply multiplied by 32.174 (there are 32.174 lbm in 1 slug); try it for yourself. On the other hand, had you been asked to find the weight of the ground beef given a mass of 2.45 lbm, you'd want to be careful not to fall into the temptation to simply multiply by 32.174 ft/s^2 -- you still have to use the definition to convert! [If you multiply 2.45 lbm by 32.174 ft/s^2, you get 78.8263 lbm-ft/s^2; but remember, one lbm-ft/s^2 does not equal 1 lbf….the definition states that 32.174 lbm ft/s^2 equals 1 lbf, so after multiplying by 32.174, you immediately have to divide by 32.174, which is why the mass and weight end up being the same value]. In actuality, you don't have to multiply the mass in lbm by anything to get the weight in lbf (at least, not on the Earth's surface), as an object's mass in lbm is numerically equal to its weight in lbf. But be aware: this is only true on the surface of the Earth. Had we performed this calculation for the same amount of ground beef, but it was weighed on a different planet, the mass would still be 2.45 lbm, but the weight would be numerically different, depending on the local acceleration due to gravity.

Dimensional Analysis

As can be seen in the previous example, conversion between units is often necessary. Sometimes the conversion takes place within a given system of units, and sometimes the conversion is used to switch between systems of units. In either scenario, dimensional analysis is the useful and fool-proof method for converting units. Dimensional analysis can be seen in the last mathematical line of the previous example, where the units of $lb_f\, s^2/ft$ were converted to lb_m. Using the above demonstrated method ensures you always have the conversion correct and that you're not accidentally taking the reciprocal of the conversion. For example, let's say you want to convert a speed of, say, 100 miles per hour to feet per second. Knowing that there are 5280 feet in one mile and 3600 seconds in one hour, the conversion would be as follows:

$$100.0\frac{\text{miles}}{\text{hour}}\ \text{x}\ \frac{5280\text{ft}}{1\text{mile}}\ \text{x}\ \frac{1\text{hour}}{3600\text{seconds}} = 146.7\frac{\text{ft}}{\text{sec}}$$

We can be confident of this conversion, because the units, from which we are converting, cross out, and we're only left with the units we wish to keep, as shown below.

$$100.0\frac{\cancel{\text{miles}}}{\cancel{\text{hour}}}\ \text{x}\ \frac{5280\text{ft}}{\cancel{1\text{mile}}}\ \text{x}\ \frac{\cancel{1\text{hour}}}{3600\text{seconds}} = 146.7\frac{\text{ft}}{\text{sec}}$$

If you do not use dimensional analysis, it can be easy to flip conversions and end up with a very incorrect answer. Had we tried to convert this without dimensional analysis, we might accidentally multiply by 3600 and divide by 5280, which would give an answer of only 68.18 ft/sec. This is less than half of the correct answer! Be careful when converting units; always use dimensional analysis and ALWAYS give units with your answers!!

Significant Digits

The practice of showing your results with appropriate significant digits is a very important habit to get into. Not only does it show that you are a mindful engineer, aware of the level of certainty of your input values, but it could save your company money! Giving overly precise values on drawings can cause the price of the part to be vastly larger than if the significant digits are kept to their appropriate level. Take for example a brake rotor. A brake rotor is a thin, flat, circular "plate" that is fixed to a car or motorcycle wheel and spins with the wheel. When you want to brake your vehicle, brake pads squeeze against the rotor, causing the rotational speed to slow through friction. Because of this squeezing action by the brake pads, it is VERY important that the rotor be extremely flat and smooth for comfortable and safe braking. If you were to specify the thickness of the rotor, which let's say is 1/8 of an inch thick, you might specify it as 1.250×10^{-1} inches, with a tolerance of ±0.0005 inches of that value. The last zero signifies that the part must be precise to that level, and the tolerance tells the machinist how much he/she can be off from the nominal value of 0.1250 inches. The process in which the rotor is fabricated involves the machinist using a machine that planes material off of the two faces of the rotor. The rotor is first machined down to a little larger than 1/8 of an inch, and then the machinist planes off one extremely thin layer at a time, measuring the thickness at numerous (possibly hundreds, to ensure flatness as well) locations around the rotor either using a caliper or some other sophisticated measuring tool after each pass. This is done to ensure not too much is taken off during any one pass with the planer. As you can imagine, the more precise the value for the thickness, the more steps this will take as the fineness of each pass would be smaller. More time to fabricate equals higher cost. The lesson here is to only provide the level of precision you *know* and *need*.

So how do you *know* to what level of precision your values should be? One important rule to remember is: **<u>you can never be more precise than your least precise input</u>**. For example, if you are given a diameter of a hole as 0.375 inches and asked to provide the area of that hole, your answer should be 0.110 in^2. The number your calculator gives is actually 0.110446617…, but your answer cannot actually be that precise given the input value of 0.375. The last digit provided may be close to the actual value, but is not certain. You're told that the hole is 0.375 inches, but using a machinist's measuring tape with graduations every 64^{th} of an inch, that value could be off by ±0.005 (here the actual tolerance range of ±1/128 of an inch has been simplified to ±0.005 since engineers typically use decimal-inch scales – Engineers scales – that divide inches into factors of 10). See how difficult that value is to differentiate with your eyes in Figure 7.1.

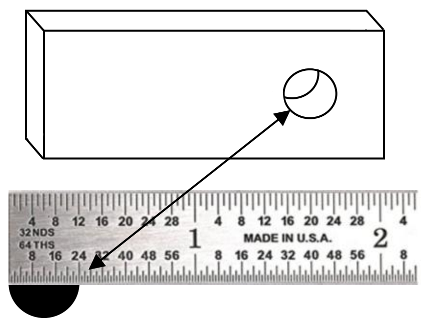

Figure 7.1 – Measurement using a machinists' scale

This ±0.005 is related to the *tolerance* of the measurement. The tolerance value is actually the difference between the maximum and minimum values of the allowable size (so in this case, the tolerance is 0.01), but when given as a note, the bilateral tolerance note (± "half tolerance value") is typical. When the tolerance is not explicitly specified - for instance, you could specify the it to be ± 0.002 if you need the tolerance to be tighter - the bilateral tolerance is generally taken as plus or minus half of the last significant digit's ***<u>place</u>*** (for 0.375, that would be ± 0.005). So in this case, the hole could actually have a diameter as large as 0.380 inches or as small as 0.370 inches or anywhere in between! The area associated with the largest diameter is 0.1134115 in^2 and with the smallest diameter, 0.1075210 in^2. Since the diameter of the hole is really 0.375 inches ± .005 inches, you cannot say with any certainty that the area is 0.1104466… in^2; the best you can give is 0.110 in^2 (with same number of significant digits as the hole) which implies that the area also has a value range with that last digit being uncertain. The ± part is implied within the last value if not stated specifically, which is the significance of significant digits! By only giving the values you know for sure, you're letting the fabricator know to what level of precision he/she has to machine, and you're letting the designer of the shaft (that has to go through the hole) know how big or small the shaft needs to be. Depending on the type of fit desired for the hole/shaft interface (clearance, interference or transition), the shaft size must be smaller than the smallest hole size, larger than the largest hole size or somewhere in between. Classes of fit is a whole other discussion that will be covered along with other topics related to tolerance in EGR120 for those of you required to take it.

The best concept to remember when determining significant digits is that your final output cannot be more precise than your least precise input[1]. For instance, if you are given three values with which you must perform a calculation involving multiplication and division, and these values are say: 250 Nmi, 32.174 ft/s^2, and 3443.9 Nmi, then how many significant digits should your answer contain? The least precise number given is the 250 nmi. Technically, it only has two significant digits since there is no decimal point after the zero in the single digits space. In this case, then your answer should have only two significant digits. On the other hand, the resource providing you with that value of 250 nmi may not have been careful, and perhaps it should be carried to three significant digits. If you are given a value, and you are unsure of its level of precision, 3 significant digits is generally a good rule of thumb.

For more on significant digits, and how to determine them, check out any chemistry textbook in the library, such as *Modern Chemistry*, by Davis, Metcalfe, Williams and Castka. The discussion in *Concepts in Engineering* by Holtzapple and Reece is also very useful. As a quick guide, when adding or subtracting values (written in scientific notation), the result should have no more digits to the right of the decimal place than the input value with the least number of digits to the right of the decimal. When multiplying or dividing values, the rule given in the previous paragraph applies: the result should have the same number of significant digits as the input value with the least number of significant digits[2]. There are some that contend that when multiplying and dividing, the answer will have one extra significant digit than the least (consider multiplying 3 x 5, these inputs each have only one significant digit, but the answer clearly has two significant digits). This is not common practice, but should certainly be considered. Finally, when performing intermediate calculations, at least two extra digits beyond the "most" significant digits should be carried on to avoid rounding errors. But remember when specifying a final value, especially a measurement for a part, always specify the appropriate significant digits.

Accuracy vs. Precision

In the discussions above, there was reference to precision, but not really to accuracy. What is the difference or can the terms be used interchangeably? The answer to the latter question is no. Precision essentially refers to the level of significant digits of a value (the "closeness" of a set of measurements of the same value, but not necessarily the true value). The more significant digits a value has, the higher the ***precision*** of that value. Accuracy refers to how close to some nominal value the measured value is, regardless of precision[3]. For instance, let's say the real and true diameter of a hole is exactly 3 inches. 3 inches is the nominal value. Now let's say two engineers measure the diameter of the hole. In the practice of "sound" science, each engineer measures the diameter 5 times, in order to have a sample from which they can determine an average measurement. The first engineer is using a ruler with the inch divided into 10 graduations. The second engineer has a ruler with the inch is divided into 100 graduations). Table 7.2 shows their results.

Table 7.2 Sample measurements to demonstrate the difference between Accuracy and Precision

	Engineer 1	**Engineer 2**
Measurement 1	3.10	4.015
Measurement 2	2.95	4.015
Measurement 3	3.05	3.995
Measurement 4	3.00	4.005
Measurement 5	2.95	4.010
AVERAGE	**3.01**	**4.008**

Looking at the above measurements, it should be immediately clear that engineer 1's measurements are better – but exactly *how* are they better? Engineer 2's measurements are more ***precise***, but engineer 1's measurements are more ***accurate***. Engineer 2's measurements are more precise because of the level of precision of his ruler; it allowed him to measure with confidence up to the hundredth's place of an inch, and then adjust ±0.005 if the edge of the hole is just shy or goes beyond the graduation. Engineer 1's ruler, on the other hand, only allows precision up to tenth of an inch. Depending on the application, this difference in precision could prove to be an issue. But when we look at the average value from the measurements, we see that Engineer 1's average value is closer to the actual true value of the part. Her measurements are more accurate; they are closer to the actual, nominal, value. What likely happened with Engineer 2's measurements is that he purposely started his measurement not at the end of the ruler, but at the "1 inch" mark on the ruler, with the intent of subtracting out the 1 from his measured values. This is sometimes done if the end of a measuring tape and/or ruler make it difficult to see the exact end of the device (i.e. some rulers are curved on the end and measuring tapes have the little metal "bracket" on the end, or the end has simply worn down). Engineer 2's method introduced what is called systemic error, versus Engineers 1's random error. Engineer 2 simply forgot to actually subtract out the extra inch. In this example, the systemic error can be easily corrected for since it is known, but in practice, we have to determine any systemic errors our measuring devices might have. Some measuring devices could have bias or drift (especially electronic measuring devices), and so accuracy must be rechecked regularly against some primary standard; this is referred to as calibration.

Exercises

1. What is the difference between a dimension and a unit?
2. What are the three systems of units that will be commonly used in engineering (give the full names, not just initials)?
3. Fill in the table below:

DIMENSION	SI Unit	BG Unit	EE Unit
Length			
Time			
Mass			
Force			

4. Which relationship is correct?
    a. 1 N = 1 kg x 9.81 m/s^2
    b. 1 lb_f = 1 lb_m x 32.2 ft/s^2
    c. 1 lb = 1 slug x 32.2 ft/s^2
    d. None of the above
5. T or F - One pound-force represents the same force as one pound.
6. T or F - In the EE system of units, the mass and weight of an object are numerically equal at the surface of the Earth.
7. What is the difference between accuracy and precision?
8. What is the primary rule of significant digits to remember when performing calculations?`
9. If you are unsure about the level of precision to use, what is the rule of thumb, as given in your text, on the number of significant digits that should be used?
10. Why are significant digits important?
11. What is one use of Dimensional Analysis?

References

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[1] Tipler, *Physics for Scientists and Engineers*, 3rd Edition, Worth Publishers, 1991, Pg 8
[2] Davis, Metcalfe, Williams and Castka, *Modern Chemistry*, Harcourt Brace and Company, Holt, Rinehart and Winston, 1999, pg 46
[3] Davis, Metcalfe, Williams and Castka, *Modern Chemistry*, Harcourt Brace and Company, Holt, Rinehart and Winston, 1999, pg 44

Chapter 8
Project Management and Teamwork

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Project Management

Project management is the application of knowledge, skills, tools, and techniques to provide activities (or tasks) in order to meet or exceed stakeholder needs and expectations from a project. Meeting or exceeding stakeholder needs and expectations involves balancing competing demands among:

- Scope, time, cost, and quality.
- Stakeholders with differing needs and expectations.
- Identified requirements (needs) and unidentified requirements (expectations).[1]

Terminology

Planning and design, together with management, are used to bring an engineering project from the initial problem recognition phase through to successful implementation.[2] Broadly speaking, **planning** is a deliberative mental process that is undertaken to ensure that a proposed action will be successful. It involves deciding on the goal you want to achieve and then identifying the steps needed to achieve the goal. These steps, when clearly formulated, constitute a **plan**. Planning plays a crucial role in any engineering project. **Design**, as distinct from planning, is undertaken to produce the information needed to create a new system or process. Design work is also undertaken when an existing system or process is to be modified or improved. **Management** refers to the effective use of available resources to achieve the designated outcome. Management is the means by which the results of engineering planning and design are brought to a successful finish.

An Example

A township desires to improve the quality and quantity of water supplied to them for the next quarter century. Below is an outline of an example planning process that might be used to develop the new water supply system.

- Initial Planning
    - Details of present water supply system
        - Quantity of Water
        - Quality of Water
        - Details of Delivery System
    - Future Requirements and Demands
        - Expected Demographic Changes
            - Increase of Population and Industry
            - Changing Distribution of Population and Industry

        - Possible New Sources of Water Located
            - Groundwater
            - Water Tanks
            - Possible Locations for Dams and/or Reservoirs
        - Recycling of Water
        - Pricing Policies to Encourage Water Conservation
        - Modification/Adaptation/Replacement of Current Supply System
    - Design
        - If Dam Is To Be Constructed
            - Site Location
                - Rainfall and Runoff Patterns Discerned
            - Size and Shape of Dam Wall
            - Construction Plan
                - Providing Access Roads
                - Bringing Heavy Equipment
                - Soil and Rock Excavation
                - Foundation Shaping and Preparation
                - Construction of Main Wall
                - Delivery System (Piping)
                - Pumping Stations
                - Holding Tanks
                - Pressure Tanks

Planning and Design As Problem Solving

Engineering problems, in addition to being complex, can be open ended and ill defined. An open ended problem can have more than one solution. It is common for engineering problems to have many alternative, potentially acceptable solutions. The true challenge becomes not to find "the" solution but rather to find the "best" solution out of many possible solutions.

A problem usually has three components: a starting state, a goal state, and set of procedures that are used to reach the goal state from the starting state. A well defined problem is one for which all three components are clearly specified. Board games, such as chess provide to a player a well defined problem with a clear starting state, a target end state (checkmate of your opponent) and precisely defined intermediate steps, or moves.

It can not be assumed that a well defined problem is easy or simple to complete. The three components of chess are clearly defined; however it can be quite challenging and exceedingly complex to achieve the goal of checkmating your opponent.

Project Planning Techniques

The execution of large engineering projects involves the coordination of many activities. Careful planning is required to ensure that a project is completed on time and within budget. Three approaches utilized in the planning include the Gantt Chart, the critical path method (CPM), and the program evaluation and review technique (PERT). These three approaches will be discussed in more detail.

Project planning deals with the interrelationships between, and the timing of, the various activities that comprise a project. Detailed planning entails:

- Identification of Activities
- Estimated Time Duration of Each Activity
- Identification of Order of Importance (which activities must precede others)
- Development of Accurate Schedule/Organizational Network

The defined schedule or organizational network can be used to provide the following information:

- Minimum time to complete the project if all activities run on time;
- Activities critical to ensure project is completed in minimum time;
- Earliest start time and the latest finish time for each activity, if the project is to be completed on time; and
- Amount of time by which each activity can be delayed without delaying the project as a whole.

Gantt Chart

The Gantt Chart (see Fig. 8.1) was developed in 1917 by mechanical engineer, Henry Laurence Gantt, to aid in the building of ships during World War One. It is a graphical representation of the duration of tasks against the progression of time.[3] The horizontal axis represents time and the vertical axis lists the required activities to complete the project.
A Gantt chart will:

- Allow you to assess how long a project should take.
- Lay out the order in which tasks need to be carried out.
- Help manage the dependencies between tasks.
- Allow you to see immediately what should have been achieved at a point in time.
- Allow you to see how remedial action may bring the project back on course.

A Gantt Chart will be provided to you and your team should your class participate in the Launch Vehicle Project (LVP). A hardcopy of the LVP Gantt Chart and a Milestone Table are provided in Appendix III of the LVP (the second project in the Projects section of this text). An editable copy of the Gantt Chart is available as an Excel file. Ask your professor for a copy should you be interested in modifying the duration of the tasks.

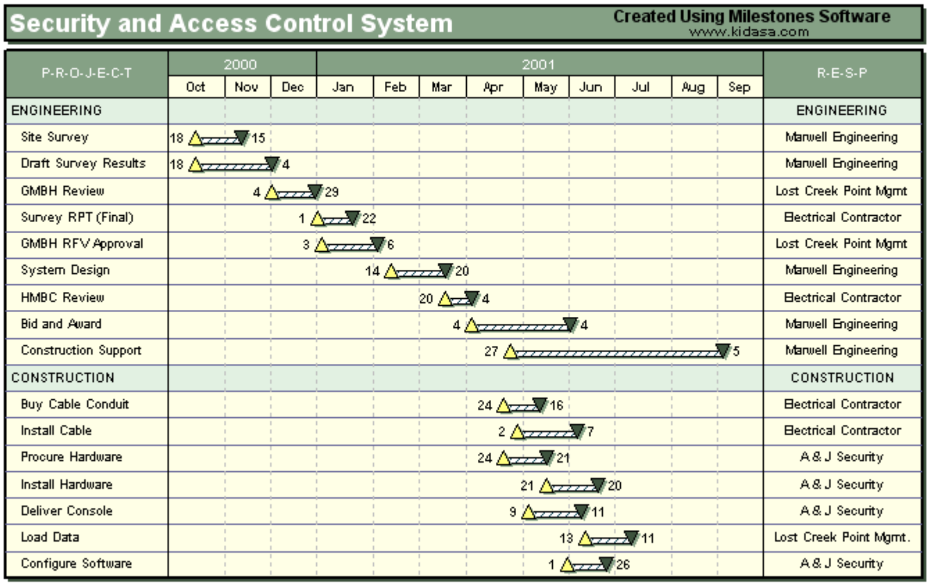

Figure 8.1 Basic Gantt Chart[4]

Critical Path Method (CPM)

CPM was developed in the late 1950's by Morgan Walker and James Kelly, to aid in the scheduling of maintenance shutdowns of chemical processing plants.[5] CPM models the activities and events of a project as a network. Activities are depicted as nodes on the network and events that signify the beginning or end of activities are depicted as arcs or lines between the nodes (see Fig 8.2). Although this process can be performed explicitly by the engineer, most Gantt Chart software programs automatically determine the critical path (with no additional effort on the part of the engineer) based on the same procedure defined below.

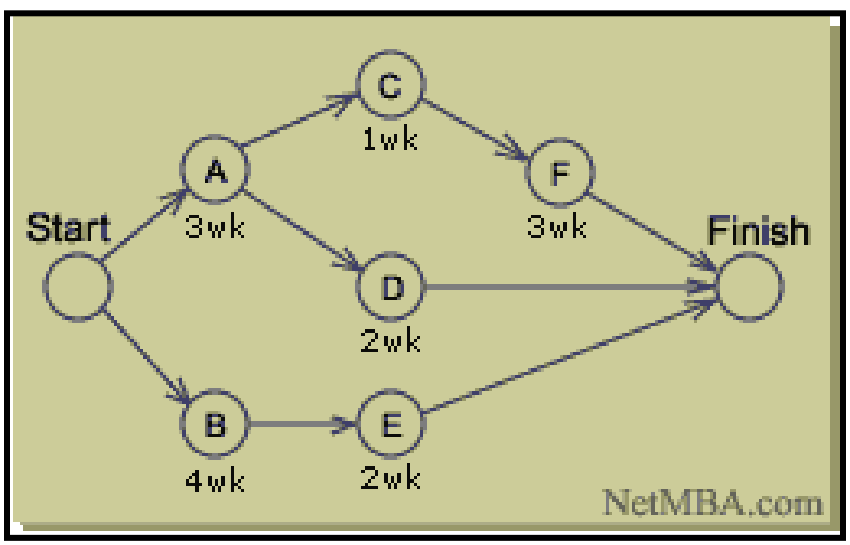

Figure 8.2 - Critical Path Method Diagram[6]

- Steps in CPM Project Planning
    - Specify individual activities
        - From the work breakdown structure, a listing can be made of all the activities in the project.
    - Determine the sequence of the activities
        - Some activities will be dependent on the completion of others.
    - Draw network diagram
        - Once the activities and sequencing have been defined, the diagram can now be drawn.
    - Estimate the completion time for each activity
        - Estimated time can be guided by past experience or the estimates of subject matter experts.
    - Identify the critical path (the longest path through the network)
        - The significance of the critical path is that the activities that lie on it can not be delayed without delaying the project.
    - Update the CPM diagram as the project progresses.
        - As the project progresses, the actual task times will be known and the diagram can be updated to include this information. A new critical path may emerge.

<u>Program Evaluation and Review Technique (PERT)</u>

PERT was developed in the late 1950's by the US Navy and Booz, Allen and Hamilton, to aid in the coordination of the thousands of contractors working on the Polaris missile program. The CPM is a deterministic method that uses fixed time estimates for each activity; it does not consider the time variations that can have great impact on the project completion time. PERT allows for randomness in activity completion times, and so gives a more realistic project completion date estimate. Of course, to have a better completion date estimate, more information is required upfront. Extensive data from previous and similar projects are needed so that the mean and standard deviation data can be estimated for each task. Although previous experience is also needed for the CPM method, the additional mean and standard deviation knowledge is not required.

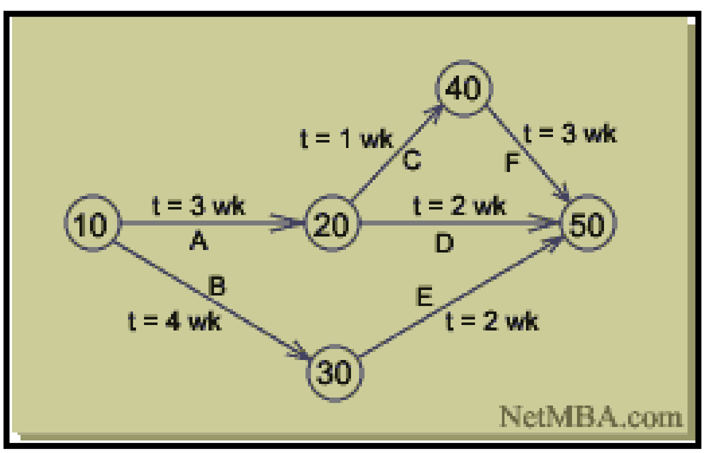

Figure 8.3 – Program Evaluation and Review Technique Diagram[7]

- Steps in PERT Planning Process
    - Specify activities and milestones
        - Activities are the tasks required to complete the project, milestones are the events marking the beginning or end of an activity.
    - Determine the sequence of the activities
    - Construct network diagram (Fig. 8.3 above)
        - A network diagram can be drawn showing the sequence of the serial and parallel activities, similar to CPM.
    - Estimate the completion time for each activity
        - Usually denoted by weeks.
            - Optimistic Time – generally the shortest time, usually specified 3 standard deviations from the mean (so less than a 1% chance that this time will be met).
            - Most Likely Time – having the highest probability of actual completion time.
            - Pessimistic Time – longest time usually specified 3 standard deviations from the mean, so less than a 1% chance, as in optimistic time.
            - Expected Time - (Optimistic + 4*Most Likely + Pessimistic)/6
    - Determine the critical path (the longest path through the network)
        - The significance of the critical path is that the activities that lie on it can not be delayed without delaying the project.
    - Update the PERT chart as the project progresses.
        - As the project progresses, the actual task times will be known and the diagram can be updated to include this information. A new critical path may emerge.

<u>Eight Key Questions for Project Management</u>

When beginning the planning stages of any project, below are some basic questions you can ask yourself to get your planning started.

1. What does the team do first?
2. What should come next?
3. How many people are needed to accomplish the project?
4. What resources are needed to accomplish the project?
5. How long will it take?
6. What can you get accomplished within the available time structure?
7. When will the project be finished?
8. How will you know you are finished with the project?

Teamwork

Teamwork is essential for competing in today's global arena, where individual perfection is not as desirable as a high level of collective performance. In today's technology oriented industry, teams are the norm rather than the exception. Most companies realize that teamwork is important because either the product is sufficiently complex that it requires a team with multiple skills to produce, and/or a better product will result when a team approach is taken. Therefore, it is important that students learn to function in a team environment so that they will have teamwork skills when they enter the workforce. Here at ERAU, students will participate as a member of a team in a number of courses throughout their education. One of the purposes of this class is to allow the students to participate in a number of teamwork activities. As you may experience, successful team management is sometimes the most difficult part of project management, and thus is a very important skill to hone.

Teamwork is defined in Webster's New World Dictionary as "a joint action by a group of people, in which each person subordinates his or her individual interests and opinions to the unity and efficiency of the group". This does not mean that the individual is no longer important; however, it does mean that effective and efficient teamwork goes beyond individual accomplishments. The most effective teamwork is produced when all the individuals involved harmonize their contributions and work towards a common goal. A critical feature of a team is that they have a significant degree of empowerment, or decision-making authority.

Every *group* does not necessarily form a *team*, but all teams are groups. The difference between a team and a group is that a team is interdependent for overall performance. A group qualifies as a team only if its members focus on ***helping one another*** to ***accomplish organizational objectives***. Table 8.1 highlights some of the differences between a group and a team.

The following are eight characteristics of effective teams that were identified by Larson and LaFasto in their book titled *Teamwork: What Must Go Right/What Can Go Wrong* (Sage Publications 1989).

1. **The team must have a clear goal.** Avoid fuzzy statements. Team goals should call for a specific performance objective, expressed so concisely that everyone knows when the objective has been met.
2. **The team must have a results-driven structure.** The team should be allowed to operate in a manner that produces results. It is often best to allow the team to develop the structure.
3. **The team must have competent team members.** In the education setting this can be taken to mean that the problem given to the team should be one that the members can tackle given their level of knowledge.
4. **The team must have unified commitment.** This doesn't mean that team members must agree on everything. It means that all individuals must be directing their efforts towards the goal. If *an individual's efforts are going purely towards personal goals, then the team must confront this and resolve the problem*.

5. **The team must have a collaborative climate.** It is a climate of trust produced by honest, open, consistent and respectful behavior. With this climate, teams perform well...without it, they fail.
6. **The team must have high standards that are understood by all.** Team members must know what is expected of them individually and collectively. Vague statements such as "positive attitude" and "demonstrated effort" are not good enough. Also, consequences of not meeting these expectations should be agreed upon by all team members as well. The **Code of Cooperation** (discussed in detail later in this section) is an excellent vehicle for declaring these items.
7. **The team must receive external support and encouragement.** Encouragement and praise works just as well in motivating teams as it does with individuals.
8. **The team must have principled leadership.** Teams usually need someone to lead the effort. Team members must know that the team leader has the position because they have good leadership skills and are working for the good of the team. The team members will be less supportive if they feel that the team leader is putting him/herself above the team, achieving personal recognition or otherwise benefiting from the position.

Table 8.1: Differences between Groups and Teams

Groups	Teams
Members work independently and they often do not work towards the same goal.	Members work interdependently and work towards both personal and team goals, and they understand these goals are accomplished best by mutual support.
Members focus mostly on themselves because they are not involved in the planning of their group's goals.	Members feel a sense of ownership towards their role in the group because they committed themselves to goals they helped create.
Members are given their tasks or told what their duty/job is; suggestions are rarely welcomed.	Members collaborate and use their talent and experience to contribute to the success of the team.
Members are very cautious about what they say and are afraid to ask questions. They may not fully understand what is taking place in their group.	Members base their success on trust and encourage all members to express their opinions, varying views, and questions.
Members do not trust each other's motives because they do not fully understand the role each member plays in their group.	Members make a conscious effort to be honest, respectful, and listen to every person's point of view.
Members may have a lot to contribute but hold back because of a closed relationship with the team.	Members are encouraged to offer their skills and knowledge, and in turn each member is able contribute to the group's success.
Members are bothered by differing opinions or disagreements because they consider it a threat. There is not group support to help resolve problems.	Members see conflict as a part of human nature and react by treating it as an opportunity to hear new ideas and opinions. Everybody wants to resolve problems constructively.
Members may or may not participate in group decision-making, and conformity is valued more than positive results.	Members participate equally in decision-making, but each member understands that the leader might need to make the final decision if the team can not come to a consensus agreement.

Table source: http://www.ndt-ed.org/TeachingResources/ClassroomTips/Teamwork.htm

Throughout the semester, we will have a number of teamwork activities in which you are required to participate. The following represents a team structure as it is defined for this class.

Team Structure

Each team should have members who serve in various functions. The fundamental positions are the Leader (L), Recorder (R), Time Keeper (TK), Gate Keeper (GK or Encourager), and Facilitator. Aside from the Facilitator, all functions should be rotated within the team from time to time, perhaps with each new project or activity, so that each individual on the team has an opportunity to serve in different roles. For lengthy projects that span two or three weeks, roles may be rotated on a weekly schedule.

- The **Leader** is to ensure that all teamwork is accomplished, including scheduling meetings outside of class and encouraging each member to participate. The Leader does not have any special authority or eminence other than the obligations of the position. He/she is especially responsible for ensuring that the various positions are always filled and that every member knows who is serving in what capacity.
- The **Recorder** must write down, at least in summary, all the significant projects, achievements, discussions, decisions and work assignments of the team. The Recorder will keep what amounts to a journal or "log" of the team for all its class related functions so long as he/she serves in that position.
- The **Gatekeeper/encourager** is assigned the task of making sure that every member of the team participates and has the opportunity to participate. He/she avoids letting one or two members dominate the team discussions or projects, and praises all the members for their contributions in order to help everyone feel better. His/her main tasks are to promote team morale and assure a balanced effort. Many teams choose to add these responsibilities to the Leader position, rather than having a separate role.
- The **Timekeeper** will make certain that all teamwork proceeds appropriately. He/she need not watch every second tick by, but if the team has five minutes, for example, to complete an assignment or discussion, he/she must make sure that the assignment is completed when the allotted time has expired. He/she does this by keeping aware of the passing time and by encouraging the team to remain on-task. He/she also makes sure that the team does not spend too much time, even in out-of-class meetings, on a specific task to the detriment of other necessary tasks. Again, many teams opt to add these responsibilities to the Leader position, rather than having a separate role.
- A **Member** (M) is one who does not currently hold another position, but his/her obligations are not special. Every member of the team, whether the leader or the gatekeeper, must abide by the requirements and obligations of a member. Members are responsible for completing tasks assigned to them (or for which they volunteered), for asking for help when they need it, and for helping their teammates when they need it. All members of the team are expected to review one another's work and to share the workload equally.
- The **Facilitator** is the faculty member (and peer mentor) assigned to teach the class and serves as a guide who stresses ways and methods in which learning and doing may become more productive and by which the team becomes more motivated.

Occasionally the Facilitator will introduce new concepts or theories by way of lectures to initiate an activity or to resolve points of confusion that may be observed in the process of working through a project.

<u>Some Tips for Team Members</u>

- Each member will suffer if the whole team is non-responsive or non-productive, so if you want an "A" in the course, but all the other members of your team are willing settle for a "B" or even a "C," then you must personally work harder to spirit the team toward a higher achievement. If you let other team members dominate the decision making process, like settling for a lower grade, then you will probably earn that lower grade as well. One obligation of being a member is to participate in deciding on the goals of the team, including the desired grades. If you simply cannot convince the team to work harder or to put in as much effort as you, approach your instructor for help.

- If you do not understand a concept, you should be encouraged to first ask the members of the team. If no one on the team knows how to proceed, then request help from the peer mentor and/or professor.

- Team answers or solutions must be subscribed to and accepted by each member. If you absolutely cannot accept a solution, then the team must be encouraged to continue debating and analyzing the issue until you all can agree. However, be prepared to compromise; so that you don't debate forever, and never accomplish anything. On the other hand, never compromise for a poor solution that does not meet sound principles. If you can demonstrate that a solution will fail (by not meeting the requirements, constraints and objectives), then the debate should not last very long. If you cannot demonstrate that the solution will fail, then perhaps you should give it more consideration and hear out the arguments of your teammates.

- There is a good possibility that your team members have some conflict with each other at one point or another during the project. Conceivably, you could be the problem. Occasionally personality conflicts arise, for no discernible or apparent reason, but you must learn to get along, even with someone you may not like. You must try to resolve the problem on your own in your team. If the parties involved cannot resolve their problems, invite comments from other members, and be open-minded. The issue in teaming is not whether you like everyone, but rather, whether you can cooperate and do what you must to help the team succeed. If the team cannot resolve the conflict, you *<u>may</u>*, as a whole **team,** bring the matter up to your facilitator. He/she may examine the situation further for the opportunity to find some way to resolve the conflict. But if there is no resolution to be had, you must live with the conflict and succeed as well as you can. The major point is to cooperate so that you will benefit, like your teammates, from a successful team. It would be a shame if you earned a poor grade just because you could not cooperate or help to make a successful team.

Code of Cooperation and Log books

Code of Cooperation

A Code of Cooperation should be developed, adopted, improved or modified by all team members. It should always be visible to team members. It is to set a norm for behavior (Code of Ethics for your team). Please see Appendix 1 for some sample codes.

Teams must have a **Code of Cooperation,** and each member of the team must be able to accept each provision of the Code. The Code should be composed as a collaborative homework exercise by the team and should contain elements for solving or evaluating a team's problems. The Code must relate to personal and mutual responsibilities, the importance of mutual assistance, being positive and constructive, honest, committed, requiring candidness from each member, not pretensions, and the probability of enjoying a team if it is handled or designed successfully. This Code must be recorded (typed), easily available to each member, and provided to the facilitator. This Code is the "Constitution" of each team. It should clearly list the *expectations* of each team member AND the *consequences* of not meeting these expectations! Ensure your Code of Cooperation contains the following:

1. Your team name
2. All team members' names (first and last)
3. A list of the team roles [Leader, Recorder and Timekeeper, Gatekeeper if you choose to keep those as separate roles]
4. A list of specific expectations for the team members
5. The consequences for not meeting those expectations (i.e., the peer evaluation is an especially effective tool for imposing consequences)

The structure must be **democratic,** especially in the sense that each member has the opportunity and the obligation to participate and contribute to the overall success of the team. Any member may make observations and constructive criticisms of the team whenever the structure is not working the way it should. Each member of a team benefits from the successes and suffers from the failures of the whole team.

Ten Elements of an effective team:

1. Help each other be right, not wrong
2. Look for ways to make new ideas work, not for reasons they won't.
3. If in doubt, check it out! Don't make negative assumptions about each other or ideas.
4. Help each other win, and take pride in each other's victories.
5. Speak positively about each other and about your team at every opportunity.
6. Maintain a positive mental attitude no matter what the circumstances.
7. Act with initiative and courage, as if it all depends on you.
8. Do everything with enthusiasm; it's contagious.
9. Whatever you want; give it away.
10. Don't lose faith and have fun!

Log Book Use and Procedures

Once a task has been assigned and undertaken by the team this logbook should be used to perform and record all of your individual work on a project. This log book will be turned in for a grade at the end of the project and will be reviewed from time to time during the project by the faculty and peer mentor. Each member of the team should keep their own log book. Additionally, if you are the Recorder for your team, use your logbook to file brief but accurate records of all meetings/activities by each team member.

Procedure

The log book should be a composition notebook. These are available for purchase in the bookstore or it is possible that your professor has a supply of old ones from which you can borrow yours.

These instructions should be the very first page of your log book; the electronic copy of the instructions can be obtained from your instructor.

Your Team's Code of Cooperation should be the very next page following these instructions. Each meeting/activity should be recorded by the assigned team Recorder on one (or more) pages as needed. Although technically all pages should be numbered in sequence and dated (especially if you were working on a patentable design), it is not necessary for this class.

The following list pertains to the Recorder's responsibilities. Each record of a team meeting should contain the following:

- The date and time - The beginning and end time of each meeting (or how long did you meet?)
- Dispositions of assigned/accepted tasks
- Roll call (Who was present. If all - say all or note absences)
- Topic(s) of discussion or the agenda
- Notes regarding discussions, discoveries, action items, assigned activities or work given to or accepted by any team members.
- Any decisions agreed to by the team
- Schedules of planned activities.
- The next meeting time if appropriate

Everyone in the team should record in their own individual log book:

- **All of your individual calculations, sketches, ideas, etc.**

The individual notes in your logbook need not be super neat or organized, but everything you write down pertaining to the project should be written down in the logbook. If you should happen to forget to bring your logbook to class or to a team meeting, you may write down your work on loose sheets, but they must be taped or stapled into the logbook in the appropriate location to maintain the correct sequence of work.

This log is the property of you and your professor, and thus may also contain any additional information or comments of any one member needed to express teaming experiences, problems, or insights dealing with matters technical, philosophical, social or interpersonal.

Please find additional Log Book Information sheets in Appendix 1 of this textbook.

Exercises

1. What is the difference between the CPM and PERT approaches for estimated project completion dates?
2. Why is a CPM diagram useful?
3. What is a Gantt Chart?
4. What are the three components needed for a successful completion of an engineering project?
5. What are the four main steps in developing a project plan?
6. What sort of information is gained by developing a plan?
7. Why else are project plans (or schedules) so important?
8. What are three differences between a group and a team?
9. What is a Code of Cooperation?
10. What is a log book used for? What are three examples of what is recorded in a log book?
11. Who is required to keep a log book?
12. List the team roles as described in this chapter and give a one sentence description of what the responsibilities are for each role.
13. What are some advantages of working in a team?
14. What are some disadvantages of working in a team?

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Chapter 9
Ethics and Professional Responsibility

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Introduction

"Character is the house we live in, and it's built piece by piece by our daily choices."
Michael Josephson

Ethics involves a philosophy and a code of conduct that involves making decisions by choosing between right and wrong actions and living a "good" life. But, it is being able to determine what is right and what is wrong and having the courage to do the right thing that makes life difficult. Choosing the correct course of action may very well be the most difficult thing we are *required* to do in our life.

Oftentimes people choose to do the ethically wrong thing. Why did they do it? Was it because of peer pressure? Peer pressure is not a justifiable excuse for doing wrong. One must take responsibility for one's own actions. Was it because of the pressure to achieve a higher grade on an assignment or an examination? No grade is worth compromising one's integrity. Was it because everyone else did it? If a thousand people did something that was wrong, it was still wrong.

There have been entire books written on the subject of ethics. The purpose of this single chapter is to introduce the fundamental concepts of ethics and professional responsibility and encourage the reader to explore those concepts in more depth as their academic and professional careers progress.

Honesty, Truthfulness and Integrity

Honesty, truthfulness and integrity are fundamental qualities of an ethical person. To be an honest person, one must be truthful. To be a person with integrity, one must be honest and have the courage to make the correct decisions to live a good life. In the case of an engineer, one must also practice the engineering profession in an ethical manner. A study conducted in 1993 by Kouzes and Posner requested that thousands of people submit a list of traits that they most admire in their leaders. The number one trait was honesty.[1] When death knocks on our door, and it will for each of us, the only thing that we will take with us is our integrity. Make sure it has value.

"Honesty is the first chapter of the book of wisdom."
Thomas Jefferson

Code of Ethics

Engineers have a professional obligation to be honest and truthful in the fulfillment of their duties and above all, protect the safety of the public. The National Society of Professional Engineers Fundamental Canons are presented on the following page. Some of these cannons will be referenced and detailed with ***<u>Rules of Practice</u>*** and ***<u>Professional Obligations</u>*** throughout this chapter. Be on the lookout for them. Additionally, *Case Studies* may be used to provide context for these rules.

<u>Fundamental Canons</u>

Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession."[2]

"Relativity applies to physics, not ethics."
Albert Einstein

Public Safety

<u>Rules of Practice</u>

1. Engineers shall hold paramount the safety, health, and welfare of the public.
   a. If an engineer's judgment is overruled under circumstances that endanger life or property, they shall notify their employer or client and such other authority as may be appropriate."[3]

Case Study #1: Aloha Flight 243

On April 28, 1988, Aloha Flight 243 was en route from Hilo to Honolulu. The aircraft was a Boeing 737-200 manufactured 19 years earlier with 35,496 flying hours and 89,680 take off and landing cycles. At a cruise altitude of 24,000 feet the aircraft experienced major structural damage. The following is from the transcripts from the cockpit voice recorder of a conversation between the Co-pilot and Maui tower:

Co-pilot: "Maui tower, Aloha two forty three, we're inbound for landing. We're just, ah, west of Makena, descending out of thirteen [13,000 feet], and we have rapid depr - we are unpressurised [sic]. Declaring an emergency…"[4]

A 380 square foot section of the fuselage had separated from the aircraft, exposing passengers and crew to rapid depressurization of the cabin and winds of 300 miles per hour. With a significant portion of the fuselage missing, many passengers had no supply of oxygen and would quickly experience hypoxia and become incapacitated. All were exposed to temperatures of -50 degrees F.[5]

Passengers had their seat belts buckled, but the three flight attendants were standing as they were assisting passengers. The number one flight attendant was near the opening left by the separation of the aircraft's skin and was immediately swept out of the cabin. She was the lone casualty. The second flight attendant suffered minor bruises and the third, along with several passengers received serious injures.[6]

The aircraft was designed for a 20-year service life and 75,000 flights. This aircraft was 19 years old and had experienced 20% more take offs and landings than that for which it was designed. At the time of the incident, only one other Boeing 737 had made more flights.[7]

Boeing engineers were aware that there were problems with the loss of bonding of the epoxy adhesive at the lap joints of the fuselage skin. Boeing notified its clients of the problems and provided technical directives with corrective actions. Subsequent aircraft had improved designs and Boeing assumed that aircraft already in service would be subjected to enhanced inspections. In fact, at what may have been urging by Boeing, Aloha invited Boeing engineers to inspect their fleet. Boeing concluded that Aloha's aircraft had problems and reported that to Aloha's executives, but they did not tell the FAA. (Primarily due to this incident, Boeing has since changed its policy and will now report any adverse findings to the appropriate regulatory agency immediately).[8]

Various studies subsequently concluded that a combination of things led to the structural failure. Metal fatigue was declared to be the major culprit accelerated by corrosion at lap joints and at the grain boundaries of the aluminum skin. Fatigue is a property of a material where the material is subjected to cyclic loadings, as those experienced by the fuselage during pressurization and depressurization. This is analogous to filling a balloon with air and releasing the air and repeating this cycle thousands and thousands of times. Each cycle causes microscopic structural changes in the metal's crystalline structure until eventually the atomic bonds holding the metal together break and cracks propagate.

Corrosion is the deterioration of a material. In metals, it involves the transfer of electrons as the metal reacts with a non-metal and forms a compound. In the case of aluminum, this corrosion compound has a greater volume than the aluminum metal. Intergranular corrosion involves corrosion at a metal's grain boundaries, the compound (the corrosion) not only forces the metal apart at the grain boundaries due to its greater volume, but causes the elimination of metallic bonding necessary to hold the metal together.

For Aloha's 737, the epoxy bonding had become ineffective. The loads were carried by the rivets and the credit card thin aluminum skin between the rivets. Cracks formed. Hawaii's humid, saltwater mist environment fed the intergranular corrosion and that resulted in the reduction in the cross-sectional area of the aluminum skin. With a smaller cross-sectional area, the stresses became greater. The aircraft's fuselage had been subjected to almost 90,000 cycles of pressurization and depressurization, with each cycle involving the application and release of tensile forces. On April 28, 1988 the fatigue life of the aluminum was surpassed and the "balloon" burst.

In spite of the severe structural damage, the pilot and co-pilot were able to land the airplane safely at Kahului airport on the island of Maui, where normally heavy winds had subsided. Rescue personnel at the landing site remarked that due to the abnormally calm winds, the aircraft was able to land safely. Under normal wind conditions, the aircraft would have broken apart.[9]

It has been reported that at least one passenger observed cracks in the aluminum skin fuselage when boarding the aircraft but trusted the airlines to fly only safe aircraft.[10] Since the Aloha incident, legislation was passed by Congress supporting research that led to a better understanding of aging aircraft along with more rigorous maintenance procedures. It is generally accepted that had a proper maintenance program been followed by Aloha, the failure would not have occurred.

An engineer's responsibility to his employer or client is one that should not be taken lightly. But under no circumstances shall the engineer's responsibility to his/her employer override the engineer's responsibility to the safety, health, and welfare of the public. From the NSPE Code of Ethics:

Questions to Consider

1. Is it easy to place the "blame" in this case?
2. If you were an engineer involved in the inspection of Aloha's fleet and learned that Aloha executives basically ignored your findings that the fleet had problems, what would you have done?
3. Are people in business excluded from having to follow ethical guidelines?

Right and Wrong

Right is the opposite of wrong. Wrong is the opposite of right. Life's choices would be simple if deciding if something is either right or wrong were as easy as selecting a color that is either black or white. But just as the world is full of many more colors than black and white, our world is not comprised of all absolutes. It is often said that the one thing that separates mankind from other animals is our ability to determine the difference between right and wrong and make the choice of which to follow.

Consider this question, "What is the most important 'thing' one can take from a human being?" Years ago, a wise Tampa police detective, with years of experience, supplied the answer. The most important thing that can be taken from a human being is their life. Is killing a human being wrong?

The killing of a human being is defined in law as the unlawful taking of a human life. The majority of our states legally take human lives. Seventy-two percent of the states in the United States have laws that allow capital punishment if convicted of certain crimes.[11]

Those that serve in our military may be required to take human lives. As an engineer, one may be required to work on a weapons system that has the sole purpose of killing people. History has shown that there have been many times when the taking of some lives resulted in the saving of many lives. So was it wrong to kill those few? This is difficult to answer.

Philosophers and theologians have debated the definition of right and the definition of wrong for years. Consider the words of Socrates:

"I cannot teach anybody anything, I can only make them think."

Cheating

Cheating is being dishonest and it is wrong. It not only erodes the integrity of the person that cheats, it tarnishes the reputation of the institution the person represents. Studies have shown that in the worst case scenario, one out of three students, if given the opportunity, will cheat. [12]

Our student body is comprised of people from not only all parts of the United States, but from countries all over the world with various religious and cultural backgrounds. Norms vary from region to region. Regardless of accepted norms, dishonest behavior is generally well understood, even if it is accepted in a particular culture.

The following academic integrity statement (or some version thereof) is supposed to be included in each syllabus provided to students at the beginning of each semester:

"**Academic Integrity:** The Instructor of this course is committed to intellectual integrity and considers academic dishonesty a very serious offense. Such offenses include cheating (accepting unauthorized assistance in preparing assignments), fraud (gaining unfair advantage through deceit, trickery, or falsification of records), or plagiarism (taking the ideas, writings, words, and/or work of another and representing them as one's own without appropriate acknowledgment). A student who cheats, commits any form of academic fraud, or plagiarizes in this course may receive an F for the course, or any other penalty deemed appropriate by the Instructor. In addition, the incident may be reported to the appropriate person or office. If any other academic integrity violations have been documented, the student may be recommended for dismissal."

If, at any time, the student is not clear of what is allowable, he/she is obligated to ask their professor for clarification and guidance.

Friendship and Ethical Dilemmas

Friendship is one of the most important basic human emotional needs. Physically we need oxygen, water, nutrients and protection from the harsh elements of the environment in order to live. But, without friends, life would be an emotional desert. Friends are important. But sometimes a person may be asked by a friend to be dishonest. One may become torn between keeping the friendship or committing an unethical act. A true friend would never ask another friend to do something unethical. Presented with such a dilemma, an appropriate response is, "If you were a true friend, you would not ask me to do that."

Case Study #2: Engineering Freshmen, Final Project

Bob and Frank developed a friendship the very first day they arrived on the ERAU campus. They found themselves taking several of the same classes, one of which was EGR 120, Graphical Communications. Although they were in different sections, they both had the same professor.

Bob just seemed to have a knack for the subject and throughout the semester, he achieved high marks in the course. It was not surprising that toward the end of the semester, he had an "A" average prior to submitting the final project. The final project was quite involved, employing skills and knowledge developed throughout the semester with drawings submitted employing a CATIA CAD drafting program.

Frank, on the other hand, struggled throughout the semester. By the end of the semester, he found himself hopelessly behind. Whether he received a passing grade depended upon his grade on the final project. Being desperate, he called upon his friend, Bob, pleading with him to provide him with a copy of his final project. Bob agreed, but advised Frank to "change some things" so that the projects would not look the same.

Frank could not imagine how the professor could possibly recognize that two projects submitted in different sections were identical considering that the professor had over 100 projects to grade. Frank submitted the exact same project that Bob had given him, in the process, claiming that it was his work.

The professor did recognize that both projects were identical (it is actually quite easy for professors to spot cheating, despite students' efforts). Project grades were assigned and Bob and Frank both received a zero for the project. Bob "lost" his "A" for the course and received a "B." Frank received an "F" for the course and both names were submitted to the Dean of Students so that a note of cheating would go on their student records. If this had been the second time caught cheating, the students would be required to sit in an Honor Board hearing regarding their case and possibly be dismissed from the University.

Questions to Consider

1) Was it justified to penalize both students?
2) Was it OK for Bob to give the work to Frank under the condition that he "change something?"
3) If you were Bob, what would you have done?
4) Is there an obligation for the instructor to advise the students that copying work and taking credit for it is unacceptable?

Professional Responsibility

Senior engineers mentor junior engineers as to their professional responsibility to their company, their profession and to themselves. All the major branches of engineering are represented by professional societies comprised of engineers practicing in their respective areas of engineering. The American Institute of Aeronautics and Astronautics (AIAA) represents the aerospace engineering profession. American Society of Civil Engineers (ASCE) represents the civil engineering profession. The American Society of Mechanical Engineers (ASME) represents mechanical engineers. The Institute of Electrical and Electronics Engineers (IEEE) represents electrical engineers. Association for Computing Machinery (ACM) represents computer engineers. Software engineers are generally represented by both IEEE and ACM, since software engineering, as a separate discipline, is a relatively young discipline. The National Society of Professional Engineers (NSPE) represents all engineering professions with particular emphasis on those engineers that are registered. Each organization has a code of ethics that their members are required to follow. Below is the Preamble to the NSPE Code of Ethics:

"Engineering is an important and learned profession. As members of this profession, engineers are expected to exhibit the highest standards of honesty and integrity. Engineering has direct and vital impact on the quality of life for all people. Accordingly, the services provided by engineers require honesty, impartiality, fairness, and equity, and must be dedicated to the protection of the public health, safety, and welfare. Engineers must perform under a standard of professional behavior that requires adherence to the highest principles of ethical conduct."[13]

In addition to the requirements of high standards of ethical conduct imposed by professional societies, the organization that accredits engineering programs in the United States, the Accreditation Board for Engineering and Technology (ABET), has a requirement that accredited programs provide adequate coverage of not only the mathematics, sciences, humanities, and engineering sciences, but professional and ethical responsibility as well. ABET accredited programs must meet criterion involving student education in the area of professional and ethical responsibility.

Accreditation Board for Engineering and Technology (ABET)

"In the United States, accreditation is a non-governmental, peer-review process that assures the quality of the postsecondary education students receive ……. ABET accreditation is assurance that a college or university program meets the quality standards established by the profession for which it prepares it students."[14] ABET has established criteria with which they evaluate baccalaureate level programs. Excerpts from ABET criteria for accreditation are presented below.

Criterion 3. Program Outcomes

Engineering programs must demonstrate that their students attain certain outcomes, one of which is "(f) An understanding of professional and ethical responsibility."[15] Engineering educators have a duty to expose students to their ethical and professional responsibility, not only because they represent ERAU, but also because they are entering the profession of engineering. An engineer's responsibility of adhering to high ethical standards begins in their academic years. Everyone enrolled in an engineering program is bound by the same code of honesty and ethical responsibility as required of a graduate engineer.

Responsibility to the Employer

Engineers have an ethical and professional responsibility to not only serve the public interest but also serve and represent their employers in an honorable and responsible manner. Engineers are obligated to protect the information that they may be working on from "exposure" to those outside the company, unless permission has been given from the employer to share information or it is already part of public domain. Many companies require their employees and consultants to sign confidentiality statements. In many cases, information that is of a proprietary nature will be marked as such. This helps eliminate any confusion, but even without such formal procedures there is an implied responsibility of confidentiality of information that exists between the employee and the employer or an agent of the employer. This is emphasized in the NSPE Code of Ethics:

Rules of Practice

1. Engineers shall hold paramount the safety, health, and welfare of the public.
   c. Engineers shall not reveal facts, data, or information without the prior consent of the client or employer except as authorized or required by law or this Code."[16]

Professional Obligations

4. Engineers shall not disclose, without consent, confidential information concerning the business affairs or technical processes of any present or former client, employer, or public body on which they serve."[17]

An example of a confidentiality agreement between a company and a consultant is presented at the end of this chapter.

Case Study #3: Young Naïve Engineer

A young engineering graduate of ERAU's Aerospace Engineering program was working at a well-known aerospace engineering company. He was working on a very interesting, but confidential project. Since the project was so interesting, he began e-mail communication with a fellow ERAU alumnus who worked at a different company who he had known since they were first year college students. While not actually discussing specific technical information, he did discuss aspects of the design that were not commonly known outside the company that he worked for. All employees were provided notification that their e-mails may be monitored. His was. He was terminated from his position.

Questions to Consider

1. Was his termination justified?
2. Should he have been given a warning?
3. What portion of the NSPE Code of Ethics was violated?

Whistleblowing

Whistleblowing is an action taken generally by any employee or ex-employee whereas he/she takes a course of action to expose unethical or unlawful conduct observed within a company or organization by blowing the whistle and bringing the information to the attention of others outside the company or organization. It may involve a fraud, corruption or a situation in which public safety is threatened.

An engineer may be involved in a project and discovers that laws have been broken or unethical deeds have occurred. This places the engineer in a very difficult position. To uphold the honor of the engineering profession, he/she must have to courage to do the right thing. The engineer is faced with several courses of action. One would be well served to exhaust all internal avenues to address and correct the problem before going outside the company. If all internal channels have been addressed without resolving the issue, the engineer may be required to take whatever action he/she deems necessary to resolve the issue. The engineer should be aware that such a course of action could have consequences to all parties involved.

Case Study #4: Fitzgerald and Lockheed C-5a Galaxy

To understand the courage that it takes to blow the whistle and do the right thing and also suffer the consequences, review the case of Ernest Fitzgerald, a civilian cost analysis who worked for Leonard Mark, Air Force Assistant Secretary for Financial Management, who testified before congress in 1968 regarding almost $2,000,000,000 (that's $2 billion) in cost overruns of the $3,200,000,000 anticipated cost for the development of the C-5a jet transport designed and built by Lockheed. The initial design incorporated design elements that specified reduced component thicknesses in order to save weight. Tests later showed that the wings were prone to premature metal fatigue failure. Air Force officials brought this to Lockheed's attention, whose management was either unable or unwilling to correct the problem. Wing failures began to occur in operational aircraft and there were other design problems as well.[18]

Congress, concerned with the enormous 62.5% cost overruns that were allowed to take place with the approval of governmental agencies, convened hearings. Ernest Fitzgerald was called upon to testify. Ignoring pressure from his employer to not testify, he did so and was truthful. Consequently, he was reassigned to trivial projects, one of which was to review cost overruns of the construction of a bowling alley in Thailand. Shunned by his co-workers, within months the bureaucracy was restructured and his position was eliminated. After four years of litigation and costs of approximately $900,000 in legal fees, federal courts ordered him reinstated into the previous position.[19]

"We must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military-industrial complex."

Dwight D. Eisenhower
Five Star General and 34th President

Licensure of Engineers (Professional Registration)

In order to protect the health and safety of the public, states have laws regulating the practice of engineering within that state. While each state's laws are specific to that state, the common element is the intent to protect the safety and welfare of the people of that state by requiring the licensure of engineers practicing engineering within the state. The state of Florida addresses licensure of engineers in Chapter 471 of the Florida Statutes. The following is from section 471.003 Qualifications for Licensure:

"(1) No person other than a duly licensed engineer shall practice engineering or use the name or title of 'licensed engineer,' 'professional engineer,' or any other title, designation, words, letters, abbreviations, or device tending to indicate that such person holds an active license as an engineer in this state."[20]

There are exemptions to this that the student must be made aware of. Continuing from the same statute in the same section:

"(2) The following persons are not required to be licensed under the provisions of this chapter as a licensed engineer:

(j) Any defense, space, or aerospace company, whether a sole proprietorship, firm, limited liability company, partnership, joint venture, joint stock association, corporation, or other business entity, subsidiary, or affiliate, or any employee, contract worker, subcontractor, or independent contractor of the defense, space, or aerospace company who provides engineering for aircraft, space launch vehicles, launch services, satellites, satellite services, or other defense, space, or aerospace-related product or services, or components thereof."[21]

Because of this exemption, engineers working in the aerospace industry generally do not take the necessary steps to obtain professional engineering licensure. But, should an engineer choose to practice engineering outside of the aerospace industry, licensure may be required. This has been a superficial presentation of the material chapter 471 to introduce the reader to the subject of licensure and the reader is advised to read the entire statute for a thorough understanding of the law.

Jobs in the aerospace industry are sensitive to federal budgets and political priorities. Those that practiced engineering in the early 1970's were witness to what happens when national priorities change from space exploration to environmental issues. Thousands of aerospace engineers lost their jobs and were forced to change careers, many returning to college to obtain degrees in Environmental Engineering.

Some graduates of ERAU's Aerospace Engineering program find job opportunities outside the aerospace industry and are required to be licensed. While licensure can be obtained later in one's engineering career, it is generally advantageous to begin the processes of licensure either as a senior engineering student or as soon as possible after graduation.

While the specific requirements of professional registration are determined by each state, common elements are the passing of the Fundamentals of Engineering exam followed by a requirement of engineering experience and then the successful completion of a Principles and Practice exam. Most states require graduation from an ABET accredited engineering program. Students considering pursuing professional registration can easily educate themselves to the procedure required by going to www.ncees.org for the necessary information. Specific information about licensure within the state of Florida can be found at www.fbpe.org.

Whether or not licensure is pursued is an individual decision, but it is one that should be given serious consideration. It is extremely important for engineers practicing in Civil Engineering to be licensed. In many cases, it is a condition of employment.

Summary

- Ethics is a part of our everyday lives. Ethics involves a philosophy and a code of conduct that involves making decisions by choosing between right and wrong actions and choosing to live a "good" life.

- Cheating is an act of dishonesty and is not acceptable behavior. Students have an obligation not only to themselves, but also to the ERAU community to conduct themselves in an honest and ethical manner.

- Friends are important to our emotional health. Friends sometimes ask other friends to be dishonest. Integrity is more important than friendship and true friends would not ask one to be dishonest or unethical.

- Engineers have an obligation to understand their personal and professional responsibility to society and to uphold the highest standards of ethical behavior, not only in their personal lives, but in fulfilling professional responsibilities as well. Engineers are bound by a code of conduct that holds paramount the safety and welfare of the public.

- Faculties of ABET accredited engineering programs have a duty to assure that their graduates have an understanding of their professional and ethical responsibility.

- Whistleblowing is an action taken generally by any employee or ex-employee whereas he/she takes a course of action to expose unethical or unlawful conduct observed within a company or organization by blowing the whistle and bringing the information to the attention of others outside the company or organization.

- Engineers practicing in the aerospace industry are generally exempt from professional registration. However, should one's career change direction, professional registration may become a requirement for employment. In some branches of engineering professional registration is a must and students in those disciplines should begin their process of obtaining licensure while in school.

Epilogue

This has been one of the most important and also one of the most challenging chapters to write. The lack of absolutes about what is the right thing to do and what is the wrong thing to do presents us with daily dilemmas. If one strives to live a good life, he/she will make the right choices. Lead by example. Some people will seek to gain an unfair advantage by cheating. Not all people will make the right choices. Follow a different path. Do not cave in to the temptation to be dishonest. A true friend would not ask one to be dishonest. Seek out the wisdom of those with experience. Remember what Mark Twain said, "When I was a boy of 14, my father was so ignorant that I could hardly stand to have the old man around. But when I got to be 21, I was astonished how much the old man had learned."

"Try not to become a person of success but rather try and become a person of value."
Paraphrased from Albert Einstein

Exercises

1. In your opinion, is there an awareness and adherence of ethical principles among students at ERAU?
2. Develop a pledge of honor that ERAU students should be required to sign for every examination taken.
3. Develop a list of the character traits you would expect in the President of the United States, or the leader of your country if you are not an American citizen. How do you think those characteristics influence the decisions that person will make?
4. Devise a role-playing scenario in which another student asks you to cheat in some way, it could be by providing him/her with questions that were on a test you had taken and he/she is about to take, allowing him/her to copy during an exam, allowing him/her to copy a work assignment, etc. Develop a response that is ethically the right thing to do and comment on the difficulties with following through on that response.
5. Obtain a copy of the code of ethics for 2 of the following organization(s): (a) National Society of Professional Engineers, (b) American Institute of Aeronautics and Astronautics, (c) American Society of Civil Engineers, (d) American Society of Mechanical Engineers, (e) Institute of Electrical and Electronics Engineers, (f) Association of Computing Machinery
6. Prepare a multimedia presentation involving a case study involving an ethical dilemma. If it involves an act of engineering, present the section(s) violated in the NSPE Code of Ethics, or if you desire, a different Code of Ethics.
7. Access and read the following case study from the files of the National Society of Professional Engineers Board of Ethical Review.
   http://www.niee.org/cases/78-88/case82-5.htm
8. Develop a multimedia presentation discussing the ethical considerations behind a University requiring students to have health insurance.
9. List the steps necessary to attain professional licensure.

Embry-Riddle Aeronautical University,

Gulfstream Aerospace Corporation

And

***Name (print):*____**

Proprietary Information Agreement

This Agreement (hereinafter referred to as the "AGREEMENT"), made and dated this 30th day of January, 2008, by and between Embry-Riddle Aeronautical University (hereinafter referred to as "ERAU") as a representative for Gulfstream Aerospace Corporation (hereinafter referred to as "GAC"), and ____, who shall also hereinafter be referred to as the "Party," respectively.

WHEREAS, ERAU represents that it possesses or may in the future possess certain technical business, financial and other information that GAC considers proprietary its business areas, hereinafter call "PROPRIETARY" or "PROPRIETARY INFORMATION".

NOW THEREFORE, in consideration of these premises, and of the mutual promises and covenants contained herein, the Parties hereto agree as follows:

1. That this AGREEMENT shall not be construed as a Teaming, Joint Venture or other such arrangement; rather, the Parties hereto expressly agree that this AGREEMENT is for the purpose of protecting PROPRIETARY INFORMATION only.

2. That GAC does not have an obligation to supply PROPRIETARY INFORMATION hereunder.

3. That nothing in this AGREEMENT shall be deemed to grant a license directly or by implication, estoppels or otherwise under any patent or patent application or to any PROPRIETARY INFORMATION disclosed pursuant to this AGREEMENT.

4. That during the term of this AGREEMENT, the Parties hereto, to the extent of their right to do so, may exchange technical information and other data which is considered by the disclosing Party to be PROPRIETARY. In order for such information and data to be considered PROPRIETARY subject to this AGREEMENT, it shall be identified in writing at the time of the disclosure. Any PROPRIETARY INFORMATION that is exchanged between the Parties orally or visually, in order to be subject to this AGREEMENT, shall be identified to the receiving Party orally at the time of disclosure.

5. That for a period of ten (10) years from the first date of receipt of PROPRIETARY INFORMATION which has been or will be exchanged relative to this AGREEMENT, the receiving Party shall take reasonable steps to preserve in confidence such PROPRIETARY INFORMATION and prevent disclosure thereof to third parties. The receiving Party shall further restrict disclosure of such PROPRIETARY INFORMATION to only those who have a need to know as directed by the Project Coordinator and who have been advised of the restrictions on disclosure and use.

6. That such PROPRIETARY INFORMATION delivered to the receiving Party shall be for use in connection Gulfstream projects. No other use of the said PROPRIETARY INFORMATION is granted without the written consent of GAC.

7. That the obligations with respect to disclosing and using such PROPRIETARY INFORMATION, as set forth in paragraphs 5 and 6 of this AGREEMENT, are not applicable to any such technical information or other data if the same is:

(a) In the public domain at the time-of receipt or comes into the public domain thereafter through no act of the receiving Party in breach of this AGREEMENT, or

(b) Known to the receiving Party on an unrestricted basis prior to disclosure, or

(c) Disclosed with the prior written approval of GAC, or

(d) Independently developed by the receiving Party, or

(e) Lawfully disclosed on an unrestricted basis to the receiving Party by a third party under conditions permitting such disclosure; or

(f) Disclosed by the originating party to others on an unrestricted basis.

8. This AGREEMENT shall (unless extended by mutual written agreement) automatically terminate on May 5, 2008. Termination shall not, however, affect the rights and obligations contained herein with respect to PROPRIETARY INFORMATION supplied hereunder prior to termination.

9. This AGREEMENT shall be governed by and interpreted in accordance with the laws of the State of Florida.

10. This AGREEMENT contains the entire understanding between the Party and GAC relative to the protection of PROPRIETARY INFORMATION and supersedes all prior and collateral communications, reports, and understandings between the Parties in respect thereto; except that nothing in this AGREEMENT shall supersede or in any way modify any of the terms and conditions, or the rights and obligations of the Parties. No change, modification, alteration, or addition to any provision hereof shall be binding unless in writing and signed by authorized representatives of both Parties.

This AGREEMENT shall apply in lieu of and notwithstanding any specific legend or statement associated with any particular information or data exchanged, and the duties of the Parties shall be determined exclusively by the aforementioned terms and conditions.

For: Embry-Riddle Aeronautical University And Gulfstream Aerospace Corporation-	Party-
By:	By:
Print Name:	Print Name:
Tile:	Date:
Date:	

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Chapter 10
Professional Preparation

S. Lehr, M.S.
Former Associate Professor

Now that you have chosen to be an Engineer, it is a good time to start planning and preparing for your career. In this chapter we encourage you to start thinking about your career, discuss how to prepare for your dream job and how to develop a resume, and introduce you to some resources on campus that will help you with your professional progression and job placement.

Planning

It is highly likely that you already have a career goal in mind. Students that attend Embry-Riddle are very career and goal oriented. Have you identified where you want to work and what job title you might like to have? These are important questions; take some time to think and set some career goals. If you are uncertain right now, keep those questions in mind as you go through your courses and try to develop some options soon. Your goals are not written in stone, and can absolutely change, but without specific goals in mind, the path you end up taking may not lead you to a place you want to be. For instance, if you want to work for Boeing (or many other defense-contracted companies), you very well may need to obtain a security clearance after graduation. Where you travel, people you associate with and the state of your finances (i.e. debt) could have a negative impact on your ability to obtain a clearance. If you weren't aware of those factors, you might jeopardize your chances without even knowing it. So it is wise to have a goal, determine the steps and requirements needed to reach that goal, and make a plan to succeed at completing each step and meeting each requirement. In other words, once you have a goal, you must then make a plan.

Let's assume you want to be a Project Engineer at a large engineering firm, like Rolls Royce. Your starting point is where you are at right now: a smart high school graduate, enrolled in an engineering program at the number one undergraduate Aerospace Engineering school in the US. Draw a triangle of where you are and what you want to achieve; with four years of college between you and your end goal (see Figure 10.1).

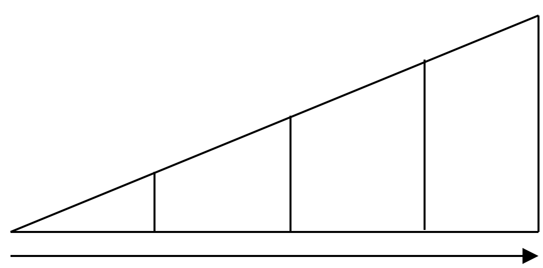

Figure 10.1 Illustration Career Planning Timeline – building the skills to meet your goal.

Our picture represents skill accumulation versus time. You have considerable time to add skills, knowledge and experience to get you from where you are to where you want to be. Regardless of whether you want to be a NASA Engineer, an Air Force Pilot, a Software Engineer for Lockheed, a Civil Engineer for the firm of Grant, Fugler, and Gurjar; or a Mechanical Engineer for NASCAR; the process is the same. You have the time to build the necessary credentials to get that dream job. The dream may change, but you still need to accumulate skills and experiences to get the ideal job. By the time you earn your 4-year degree, your triangle should be filled with several interim goals which have been successfully met (like shown in Figure 10.2 at the end of this chapter). What those interim goals are must be determined by you so you can begin working toward them!

So let's now analyze further the things required to get that Project Engineering position. What is going to be required of a person to get a Project Engineering position at Rolls Royce? An Engineering degree is a must; you can not be called an Engineer without an engineering degree. Is that enough? What other things will a person need? Will they need drafting skills? Will they need management skills? Will they need to know certain software that isn't specifically taught in any of your courses? Think about a resume and then start filling in the necessary sections: objective, education, skills, projects, experience, hobbies, and references.

Resume

A typical professional resume has the following sections: Objective, Education, Skills, Project Experience, Work Experience, and if there is room, Hobbies/Activities. We are going to go through these sections and discuss what things you should be focusing on as a student to help build your resume.

<u>Objective</u>

This section should be related to your employment goal; it should be specific and related to the company to which you are applying. For instance, the following might be an objective: *To obtain a Project Engineering position with Rolls Royce in the Combustion Technology Department*. Each company to which you submit a resume should have a uniquely tailored objective; the objective must meet both your needs and the company's needs to make a positive impression on them and result in a job offer that you actually want.

In addition to your career objective, include a statement declaring your personal strengths. Stating your strengths provides the resume reader a picture of the person they want to put in that position. You are trying to help answer the question, "Why should we hire you?" For example: *To obtain a Project Engineering position with Rolls Royce in the Combustion Technology Department; utilizing my personal strengths of being a good team leader, dependable worker, and innovative thinker.* Now this gives the hiring manager a snapshot of what you want, and who they are looking at. And just as importantly, you want the remainder of your resume to provide evidence of those qualities through the skills, work and project experience sections. For example, if you claim to be a good team leader, then there needs to be evidence that you've held leadership roles, either on a class project, on a competition team like AIAA's Design-Build-Fly team, organizing a professional club event or in any work experience. Take some time to think about what has made you successful so far, list them below; then develop a clear sentence modestly stating your strengths.

My personal strengths (list 6)

____________________________	____________________________
____________________________	____________________________
____________________________	____________________________

Finish the sentence: utilizing my personal strengths of

Objective statement: (*fill in your objective statement*)

Education

This section will look similar for all first year engineering students here at ERAU. Your statement should state: ***Pursuing an Engineering degree at Embry-Riddle Aeronautical University. Expected graduation date May 20__.*** When you are a first or second year student, and you are passing out your resumes, all of your fellow engineering students will likely have about the same set of courses under their belt. At this point your biggest strength is your ability to solve problems, your ability to learn new things quickly, and your persistence.

If you are trying to get a job or internship at a local engineering firm, it might be best to leave off the word Aerospace; as they might be intimidated by the word. Of course if you are applying to NASA or Gulf Stream, then it would be important to include the word Aerospace. When I was trying to get my first job, I have to admit it did not help going into a local surveying company and saying I'm studying aeronautical engineering and would like a job; I eventually learned to just say engineering, and then if asked which branch of engineering I'd tailor my response appropriately.

You might currently think that your education is what is going to get you the job; really it is only ***one*** of the critical pieces. Next we will discuss the other critical areas: skills, projects, and work experience.

Skills

So you want a job? What can you do? What can you do to convert time into money; enough money that an employer can pay you, and make some profit on it? Consider a starting salary of $50,000 a year, given 40 hours a week * 52 weeks a year yields 2080 hours and $24.00 per hour (50000/2080 = $24.00). Now the company has to pay 7.5% of your salary in employment taxes, and you of course want some benefits like 2 weeks off a year, health insurance, and perhaps some sort of retirement program. Typically it costs a company another 25% of a person's salary to pay for other employment benefits like those just mentioned. Additionally we need to tack on another 10-25% of your salary just to provide you with an office, a computer, etc. Do not forget companies exist to make a profit. Typically, companies charge about double your salary for your time. That is a $50,000 a year employee would get billed out at least at $50.00 per hour. So I ask you again, what can you do to translate time into money?

Fortunately, even in your first year here at ERAU you will be taking engineering courses such as EGR101, EGR115, and EGR120. EGR101 will teach you vital team skills, project skills, and problem solving skills. EGR115 will teach you to develop computer programs in MATLAB. EGR120 will teach you how to understand technical drawings, create 2-D drawings of a 3-D object and develop 3-D CAD Models in CATIA. Each of these skills is very marketable. Take time in these courses to learn these skills and make yourself more valuable. Spend extra time to produce excellent course projects as they can be included in a portfolio to present to a prospective employer. Other skills you can develop in your first year: Microsoft Office Suite programs (i.e. Excel, Word, Power Point; Microsoft Project); typing; welding; flying.

A typical skills section on a resume looks like:

COMPUTER	**Software:**	Word, Excel, Access, Power Point, CATIA, and Maple
SKILLS	**Languages:**	C, MATLAB, and HTML

Project Experience

This is a very important section on a young engineer's resume; it shows what you have actually *accomplished*. Even if you do not have paid work experience, you have done work that is similar to the engineering work you will do in the work place. You will work in teams, meet deadlines, solve problems, deliver presentations, and submit written artifacts describing the solution to the problem with which you were presented. Again, take extra care this year in EGR101, EGR115, EGR120 to produce high quality projects that you can write about and put on your resume. For example, if your class works on the Launch Vehicle Project, you might be able to include a statement similar to the following on your resume:

Launch Vehicle Project*: Worked on a four person team to research and produce a conceptual design of a 2-stage liquid-fueled launch vehicle that would deliver a payload of 5000 lb to an equatorial orbit around Earth. MATLAB was used to optimize the stage mass fractions. Propellants were selected, engines were sized, internal support structures were designed and analyzed, and the propellant delivery system was designed in addition to the overall geometry of the vehicle. Excel was used to approximate vehicle trajectory and validate thrust to weight ratios. 3-D models were developed in CATIA. Code in C was created to optimize the project costs.*

Notice the importance of bringing your listed skills mentioned in the ***Skills*** section of the resume into the project description. Employers like to see that you applied the knowledge and delivered a project, not just took a course. Demonstrate that you actually learned a skill and then later applied the skill to solve a problem. It is one thing to *say* you can use CATIA and that you are a good team member, but citing examples which *demonstrate* these skills and attributes is much more powerful. Print out and keep your course projects to take with you on interviews to help demonstrate your abilities and show what you are capable of producing. Again, you are going to have time to apply and master these skills, but start acquiring project artifacts right away. When you have more examples in your portfolio than you need, you can remove the older, less impressive ones.

Work Experience

Here is where the rubber meets the road. Each position you get should build off the previous one and bring you a step closer to your overall objective. Go back to the triangle. Rolls Royce is not likely to hire you today, however if you have the correct progression of jobs between now and your senior year, you will be a much different person. Your current cashier or serving job is important right now as it shows responsibility, and that will help you get your next job. The following would be a logical progression to obtain a position at Roll Royce: waiter, internship at a surveying company, internship at Pratt and Whitney, position at Rolls Royce. Companies like NASA, Boeing, Lockheed, Sikorsky, Teledyne, etc. are all going to evaluate what skills, projects, and experiences you have when deciding to hire you for a permanent position.

One more note about many of the big engineering companies: the easiest way to get a job with one of them is through their Internship/Cooperative Program (CO-OP). Typically they accept students in these programs after their sophomore or junior years. You only have three summers before you graduate. If it takes two summers for you to build your skills to get hired, it means this summer you should be doing something to increase your technical skills. Some students do delay their graduation in order to get a CO-OP with their favorite company; and internships/co-ops can be performed during summer, fall or spring semesters.

Cooperative Education and Internships

Co-ops and internships are two ways of get engineering work experience through designed programs at the University and at big companies. Smaller companies might call it a summer job, as they may not have defined programs. Any engineering work experience is useful work experience, and you want to start acquiring as soon as possible.

CO-OP

This is a program where you get work experience at a company and potentially get technical elective credits that apply to your degree program. This is an excellent way to reduce the cost of your college education. The career services office accepts students into the CO-OP program after they have completed 30 credit hours toward a degree. You can obtain up to twelve credit hours of CO-OP education experience, but typically engineers can only apply six credits toward their degree. You pay for one credit, but then you can obtain multiple credits toward your degree. Engineering students typically get paid for CO-OP positions; but they have to be set up with the Career Services Office prior to starting your job to receive credit hours towards your degree (be sure to personally work with Records and Registration early on to ensure you can get credit for your CO-OP position; agreement between you and the University *before* you begin the internship is required to be considered for credit). For more information check out: www.erau.edu/career/co-op_internships/index.html

Internship

This is a program where you take a semester off of college and go work for a company like Boeing, Sikorsky, NASA, etc., and obtain work experience. Typically these are paid positions, and lead to future employment opportunities. The primary difference between CO-OP and internship is that a student is not getting credit. These positions can be obtained from companies directly or through the Career Services Office. Generally, internships are singular experiences; whereas, CO-OPs may provide multiple semesters of experience. The type of work is the same in both cases, and either one will provide very important experience that will set you apart from the crowd.

You can also get an Engineering (or non-engineering) job on your own, and start building your skills and experiences without the Career Services Office. Perhaps there's a local job you can obtain that works around your class schedule. Though any job builds experience, be sure to take advantage of any engineering-related work opportunities, as once you get your first engineering job, the second one will be much easier to acquire. Ideally each job you get will involve more skills and more responsibilities. At each position, strive to get an excellent letter of reference from your employer and keep it in a file. A good word on your behalf will open a lot of doors.

Networking

As mentioned in the last section, a good word on your behalf will open a lot of doors. Through your years and experiences as an engineering student you will meet many people. The people you meet over the next few years will very likely influence the job offers and positions you obtain. You will meet people through courses, projects, professional societies, clubs, activities and other networking events. It is very important to start developing good people skills:

- Being polite
- Remembering people's names and something about them
- Having a firm handshake
- Establishing strong eye contact
- Having a well-groomed appearance
- Establishing rapport with people
- Staying in contact

Almost every job I have received in my professional career came from someone I had met and established a relationship with before. Only one came from an anonymous post on a website. Establish good skills and a good reputation and you will soon have opportunities.

Clubs and Activities

Embry-Riddle Student Activities provides over 100 clubs on campus for special interests. Clubs range from sky diving and sport aviation to dance and pep-band. The complete list can be found through the Connections link on ERNIE. An Activities Fair is held each September to introduce students to all the clubs on campus.

Studies show students who are involved in extracurricular activities are more likely to be successful at college. These students meet and bond with other students who are like themselves; they are happier, and are better adjusted to campus-life. They have a support network to help them when they stumble.

The College of Engineering faculty advises clubs for each of the engineering disciplines (see Table 10.1). These clubs can provide opportunities to get involved with hands on projects, attend conferences, and meet professionals in the industry. Meeting times and places for these clubs can be found in Connections as well, assuming the club stays current on posting information about themselves. There are other engineering clubs at ERAU, but these are the student chapters of the national, professional engineering organizations

Table 10.1 Some Professional Engineering Organizations Available at ERAU

Club	Name	Engineering Discipline or Demographic Group
AIAA	American Institute of Aeronautics & Astronautics	Aerospace
ASCE	American Society of Civil Engineers	Civil
IEEE	The Institute of Electrical and Electronics Engineers	Computer/Electrical
ASME	American Society of Mechanical Engineers	Mechanical
ACM	Association for Computing Machinery	Software
NSBE	National Society of Black Engineers	African-American Engineers
SAE	Society of Automotive Engineers	Aerospace/Mechanical
SHPE	Society of Hispanic Professional Engineers	Hispanic Engineers
SWE	Society of Women Engineers	Women Engineers

Career Expositions

Every year Aerospace, Aviation and Engineering companies from around the country come to Embry-Riddle to interview students for employment opportunities. This “career expo” is an excellent resource to practice interviewing skills, find out what companies are looking for, and actively participate in the job market. As a first year student, you should develop a resume and visit the career expo this fall. Check out who’s coming by visiting ERAU’s Career Services webpage.

The career expo is put on by the Career Services Department. The purpose of this office is to help students polish their resumes and interviewing skills, facilitate the search for co-ops and internships, and maintain the job listings for ERAU students. One of the best choices you can make is to register with their EagleHire Program, which will give you access to who is hiring, corporate seminars, and other useful career information.   To access Eagle Hire:

- Log in to ERNIE
- Click on the "Personalize" button under the "ERAU Tools" section on your ERNIE home page
- Check the box for "EagleHire" and it will show up on your home page in ERNIE
- Once back on the ERNIE homepage, click the EagleHire icon and you will automatically be logged into the system and can create or update your profile

Once you upload your resume, it will be reviewed by someone in the Career Services office. Once it is "released" it will be searchable by employers with whom ERAU has relationships!

Conclusion

As you can see, experience comes from a lot of places outside of the classroom. Get involved in clubs and hands-on projects; start thinking of where you can get work experience and where you can start adding to your skills inventory.

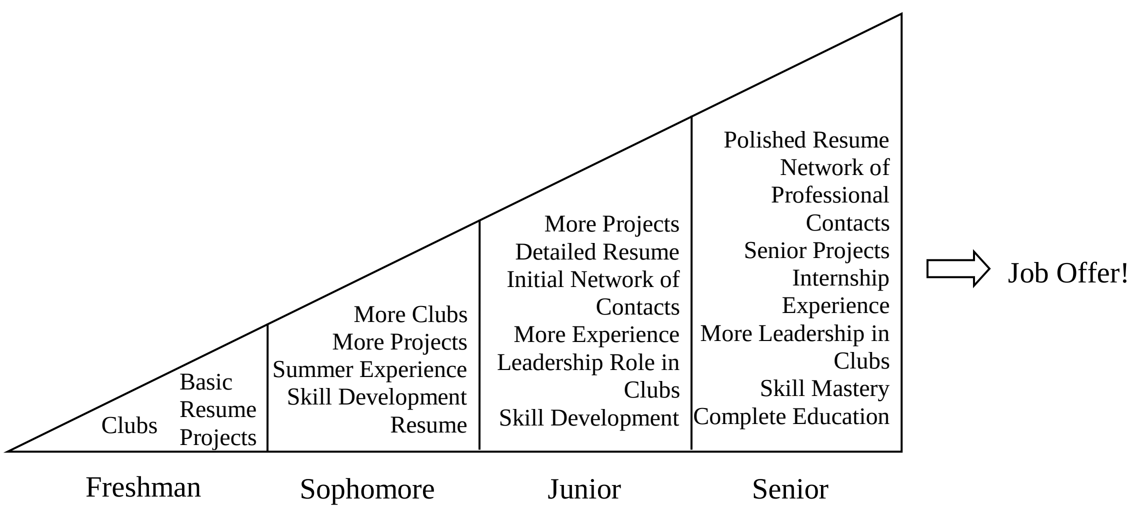

Figure 10.2 Illustration of Career Planning Timeline - after 4 years of skill and experience building.

You have time to build up your skills, projects, and experiences while you are pursuing your engineering degree. Resume building is vital to landing the ideal job, and can be done via summer work experiences, clubs and activities, and course projects.

Utilize the Career Services Office and research the companies for which you might want to work. Start building a plan on how you are going to get yourself prepared for the dream job. Get your resume completed and load it onto Eagle Hire. The Career Services office is here to help you; you are the one who has to take the initiative and the responsibility to get these tasks completed and ensure your own future opportunities.

Exercises

1. Create or modify your resume to include your current information. An example resume is available in Appendix 2.

2. Research two engineering company websites (choose companies at which you might be interested to work). Give the company name, a brief synopsis of the company, what type of internship or co-op program they offer and what the requirements and application dates are.

3. Begin a profile on Eagle Hire and take a screen shot to turn in to your professor.

4. Write down where you are now (status, skills, credentials) and your current career goal (either right out of college or later if you have already thought that far ahead), and make a plan on how you will get from here to there.

5. Research what the co-op program (here at ERAU) entails and submit a ½ page paper to your professor.

Future "Homework":
Review and update your plan and resume every semester.
Go to the Career Expo every year you are here at ERAU.
Take pride and put in extra effort on all your course projects.

Chapter 11
Engineering Disciplines at ERAU

Aerospace Engineering

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What is Aerospace Engineering?

Engineers design, analyze, build, and test machines. Aerospace engineers specialize in flying machines. "Aerospace" is the shortened version of "aeronautics and astronautics" or "aeronautics and space." That is, it refers to both flight within the Earth's atmosphere and flight outside the Earth's atmosphere. So if you see your career as being the development and operation of flying machines, both aircraft and spacecraft, aerospace engineering is one degree that you should seriously consider. It is also interesting to note that despite the fact that the name aerospace engineering sounds like a highly specialized degree program, the curriculum is actually quite broad and about half of AE graduates end up working in jobs outside the aerospace industry.

What do aerospace engineers do?

What do you picture yourself doing ten years from now? Aerospace engineers do a broad variety of jobs involved in designing, analyzing, testing, building, operating, and repairing aerospace vehicles. Such vehicles include aircraft and spacecraft, and some like the Space Shuttle are both. Undersea vehicles such as submarines follow many of the same performance and stability principles as aircraft and you might be surprised to find how many AEs work in that field.

Developing a new vehicle is a complex and demanding task that involves many far flung areas of expertise and activity. This is why many fields of engineering besides aeronautical/aerospace are always involved in the process. The first job is to assess the details of the mission to be performed and to determine specifically what performance characteristics of the vehicle and its systems are required in order to accomplish the mission. This job is done by all successful engineers, but is also sometimes separately referred to as systems engineering. Then, the size and weight of the vehicle and its systems must be designed and analyzed. This involves material selection, determination of applied loads, analysis of the strength and flexibility of the design, and testing to verify that the calculations are accurate. Determination of the performance of the vehicle requires selecting or designing the propulsion system, usually air-breathing (piston engines and jets) for atmospheric flight and non-airbreathing (rockets) for space flight. In atmospheric flight, aerodynamics is used to determine the forces acting on the moving vehicle and the forces are then matched to the proper size of the propulsion system. In space flight, the gravitational pull of planets and various other bodies are the source of the predominant forces on the vehicle.

Regardless of where the vehicle flies, the electronic systems and software to control its attitude, navigate it to the right location, and allow it to perform the details of its mission are a large segment of the engineering job. These systems are also a big factor in the cost of the vehicle and cost can never be left out of the thought process. As you are probably aware, new vehicles and new missions are often limited by available budget rather than by what is technically possible. Many AEs work in these fields and there are also degree programs which specialize in these fields.

As far as career planning thoughts go, aerospace industry employers tend to be in large cities like Atlanta, Los Angeles, Seattle, Denver, St. Louis, Washington D.C., and Dallas/Ft. Worth. Testing facilities, particularly engine testing, flight testing, and weapons development tend to be in remote locations for safety reasons, so if you prefer to live in a more rural setting those possibilities exist also. The job market tends to be a bit cyclic in this industry but is pretty good now. In fact, there is great concern among most large employers that interest in science and engineering study is dwindling and that in the foreseeable future there will not be enough engineering graduates to fill their job needs. Starting salaries are good and are among the highest paying careers. Starting salaries for new graduates vary widely in different parts of the country but seem to be currently in the $50-60,000 per year range. Principal employers from a recent three year period are: Lockheed Martin, 18%; Cessna, 15%; Boeing, 14%; United Space Alliance, 13%; U.S. Air Force and U.S. Army (officers, primarily through ROTC), 10-15%; U. S. Navy (civilian), 4%; U. S. Air Force (civilian), 3%; Gulfstream Aerospace, 3% .

Notable student achievements

With the expansion of the College of Engineering there are numerous professional activities available for students to participate in. Most of these are now inter-departmental and the student chapters of the AIAA (American Institute of Aeronautics and Astronautics – the governing professional organization for AE) and SAE (Society of Automotive Engineers) manage most of them. Some of the successful competitions and awards that have been accomplished by these organizations include:

- NASA/FAA National General Aviation Design Competition: 1st Place in 1999 (a model of this light jet design hangs in the stairwell of Lehman Center), 1st Place in 2001.
- AIAA Graduate Student Aircraft Design Competition: 1st Place in 1998.
- SAE Aero Design, Radio Controlled Model Cargo Aircraft Competition: Best design, Eastern Division, Standard Class, 1997; 1st Place overall, Eastern Division, Standard Class, 1998 (this airplane hangs in the stairwell of Lehman Center); Best Design, Eastern Division, Open Class, 1998; Best Design, Eastern Division, Open Class, 1999; 2nd Place overall, Western Division, Standard Class, 2001
- Project Icarus, 2-stage sounding rocket launched from NASA Wallops Island launch facility in 2007 achieved the highest altitude ever reached by a student-made vehicle (28 miles).

Among noteworthy graduates of the AE program in Daytona are two space shuttle astronauts, Susan (Still) Kilrain (see Fig. 12.1) and Nicole (Schaeffer) Stott (see Fig. 12.2). Susan Kilrain was a Navy fighter pilot who became the second female space shuttle pilot; she flew on STS-83 and STS-94 in 1997. Nicole Stott was a crew member for a 3-month space station mission in 2009 (STS-128 and 129), and flew again on STS-133 in 2011. She was joined by another ERAU alumnus, Col. Alvin Drew. Col. Drew also flew on STS-118 in 2007. Embry-Riddle Worldwide alumnus, Ron Garan, flew on STS 124 (2008) for a mission to the International Space Station (ISS), and participated as part of the crew for Expedition 27/28 in 2011, though his travel to the ISS was provided by a Soyuz spacecraft. Terry Virts, who piloted STS-130 in 2010 and Daniel Burbank, who flew on STS-106 (2000), STS-115 (2006) and was a crew member of Expeditions 29/30, were both ERAU graduates as well. In total, ERAU has graduated six U.S. Astronauts.

Figure 12.1 Astronaut Susan (Still) Kilrain

Figure 12.2: Astronaut Nicole Stott (center) visiting with her former Professors (from L to R): Dr. Hill, Prof. Eastlake, Dr. Ladesic, and Prof. Novy

Civil Engineering

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What is Civil Engineering?

Civil engineering, often referred to as the "grandfather of all engineering," is the engineering discipline from which all others have evolved. Although civil engineering projects date back to the days of the Pyramids in Egypt (2700 – 2500 BC), the first widespread use of engineering came about during the early days of the Roman Empire. During the expansion of the Empire, engineers working with the military (thus titled "military engineers") were called upon to design the road and bridge system needed to quickly dispatch Roman military forces to trouble spots. Some of these same military engineers subsequently applied their design and construction skills to the civilian community and were then titled "civilian" or "civil engineers." Many of these roads, viaducts, and facilities built during this era are still in existence today and stand as a testament to the relatively advanced engineering design skills of their time.

Civil engineering can be best defined as the engineering science that addresses the need to control or adapt the environment to make life possible for contemporary mankind. There is no single aspect of modern living that does not depend substantially on the efforts of a civil engineer. Water management, transportation, housing and industrial construction, communication, pollution mitigation, etc., all are addressed by today's civil engineering practitioner. Moreover, civil engineering skills are no longer restricted to earthbound projects. Space station design and lunar and Martian habitat design fall into the realm of civil engineering since they, by definition, require the need to control or change the environment to permit human habitation.

Though thousands of years old, the civil engineering profession is far from behind the times in the use of high technology. In fact, civil engineers are responsible for creating and utilizing some of the most advanced materials and analysis tools used by designers in all the other engineering fields. Civil engineers pioneered the use of finite element analysis to study structures and fluid flow. Composite material technology, the combination of two or more different materials in which the strengths of one material offset the weaknesses of another, has its roots in the science of reinforced concrete design that civil engineers developed.

There are major and minor sub-disciplines within civil engineering that reflect the wide range of skill sets necessary to practice civil engineering in the modern world. Among the major subspecialties are environmental engineering, geotechnical engineering, structural engineering, water resources management, transportation engineering, and materials engineering, each detailed in the following paragraphs. The minor subspecialties include surveying, coastal engineering, and construction engineering. At one time, civil engineers practiced architecture but today architects receive unique training in their field. Architectural engineering, often a subspecialty of civil engineering, combines some aspects of both civil engineering and architecture.

What do Civil Engineers do?

Structural engineering involves the design and structural analysis of buildings, bridges, tunnels, towers, as well as a myriad of other similar structures. In addition, as a result of their understanding of loads, stresses and material behavior, structural engineers often work in related engineering fields such as aerospace and mechanical engineering. Regardless of the particular assignment at hand, all structural engineers work to ensure that the final design incorporates all the considerations of safety, cost, constructability, aesthetics, and serviceability. The contemporary structural engineer has a wide range of materials and computer-based design capabilities available to help create new and exciting design solutions.

Transportation engineers strive to develop systems for moving people and goods both efficiently and safely. To do this, transportation engineers study the interaction of airports, highways, canals, mass transit, sidewalks and bikeways, etc., in an effort to develop the most efficient and sustainable design solution. Today, the increasing cost of transportation and the adverse environmental impacts of complex transit systems have challenged transportation engineers to develop unique and efficient design concepts.

Civil engineering materials are used in massive quantities – in fact, concrete is second only to water as the most consumed item on earth. Even small improvements in material properties can save millions of dollars in large scale projects. Materials engineers investigate the application of new and existing materials to civil engineering design problems to both reduce cost and to increase serviceability of the design. These materials may include the familiar steel, concrete and asphalt of the past, but aluminum, carbon fiber composites, and polymer plastics are becoming more prevalent in civil engineering design.

Geotechnical engineers use their unique training in geology, materials science, and hydraulics to design building foundations, retaining walls, tunnels and similar structures. In addition, environmental concerns have required that geotechnical engineers understand the sources and underground movement of environmental contaminants.

Environmental engineers are tasked with using their knowledge of chemistry, biology, and engineering processes to minimize the impact on the environment from chemicals and processes used by modern civilization. Waste reduction and control, hazardous waste control, as well as contaminant remediation planning, are all concerns of the environmental engineer. As cities continue to expand into undeveloped spaces and with the growing importance for conserving dwindling natural resources, the role of the environmental engineer has gained added importance over the thirty years.

Civil engineers enjoy a wide range of employment opportunities. Many choose to work in government positions which offer job stability, good benefits, and the chance to apply important engineering skills for the benefit of all society. Still other civil engineers will work in the private sector for both large and small firms with varying specialties. These companies are located throughout the nation and the world – wherever civilization exists, civil engineers are needed. The military also employs many civil engineers, each branch having civil engineering specialists to support their unique mission. Finally, some civil engineers, having gained a professional engineering license, will form their own company and sell their services directly to the client. This group can achieve great personal and financial success; the most driven civil engineers can become multimillionaires in only a few years!

Computer Engineering and Computer Science

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What is Computer Engineering?

The field of computer engineering deals with all aspects of computer systems. The common perception of the term “Computer Engineer” is a person who deals primarily with the hardware side of the computing systems, but in reality a computer engineer must have a great deal of knowledge about Software Engineering as well as Electrical Engineering and Systems Engineering. Some even say “Computer engineers are electrical engineers that have additional training in the areas of software design and hardware-software integration.”[1] The Try Engineering site (sponsored by the IEEE) states: “The work of a computer engineer is grounded in the hardware—from circuits to architecture—but also focuses on operating systems and software. Computer engineers must understand logic design, microprocessor system design, computer architecture, computer interfacing, and continually focus on system requirements and design.”[1] In many cases, terms such as “computer hardware engineer” and “computer software engineer” are used to distinguish the two main areas in the field of computing.

What do Computer Engineers do?

Computer Engineers use their knowledge of digital systems, microprocessors, computer architecture, electronics, electricity, and software to design and built computer-based systems to be used in all aspects of our lives today. Anything from microwave ovens to supercomputers, from cell phones to toilet seats, and from alarm clocks to F-22 jet fighters has one or many computers involved in its operations. Computer hardware engineers generally design, develop, test, and supervise the manufacturing of computer hardware systems. In the work place, a computer engineer can specialize in any of many facets of the field such as communication and networking systems, complex electronic circuit design, (including microprocessors, microcontrollers, and application specific integrated circuits), research and development, gaming consoles, real-time systems, PC and laptop design, hardware simulators and controllers, and many others. In aviation related fields they design and integrate controller boards that control many of the aircrafts functionalities and data collections. They can even specialize in designing and implementing software for embedded systems. They often work as a member of a team which is involved in research and development of new and challenging computer technology in a myriad of consumer, industrial, commercial, and military applications.[2]

Like software engineers and indeed any engineering discipline in these modern days, computer engineers use tools specific to the discipline for modeling, simulating the operation, verifying, and constructing the hardware part of the system. They have to systematically and creatively decide on decomposing a complex problem into manageable and functional sections, and they have to decide what tools, methods, hardware components, and techniques to use to build a complete computing system in a cost effective manner and deliver it on time.

They often use VHDL to design the hardware system such as mother boards for PC, controller circuitry for targeting system of a jet fighter, controller boards for the security system of a building, etc. VHDL is an acronym for "Very High Speed Integrated Circuit Hardware Description Language" which is a programming language used to describe a logic circuit by function, data flow behavior, or structure.

In general, computing hardware system design and development consists of the following phases. In each phase the product of that phase is subject to verification (Are we building the system right?) and validation (Are we building the right system?).

Requirements Specification
- What are the customer needs and desires? This is one of the most important phases of computing system development. The requirements for the system must be gathered from the customer and domain expert. The computer hardware engineer must also acquire as much expertise in the domain as possible.

Analysis
- What are the possible solutions for the system with the stated requirement? Is it even possible to develop that system or do the requirements need to be changed or reconsidered?

Design
- How is the solution put together? What is the plan to build the hardware device? What components are needed? Decompose the whole problem into smaller pieces, develop each piece and put them together for the final solution. Use Hardware Design Languages to simulate, synthesize, and test the design before prototyping the hardware.

Construction
- Construct the hardware (circuit boards and other devices) from the design schematic. This is usually done by hardware manufacturers with automated machines, supervised and validated by the designer.

Testing the system
- Does it work the way it is supposed to work? Develop test plans based on the requirements and thoroughly test the hardware. The system must work as it was intended.

Maintenance
- After the deployment of the system, it must be maintained. There could and often are problems when the system is first deployed to be used in the field. These are errors that were not caught during the testing phase for one reason or other. The cause of these errors or malfunctions could be: changing to new environments, upgrading computers, changing or adding requirements, or unpredicted sequence of events. If the change is simple (adding a jumper or adding a small component such as a resistor), the existing electronic circuitry is modified, but if the modification to maintain the system is more

complicated the design will be revised with new and more updated components and a new electronic circuitry is manufactured.

There are numerous career opportunities in the Computer Engineering field. The future promises more technology, smaller and more powerful computer hardware components, and hardware gadgets that are not invented yet. The fact is that employers will continue to seek computer professionals who possess the ability to combine strong engineering skills with good interpersonal and business skills.

What is Computer Science?

There are various but similar definitions of Computer Science. The one that is fairly general yet encompasses the essence of the field is: Computer science is the study of the theoretical foundations of information and computation and their implementation and application in computer systems. Computer science includes many sub-fields; some emphasize the computation of specific results (such as computer graphics), while others relate to properties of computational problems (such as computational complexity theory). Still others focus on the challenges in implementing computations. For example, programming language theory studies approaches to describing computations, while computer programming applies specific programming languages to solve specific computational problems. A further subfield, human-computer interaction, focuses on the challenges in making computers and computations useful, usable and universally accessible to people.[3]

These days many universities are redefining their computer science curriculums from a set of traditional courses taken by all students to a set of core courses plus specialized courses in different areas of concentration such as: mathematics, business, meteorology, etc. The term computer science is often used as a general term for many specialties in the computer industry. “Some of the major sub-specialties of computer science are algorithms and data structures, programming methodology and languages, software engineering, computer architecture, artificial intelligence, networking and communications, database systems, parallel computation, distributed computation, computer-human interaction, computer graphics and operating systems.”[4] Edsger Dijkstra, a pioneering computer scientist, said, "Computer science is no more about computers than astronomy is about telescopes."

What do Computer Scientists do?

Computer scientists can work in variety of different branches of the computing arena. They can work as researchers, theorists, programmers, or inventors. In academic institutions they work in areas ranging from programming language design, to complexity theory, to operating system design. Many do research to find better solutions to enhance the existing computing systems. Some work on multi-disciplined projects, such as developing and advancing use of virtual reality in robotics. In private industry, they work in areas such as applying theory, or developing games, or creating specialized languages for particular systems, or information technologies, or designing programming tools, or database systems, or knowledge-based systems, or even educational software.

"Computer scientists often require knowledge of other disciplines besides computers. Because they work in an inventive and developmental role, they must have at least some expertise in the discipline for which they are creating solutions." [5]

Good communication skills are a must for computer scientists. They also need to be able to think logically and deal with multiple tasks simultaneously. And indeed, for any computer professional, the ability to concentrate and pay close attention to detail is important.

Computer scientists can work independently, but often they work on a large project as a member of a team. They have frequent contact with their team mates, managers, staff, and clients.

As a computer scientist, you can choose to pursue the area of your interest in industry. You can write programs to control the machine that performs Lasik surgery on the eye, you can work on a program that controls the launch sequence of a rocket, you can work on a program to enhance airline operation, you can work on program to determine the sequence of three billion chemical base pairs that make up human DNA, you can write programs for the gaming industry, you can work in the film industry creating computer generated special effects, you can work on programs in artificial intelligence (making computers "smarter"), you can work on information retrieval systems (search engines), or you can work as a consultant assisting others in a variety of disciplines. You can work as a system analyst who uses his or her knowledge to figure out how to implement computers for a specific purpose, including activities such as determining what computers to buy, which software to use, what tools are needed, how to set up the network, and how to maintain the system. Depending on how small or large the company is, you might work alone or as a member of a team.

The opportunities are numerous and the future is very promising. Computers and computer applications are not going away; they are here to stay and you can make them work better than ever before. The fact is that employers will continue to seek computer professionals who possess the ability to combine strong programming and traditional systems analysis skills with good interpersonal and business skills.

Electrical Engineering

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What is Electrical Engineering?

Electrical engineering has two main objectives:[6]

1. To gather, store, process, transport, and present *information*;
2. To distribute, store, and convert *energy* between various forms.

In today's technological society, people use a wide range of electrical and electronic products and systems. It is not surprising that electrical engineering has become arguably the most diverse and populated engineering discipline. Electrical engineers play an essential role in the high-technology world of computers, lasers, robots, space exploration, communications, energy, and many other applications[7].

What do Electrical Engineers do?

Electrical engineers are involved in the conception, design, development, and production of the electrical or electronic systems. To get a basic understanding of this broad field, let us look at some major areas that electrical engineers work in:

Communication systems

Electrical engineers are responsible for the explosion of the communication technology. With today's communication systems, almost any two people in the world can talk to each other instantaneously despite the physical distance between them. Examples of communication systems include cellular phone, satellite TV, internet, radio, Global Positioning Systems (GPS), fiber optics and laser communications.

Computer systems

Due to the advantages of processing and storing information in digital form, computer systems have been adopted virtually everywhere. Computer Engineering was originally encompassed within the field of Electrical Engineering, but since there has been an increasingly high demand for engineers specialized in computer technology, computer engineering has become a separate engineering discipline.

Control systems

Most modern machines and systems are controlled by electronic systems, which efficiently monitor and correct parameters in various physical processes. For example, in a home temperature control system, temperature is monitored through a thermostat and the air conditioning unit is turned on automatically as needed to maintain the room temperature at a preset constant. Electrical engineers design, develop, operate and maintain control systems.

Power systems

To generate, transmit and distribute electric power, electrical engineers work with mechanical and materials engineers on power systems to ensure reliable, efficient and cost-effective power services. As the most traditional aspect of electrical engineering[8], power systems are essential to our civilization because of modern society's increasing dependence on electricity.

Signal processing systems

Often, signals from instrumentations, sensors and communication systems must be conditioned before useful information can be extracted from them. Electrical engineers design and develop signal processing systems that filter, amplify and modify signals so information is properly represented and/or displayed. Examples of signal processing applications include voice/facial recognition, noise reduction for electronic equipment, image compression, etc.

The above is only a partial list of areas in electrical engineering. Other areas, such as microelectronics, instrumentation, bioengineering, electromagnetics, and photonics, are typically considered as important areas of electrical engineering as well.

What is the Major Professional Organization for Electrical Engineers?

The Institute of Electrical and Electronics Engineering (IEEE) is the largest and most prominent professional organization for electrical engineers. It is also considered the world's leading professional association for the advancement of technology. Headquartered in New Jersey, IEEE is an international organization composed of 38 technical divisions, with more than 365,000 members in over 150 countries around the world. IEEE publishes nearly a third of the world's technical literature in electrical engineering, computer science and electronics. Each year, IEEE sponsors or co-sponsors more than 300 conferences. In addition, IEEE is a leading developer of international standards for many telecommunications, information technology and power generation products and services[9]. IEEE is also often considered to be the governing organization for computer and software engineering due to their strong roots within electrical engineering.

Engineering Physics

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What is Engineering Physics?

As the name implies, this program is a perfect blend of 'Engineering' and 'Physics', with some mathematics and space science sprinkled on top. EP students not only learn to engineer devices and instruments, but also get to do science with the devices they build. Embry-Riddle's Engineering Physics program is one of the largest such programs in the nation, and is the only one with strong emphasis on space science and engineering. Fundamentally speaking, Engineering Physics and Aerospace Engineering at Embry-Riddle are first cousins. The two programs not only share several classes, but they also share the emphasis on *space*. The difference is that AE majors concentrate on 'flying machines', whereas EP majors concentrate on 'what to do with the flying machines'. In other words, EP majors specialize in the science questions driving space missions, and in the operational aspects of payloads and instruments used to investigate those questions.

Embry-Riddle's Engineering Physics program is broad in its curriculum. Students get an in-depth understanding of physics, mathematics, and one of the two flavors of engineering: mechanical or electrical. Beyond the fundamental physics covered in Physics I, II, and III, EP students also take Modern Physics, Space Physics, Quantum Physics, Electricity and Magnetism, and Classical Mechanics. A Mathematics minor is automatic and built into the program. The program has two areas of concentration: the Systems AOC is centered on fundamentals of mechanical engineering, and the Instrumentation AOC is centered on fundamentals of electrical engineering. Students in both the tracks take classes in Spaceflight Dynamics and Space Systems Engineering. Both tracks culminate in a year-long Space Systems Design capstone project.

What do students majoring in Engineering Physics do?

Research and development is at the core of the Engineering Physics program, and it is enhanced by a focus on experimentation and hands-on learning. The Physical Sciences Department has a very active research program in space sciences and engineering, with more than a dozen faculty engaged in federally or commercially funded research. Talented students, at all levels, get abundant opportunities to participate in hands-on field research as well as computational and modelling research on cutting edge computing facilities. Students have participated in sounding rocket launches from Alaska and New Mexico, and have travelled as research assistants to high altitude and latitude optical installations including Chile and Antarctica. EP students work on projects ranging from space systems engineering and satellite design, to the control and dynamics of autonomous vehicles on ground and in air.

Active Research Areas:

- Aeronomy/Upper Atmosphere Physics
- Astronomy/Astrophysics
- Dynamics and Control applied to Ground, Aerial and Space vehicles
- Robotics/Autonomous Systems
- Space Physics/Space Plasmas
- Space and Upper Atmosphere Remote Sensing
- Spacecraft Instrumentation/Systems Engineering

About a third of BSEP graduates go on to graduate school. A small sample of graduate schools where our students have pursued MS and PhD degrees includes: Univ of Florida, M.I.T., Caltech, Stanford, Penn State, Cornell, Notre Dame, Univ of Colorado, and the National University of Singapore. While the majority of our students remain in the *Space* field, many go on into medical physics, oil and gas engineering, biomedical engineering, chemical engineering and even Wall Street.

The space industry job market tends to be cyclical but with a thorough background in mathematics, physics, and engineering fundamentals, opportunities for EP graduates are always present.

The majority of our students enter the workforce as ABET-accredited engineers, and a small sample of employers includes: SpaceX, Orbital ATK, Northrop Grumman, Boeing, Lockheed Martin, and various NASA labs. These employers also lead the list of companies that offer our students summer internships and co-ops during the spring or fall semesters.

Mechanical Engineering

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What is Mechanical Engineering?

Mechanical engineering can be defined in a brief statement as the field of engineering focused on the transfer of energy or mass. This usually involves any system you can think of that either involves moving parts or moves as a whole itself. Systems such as those in power generation and transfer (i.e. hydro-electric power plants, nuclear power plants, engines, transmissions, clutches, flywheels), transportation (i.e. automobiles, airplanes, submarines, roller-coasters), heat and mass transfer (i.e. air conditioning and ventilation systems, pumps, compressors, heat exchangers, conveyor systems, mass production machinery), vibration control (i.e. suspension systems, robotics, landing gear), tool design and manufacturing processes (heavy presses, dies, tooling bits, forging presses, extruders, benders) and many others are examples of application of the mechanical engineering field of study.

You might notice that in each example, either energy or mass (or sometimes both) is transferred from one form to another or one location to another. Power plants transfer stored energy (fuel) into either electrical or mechanical (moving) energy. Transportation systems also transfer stored energy (fuel) into kinetic energy (motion of the vehicle and its passengers), but they also transfer mass by moving the vehicle and its passengers from one location to another. Heat and mass transfer systems move heat or mass from one location to another. Vibration control systems transfer mechanical motion (i.e. unwanted oscillations) into dissipated heat. Tool design and manufacturing processes produces tools or machines that transfer energy to the working material in an effort to change its form (i.e. forging, welding, extruding).

Related to today’s difficult challenges, mechanical engineers are also heavily involved in nanotechnology research, fuel cell science, bio-medical engineering, and solar-cell science, just to name a few areas. As is evident from the examples, any system designed by a mechanical engineer is a system that involves some form of energy or mass transfer.

What do Mechanical Engineers do?

You can think of mechanical engineers as those who design any “moving” system. As in the examples given above, this involves applying the design process (see Chapter 12) to design parts and systems that transfer energy. For example, a mechanical engineer might design something as specific as an impeller for a pump of a nuclear submarine or as complex as the entire heating and ventilation system for a new building. Mechanical engineers, like Civil and Aerospace engineers, must design their parts or systems and perform numerous calculations to analyze their designs. Analysis includes (but is not limited to) calculating loads, verifying structural strength, verifying functionality and manufacturability.

Another large part of mechanical engineering is mechanical design and drafting. Mechanical design involves the design of parts and systems of a mechanical nature (i.e. machines, devices, instruments)[10]. A large part of mechanical design is the consideration of attachment methods and linkages between moving parts. Mechanical engineers are often the ones responsible for the mechanical joints that attach or link parts of a system together. This is not limited to simply brackets and bolts, but also includes processes such as welding, brazing, or even riveting. Though this may not sound very exciting, it is vital and necessary to the success of the system, and if left as an afterthought, can cause inefficiencies or even failure of the system.

Drafting is the detailed drawing of each specific part of the system. This is not unique to mechanical engineering, but it is certainly a ubiquitous part of mechanical engineering. With the advent of computer aided design (CAD) software packages, with the capability of solid modeling and parametric design, drafting has become an integral part in the design process and not simply a tool for fabrication procedures. Part interferences, system interfaces, assembly procedures, and maintenance access points can all be analyzed with today's solid modeling and drafting packages. Parts can even be animated to ensure proper function, assembly and disassembly. In addition, most packages now either contain or have easy interface with analysis packages. These software analysis packages can analyze the stresses within the structure when under loading (FEA – Finite Element Analysis), or even the fluid flow around the structure when applicable (CFD – Computational Fluid Dynamics). These are all very powerful and have truly increased the innovative power of today's mechanical engineer.

As you can see from the above listing of examples, mechanical engineering is a very broadly-based field of engineering; in fact, it is one of the most broadly-based fields[11]. Within it are numerous sub-categories, which often appeals to students. A young professional with a mechanical engineering degree has many open doors through which they can find their career. You might also notice, if you compare the curriculum of aerospace and mechanical engineering, there is a strong overlap. It is beneficial to recognize that a degree in either discipline will yield you many opportunities in similar, if not identical applications.

What is the Major Professional Organization for Mechanical Engineers?

The governing professional society for mechanical engineers is ASME, the American Society of Mechanical Engineers. Within this professional society there are opportunities to: 1) network through the society's "Communities of Practice" program, 2) share cutting-edge research, development and design technologies through publication in any of the 22 technical journals published by ASME, 3) participate in professional development through short courses and seminars sponsored by ASME and 4) for students, apply for scholarships. There are many other benefits to being involved in a professional society, but these are the most common and impressive benefits to being a part of any professional society. In addition to ASME, SAE (the

Society of Automotive Engineers) is generally associated with ME, although it has strong connections to AE as well.

Software Engineering

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What is Software Engineering?

"The applications of a systematic, disciplined, quantifiable approach to the development, operation and maintenance of software; that is the application of engineering to software and the study of such approach."[12]

Software engineering is the form of engineering that applies the principals of computer science, mathematics, management, and engineering knowledge and principles to build complex software systems that are cost effective, efficient, and safe.

What do Software Engineers do?

"Software Engineering" a software product is somewhat analogous to the engineering of an airplane. In both cases, engineers work from a set of desired functions (requirements) using scientific and engineering techniques in a creative way. Techniques that have been applied successfully in the construction of physical artifacts are also helpful when applied to the construction of software systems: development of the product in a number of phases, a careful planning of these phases, continuous audit of the whole process and individual phases, construction from a clear and complete design, testing of the system or the prototype, and maintaining the system.[13]

Software engineers use tools specific to the discipline for modeling, verifying, and constructing the software system. They have to systematically and creatively decide on decomposing a complex problem into manageable and functional sections, they have to decide what tools, methods, languages, and techniques to use to build a complete software system in a cost effective manner and deliver it on time.

As software engineer, like a computer scientist or a computer engineer, you can work in many different sectors of industry. In the medical sector you can design software that controls a pacemaker for the heart or the software to keep track of patient information. In the film industry, you can design programs for animation and special effects in motion pictures. In the aerospace industry, you can design programs for many aspects of a spacecraft's operation and simulation, or the control system of Unmanned Aerial Vehicle (UAV). In the automobile industry, you can design programs to control the robots that assemble cars or the programs that manages the operation of the cars. You can design and produce your own software and market it. You can be a software designer, or manage the software development team, or be in charge of quality control (i.e. determining how well the software works), or test software systems. You can work on any specific phase of software development process. The opportunities are endless.

In general, software system development consists of the following phases. In each phase the product of that phase is subject to verification (Does the system meet its requirement? Are we building the system right?) and validation (Does the system meet the customer's need and requirements? Are we building the right system?). A software engineer can engage in any of these activities.

Requirements Specification

- What are the customer needs and desires? This is one of the most important phases of software development. The requirements for the system must be gathered from the customer and domain experts. The software engineer must also acquire as much expertise in the domain as possible.

Analysis

- What are the possible solutions for the system with the stated requirement? Is it even possible to develop that system or do the requirements need to be changed or reconsidered?

Design

- How is the solution put together? What is the plan to write the code? Decompose the whole problem into smaller pieces, develop each piece and put them together for the final solution.

Implementation

- Code based on the design. Once the design is done (the blue print is ready), write the code.

Testing the system

- Does it work the way it is supposed to work? Develop test plans based on the requirement and exhaustively test the software. The system must work as it was intended.

Maintenance

- After the deployment of the system, it must be maintained. Fixing errors that were not caught during the testing phase (these errors might arise from changing to a new environment like upgrading the computers, changing or adding to the requirements, and unexpected problems). For these reasons, the system must be easily maintainable.

Career opportunities in Software engineering are numerous and the future is very promising. Computers and software applications are not going away – they are here to stay and you can make them work better than ever before. The fact is that employers will continue to seek computer professionals who possess the ability to combine strong engineering skills with good interpersonal and business skills.

Exercises

1. Which discipline of engineering is the oldest?
2. Aerospace Engineering is the combination of what two engineering fields?
3. Do computer engineers need knowledge in software design, or is that restricted to Software Engineering? Explain.
4. What professional organization represents Computer, Electrical and Software Engineering?
5. Name 3 major areas within the Electrical Engineering discipline.
6. Which engineering discipline would primarily be responsible for the design of a jet engine?
7. What are the 6 main activities described for Software Engineering?
8. Which discipline is associated with designing systems that transfer energy and/or mass?
9. AIAA is the governing professional organization for which engineering discipline?
10. SAE is associated with which 2 disciplines?
11. Which discipline is defined as that which addresses the need to control or adapt the environment to make life possible for contemporary mankind?
12. What are the 2 main objectives of Electrical Engineering?
13. Regardless of the engineering discipline within which an engineer earns his/her degree, there are "functions" that categorize an engineer's main responsibilities, or describe their "job". For instance, some engineers are responsible for the functional design of a system (Design Engineers), some are responsible for analyzing the structural integrity of the design (Structural Engineers), and others are responsible for analyzing the schedule and budgets of the project (Project Engineers). Find at least 2 legitimate resources (i.e. NOT Wikipedia by itself) and compile a common and complete list of these functions. Provide a 1 sentence description of each function.

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Chapter 12
The Engineering Design Process

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The Engineering Design Process

When engineers decide to *design* a product, service or solution to any problem or need, they begin with the engineering design process. The engineering design process is a well-defined procedure that guides engineers through the most effective path to the desired end. It is akin to the scientific process, but is tailored more to the creation of something new, rather than the study of something that already exists. The process of designing something may be new to you, and indeed, it will not be the focus of your undergraduate classes likely until your senior year. Most of the problems you will be given in these fundamental courses will be closed form solutions. This means there is one correct answer for which you are searching. On the other hand, design problems (and even some analytical problems) are open-ended. This means there can be many possible solutions, some better than others. Your job as an engineer is to come up with as many solutions as possible, perform analysis on each alternative (some choices will not be analyzed as rigorously as others) in an effort to choose the best solution that meets the requirements. This is all part of the engineering design process. As you will see in the projects you will be undertaking for this class, the engineering design process is an essential tool for engineers.

The process begins with the complete understanding of the problem which we, as engineers, are trying to solve. In many of your classes, especially in the first two years of fundamental courses, the problems you will be asked to solve will be well-defined, with all needed information given and the unknown value or values explicitly defined. As a practicing engineer, however, this will not usually be the case. In order to define the problem, you are required to know what is expected of your design by the customer, what they want the solution to do for them (not what they *think* the problem is - assumed problems could over-constrain the engineer), why any current products or services do not fulfill their needs, and any constraints within which you must work. Once the problem is fully understood, you must then clearly define for yourself the detailed requirements of the final solution. These requirements could be functional, physical, financial, environmental, ethical, logistical or temporal (time driven) in nature.

<u>Functional:</u> Functional requirements include *what* the product or service will *do* for the customer, i.e. “it” must fly at a certain speed, deliver a particular size, weight and shaped object, compute a specific value, pump fluid at a specified flowrate, span a river of a certain width and support a certain number of vehicles per hour, control one section of a robotic assembly line, analyze the efficiency of the assembly line, or open a container. Those are all general functional requirements of different systems. You would also need to know the specific requirements and/or constraints. For example, for the last device which is to open a container, you would need to know what range of sizes of containers are expected to be opened, what material the opener would have to be able to penetrate, whether the container can be damaged when being opened, or must it remain re-sealable, how quickly the containers must

be opened, whether the opener is part of an assembly line, and do they want it to do anything else. There would be many more specific requirements, but this is a sample to give you an idea of what is meant by "specific requirements".

Physical: Physical requirements include the physical characteristics of your design such as weight, size, shape, and materials from which it is made. Again for the above example, the customer may require that the opening device weigh less than a certain amount and fit within some specified space, so that there are size and/or material limitations. Some of these physical requirements could adversely affect the functional performance of your design (i.e. the weight restriction hinders your design options); we call these *opposing requirements*, and you will encounter them often as an engineer. And it's not always physical vs. functional requirements that are opposing. You can have opposing functional requirements, opposing physical and financial requirements, or ethical and financial requirements, etc., etc. You might also find that financial requirements are almost always in opposition of most other requirements.

Financial: Financial requirements are primarily budget related. But for the customer, these may also include efficiencies of your design which will affect the lifetime costs of using the product or service and not just the up-front, one-time cost of developing and purchasing it.

Environmental: Environmental requirements are particularly important in today's world. The impact of your design on the environment must be considered, in fact, there are many government regulations that impose constraints on your design for the protection of our Earth. The customer for which you might be designing your product or service may also have certain environmental requirements/constraints for you to meet. The environment may be defined locally, regionally, or globally. Depending on the definition, the requirements could be vastly different, or even opposing.

Ethical: Ethical requirements are not generally defined by the customer, but your employer will undoubtedly have expectations, written or not, regarding your engineering ethics. Always making decisions based on sound ethical principles is not only an honorable way to live, but it helps your company and you avoid lawsuits, loss of professional licenses, or even worse, the loss of life (that of the consumers).

Logistical: Logistical requirements are those that involve getting the product or service to the customer, getting the parts or materials needed to produce the design, and or the implementation of the product or service. There are cases where the method of transporting of the final product from the manufacturing site to the customer has actually driven the design.

Temporal: Finally temporal requirements are, as the name implies, time requirements. There will always be deadlines for your design. Intermediate deadlines, final deadlines, deadlines on the design, deadlines for production. Unfortunately, financial and temporal requirements are usually the most limiting (and opposing) of all the requirements, and are usually the requirements that result in unethical decisions.

You might guess, from the discussion above, that clearly defining all requirements and constraints is a very necessary and important part of the design process. Again, in most of your classes, these requirements will be clearly given. But as a practicing engineer, obtaining requirements can be one of the more difficult tasks.

With the problem and requirements now well-defined, it is appropriate to begin collecting data on resources, technologies, materials, existing designs, off-the-shelf parts, research and development results, and expert opinions so that you can be prepared for the remaining steps in the process. The step of data collection is an on-going process that may continue until and even through the final production of the designed product or service. However, before you can even begin to conceptualize a solution, some data will be needed. The requirements will help to guide the data collection process. For instance, if a minimum weight of the overall system is given as a major requirement, different types of lightweight materials should be researched and sourced (sourcing is the process by which you find vendors that can provide the product you need within the allotted budget). If the design must withstand a specified amount of loading as one of the requirements, then the strengths of the materials will also need to be known. As more and more requirements are considered, the choices will be narrowed down based on their ability to fulfill the requirements. You can see how just the choice of material can become increasingly difficult, especially if the material you need is not readily available.

Constructing the preliminary solutions is the next step in the engineering design process. At this point in the process, creativity is crucial. Input from as many different perspectives is essential, and teamwork is the key to success. If you or your company is going to truly design the *best* solution, then it is imperative that as many possible alternatives be conjured up for analysis and consideration. The overlooked solution could potentially be the best one. In engineering, the *best* solution is the one that meets and/or exceeds all of the requirements in the best way. A good solution is one that meets all of the requirements. To be confident you have the best solution, you have to have many *good* ones from which to choose the best! Unfortunately, this part of the process cannot really be taught; success in this step will become easier as you harness your creativity and accumulate experience.

Once you have at least two different solutions (the solutions don't have to be completely different, sometimes they are just variations of the same solution), preliminary analysis can be completed. This is where all the concepts you learn from your engineering courses will come into play. You can now analyze each solution to see how well it meets any functionality, physical, financial or other requirements, and other considerations such as ease of fabrication. As the analysis progresses, it will become clear which solutions are no longer worthwhile and those on which the design should focus. Oftentimes, a decision matrix[1] is used to help justify final choices between alternate solutions. A decision matrix is something you've likely had experience with if you've ever listed the "pros" and cons" of two options in an effort to make your choice easier. A decision matrix lists all the alternate solutions (usually in the first column) and all of the requirements (usually along the top row) in a *matrix* format. The engineer then *judges* each solution on how well it meets each requirement. Some standard grading system is used (i.e. 0 = requirement not met up to 10 = requirement fully met) and total scores for each solution are then tallied. There are other rubrics for choosing between options, but this is one standard method commonly used.

The process from here becomes very repetitive. A single solution has been chosen to go ahead with, but this solution was simply a preliminary solution, meaning not many details have been worked out. For instance, a preliminary solution to the requirement of designing a cargo aircraft might be to use a conventional wing and empennage (that's the horizontal and vertical stabilizers) configuration. Preliminary calculations are done to show that the approximate size and shape of the aircraft, along with the required area of the wing for lift and the required area of the empennage to maintain stability are all reasonable. When compared to other alternatives, this is the solution you decide to choose. Now it is time to actually design the aircraft! Choosing the airfoil shape, what type of high lift devices, their size, what mechanical system will be used to deploy them and the "fit" of that system within the wing, how many rivets will be used to hold the airframe skin pieces together, how thin or thick the skin will be in each region, what the support structure will be inside the aircraft fuselage and wings and empennage, where the hydraulic lines will be run, where the electrical lines will be run, what type of computerized system will be employed, the list goes on and on. Some of the above listed items are high level details (i.e. the support structure) and some are low level details (i.e. number of rivets), but at some point, all of those details must be determined, justified and worked into the design. As you might imagine, choices made early on can end up limiting your available choices later in the process. Not only that, but in almost every system, as you're determining the lower level details, you will have to continually update your original estimates to reflect the new information that results from the details. For instance, in keeping with the aircraft example, before you can really begin the preliminary design of an aircraft, you must have ***some*** idea of how much the aircraft is going to weigh (payload, structure, engines, fuel, etc.). You cannot very well properly size the wings without knowing how much weight those wings will have to support. Of course, until you've designed the wings (and everything else) you don't actually *know* the weight. So how do you get yourself out of this apparent "catch 22"? You begin with baseline estimates. You *estimate* the gross (total) weight based on payload weight (which should be a requirement provided by the customer) and existing designs which have similar requirements as yours (i.e. range, cruising speed and altitude, payload weight, and the conceptual design). But as you and your team begin to design the details of your unique airplane, that gross weight estimate becomes an ever firmer number. The problem is that you've made the calculations for the wing area, fuel weight, engine thrust, etc. based on the *estimated* gross weight. So what happens now? You *iterate*. Iteration is the process of calculating values based on initial - and educated - guesses, and then *re-doing* the calculations with intermediate values until the initial and final values begin to converge towards the same value. For instance, you begin with an estimated gross weight for the aircraft you're designing. You perform some preliminary calculations to determine wing area, fuel weight, engine thrust, etc. As these items are calculated, you can now begin to determine the weight of the wings, the fuel and its tanks, the engine weight, etc. With these weights, you can update the estimated gross weight to reflect their weight. But you're not finished; the wing area, fuel weight and engine thrust were calculated based on the first estimated gross weight. You must now re-calculate those values based on the new updated weight. Of course, they will not be the same as before, so the gross weight must once again be updated. This is the iteration cycle. You continue this process until some intermediate gross weight that you begin the calculations with is the same as the final updated gross weight, or within some pre-determined tolerance, such as within 0.5 percent. It should be apparent that the more detailed the design becomes, the more complicated and time consuming this process can become. This is why engineers must work in teams. It is simply impossible for one person to design a system as complicated as an aircraft all by themselves. Perhaps it could be done, but not within an acceptable time frame, and it would not have been checked by anyone other than the single designer. This would not be an aircraft that anyone would want to ride in.

Once a detailed design is complete, a final check against the requirements must be made to ensure the final design still meets all requirements (this is done continually throughout the process). If the design proves to be structurally, functionally, financially sound and is manufactureable within the budget and time frame, the design is ready for prototyping and testing! This is a whole field of engineering in itself. Testing is employed to ensure that the engineering analysis was correct and that the system is safe. If the design passes all tests, it is ready for production. At this point, the engineer's job is still not over, the design process is complete, but the design cycle is not.

The design cycle includes the design process that results in the design of a new system, mass production of that system, and finally the disposal of that system at the end of its life. Engineers are responsible for quality assurance during production and addressing any manufacturing problems that might arise. Of course, these problems are addressed by a different set of engineers, but if you are the lead design engineer you would likely be required to aid in any manufacturing issues as you would be the most familiar with the design. Even after the designed system is produced, engineers are not out of the picture. Most systems require operation, maintenance and repair, and it is the engineers who write the operation/maintenance and troubleshooting manuals for the systems they've designed. They are also generally "on-call" for technical support. Although the projects you will be undertaking in this course will not take you to the final phases of the design cycle, the majority of the design process will be employed.

As you begin these projects, you must keep in mind the design process. Although the projects are very well-defined, much of the data collection has been done for you and the analysis equations are provided to you, the process of creating alternate solutions, choosing the superior solution and iterating through your solution to add detail is still up to you. And although a minimal data collection has been provided to you (materials and off-the-shelf products), you are highly encouraged to research other data on your own. Not only will this make your design more unique, but you will gain much more knowledge through this process. These projects will be a challenge, but you will truly feel accomplished at their completion if you put forth a valiant effort.

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Chapter 13

PROJECTS

Satellite System Project

Satellite Imaging System Project Request for Proposals (RFP)

A Request for Proposals for the preliminary design of a reconnaissance satellite is described in this section. This satellite should capture and transmit digital images of portions of Earth's surface. It is expected that the imaging device used in the optical system will be selected from existing sources and will not rely on unproven technology. The primary mirror, power system and support structure will be designed, at least at a conceptual level, in order to be considered. It can be assumed that the satellite will be part of a security system which will be placed in a low earth orbit. System Constraints and Requirements are given below. Deliverables will be described in a subsequent section.

Critical System Constraints and Requirements

The ideal orbit height (termed *H* for this project) is around 120 nautical miles, but you are free to choose orbital heights between 100 nautical miles and 200 nautical miles. A Charge-Coupled Device (CCD) in the image plane will capture the images as a two-dimensional array of voltages. The CCD can be chosen from the provided list or newer options may be researched; however, undeveloped and/or untested technology will not be accepted. The area on Earth that should be imaged in the focal plane of the primary mirror should be a circle with a diameter of at least 750 m; the actual area that is sampled by the CCD depends on the geometry of the particular CCD. At a minimum, the diagonal of the rectangular CCD should correspond to the diameter of the imaged area, as shown below.

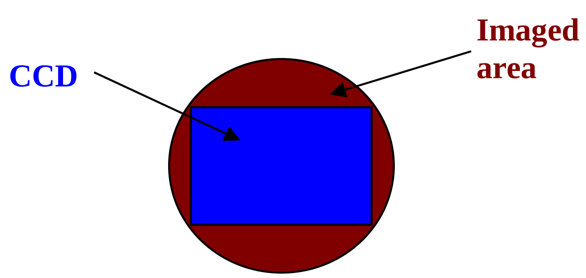

Figure 1: Imaged area (circular) versus captured area (rectangular)

Your design should yield images with a resolution of 2.5 m or less. That is, objects whose size is about 2.5 m should be resolvable in your telescope's images. The optical power (due to light energy) hitting the CCD must be at least the minimum specified for the CCD in nano Watts (= 10^{-9} Watts), or as specified by your customer (instructor).

It is desirable to have as small a mirror as practical to conserve weight and enhance orbit insertion and orbit keeping. Conversely, power requirements dictate that the mirror should be as large as possible, in order to capture adequate optical power. As the mirror size increases so does its weight. The mirror must fit inside of a cylinder no greater than 1.83 m in diameter and no longer than 3.05 m (6' by 10') – this is known as the available space envelope. Thus the design conundrum of opposing constraints must be dealt with here. It is important to realize that you are not being asked to produce an optimum design -

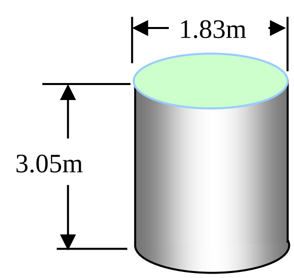

Figure 2: Space envelope

for in fact it may not exist relative to the imposed constraints - but to produce a design that meets all the requirements.

The electrical system for the satellite embodies four major components. They are:

1. the electrical power system
2. the command / data control system
3. the communication system
4. the image processing system

A DC supply voltage V is to be provided to the various electrical systems from a solar cell array and a battery array. The provided solar cells and NiMH (Nickel Metal Hydride) batteries are available in-house. You are not restricted to using these particular parts, but if you choose to research other options (which you are encouraged to do), be sure to obtain all of the specifications for your part which are provided for the in-house parts (as provided below). The solar cell array is the major power supply mechanism in orbit. The battery array supplies the power when the solar cell is not able to operate (not in sunlight).

The in-house solar cell available for use in the power system measures 2 cm x 4 cm x 0.3 cm and is rated at 0.5 volts producing a maximum current of 0.080 amperes. Each cell weighs 2.5 ounces when mounted in an array. Each cell costs fifty dollars ($50.00). The in-house battery available is rated at 1.2 volts and can provide 2.88 watt-hours of energy when discharged at a C/12 rate (this means when depleted over 12 hours, it will provide 0.2 amperes – noting that 1.2volts x 0.2amps x 12 hrs = 2.88 watt-hrs). These batteries will provide only 2.0 watt-hours at a 1C discharge rate (depleting the battery in one hour will give you 1.67 amps of current). The maximum continuous discharge current is 2 amps and the recommended charging current is 0.8 amps. Each battery weighs 1.6 oz, is a cylinder that measures 2" length x 9/16" diameter and costs fifteen dollars ($15.00).

The sizes of the battery array and the solar cell array must be determined. The weight and cost of each array must also be determined in order to see if they are significant components that must be included in the total satellite design.

In determining the size of the solar cell array, some of the items that must be considered are:

1. the hours that each or any of the systems will be operating;
2. the maximum total power requirement (watts) at any point in the orbit;
3. the total energy requirement for an orbit (watt hours);
4. any safety factor in regards to the total energy requirement;
5. the efficiency of the battery charging process.
6. the efficiency of the solar cell array in generating power.

In determining the size of the battery array, some of the items that must be considered are:

1. the operating or supply voltage required by operating equipment;
2. the number of hours that the solar cell array may be used during an orbit;
3. the total energy requirement for an orbit;
4. the efficiency of the battery charging process.

Due to the changing angle of incident of sunlight on the solar cell array during the orbit, the efficiency of the solar cell array in delivering power to the charger is 70 percent.

Due to the heat that is generated during the charging process, the efficiency of the charging process from solar cell to battery is 60 percent.

The Command/Data Control System(C/DC)

The software provided for the command / data control system provides:

1. for scheduling power for image acquisition;
2. for scheduling power for transmission of image data and telemetry;
3. for intelligent recharge of batteries via solar cells during day orbits;
4. for intelligent distribution of power from batteries during night orbits;
5. for communications with the ground station.

The command / data control system is run by a current state of the art 32 bit processor. The processor has multitasking capabilities built in and has a history of use in space applications. The memory system uses static ram chips with error detection and correction. There are high speed links from the processor to ground station and to data signal processing where the data is stored for transmission to ground station. ***The physical specifications (dimensions and weight) of the C/DC will be specified at a later date by the customer***.

The microprocessor is programmed to detect low power state of the batteries. It also controls battery charging by the solar cell array consistent with the location in orbit.

The power consumption of the command / data control system in base configuration with no operation of the imaging processing equipment is 4 watts. The power consumption of the command / data control system when transmitting of data and/or the operation of the imaging processing system is 10 watts (this does **not** include the power for either the IPS or the CCD itself). The supply voltage required to operate the equipment is 6 volts.

The Communication System (COM)

It may be assumed that the amount of data to be transmitted is such that the communication system will be transmitting data continuously over a 24 hour period. When transmitting the power requirement for the communication system is 3 watts. ***The physical specifications (dimensions and weight) of the COM will be specified at a later date by the customer.*** The supply voltage required to operate the equipment is 6 volts.

The Image Processing System (IPS)

The power requirement for the image processing system when operating requires 4 watts plus the specific requirement for the CCD (see CCD choices in Table 1 in the Imaging System section above). When it is in standby or not operating there is no power requirement. ***The physical specifications (dimensions and weight) of the IPS will be specified at a later date by the customer.*** The supply voltage required to operate the equipment is 6 volts.

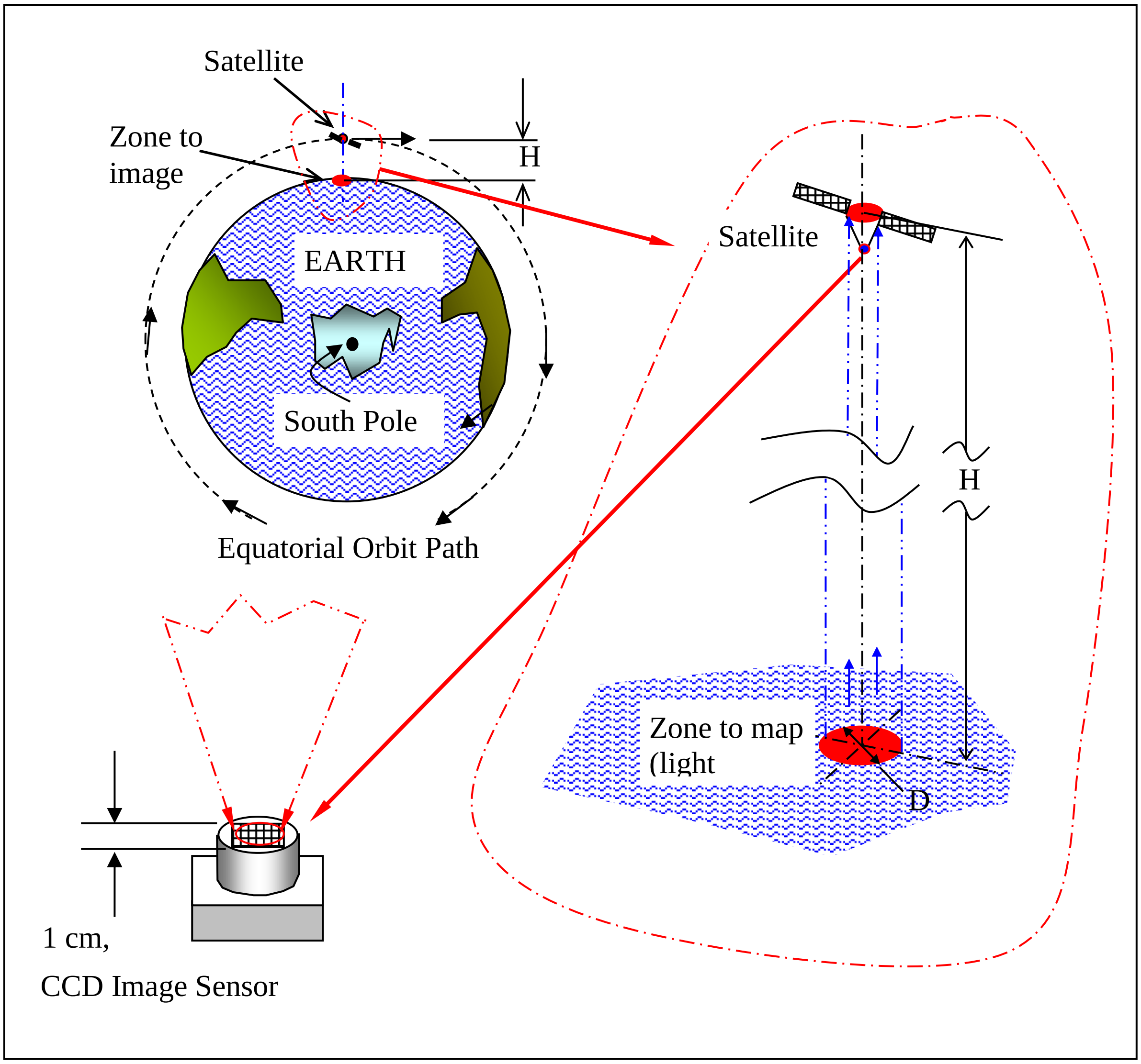

Figure 3. General Layout

You can assume either an equatorial or polar circular orbit for your satellite. Whichever you choose must be specified in your report as it will affect the launch requirements. It is up to you to determine which is most appropriate, why, and justify your choice so that it is apparent to the customer. The main tasks for your team to address on this project are:

1. Select a CCD from the list given (**Table 1**), or from additional research, that yields the desired resolution and coverage – be sure your choice will meet the sampling resolution criteria.
2. Determine the size of the mirror (its aperture *a*, radius of curvature r_m, depth b, thickness t, image distance *q*, and focal length *f*) required for your orbit height. The mirror dimensions must be selected such that the CCD receives at least the minimum amount of optical power required to operate (see CCD specifications in **Table 1)**.
3. Verify your resolutions (optical and sampling) meet the requirement.

4. Determine the volume, weight, and estimate the cost for your mirror design. Preferred materials are provided in **Table 2**.
5. Consider alternatives that may cost less or weigh less.
6. Design the support structure that positions the CCD in relation to the primary mirror, houses the electrical systems and protects all systems; estimate its cost (no formal guidance is provided for this task).
7. Size the power system for the satellite and determine its cost and weight.
8. Produce drawings, a report and a presentation as described below.

Project Deliverables

Your company will need to prepare the following items for submission by the proposal due date:

1. A report that details <u>all</u> calculations supporting your design. Including all diagrams, sketches and information required in items 3 (below) and thereafter. (See Chapter 3 for guidance on technical report writing and for report format guidelines.)
2. A PowerPoint presentation highlighting your design decisions and results – a brief oral report using this PowerPoint presentation will also be required.
3. A scaled and dimensioned drawing of the mirror with dimensions identifying its key features and specifications (similar to **Figure 6** in the background section following this RFP – do NOT copy this diagram and simply paste your team's numbers in – your drawing should be to scale.); i.e., radius r_m, thickness t, and dimensions a and b. <u>The **center** of the radius of curvature need not be included in the diagram as this causes the drawing of the mirror itself to be very small</u>.
4. The resolution (**both sampling and optical**) of your design, the diagonal dimension of the imaged area, and the amount of light power hitting the CCD must be clearly expressed in the report.
5. The CCD choice, its size, its pixel dimension, and its cost must be clearly specified. (CCD cost includes cost of mounting hardware.)
6. The mirror weight calculations.
7. An estimate of the mirror cost.
8. A detailed drawing of your optical system which includes the mirror, CCD, and the structural components that connect the two, as well as any support structures for your mirror (this is where you can be creative). This drawing should also be properly scaled.
9. The size of the battery array (number of batteries) indicating the number of rows and columns in the array. Indicate the output voltage V and overall power for the battery array. Supporting calculations must be shown.
10. A scaled (and dimensioned) drawing of the battery array.
11. The size of the solar cell array (number of cells) indicating the number of rows and columns in the array. Indicate the output voltage and overall power for the solar cell array. Supporting calculations must be shown.
12. A scaled (and dimensioned) drawing of the solar cell array.
13. Indicate what safety factor you used in regards to the total energy requirement placed on the solar cell array and indicate what factors you used to come to that decision.

14. An electrical schematic of the entire system (solar array, battery array, the Command/Data Control system, the Communication system, the Image Processing system, any switches, regulators, or other electrical components you deem necessary). This is another opportunity to be creative. At a minimum, there should be some switches to regulate when the solar or battery arrays are being used or charged (as appropriate).
15. A drawing of the entire satellite in launching configuration. Dimensions should be given that verify the satellite's adherence to the required space envelope (see beginning of project).
16. A drawing of the entire satellite in its fully operational configuration for orbit. If intermediate drawings are needed to show how the satellite expands, unfolds or otherwise "opens-up", these should also be included. These drawings (in items 15 and 16) need not be scaled, but they must be neat and drawn with instruments (not free-handed), and should include some overall dimensions.

Satellite Imaging System Background

You are going to design an integrated telescope and image processing system that will be part of a low Earth orbit reconnaissance satellite system with security applications. This section introduces theory and issues with the telescope design and presents an overview of some issues concerning digital imaging systems.

A block diagram for the system is shown in figure 4 below. The telescope collects light from Earth and yields an image in its focal plane. The focal plane image is captured and stored as digital information—that is, as 1s and 0s—by the satellite's image processing system (IPS). The digital image is then sent to Earth by the satellite's communication system (COM). Figure 1 shows a block diagram describing the flow of information processing in the satellite.

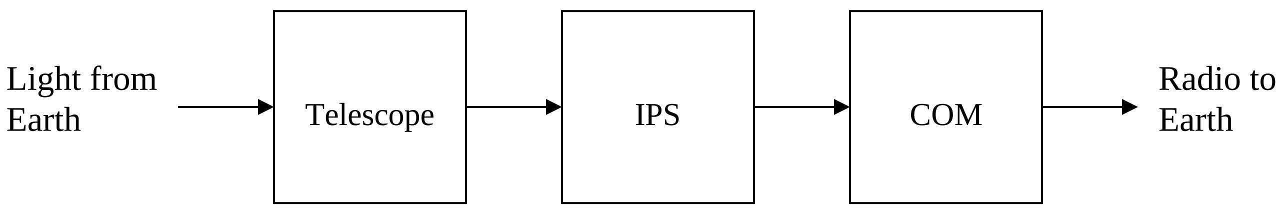

Figure 4. Image Processing and Communication Systems

The IPS is an example of an embedded system: a special-purpose digital system that implements part of a larger system. Embedded systems are ubiquitous in modern engineering design. A contemporary satellite would have tens or hundreds of embedded systems. Embedded systems are sometimes implemented using general-purpose microprocessors, but they often employ special-purpose microprocessors such as microcontrollers (μ-controllers) or digital signal processors (DSPs[1]). Sometimes embedded systems are implemented by designing ASICs (application-specific integrated circuits) or by configuring FPGAs (field-programmable gate arrays) appropriately.

The IPS is a system made up of several subsystems[2], each with a different task in converting light at the telescope's focal plane into the bits of the digital image (see Figure 5). The conversion from light to the digital image takes place in three steps:

1. The image is broken up into a number of pixels (PICture ELements) covering the focal-plane area. The light intensity, which varies continuously across the focal-plane area, is converted into a discrete two-dimensional array of voltages, one voltage for each pixel. The number of pixels along each dimension of the image determines the image resolution. In our image processing system, the conversion

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1 The acronym DSP is used not only for digital signal processors, but also for the field of digital signal *processing*, the mathematical theory of processing signals using digital technology.
2 Thinking of a system as being made up of interconnections of subsystems is called a *hierarchical description*. The subsystems are often thought of as "black boxes." Designing a system by thinking of it in terms of how it behaves at the upper levels without initially worrying about the details of how the subsystems are implemented is called a *top-down* design.

from light intensity to pixel voltage is performed by a charge-coupled device (CCD), as it is in most consumer digital cameras.

2. Each pixel voltage, a continuously varying quantity, is quantized into a finite number of discrete levels. Each voltage level is represented by an integer, and that integer is stored as a binary (sums of powers of two) number. Since the value that is stored is an inexact representation of the pixel voltage, quantization introduces error, or noise, into the image. This stage results in what is termed the raw image. In our system, quantization is performed by the analog-to-digital converter (ADC).

3. The raw image is compressed to reduce the amount of storage necessary for each image. Compression can be either lossless, in which case the raw image can be recovered exactly, or lossy, in which case one can recover an approximation to the raw image. Compression often is implemented by numerical algorithms running on a special-purpose microprocessor. In our system, the compression is performed by a digital signal processing microprocessor (DSP).

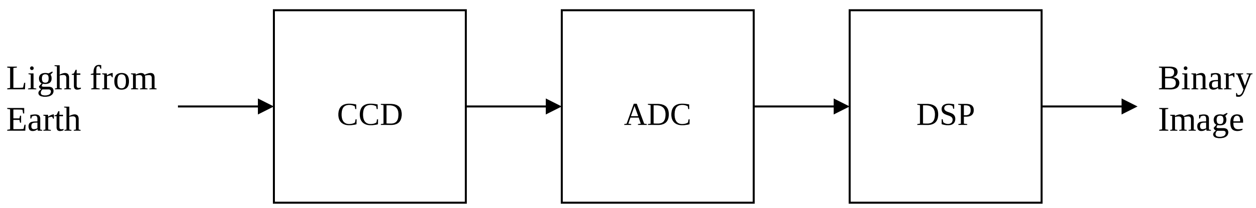


Figure 5. IPS block diagram.

There are, of course, lots of details concerning the operations of each of the elements of the IPS; we will ignore those other details. In your design project you will concern yourself with designing the telescope and choosing the CCD to ensure that the resulting image has appropriate resolution.

Details about how CCDs, ADCs, and DSPs operate are beyond our scope right now. If you pursue either the Computer Engineering or Electrical Engineering degrees, you will run into some of them in future courses. Also beyond our current scope are the details about the many options for the COM system: the various modulation schemes, how much power they use, and how they ensure that digital messages are transmitted with negligible errors. Again, those of you pursuing Computer Engineering or Electrical Engineering degrees will see more about communication systems in the future.

Optical Imaging: Mirror Design

Your telescope design concerns an orbiting reflecting telescope using at least a single primary mirror (as in Figure 6). Equations are provided for both spherical and parabolic mirrors. You are responsible for deciding which shape best suits your needs. If you choose to use a different mirror shape you are responsible for researching the equations that 1) describe the relationship between the object distance, focal distance and image distance and 2) find the surface areas of the mirrors. If you choose to use multiple mirrors (as in a Newtonian or Cassegrain design), you must also determine how to apply the Dawes Equation for secondary and higher mirrors to find the optical resolution.

Mirror Background

For a mirror (either spherical or parabolic) with object distance *H* and image distance *q*, the magnification *M* is:

$$M = -\frac{q}{H} = -\frac{I}{O}$$

Equation 1. Magnification equation

where *O* is a characteristic linear dimension of an object being imaged and *I* is the corresponding size of the image. For a telescope, *M* is much less than one in magnitude. For example, if the telescope's magnification is $M = -1 \times 10^{-6}$, then an object one meter long on the earth would appear to be one micron (1×10^{-6}m) long in the image created by the mirror, and upside down (which is what the negative means), in the focal plane of the telescope.

For concave mirrors (both spherical and parabolic), the object distance, *H*, the image distance, *q*, and the focal length, *f*, are related through the following equation:

$$\frac{1}{H} + \frac{1}{q} = \frac{1}{f}$$

Equation 2. Mirror equation

For the case of an orbiting satellite, the object distance H is very large compared to the image distance *q*, so the focal length is equal to the object distance; that is, $H >> q \Rightarrow f = q$. (Consider the limiting case $H \to \infty$ to convince yourself of this.)

Spherical Mirrors

A spherical mirror is just as the names implies; it is a mirror with a spherical shape. Of course a spherical mirror is not the surface of a whole sphere; instead imagine just a small section of the sphere, much like a contact lens. For *spherical* mirrors with large object distances, the focal length is one-half the radius of curvature for the sphere:

$$f = r_m / 2$$

Equation 3. Focal Length for a Spherical Mirror with large object distances

For a spherical sector, like a spherical mirror of radius r_m, the surface area can be calculated:

$$A_m = 2\pi r_m b = \pi(a^2 + b^2)$$

Equation 4. Area equation for a Spherical Mirror

Here *a* and *b* are the mirror sector dimensions as illustrated in Figure 6. Selecting arbitrary values for these parameters is not recommended; it is better to determine unknown parameters using the area equations.

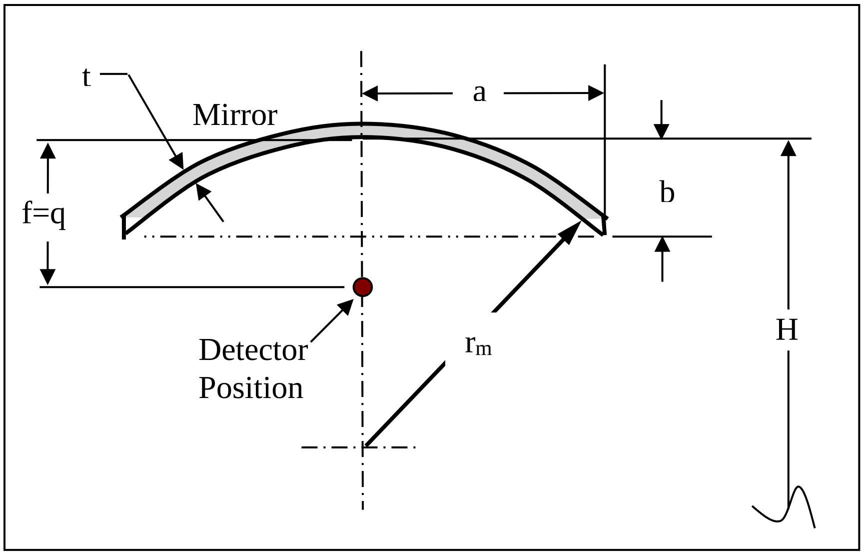


Figure 6. Mirror geometry and equations.

Parabolic Mirrors

Parabolic mirrors are similar to spherical mirrors, but instead of being a section of a sphere, the mirror shape is the surface of a paraboloid (take a parabola and revolve it around its axis of symmetry). The simplest equation of a parabola is given as:

$$y = Cx^2$$

Equation 5. Simplified equation of a parabola

where C determines the flatness of the parabola (the smaller the number, the “flatter” the parabola). The coefficient C is related to the focal length of the parabolic mirror as shown below in Equation 6-1[3]. The focal length is also related to the mirror geometry parameters as shown in Equation 6-2. Though Figure 6 illustrates a spherical mirror geometry, the variables a and b represent the same attributes for the parabolic mirror: a is the aperture radius and b is the depth of the mirror (or height).

$$f = \frac{1}{4C} \quad \textbf{(Eq. 6-1)} \qquad \text{and} \quad f = \frac{a^2}{4b} \quad \textbf{(Eq. 6-2)}$$

Equation 6. Parabolic mirror equations 6-1 and 6-2.

3 For the curious student, the derivation of this equation can be found at the following webpage: http://scipp.ucsc.edu/~haber/ph5B/parabolic09.pdf

Finally, the surface area of the parabolic mirror is described by the following equation. Just as with a spherical mirror, should you opt to use a parabolic mirror, the surface area must be adequate in size to ensure enough light is captured to register an image on the CCD.

$$A_m = \frac{\pi a[(a^2 + 4b^2)^{3/2} - a^3]}{6b^2}$$

Equation 7. Area equation for a Parabolic Mirror

Sampling Resolution (Background Information)

The image in a telescope's focal plane can be viewed in several ways. Historically, the image was viewed through an eyepiece by the human observer's visual system. The invention of photographic technology made it possible to capture the image in a photograph. In a traditional photograph, exposure of light onto photographic film causes chemical changes in silver-halide crystals in the film. In the development process, the crystals that were exposed to light are reduced into metallic silver, then the unexposed parts of the film are dissolved away leaving a negative image. Since the size of the grains of silver halide is smaller than one micron (micrometer; i.e. 10^{-6} m) in diameter, sampling resolution isn't much of an issue in traditional chemical photography.

For example, if the image in the focal plane were a square 1 cm length on each side, and if the exposed grains of silver-halide develop into blobs on the order of 1 micron in length, then there are about $10^{-2} / 10^{-6} = 10^4 = 10{,}000$ blobs along each linear dimension of the image. For the square image, there would be 10^8 total blobs representing light and dark in the image; that is, the chemical photographic image is represented by something like 100 million elements. Contrast that to the situation in digital imaging where the image is represented by rows and columns of pixels (picture elements) in the image plane. If the pixel size for a square image 1 cm length on each side is 10 microns, there are only 1,000 pixels along each linear dimension, and only 1,000,000 pixels for the entire image; i.e., one megapixel.

Is there some *lower* limit on the number of pixels one would choose to use? There is, and it is determined by what is called Nyquist's sampling rate. You may have heard of Nyquist's rate regarding digital audio, where it is usually stated that a signal must be sampled at a rate that is at least twice as fast as the highest frequency in the signal being sampled.

For example, since audible sounds occupy the frequency range between 20 and 20,000 Hz (Hertz or cycles per second), the minimum rate for audio sampling is 40,000 samples per second. The audio on CDs is sampled at 44.1 kHz, an example of slightly oversampling the signal. When an audio signal is sampled at a rate that is less than Nyquist's rate, high-frequency components of the signal masquerade as lower-frequency signals in a phenomenon called *aliasing.* Aliasing is also the phenomenon that makes strobe lights appear to stop motion; that is, something oscillating rapidly is made to seem as if it is not moving at all because its high frequency components have been aliased to a frequency of zero. Aliasing is also responsible for the seeming backward motion of wheels under florescent lighting; in that case, a positive frequency (rotation in one direction) is aliased to a negative frequency (rotation in the opposite direction). See the following website for an audio aliasing demonstration: http://ptolemy.eecs.berkeley.edu/eecs20/week13/aliasing.html

In the same way, digital images have to be sampled with a sufficient density such that rapidly oscillating patterns in the image do not appear to be slowly oscillating; i.e., to avoid aliasing. An example of aliasing in digital images is shown in figure 7 below. The "high frequency" lines in the rear building in (a) appear as "lower frequency" lines (of different orientation) in the "undersampled" images (b) and (c).

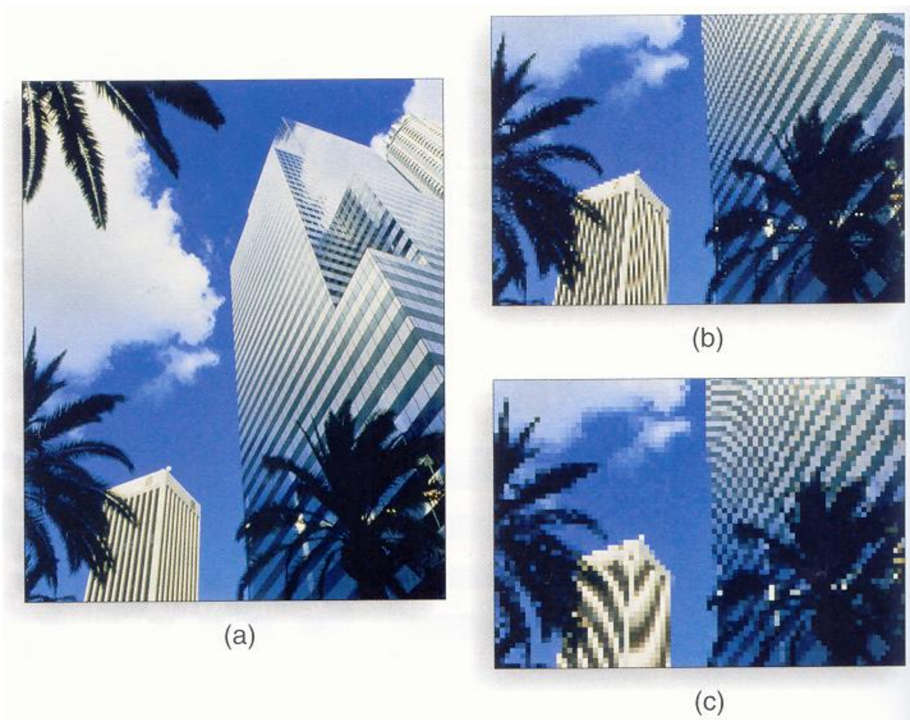


Figure 3.23 The original image of two buildings in (a) has 812 rows and 650 columns. When the linear sampling rate is reduced by a factor of four in (b), the sampling rate is too low to accurately represent the vertical structures in the more distant building in the lower left, and diagonal bands begin to appear. In (c), the sampling rate is reduced by another factor of two, and these aliasing effects become more obvious.

Figure 7. Example of aliasing in digital images. From Engineering Our Digital Future by Orsak et al. (Pierson, 2004).

Let's say our CCD has a pixel dimension that is 10μm, and that our telescope's magnification has a magnitude of 10^{-6}. The distance on Earth corresponding to one pixel dimension would then be 10m. **A rule of thumb is that the *resolution* of the image is about three times the corresponding pixel dimension, multiplied by the inverse of your magnification factor**. So for this case, the image of Earth as seen from space would have a resolution of about 30m ($3 \times (10 \times 10^{-6}) \times (1 \times 10^{+6})$). High-quality spy satellites like the KH-11 and KH-12 have resolutions on the order of a few centimeters and can supposedly resolve an object the size of a matchbook from space.

It would seem that one would simply want to have as many pixels as possible; however, more pixels means increased cost for the digital imaging device. Furthermore, more pixels means that each pixel receives a smaller fraction of the incident light, meaning that longer exposure times are required to capture the same image. Finally, more pixels per image means that more bits in each image have to be transmitted to Earth. The bandwidth of a communication channel limits the rate at which bits can be sent over that channel. Since bandwidth is limited – our satellite can transmit data back to Earth (over an inter-satellite network) at a fixed rate – there is little value in increasing the pixel density above that required by the Nyquist criterion – in fact it will slow down the transmission of data as the number of pixels is increased beyond the Nyquist criterion. To ensure you do not alias and to ensure you do not oversample and bog down the system, use the following criteria:

$$3P \leq MR_s \leq 6P$$

Equation 8. Nyquist Criterion

Where P = Pixel Size (provided in Table 1)
M = Magnification
R_s = Sampling Resolution

Optical Resolution

For telescopes, the resolution is often specified in terms of the seconds of arc between two equal intensity distant point sources that can be distinguished after being reflected from the telescope. This resolution (optical resolution) is different from the resolution just discussed (sampling resolution), as it is a result of the amount of light captured and reflected by the mirror(s) of the telescope and has nothing to do with how the light is recorded digitally. To sum up, optical resolution quantifies the sharpness of the picture produced by the mirrors (the output of the telescope), which is then input to the CCD. Sampling resolution quantifies the sharpness of the picture reproduced by the CCD. Your overall system resolution is the "worst" of the two. Dawes's formula (Eq. 9) is an empirical formula for a reflecting telescope's resolution R_o'' (in arcseconds) in terms of the aperture radius a (in millimeters) of the telescope.

$$R_o''\text{(in arcseconds)} = \frac{115.8}{2a\text{ (in mm)}}$$

Equation 9. Dawes's Equation

In order to verify your resolution, R_o'', is adequate, it must first be converted to radians (recall that there are 3600 arcseconds in one degree) and then the following equation can be used to change the resolution from radians to a linear measurement in meters:

$$R_o = HR_o'$$

Equation 10. Resolution Determination

Where R_o = Optical Resolution (in m)
H = Object Distance (your orbital height)

R_o' = Optical Resolution (in radians)

Optical Power Considerations

As you might expect, the light power reflected from Earth to the space telescope's focal plane is inversely proportional to the orbital height of the satellite and directly proportional to the telescope's mirror area. An approximate formula for the power to the focal plane (i.e., the light power to the CCD) is:

$$P_m = \frac{100 A_m}{\pi H^2}$$

Equation 11. Light Power Captured by the Mirror (in Watts)

where H is the orbital height in meters and A_m is the area of the telescope mirror in square meters. In order for the CCD to register an image, it must have predetermined minimum amount if light power hitting it. This requirement will either be given to you as one the project constraints or will be based on the CCD you choose. Inquire with your professor to determine which is the case for your project. If the professor chooses to standardize this requirement so that it is CCD independent, the optical power requirement is likely 1 nanoWatt; however, your professor may choose to provide a different constraint.

You will find a selection of CCD devices in **Table 1**. The pixels in each CCD are arranged in *m* rows and *n* columns. The "pixel dimension" is the height and width of each square pixel in the array.

Table 1: Charge-Coupled Devices Available For Imaging System

Manuf.	Part #	Hpixels	Vpixels	P	W	L	D	Power	P_M	Cost
		# pixels	# pixels	pixel dim	width	Length	Diag.l	(electrical)	(optical)	
				micro-m	mm	mm	mm	Watts	Nano-Watts	USD
Kodak	KAI-02050	1600	1200	5.5	8.80	6.60	11.0	1.19	1.07	5050
Kodak	KAI-04050	2336	1752	5.5	12.85	9.64	16.06	1.74	1.07	7350
Kodak	KAI-1010	1008	1018	9.0	9.07	9.16	12.89	1.82	0.193	2250
Kodak	KAI-08050	3296	2472	5.5	18.13	13.60	22.66	2.45	1.07	10400
Sony	ICX204AL	1024	768	4.65	4.76	3.57	5.95	0.59	0.406	3800
Sony	ICX267AL	1360	1024	4.65	6.32	4.76	7.91	0.79	0.581	5100
Sony	ICX285AL	1360	1024	6.45	8.77	6.60	10.98	1.29	2.31	3650
Sony	ICX414AL	659	494	9.9	6.52	4.89	8.15	1.18	4.33	1150
Sony	ICX415AL	782	582	8.3	6.49	4.83	8.09	1.08	3.63	1650

It is important to realize that this table is very limited, and there are many more CCDs available with higher resolution. You are encouraged to research other CCD options for your design. You are required to find all of the specifications in this table except for the last three columns; the last three specs can be ***approximated*** using the following empirical models:

$$OpticalPower = \frac{5(DRR)^2(MDR)(OS)}{6.241E18}$$ (Watts) - Variable definitions are below

$$Power = \frac{\sqrt{(\#Vpixels)(\#Hpixels)(P)^3}}{15000}$$ (Watts) – round to nearest whole number

$$Cost = \frac{20\sqrt{(\#HPIXELS)(\#VPIXELS)}}{P}$$ (USD) – round to the nearest \$50

DRR = Dynamic Range Ratio = Saturation Signal / Dark Noise (in e^- or V)
MDR = Maximum Data Rate (in Hz)
OS = Output Sensitivity (in V/e^- or V)
P = Pixel Size (in μm)

NOTE: If your design incorporates an array of CCDs, the total power (both electrical and optical) is equal to the number of CCDs in the array multiplied by the individual power requirements. This is also true for the cost.

Glass Properties

You will find a selection of appropriate glass properties in **Table 2** along with information relating to cost. The refraction index indicated for each glass type is within parameters acceptable for this application and is not a design consideration here. The thickness *t* in meters and weight *W* in Newtons of your mirror can be approximated using the following formulae (the thickness formula gives the recommended minimum based on the mirror's size and the selected material's density):

$$t = (0.0951 a\rho)\times 10^{-4} \text{ and } W = 9.81(\rho A_m t)$$

Equations 12 and 13. Appropriate thickness estimate and weight calculation

For these two equations the aperture radius *a* must be in meters, the glass density ρ in **kg/m^3** and area (A_m) in **m^2**.

The relative cost in dollars (USD) may be estimated using the equation:

$$\text{Cost (USD)} = M_{ci}(A_m)(t) + (110/n)(S_{cp})(A_m)$$

Equation 14. Cost estimate for mirror material and fabrication

where the parameters and coefficients are selected from **Table 2** for a particular glass type selected and the mirror of area "A_m" **(cm^2)** and mirror thickness "t" **(cm)**. Don't forget to include the cost of the CCD and support structure in your final cost estimate – the above equation is only the cost of the mirror! Use research and extrapolation to aid in your estimation for the cost of the support structure you design. A reasonable ballpark (with justification) is satisfactory.

Table 2: Glass Properties for use in the spherical mirror design

GLASS TYPE	n	ρ	M_{CI}	S_{CP}

BK7	1.52	2510	1.0	2.4
SF11	1.79	4740	9.7	2.0
Sapphire	1.77	3980	17.7	1.1
Borosilicate	1.47	2230	1.41	1.9

where:

n = glass index of refraction (dimensionless)

ρ = mass density (kg/m^3)

M_{ci} = Material Cost Index per unit volume (\$/cm^3)

S_{cp} = Surfacing cost parameter (\$/cm^2)

Electrical Power System Background

One of the major components of a satellite is the electrical power system. While there are various approaches to an electrical system, a combination of solar cells and batteries can be used as a workable electrical power system. In a combination of solar cells and batteries, the solar cells are arranged in an array of rows and columns to supply the voltage and current (power) to the electrical components of the system. The solar cells are capable of supplying power only as the satellite is passing through daylight. During the dark period of the orbit, the batteries supply the required power. During the light period of the orbit the solar cells must supply the power for the electrical components as well as recharge the batteries.

The dark and light periods for operation of the solar cells are determined by the altitude of the satellite and the number of orbits that the satellite will make traveling through the sunlight. In Figure 8 and 9 the X indicates the place on earth where work is being conducted as the satellite orbits around earth. That work, depending upon its nature, may be able to be conducted only in light or in both light and darkness. That is, either during a little less than half of the orbit or during the entire orbit. Solar cells may only operate during a little less than half of each orbit.

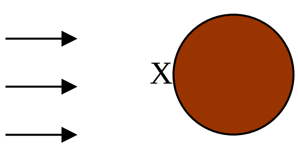


Figure 8

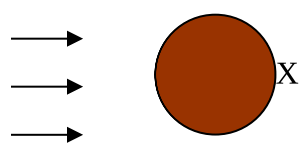
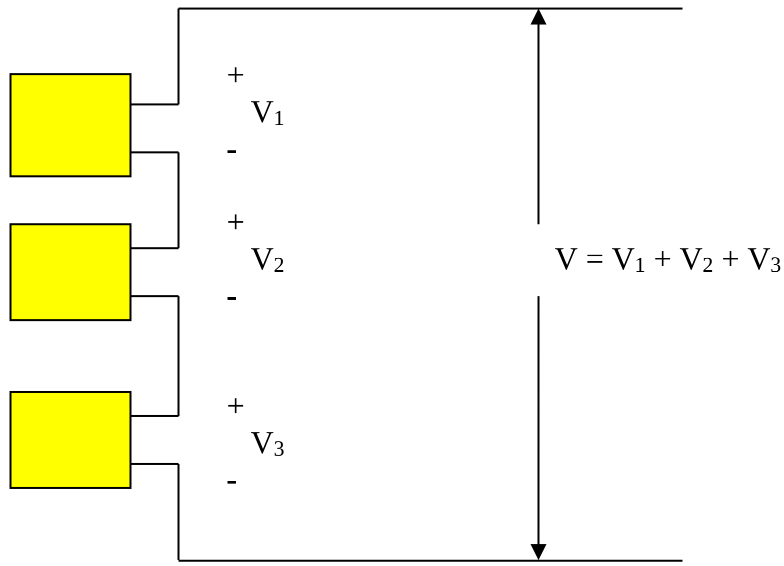


Figure 9

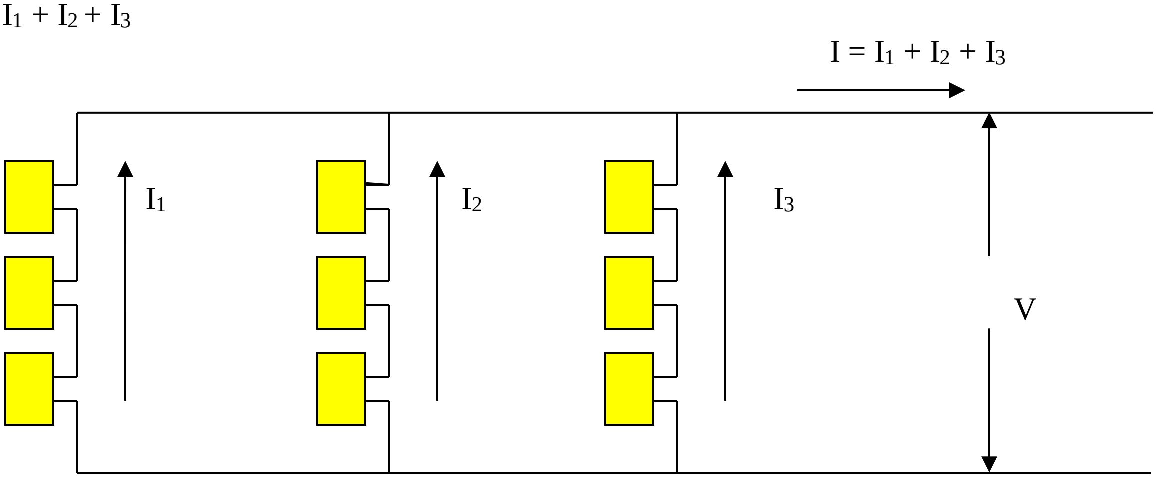
The Arrays

The solar cell array provides the major power supply mechanism for the operation of the electrical components and for recharging the batteries while in orbit. The battery array provides power to the electrical components when the renewable light source is not available (satellite is in the Earth's shadow). Both the solar cell array and the battery array consist of individual cells placed in a series-parallel arrangement. This arrangement provides the voltage and current to power the electrical systems.

Cells may be connected in series so that their voltage is additive as shown here where $V = V_1 + V_2 + V_3$



Strings of cells that are in series may be placed in parallel with each other as shown here. The currents flowing through each parallel string are additive such that the current is:
$I = I_1 + I_2 + I_3$



The current flowing through each of the cells in series is the same. For the left-hand string of cells above, each cell has current I_1 going through it. For the middle string, each cell has current I_2 going through it, and for the right-hand string, each cell has current I_3 going through it. The voltage across each string of cells connected in parallel is the same, so each string of cells in the figure above has the same voltage V across it.

The power output for the series-parallel combination of the solar cell or battery array is $P = VI$ watts. The total energy delivered by the cell array over a period of time T is power times time or PT or VIT. For example, if the solar cell array supplies 10 volts and the current that flows is 2 amperes, then the output power of the array is 10 x 2 = 20 watts. The energy supplied by the array over a 6-hour period would be 10 x 2 x 6 = 120 watt hours.

Power Requirements

The size of the solar cell array and the battery array are determined by the power requirements for the entire electrical system. The demand for power will vary during the day and night as various pieces of equipment are used and battery charging is required. The solar cell array and the battery array must be capable of supplying the maximum demand for power for as long a period of time as it will be required. It is necessary to determine the maximum power required when all the electrical components are operating. Then determine how long the equipment will be operating so that the required energy may be determined. When the battery array is operating, the solar array is not. Therefore, the total energy provided must equal that supplied by both the solar array and the battery array. Since the batteries must be recharged by the solar array, the energy supplied by the solar array must equal the total energy required by the system (be sure to account for the inefficiencies of the light-conversion and charging processes – see below) plus the energy to recharge the batteries. Since the angle of incidence for the sun rays is not always 90 degrees and the capture and conversion of light energy to electrical energy is not perfect, there is an efficiency rating for the solar array. In addition, because of heat generated during charging of the batteries, there is an efficiency rating for charging the batteries. Therefore, the total energy required must be adjusted for the solar array efficiency and the efficiency of charging the batteries.

Positioning of the Solar Array

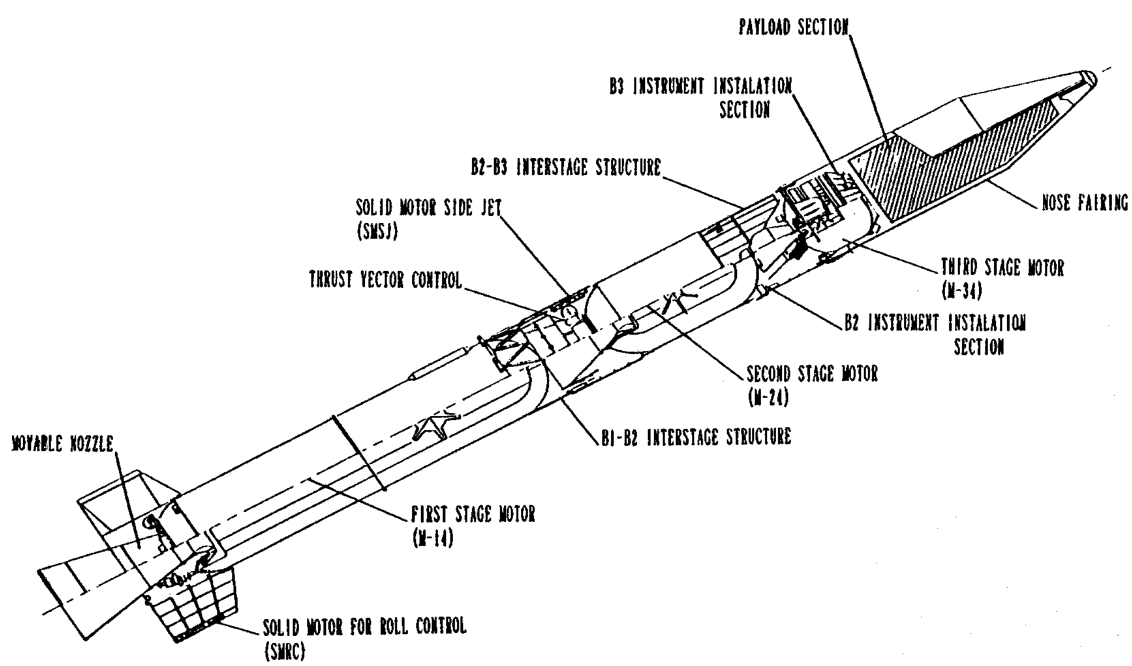
The solar array must be positioned on the satellite so that it is in a position to be exposed to the sun. For a satellite that is position controlled so that a certain point on the satellite is always pointed toward Earth, the solar array may be positioned on the opposite side. However, without position control the array must surround the satellite so that there is always an area directed toward the sun.

Launch Vehicle Project

Introduction

Imagine that NASA has just published a Request for Proposals (RFP) asking your company to create a preliminary concept of a new launch vehicle to insert a specified payload size and weight (discussed below and/or to be provided by your professor) into low Earth orbit. There is heavy emphasis on simplicity and low cost, so the vehicle should have either 2 or 3 stages. The preliminary conceptual design phase consists of making design choices, estimates and basic analysis of the feasibility of those choices. The following project description will guide you through that process, providing you the equations and general assumptions and rules of thumb you can follow when designing a preliminary concept launch vehicle. The preliminary design of the launch vehicle is now assigned to your team for study.

It is recommended that you divide your team such that each team member has a leadership role. One person should be the *Cognizant Engineer* for the design of the vehicle configuration, mass fractions and engine selections (Vehicle Engineer - sections 1-4, Appendix I and II if needed), one for the internal structures (Structural Engineer - sections 5 and 6), and one for the propellant delivery system if your instructor is requiring you to design that system (Mechanical Engineer - section 7). You should also have someone as the Team Lead and Project Engineer (responsible for all sections, including 8-10 and Appendices III and IV). If your instructor is allowing the mount analysis for extra credit, or is requiring it, then another team member should be assigned as the Cognizant Engineer for that section as well (Ground Support Engineer - Appendix V). Being the Cognizant Engineer does not necessarily mean you make all the decisions or do all the work for that subsystem, but it does mean that you ensure everything is done on time and is reviewed by at least one other person. However, it is imperative that the person who does the majority of the calculations or decision-making for any given sub-system be the one who is the primary author for that section of the report. However, as a team, it is expected that all calculations, decisions and report sections will be reviewed by each team member.



Design Process Overview

Getting a vehicle into orbit, whether it is earth orbit or interplanetary orbit, is fundamentally a matter of getting it going fast enough. The speed of the vehicle determines the shape of its orbit. The relationship between speed and orbit shape is defined by relatively simple equations. The design problem involved in how to get the vehicle moving at the right velocity is a complex interaction of size, weight, and engine thrust. We will make some simplifying assumptions to make the calculations manageable at a level of sophistication appropriate to beginning engineering students. And, as everyone is probably aware of in the current uncertain worldwide economic climate, the cost of the vehicle must be constantly kept in mind. The design process can be summarized symbolically in the two following figures. Figure 1 illustrates the general repetitive thought process involved in designing anything, similar to the "scientific method" which you probably have already studied. Figure 2 shows the specific set of steps we will follow in designing the launch vehicle for the delivery of a specified payload into Low Earth Orbit (LEO). The arrows show likely steps where you may need to circle back to a previous step to update information and re-do the subsequent steps based on the new, updated information (as was described in Chapter 13). The steps with arrows are not the only ones which may be involved in the iterating process, and it is not guaranteed you will have to perform iterations at all of the indicated steps. They are simply there to emphasize the concept that engineering design is not a linear process and often requires multiple iterations between steps.

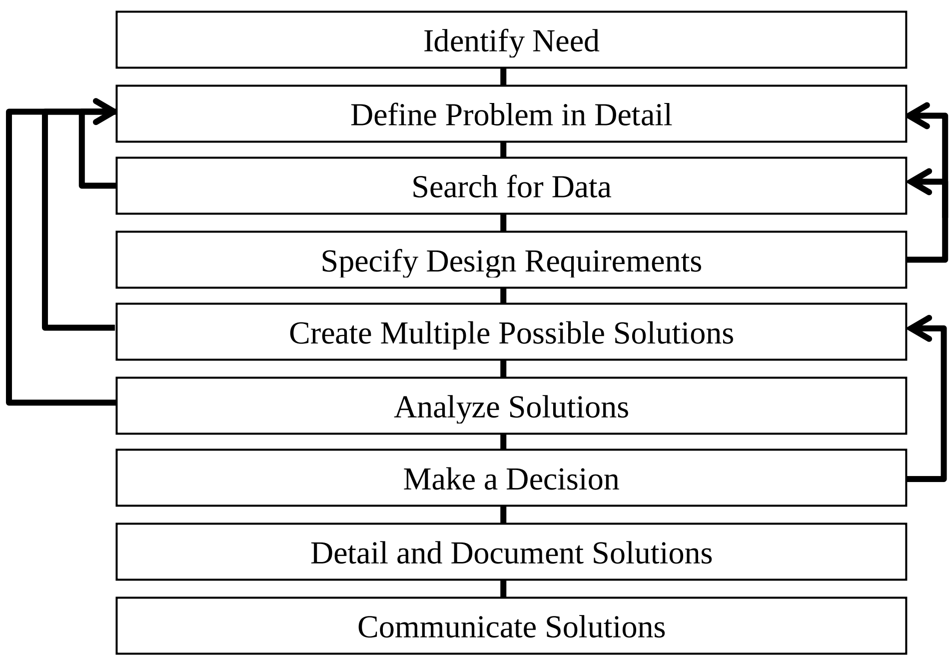


Figure 1. The Design Process

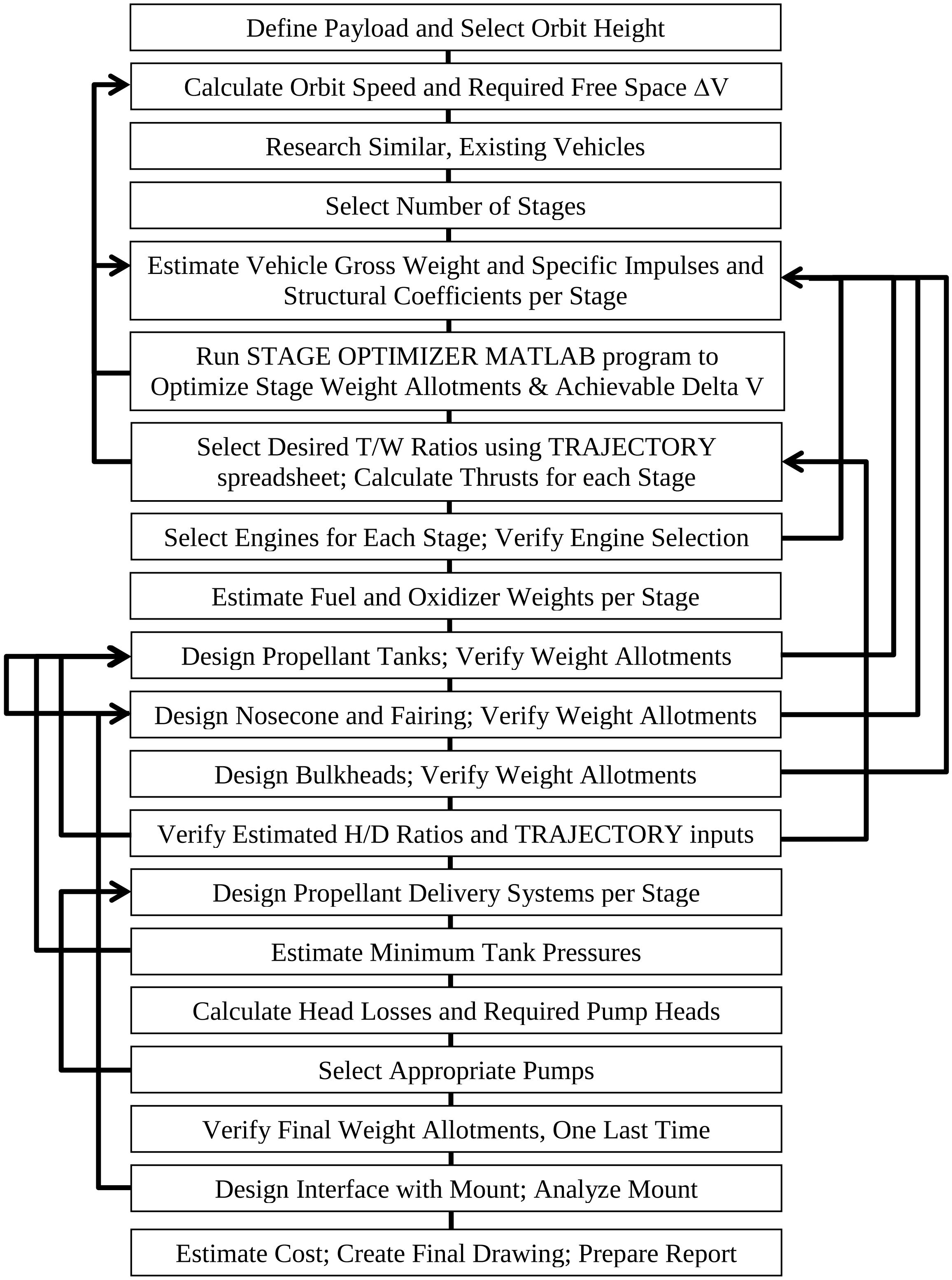


Figure 2. Launch Vehicle Design Project Sequence

Details of the Design Calculations

1. PAYLOAD

The payload for the launch vehicle is the spacecraft and its associated systems and equipment. We can approximate the weight of various portions of the spacecraft as being proportional to the weight of experiments or instruments on board the spacecraft. If your section of EGR101 first designed the reconnaissance satellite in an earlier project (the Satellite Project), use that satellite weight as the basis for the payload weight of the launch vehicle concept. Let's set the payload weight, W_{Pay}, equal to the satellite weight plus 1500 lb for an undisclosed piece of hardware (if your class did not complete the satellite project then simply use the 1500 lb as the payload weight). Its shape and size envelope are already set: The payload bay of the launch vehicle must be able to accommodate a cylinder at least 6 feet in diameter by 10 feet long, plus an additional 5 feet of length for the undisclosed hardware.

2. ORBIT SELECTION AND VELOCITY REQUIRED

In a circular orbit, the relationship between spacecraft velocity and the altitude of the orbit is

Eq. 1 $$V_{orbit} = R_e \sqrt{\frac{g}{R_e + h}} \quad \text{(ft/s)}$$

where R_e is the radius of earth = 20.92 x 10^6 feet

g is the acceleration due to gravity = 32.174 ft/sec^2 at surface of earth

h is the orbit altitude above earth surface, in feet

nmi represents the unit of nautical mile = 6080 feet

V_{orbit} will be in ft/s.

You must now determine the altitude that the vehicle must attain. If not assigned by your instructor or pre-determined by the operating altitude of the reconnaissance satellite, you must design your launch vehicle to insert the payload at an altitude between 100-250 nmi. An example **outside** of the given acceptable range would be to orbit at 260 nmi, the altitude for the Space Station, which gives us V = 25,025 ft/sec.

When we launch eastward, as we would do from Kennedy Space Center (KSC), FL, the vehicle is actually moving at 1341 ft/sec when it is sitting on the ground. This is the speed of rotation of the surface of the earth at KSC's location. It is real velocity and is "free" in the sense that the rocket engine is not required to do anything to accelerate the vehicle to that speed. So, the velocity increase which the rocket must produce is reduced by the free velocity. The velocity increase that the rocket engines must produce is known as the theoretical free space ΔV, and it must be calculated for the specific orbit height. This theoretical change in velocity represents the amount of energy required to a) get the vehicle to the appropriate orbit height, b) get the vehicle going fast enough to remain in orbit and c) overcome any losses during the ascent. The orbital speed is a function of the orbit height, radius of the Earth and the acceleration due to gravity at Earth's surface, as given in Eq. 1 above. The initial velocity (which depends on the launch location and launch direction) will be a function of the Earth's radius, latitude angle and the rate of Earth's rotation (simply using $V = \omega R$). The calculated free space ΔV is the requirement for the designed launch vehicle. You will also run a MATLAB program, from which a total ***achievable*** vehicle delta V will be outputted. The achievable delta V must be within plus or minus 1% of the calculated (required ΔV) value before moving on with any further calculations. To calculate the required ΔV, you must use the following equation. The equation was derived simply from conservation of energy as you will learn in Physics. The derivation is available in Appendix I of this project for the curious student. The equation also accounts for the aerodynamic drag of the launch vehicle. However, since aerodynamic drag is a function of vehicle shape and size, the equation simply assumes a 25% increase in energy to account for the drag since the size and shape are unknown at this stage.

Eq. 2 $$\Delta V = \sqrt{1.25(V_{orbit}^2 + 2gh - V_i^2)} \quad \text{(ft/s)}$$

Where V_{orbit} is calculated from Eq. 1 and must be in ft/s
h is still the orbital altitude in feet
V_i is the free velocity associated with the launch site.

When launches are made from Vandenburg Air Force Base, in southern California, they cannot launch eastward for safety reasons because eastward carries the vehicle over populated land. Therefore, launches from the west coast don't get the free velocity from the earth's rotation. For this particular RFP, however, the client wants to launch from KSC, thus you may use the value associated with KSC's latitude.

3. VEHICLE ESTIMATES and MATLAB STAGE OPTIMIZER

At this point, some basics design choices must be made for the launch vehicle. Once these selections are made, a MATLAB program which optimizes the weight distributions among your selected number of stages will be utilized. Before making any decisions, it is necessary that some research be completed to ensure an approximate realistic vehicle mass is chosen based on the payload mass. It is recommended that data (vehicle gross mass and payload mass) be gathered on existing launch vehicles in order to make a reasonable initial estimate for the gross mass of your vehicle. Keep in mind the different stage configurations of the researched rockets as data is gathered. It must be emphasized here that the provided MATLAB program optimizes the stage mass fractions assuming that the stages are fired and jettisoned in sequence and not in parallel. Parallel staging involves two separate stages firing at the same time, possibly with one of the stages depleting before the other and being jettisoned while the other remains attached and continues to fire. The Space Shuttle's Solid Rocket Boosters (SRBs) are an example of parallel staging with the Space Shuttle Main Engines (SSMEs). You may want to create a trend plot using gross vehicle mass vs. payload mass from the data you gather to help make the best estimate possible. The next few sections below explain the MATLAB inputs you must choose and what they represent.

3.1 MATLAB Inputs and Outputs Summary

In order to design a sequentially staging rocket, a MATLAB program developed by two ERAU Aerospace Engineering students (James McCandlish and Maxwell Hirsh) is being provided to you. This program will optimize the mass fractions (weight of propellant and structure) for each stage based on the following inputs:

A) The number of stages desired (1, 2, or 3)
B) The specific impulse planned for each stage (seconds)
C) The total vehicle mass (lbm) including propellant, structural, and payload mass
D) The payload mass (lbm) (without the propellant or structural mass)
E) The structural coefficients for each stage

Each of these inputs will be further elaborated in the following sections. The outputs from the MATLAB program will consist of the following parameters and will be provided for each stage:

x) The structural mass (lbm)
y) The propellant mass (lbm)
z) The achieved change in velocity, delta V, (ft/s)

Additionally, the total ***achievable*** delta V is provided as an output for the vehicle as a whole. It is this output (the achievable delta V) that will be checked against the required free space ΔV calculation made in Eq. 2. If these two values are not equal (within plus or minus 1% of each other), it is necessary for the MATLAB inputs to be varied until they are.

As a check, the total mass of the vehicle (which is a user-defined input) should equal the sum of all the stage masses (outputs) plus the payload mass (input).

It should be noted that this program does not optimize the total vehicle mass for the user as it is an input and is not varied by the program; rather, the program optimizes the distribution of masses amongst the stages. The program uses Lagrange's method of undetermined multipliers to determine the most efficient distribution of weight (both structural and propellant) between the stages to ensure the largest possible change in velocity (ΔV) that may be achieved by the launch vehicle given the constraints of total mass, payload mass, number of stages, structural weight percentage and the available specific impulse for each stage (essentially, the thrust per unit weight of propellant). It is up to the user of the program to determine the lightest possible vehicle by varying the number of stages, specific impulse per stage and the structural coefficients per stage. Be advised, however, that other considerations such as cost, engine availability, trajectory, material choices, and the structural design will also impact the feasibility of the input choices.

3.2 MATLAB Inputs

As defined earlier, there are several input values that must be selected in order to run the MATLAB optimization program. For some of the choices you will feel confident in your values; others will require a bit of a guess. What is important is that you realize that you must start somewhere and feel free to vary the inputs and run the program multiple times in an effort to achieve the closest possible achievable delta V to the required free space ΔV for your orbit height. The following are the inputs described in more detail.

A) The number of stages desired (1, 2, or 3)

Using more than one stage for your launch vehicle will allow you to design a lighter and more cost efficient vehicle. This is due to the primary distinction between a single stage vehicle versus a multi-stage vehicle: the multiple stage vehicle jettisons unnecessary empty weight as propellant is consumed. Take, for example, a vehicle that has two stages that fire sequentially (one after the other). Once the first stage (which is the stage that fires first off the launch pad) propellant is completely consumed, the entire stage (including the rocket fairing, support structure, engines and propellant tanks if the propellant is liquid) is disconnected from the vehicle and allowed to drop back to Earth. This results in a significantly lower gross weight for the remaining stage(s). The propellant of the second stage is now being used more effectively to accelerate the remaining mass as all the empty weight of the first stage is gone. Compare this to a single stage to orbit vehicle where the structure, engines, and tanks all are carried all the way to the orbit height. Clearly, to take that much more weight to the entire orbit height will require more propellant.

The program allows the user to input 1 stage, 2 stages or 3 stages. There is not much gain to be had in using more than three stages, and for Low Earth Orbit (LEO), a 2 or 3 stage vehicle is reasonable. A single stage to orbit vehicle (SSTO) is something the industry has attempted to create, however, has not been economically feasible. For this reason, an SSTO is not being considered for this RFP. For a true feasibility and preliminary study, multiple design variations should be considered. Comparing a two stage to a three stage vehicle could be very interesting and serve as a great learning experience.

B) The specific impulse planned for each stage (seconds)

There is a typical design-catch 22 here; to know the specific impulse requires that you have your engines already selected, or at a minimum, have the propellant selected. The specific impulses (I_{sp}) quoted for the engines (see Table 2 in section 11) are more accurate than those quoted for just the propellants (Table 1 in section 11) since the efficiencies of the engines and nozzles have been accounted for in the engine values. But in order to choose the engines for each stage, you need to know the weight for each stage so that the required thrust can be found (see section 4, Thrust for Each Stage), and you cannot find those weights until you run the MATLAB program…hence the catch 22. This happens all the time in the engineering design process. In order to get started, we just have to start with an initial educated guess and iterate from there. It is recommended that you choose an average I_{sp}, or a value that is close to many of the engines' quoted values. As noted below, for this project the actual specific impulses of your engines do not have to be identical to the values you input into MATLAB, they just have to be within ±10% of those values.

C) The total vehicle mass (lbm) including propellant mass

Just like the specific impulse values, this value is not known at this point. Until you have actually designed the vehicle you cannot know its gross mass. However, we have to start somewhere. As previously stated, you are urged to do a little research on existing launch vehicles in order to make a reasonable first guess at this value. Be prepared to run the MATLAB program several times, adjusting this value each time until the achievable delta V value is within ±1% of the required free space ΔV value.

D) The payload mass (lbm)

This value is not a variable and is a customer requirement. You have the option of accommodating a larger and heavier payload if you so desire, but your launch vehicle must be capable of delivering, at the minimum, the customer (professor, in this case) defined payload (as discussed earlier in section 1).

F) The structural coefficients for each stage

These values are similar to B and C in that you don't really know them until all the components have been designed. But in order to know how big to make the components, we have to start somewhere. The structural coefficient for a given stage is simply the percentage of the mass that is dedicated to the structure of that stage. For example, a structural coefficient of 0.3 means that 30% of the mass of that particular stage is comprised of all the structural components including: the engines, internal support structures, the external fairing (or cover), and the propellant tanks if that stage is a liquid stage; the remaining mass is propellant. Put simply, the structure is anything that is not propellant or the payload. Typical structural coefficients range from 0.15 to 0.35, however, you are not limited to that range. Smaller coefficients generally result in more functionally efficient vehicles, but the lower coefficients will require the use of lighter and stronger materials that might either be cost prohibitive or simply unavailable.

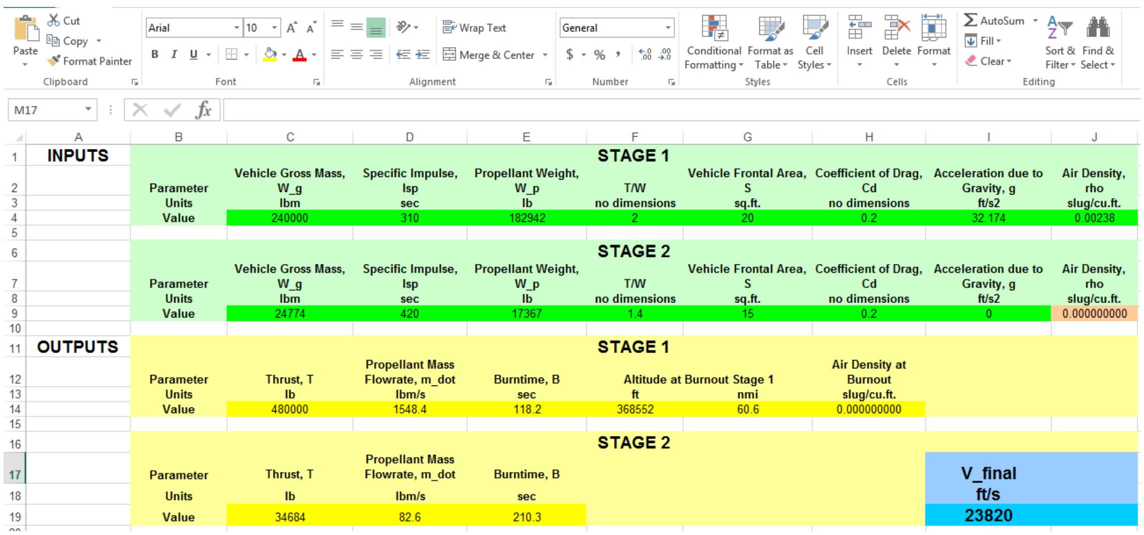
Once the initial inputs are selected (A-F above), run the STAGE OPTIMIZER MATLAB program until the achievable delta V and required ΔV match within 1% of each other. To check the outputs for feasibility the following requirements and constraints will need to be considered in section 4:

1) **The thrust of the selected (or designed) engine(s) must be within ±10% of the required thrust for that stage.** It is not appropriate (or permitted) to choose or design an engine that can produce a substantial more amount of thrust than what is required. To do this is inefficient and a waste of unused weight. To determine the appropriate, required thrust, use the TRAJECTORY excel spreadsheet in order to determine the best Thrust-to-Weight ratios, T/W, (they can be different for each stage) that result in a final speed, V_final (outputted by the spreadsheet) within **±5%** of the V_{orbit} which was calculated in Eq. 1 (as further described in the next section). This spreadsheet accounts for the change in mass of the vehicle as the propellant is consumed and as stages are jettisoned, as well as the minute decrease in the acceleration due to gravity as altitude increases to LEO. The air density is also updated for each stage.
2) **The selected engine(s) must have a specific impulse within ±10% of the specific impulse that was inputted into the MATLAB program for that stage.** Note that the existing engines are classified according to stage. If the engine is classified as a first stage engine, it is imperative that it only be used as a first stage engine for your design as the nozzle was designed for certain regions of the atmosphere. If the engine is used at significantly higher (or lower) parts of the atmosphere than originally designed, the actual specific impulse of the engine will be significantly lower that what is quoted in the table (due to inefficiencies in operation).
3) **The allotted structural mass for each stage must be large enough to accommodate the engine(s), propellant tanks, structural support and the fairing for that stage.** For the final stage (which is not jettisoned), the structural mass will also include the support structure and fairing for the payload (but not the actual payload). THIS MEANS YOU MUST DESIGN THE PROPELLANT TANKS, ROCKET FAIRING, BULKHEADS AND NOSECONE AND ACCOUNT FOR THEIR WEIGHTS FIRST!!

In order to verify that the current configuration of mass fractions (output by MATLAB) meets these requirements, further calculations must be completed (as described next). Be aware that it is not only possible, but likely, that the first run through these calculations will demonstrate that the configuration is not feasible and original inputs will have to be modified. For this reason, it is recommended that you use Excel or some other spreadsheet based software in order to complete multiple trials quickly. Of course, hand-verified sample calculations must be completed to verify that the equations were programmed into Excel properly, and also for inclusion in the technical report. Excel will just facilitate quick iterations through all the calculations.

4. THRUST FOR EACH STAGE

In order to choose (or design) engines for each stage of your launch vehicle, the required thrust for each stage must be determined. However, to determine the thrust required for each stage, the thrust to weight ratio must first be determined for each stage. These ratios are typically within a range of 1.3 to 1.5 (though you are not restricted to that range). It is not necessary to have an excessively large thrust to weight ratio, especially when the internal stresses associated with pulling multiple g accelerations are considered; however, the thrust to weight ratio (T/W) should be a comfortable margin above 1.0. For this RFP, the customer requests that the T/W ratio should not exceed 3.0 for any stage. The T/W choice will affect the size and weight of the required engine(s) and ultimately, the burn time. Use the TRAJECTORY Excel spreadsheet (shown in Figure 3) and iterate through different T/W ratios until the achieved V_final from the spreadsheet is within a 5% margin of the required orbital speed that was calculated in Eq. 1. If the required thrust for any particular stage is too large for finding a reasonable engine, consider reducing the T/W for that stage. Note that you must input values for the Coefficient of Drag and Frontal Area (the circular projected area of the vehicle as seen from the top) for your vehicle. At this point you do not know these values; however, an estimate must be made in order to move forward. The research you did on existing vehicles that are similar to your proposed design will be helpful with these initial estimates and a plot is available in section 6 (Overall Vehicle Configuration Feasibility Check) which will help you estimate the drag coefficient. Additionally, when you get to section 6 of this project, you will need to update the values for C_D and frontal area in TRAJECTORY based on your actual vehicle design and verify that your vehicle will still reach a final speed within 5% of the required orbit speed.



	A	B	C	D	E	F	G	H	I	J
1	INPUTS					STAGE 1				
2		Parameter	Vehicle Gross Mass, W_g	Specific Impulse, Isp	Propellant Weight, W_p	T/W	Vehicle Frontal Area, S	Coefficient of Drag, Cd	Acceleration due to Gravity, g	Air Density, rho
3		Units	lbm	sec	lb	no dimensions	sq.ft.	no dimensions	ft/s2	slug/cu.ft.
4		Value	240000	310	182942	2	20	0.2	32.174	0.00238
5										
6						STAGE 2				
7		Parameter	Vehicle Gross Mass, W_g	Specific Impulse, Isp	Propellant Weight, W_p	T/W	Vehicle Frontal Area, S	Coefficient of Drag, Cd	Acceleration due to Gravity, g	Air Density, rho
8		Units	lbm	sec	lb	no dimensions	sq.ft.	no dimensions	ft/s2	slug/cu.ft.
9		Value	24774	420	17367	1.4	15	0.2	0	0.000000000
10										
11	OUTPUTS					STAGE 1				
12		Parameter	Thrust, T	Propellant Mass Flowrate, m_dot	Burntime, B	Altitude at Burnout Stage 1		Air Density at Burnout		
13		Units	lb	lbm/s	sec	ft	nmi	slug/cu.ft.		
14		Value	480000	1548.4	118.2	368552	60.6	0.000000000		
15										
16						STAGE 2				
17		Parameter	Thrust, T	Propellant Mass Flowrate, m_dot	Burntime, B				V_final	
18		Units	lb	lbm/s	sec				ft/s	
19		Value	34684	82.6	210.3				23820	

Figure 3. Screenshot of the TRAJECTORY spreadsheet for a two-stage launch vehicle

For the first stage, the weight of the entire vehicle must be overcome for successful liftoff. Thus the required thrust is found by multiplying the T/W ratio for stage one by the total vehicle weight. NOTE: in the English Engineering System of units, the mass and weight of an object are numerically equal on the surface of Earth. Thus the masses specified earlier in lbm are the same as the weights in lb.

Eq. 3 $$T = (T/W) * W$$

For the second stage, the T/W for that stage is multiplied by the remaining weight of the rocket after stage one is jettisoned (meaning the stage one structural weight and propellant weight are subtracted from the gross weight). If there is a third stage, the calculation is repeated using the third stage T/W ratio and the remaining vehicle weight after the second stage structural and propellant weights are also jettisoned (subtracted).

4.1 Engines

Engines can be researched and selected or new ones sized once the required thrusts are known. Table 2 of this project provides some data for some existing liquid rocket engines. Should solid rocket motors be desired, feel free to conduct research to collect the same data as given in Table 2; however, for this project at least one stage of your launch vehicle must be liquid. If you choose to size your own engines, the methods to estimate the height, diameter, weight, propellant selection and area ratio (of the nozzle) are defined in Appendix II.

With engines selected or sized, it is at this point that the three constraints (explained at the end of section 3.2) can be considered. You must verify that the engine configurations chosen meet **both** the thrust and specific impulse requirements (according to constraints #1 and #2). Additionally, you must verify that the total weight of the selected engine(s) for the stage under consideration must be well within the allotted structural weight for that stage (constraint #3). Keep in mind that the propellant tanks (if the engine is a liquid engine) and other support structure must also fit within that allotted amount. The sum of the engine(s) weights and all of the support, fairing and tank structure weights for that given stage must be equal to or less than the stage weight that was outputted from MATLAB. If your weights are larger than what was allotted, it absolutely **cannot be more than 10% over the allowance for each stage**. The majority of the stage weight should be dedicated to the support structure, fairing and propellant tanks. As a rough ballpark, the engine should only account for roughly 20-30% of the stage structural weight, and the remainder will be dedicated to the support structures, fairing, tanks, etc.

If the engines that have been designated for each stage meet all three requirements, the configuration is feasible (thus far) and the design process can continue. If not, the parameters that were inputted into MATLAB may need to be revised and the entire process reiterated.

The selection of engines includes many options. The designer may choose from existing engines or design their own. The engines can be liquid propellant or solid propellant (so long as at least one stage is liquid). The configuration for each stage can be one large single engine or a cluster of two or more. As engines are selected, the following constraints must be considered for this project:

1) The staging absolutely must be sequential and not parallel. The permitted configuration requires that only one stage fires at a time and when the propellant is exhausted, the entire stage is jettisoned (unless it is the final stage).

2) If multiple engines are used for a given stage, it is strongly recommended that they be the same engine. If not, at a minimum, the propellant types must be identical and the specific impulses of the engines must be within ±10% of each other.

3) When clustering multiple engines together for a particular stage, the total produced thrust is simply the sum of the thrusts of each engine. For example, if a particular engine produces 10,000 lbs of thrust and the stage requires 30,000 lbs of thrust, three engines will meet the thrust requirement. The I_{sp} values are NOT added together. The I_{sp} of the engine cluster may be taken as the *AVERAGE* I_{sp} value of all the engines in the cluster.

5. PROPELLANT TANKS, BULKHEADS, VEHICLE FAIRING and NOSECONE

Even with the engines selected, the process is not complete. The major structural components for each stage must still be sized and materials selected. The masses of the external fairing, nose cone, bulkheads and propellant tanks must be estimated by determining the required sizes of each, choosing materials and thickness and finally calculating the resulting mass (or weight). To determine the propellant tank volumes and to aid in the sizing of the tanks, you will need to refer to the calculations in section 5.1. Of course, those volumes are only the internal volumes required for the propellant. To estimate the weight of the empty tanks, a wall thickness must be determined and the volume of solid material must be determined based on the dimensions of the tank and the material you choose, as will be seen in 5.1. Table 3 in section 11 provides critical data for several common materials for use in launch vehicles for tanks (as well as fairings, etc.) or you are free to research other materials on your own. Just be sure to use reputable resources and find all the same data as that which is provided in the material tables given in the text. Remember, you are simply trying to determine a reasonable estimate for these masses, not nail down a final precise value.

Additionally, the external fairing (the outside sheath that covers the rocket) and nosecone must also be sized. The diameter and height requirements for each stage's fairing are driven by the engine configuration, the tanks diameters and heights and any additional height or diameter you want to add as a buffer for that stage. Additionally, there must be some buffer added to the inside diameter of the fairing to allow room for piping and wiring to pass between the tanks and fairing (see On-Board Propellant Delivery System, section 7). Bear in mind that your launch vehicle diameter does not need to be the same for each stage. Recommended thicknesses for these components can be determined using the analysis in section 5.2.

Lastly, bulkheads (in this case, very simplified support structures) separating the stages of the vehicle and providing support to the stage components must be designed. One option is provided in section 5.3; however, those of you taking EGR120 are encouraged to modify the bulkhead designs for weight savings (by removing unnecessary material, as is done in car wheels or aircraft structural components, like ribs and spars) and run a simple FEA analysis within CATIA to determine viability of the reduced-weight designs. This is not required, but is an excellent experience and can potentially earn your team "bonus" points (check with your individual professor to verify that possibility).

Once all of the above components have been designed, the final vehicle height and diameter(s) can be approximated and a final feasibility check must be completed to ensure your rocket would perform aerodynamically. This will be described in a later section (see section 6). When the propellant tanks and fairings are sized and masses estimated, the final verification that your structural mass allotments (as outputted by MATLAB) have not been exceeded by any of your selected or designed components can be performed. This refers back to constraint #3. If your total actual structural masses exceed the allotted structural masses (by more than 10%), you have a few options: 1) choose more structurally efficient materials for the tanks or fairings, 2) consider using a different configuration of engines (sometimes using multiple smaller engines rather than one big engine or vice versa can result in a significant weight savings), 3) vary the tank diameters or wall thicknesses in an attempt to decrease the tank masses, or 4) go all the way back to the MATLAB program and input larger structural coefficients (this should be a last resort as it means you are essentially starting all over). If your total actual masses are far below the allotted masses, your structural coefficients were overestimated from the start. This, unfortunately, means that you must go all the way back to the MATLAB program and reduce the structural coefficients and start over. We will define "far below" as total actual masses that are only 60% or less of the allotted masses. It is okay if there is some unaccounted-for mass, as you are not designing the other miscellaneous internal structure and other components such as telemetry, navigation, and other electrical components and instruments.

5.1 *Propellant Tank Designs and Vehicle Diameter*

In order to determine the dimensions of the fuel and oxidizer tanks for each liquid-propellant stage, the volumes of each tank must first be found and a tank shape must be selected. The most common tank shape is a pill shape (cylinder with hemi-spherical end caps). Spherical is another option, if the volume is small enough (however, you don't want to end up with a "Marvin the Martian" shaped vehicle). Finally, a simple cylindrical tank is an option, but is not the best choice if your tanks need to be pressurized to any significant pressure, as the "corners" at the top and bottom of the cylinder do not resist the stresses caused by the pressure difference across the tank wall very well. If you have chosen an existing engine, the oxidizer to fuel mass ratio is given (column 5 in Table 2: Liquid Fuel Rocket Engines); this can be used to determine the individual oxidizer and fuel volumes. If you have decided to design your own engine(s), the theoretical oxidizer to fuel mass ratio is provided in column 5 of Table 1: Rocket Engine Liquid Fuels. You begin the tank dimension calculations by determining the fuel and oxidizer weights individually (right now you only know the combined weight, known as propellant weight, W_P – this was one of the MATLAB outputs).

Eq. 4 Fuel Weight, $W_{FUEL} = \frac{1}{(\text{MassRatio} + 1)} W_P$

Eq. 5 Oxidizer Weight, $W_{OXY} = \frac{\text{MassRatio}}{(\text{MassRatio} + 1)} W_P$

Now, we simply need to determine the volume required to house each of these individual weights. This process uses the individual fuel density and oxidizer density listed in Table 1 (columns 6 and 7). As a matter of design perspective, note here that liquid hydrogen fuel is not very dense so a large fuel tank is needed. This is one of the major drawbacks to using hydrogen for fuel. Even though the mass of liquid hydrogen fuel is only about 1/6 of the mass of the liquid oxygen used, the liquid hydrogen tank is about 75% of the total tank volume. The remaining 25% of the total tank volume is for liquid oxygen oxidizer. Also note that engines which use the same fuel and oxidizer do NOT necessarily use the same mass ratio and therefore they likely do not have the same specific impulse, as seen by comparing the first two rows of Table 1.

Eq. 6 Fuel tank volume (ft^3) = $V_{FUEL} = \frac{W_{FUEL}}{\rho_{FUEL}}$

Eq. 7 Oxidizer tank volume (ft^3) = $V_{OXY} = \frac{W_{OXY}}{\rho_{OXY}}$

Note, ρ is the variable used to denote density.

Once the volumes are determined, the diameter of the tanks must be selected (see guidance in next paragraph) and then tank lengths can be determined. It is recommended that you check to see if the entire fuel and oxidizer volumes could each be fit into a spherical tank with your selected diameter. If they do not, then you'll need to add some cylindrical length to accommodate the "leftover" volume. Also, the inside volumes for the fuel and oxidizer tanks are generally increased above the actual liquid requirements by 5-10% to account for the *ullage*. The *ullage* is the additional volume needed to accommodate the pressurized gas above the propellant. You may want to increase the actual liquid volumes a bit as well, to account for the extra propellant that gets stuck in the piping, pump, valves and residue on the tank walls; rounding up to a nice round number is fine for the level of precision required during preliminary design.

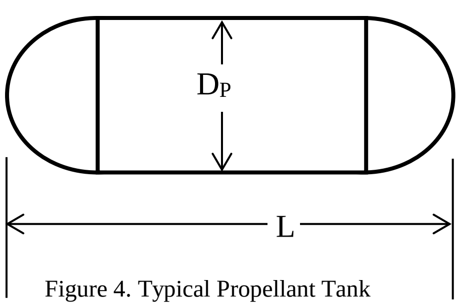


Figure 4. Typical Propellant Tank

The diameter of the propellant tanks, D_P, should be taken as roughly 85% of the launch vehicle diameter. The other 15% is used to allow for piping (consult with the On-Board Propellant Delivery System Designer, if your team is required to include that system) and the structure of the launch vehicle, similar in concept to the fuselage structure in an aircraft because a tall, thin-skinned cylinder needs significant reinforcement to withstand launch forces. The vehicle diameter can be whatever you want, but it is typically close to the diameter of the engine (or engine cluster) for that stage. The interface between the launch mount (Appendix IV) and the first stage must be considered when selecting the first stage vehicle diameter!

The common "pill" shaped tank (cylindrical tank with hemispherical end caps) is shown in Figure 4. When determining the tank length, remember to calculate the entire length of the tank, which should also include the two hemispherical heads (note how L goes from total end to end, and is not just the length of the cylindrical section). As this is simple geometry, equations are not provided for these calculations. It is left up to the student to determine how to make these calculations.

Once dimensions of the tanks are determined, calculate the height of the propellant tank segment of the launch vehicle, H_P, by adding the height of the stack of all the tanks and adding about 10% for support structure, valves, and piping. For accounting purposes, it may be useful to keep track of the separate stage heights. If you choose to do this, simply add a number to the subscripts, like $H_{P,1}$ and $H_{P,2}$. Do this for the H_E and H_B as well (see Section 6).

Lastly the tank material must be selected and wall thickness must be calculated. Table 3 provides the most common materials used for launch vehicle components. In order to calculate the minimum wall thickness necessary, the tank gas pressure, P_{tank}, must be known. <u>This is a parameter that depends on the propellant flowrate as well as the particular liquid inside the tank; this is calculated in the On-Board Propellant Delivery Section of the project</u>. The minimum wall thickness must be large enough to withstand the internal stresses caused by the pressure exerted by the propellant and the gas pressure acting on the propellant. The total maximum pressure, P_{MAX}, acting on the tank is due to the gas pressure, the hydrostatic pressure within the propellant (essentially the weight per unit area of the propellant) plus the inertial loading caused by the acceleration of the vehicle. The "worst-case" maximum acceleration of the vehicle must also be known, which is assumed to be the T/W ratio at engine burnout for that stage. Though this assumes constant thrust from the engine and zero aerodynamic drag, the latter assumption is conservative; which means that although it may not always be accurate, it provides worse conditions than in reality, resulting in a safer design.

Eq. 8 $$a_{max} = 32.174 * T/W \text{ at engine burnout} \quad (ft/s^2)$$

Where T is the currently firing stage thrust (in lbs)
W is equal to the current vehicle weight minus the firing stage propellant weight (in lbs)

Eq. 9 $$P_{MAX} = 144(P_{tank}) + \frac{(a_{max})(h_{tank})(\rho_{fluid})}{32.174} \quad (lb/ft^2 \text{ or psfa})$$

Where P_{tank} is the gas pressure in the tank (lb/in^2 or psia) - see Section 7, Eq. 24
ρ_{fluid} is the density of fluid inside whichever tank you are currently designing (lbm/ft^3)
h_{tank} is the total height of the tank you are currently designing (ft)

Finally, the minimum allowed wall thickness can be determined using the most likely failure mode: failure from the circumferential stress, also known as hoop stress.

Eq. 10 $$t_{tank} = \frac{2P_{MAX} r_{inside}}{\sigma_{yield}} \quad \text{(inches)}$$

Where t_{tank} is the tank wall thickness (inches)
r_{inside} is the inside radius of the tank (inches)
σ_{yield} is the yield strength (or stress) of the selected tank material (lb/in^2)
P_{MAX} was found in Eqn. 9, but must be converted to psia before substituting into Eqn. 10

PLEASE NOTE the UNIT for the TANK RADIUS! It needs to be in inches!
Regardless of what you calculate the minimum tank wall thickness to be, it may not be smaller than 3/16 of an inch.

Lastly, the tank weight can now be estimated. You know the internal dimensions of the tank and the minimum wall thickness. You can choose to either use the minimum thickness (so long as it is at least 3/16 of an inch), or increase it by some “factor of safety” to better ensure failure will not occur. Just bear in mind that as you increase the factor of safety, you also increase the weight and thus the cost of launch. Typical factors of safety for aerospace applications are 1.2 – 1.5. With that information, estimate the volume of tank material and use that to find the associated weight. Again, the volume calculation is simply geometry, and thus is left to the student to determine.

Eq. 11 $$W_{tank} = (V_{tank\ walls})(\rho_{tank\ material}) \quad \text{(lb)}$$

Where W_{tank} is the weight of the empty tank, in lb.
$V_{tank\ walls}$ is the volume of the actual tank material (**<u>not</u>** the volume of propellant that the tank can accommodate) in cubic inches
$\rho_{tank\ material}$ is the density of the selected material for the tank in lb/in^3

5.2 External Fairing and Nosecone Designs

The wall thickness of the vehicle fairing needs to be large enough to resist the aerodynamic loading during ascent. Though there are different modes of failure for the fairing (buckling from compression loads, material failure from bending if the angle of attack is too high, cracking under internal stresses from thermal changes or pressure differences from inside to outside the vehicle, tear outs from shearing stresses – especially at the joints – from the skin friction drag, just to name a few), the main concern that will be considered here is the material failure caused by large compression loads. The compressional loading can be estimated as the thrust from the engine acting against the inertia and drag from the vehicle. Essentially, what this means is that the vehicle wants to stay at rest or at its current speed (inertia), but the engine is producing thrust which pushes up on it, causing acceleration. The result of these opposing forces is that the vehicle is squeezed, or compressed. Think of yourself in an elevator: when just sitting still you feel your own body weight compressing your skeleton; however, when the elevator accelerates upward, that compression increases from the upward push of the elevator floor.

As the thrust is the highest for the first stage (it should be; if it is not, something with your mass fractions is incorrect – see your instructor for help), the load will be determined using the first stage values. See Eq. 12 below.

Eq. 12 $$LOAD_{fairing} = T \quad \text{(lb)}$$

Where $LOAD_{fairing}$ is the compression load acting on the vehicle in lb
T is the first stage thrust in lb

To estimate the <u>minimum</u> wall thickness required to ensure your vehicle fairing does not fail, the normal stress (LOAD / Cross-sectional area of fairing wall) in the walls of the fairing must not exceed the yield strength of your chosen material. This can be rearranged to solve for the wall thickness:

$$t_{fairing} = \frac{D_V - \sqrt{D_V^2 - \frac{4 * LOAD_{fairing}}{\pi\sigma_{yield}}}}{2} \quad \text{(inches)} \qquad \text{Eq. 13}$$

Where D_V is the diameter of the launch vehicle (inches)
σ_{yield} is the yield strength (or stress) of the selected material (lb/in^2)
$LOAD_{fairing}$ is the compression load you calculated in the previous calculation (lb)

PLEASE NOTE the UNIT for the ROCKET DIAMETER! It needs to be in inches! **Regardless of what you calculate the minimum fairing wall thickness to be, it may not be smaller than 1/8 of an inch.**

Just as with the propellant tanks, the fairing material weight must be estimated in order to verify the vehicle mass fractions. It is reasonable to estimate the fairing to be comprised of cylindrical sections. Conical sections can be treated as cylindrical sections with the diameter set as an average diameter. For instance, if your first and second stages have different diameters and thus the fairing section between those stages is shaped as shown in Figure 5, it is a reasonable estimate to treat that section as a cylinder with the same height and average diameter. Should you prefer, you are welcome to find the volume of a thin-walled conical section instead, should you desire better precision. And just as was the case with the tanks, the wall thickness is up to you; you can use the minimum you calculated (so long as it is at least 1/8 of an inch) or you can increase it by a factor of safety.

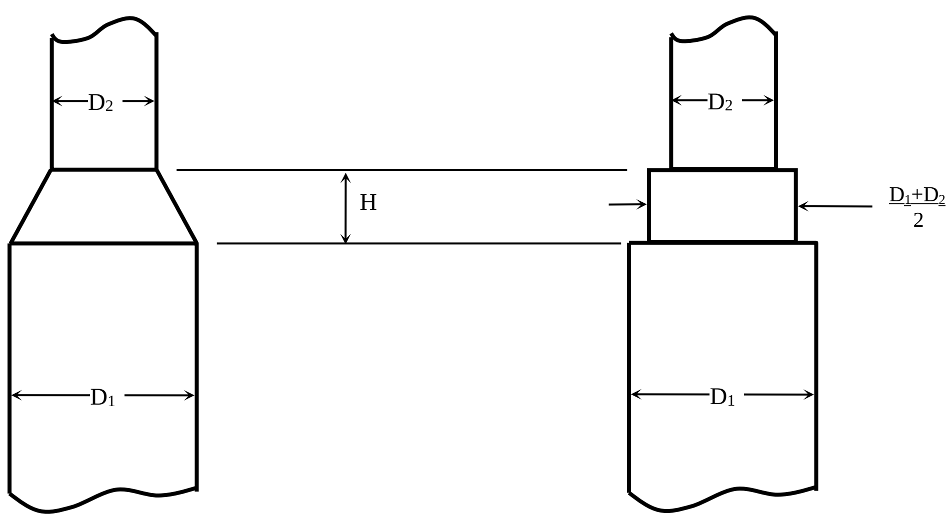


Figure 5. a) Actual configuration b) Configuration for simple fairing material volume calculation

Thus the volume of material required for the conical section could be estimated using the following calculation:

Example $$\text{Material Volume} \approx \pi\left(\frac{D_1 + D_2}{2}\right)tH$$

On the other hand, the nosecone weight calculation depends on the actual shape of the nosecone you choose. The wall thickness can be taken to be the same as the rest of the vehicle fairing, but the nose shape is up to you. It can be pointed, or rounded. It is left up to the student to devise the best way to estimate the volume of material used in the nosecone and its associated weight.

[Supplemental Equation]

Should the aerodynamic drag on the vehicle (or any part thereof) need to be estimated, for instance, you've added stabilizing wings, or you have an unconventional design and need to also verify joint design (see instructor for help if you are), the following equation can be used. The drag is a function of the frontal area of the vehicle, the coefficient of drag of the vehicle (which is a function of vehicle shape, including H/D ratio), the air density and vehicle speed. Only the last two parameters (air density and vehicle speed) change significantly during ascent (at least until a stage is jettisoned). Since neither of these will be a maximum at the same time (air density is a maximum at sea level where speed is a minimum, and vehicle speed is a maximum at the edge of the atmosphere where density is a minimum), the air density will be taken as a representative value and the vehicle speed as 2/3 of the orbital speed in order to estimate a worst-case scenario for the vehicle.

Eq. 14 $$\text{Drag} = 0.5\rho_{rep}(0.667V_{orbit})^2 C_D S \quad \text{(lb)}$$

Where ρ_{rep} will be taken at about 50,000 ft altitude (slugs/ft^3) - the atmospheric density values at different altitudes can be found in numerous resources. It is left up to the student to source that information.

V_{orbit} was calculated in Eq. 1 (ft/s)

C_D is the coefficient of drag for the whole vehicle; this is the same value inputted into the TRAJECTORY spreadsheet for stage one; needs adjusted for protruding structures.

S is the frontal (projected) area of the whole vehicle in ft^2 (also from the TRAJECTORY spreadsheet). Also needs adjusted for additional structures protruding from the vehicle.

5.3 Bulkhead Designs

For this conceptual design, the bulkheads are going to be designed as separate structures from the tanks and will be the structures upon which the stage components rest; they will be used to separate the stages and provide structural support for the entire stage and any stages above it. In the case of the first stage, that bulkhead must be able to support the entire vehicle. It will be that bulkhead which supports the vehicle above it, the first stage engines below it, and to which the launch mount will attach. You will also need to size smaller bulkheads to support the propellants tanks, if you choose to stack them on top of each other (as is the typical configuration; see Figure 6). Typically, the bulkheads are actually part of the propellant tank designs and connect to the vehicle fairing with reinforcing structural components. Inter-tank and/or inter-stage adapters are employed between those components for additional support. Stringers, or length-wise structural columns, provide the internal longitudinal support for the stacked components; however, you are not required to design those for this preliminary concept. The vehicle structural weight is being accounted for through this very rudimentary and simplified analysis of flat cylindrical bulkheads.

Only one bulkhead design option is presented here, but as mentioned previously, students who are enrolled in EGR 120 are encouraged to modify the design to reduce weight and then use the Finite Element Analysis within CATIA to analyze the viability of the modified design. Additionally, your instructor may provide you Roark's Formulae for Stress and Strain (a very comprehensive document that provides the formulae for stress, bending moments, deflections and other quantities for a multitude of loading scenarios for several structural members), which can be used to determine the stress for an annular bulkhead, should you desire to use one.

5.3.1. Solid Disk Bulkhead

To determine the minimum thickness of the bulkhead, the primary failure mode being considered is from the bending stress developed from the weight of the components supported. As you will see, the variable for which you are solving cannot be algebraically isolated as it is buried in a *transcendental* function (the natural log). Try as you might, you cannot isolate the thickness in Eq. 15 below. However, it is not necessary to solve for the thickness; you simply need to verify that the induced stress is less than the yield stress of your selected material for the thickness you choose. You will need to use the T/W at engine burnout you found for Eq. 8 and a factor of safety (FOS) of 2 has already been incorporated into the equation below. If you wish to determine your actual factor of safety, simply divide the Young's Modulus of your selected material by the yield stress that is found using equation 15, and then multiply that by 2 (since that FOS has already been included). Since each bulkhead must endure the T/W at stage 1 engine burnout, that value should be used for each bulkhead thickness calculation. This equation was borrowed from Roark's Formulas for Stress and Strain:

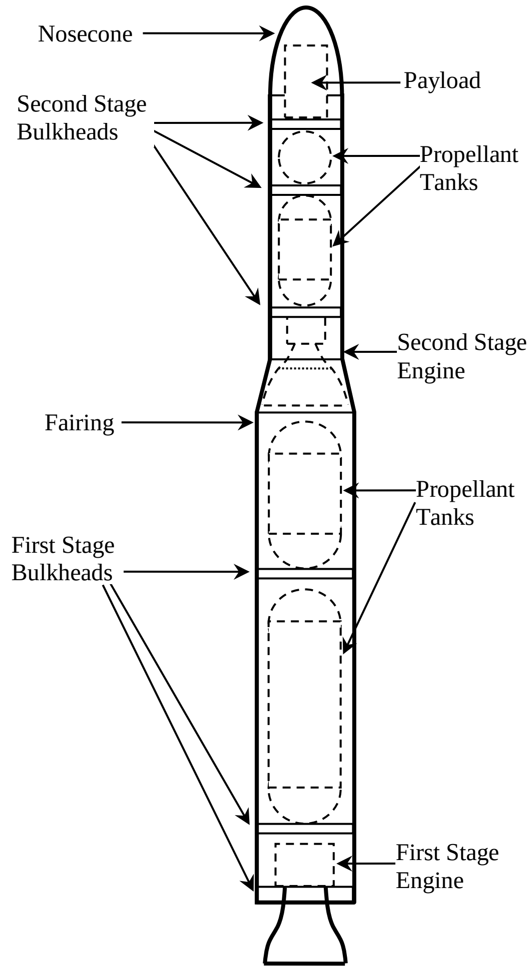


Figure 6. Sample Vehicle Schematic showing internal components

Eq. 15 $$\sigma_{yield} = \frac{12(LOAD_{bulkhead})\left(\frac{T}{W}\right)_{engineburnout}}{4\pi t_{bulk}^2}\left[(1+\nu)\ln\left(\frac{a}{\sqrt{1.6r_o^2 + t_{bulk}^2} - 0.675t_{bulk}}\right)\right] \quad \text{(lb/in}^2\text{)}$$

Where σ_{yield} is the yield strength (or stress) of the selected material (lb/in^2)

$LOAD_{bulkhead}$ is the weight of all components that will be supported by the bulkhead (lb)

$\rho_{bulk,\ material}$ is the density of the bulkhead material in lb/in^3

a is the bulkhead radius in inches

ν is Poisson's ratio for the bulkhead material (this can be found in Table 3)

r_o is the contact radius between the bulkhead and whatever component is immediately in contact with the bulkhead (inches) – can be taken to be 5 inches for a hemi-head tank interface

t_{bulk} is the minimum bulkhead thickness required to ensure failure does not occur from exceeding the yield strength of the selected material (inches)

With the thickness determined, the weight of the solid disk bulkhead can be calculated. **Regardless of the minimum thickness calculated, the bulkheads must be at least ½ inch thick!**

Once you choose a thickness (which can be the calculated minimum -as long as it is at least ½ inch thick- or a larger value with a factor of safety implemented), the weight of the bulkhead can then be determined.

At this point, verification that the weight of all the components for each stage are within the allowable ranges (no more than 10% above or 40% below) of the MATLAB outputted weight allotments should be performed.

6. OVERALL VEHICLE CONFIGURATION FEASIBILITY CHECK

If all of the engine selection and weight allotment constraints have been met, the last two steps in verifying feasibility of the vehicle design involves 1) determining the height to diameter (H/D) ratio, not only for the whole vehicle, but for each stage as well, and 2) verify the TRAJECTORY spreadsheet still provides a reasonable V_final (within a ±5% of V_{orbit}) with the most up-to-date values for the coefficient of drag and frontal area, as now you actually have a designed vehicle. If the values for V_final and V_{orbit} are no longer within ±5%, adjustments must be made to the T/W ratios. This also means that the selected (or sized) engines must be re-verified and possibly changed if the provided thrust is no longer within the acceptable tolerance of the required thrust. Recall, the actual thrust provided by the engines need only be within ±10% of the calculated thrust as this is only a conceptual design. It is important that the vehicle is both structurally sound as well as aerodynamically efficient at any point in the trajectory. Tall, thin vehicles have low drag but are structurally more difficult to design. Short, stubby vehicles are just the opposite. You do not HAVE TO do what is typical, but if what you come up with is not typical you should be careful to verify that you have done everything correctly. Of course, as the vehicle leaves the atmosphere the aerodynamic drag becomes a non-issue, so the range of H/D ratios decreases for higher stages as shown below, and are not as important as the first stage H/D ratio. In order to be able to quote a coefficient of drag of 0.2 (the minimum for a cylinder with the flow direction along its axis), the H/D must fit within the range specified for the first stage. The other two ranges are simply given for "typical" sizing. You'll notice from Figure 8 that the coefficient of drag equal to 0.2 is valid for H/D values (or l/d as in the figure) much smaller than 7. Though this is true, the much larger frontal area that would be required for a rocket with the smaller H/D ratios would cause the drag to be too high (as you might find when you update your TRAJECTORY spreadsheet with all current values). Should your H/D ratio fall outside of the range provided for the first stage, use the plot to estimate the coefficient of drag for your fairing thickness calculation as well as in the use of the TRAJECTORY Excel spreadsheet:

First stage configuration (whole vehicle):	$7 < H/D < 15$
Second stage configuration:	$5 < H/D < 13$
Third stage configuration:	$3 < H/D < 11$

Total vehicle height is the height of the stack of engine, fuel tanks, bulkheads and payload. And we add about 10 % extra height for additional components and structure. Put into equation form that is:

Eq. 16 $H_V = 1.1 (H_E + H_P + H_B + H_{Pay})$

Where H_V is the height of the entire vehicle
H_E is the height of the engine section for each stage, added together
H_P is the height of all the propellant tanks for each stage added together
H_B is the height of all of the bulkheads, added together
H_{Pay} is the height of the payload bay (see explanation below)

If the diameter for a given stage is not constant over the entire length of the vehicle (as is typical), the diameter for the stage H/D ratio being calculated should be used. The length, however, is the length of that stage plus any stage above it. For instance, for the first stage (or whole vehicle) H/D, use the entire length of the vehicle for "H", but only the stage one diameter for "D". On the other hand, stage two would include the stage two length plus the stage three length (if you have a third stage) and the payload/nosecone length for "H". "D" would just be the stage two diameter.

It is also important to note here that the engine can either be completely housed outside of the rocket body fairing or just the combustion chamber can be housed inside. The sample schematic (Figure 6) shows the first stage engine mounted with the combustion chamber inside the fairing. One important item not shown on the sample drawing is the attachment method to the launch mount. The location of the engine with respect to the attachment points for the launch mount is important to the Systems Engineer and must be incorporated into your design. How the vehicle attaches to the mount must be illustrated on the vehicle drawing, and must be compatible with the available launch mount design and drawings (Appendix IV).

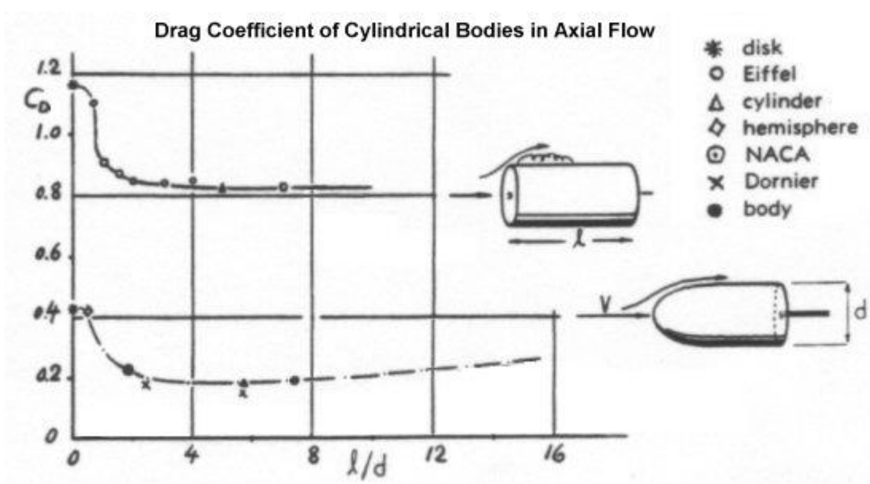


Figure 8: Plot of the coefficient of drag for a cylinder with its axis parallel to flow direction. Source: Hoerner, S. F. (1958). *Fluid-dynamic drag: practical information on aerodynamic drag and hydrodynamic resistance.* [2d. ed Midland Park, N. J.].

Minor modifications can be made to ensure the vehicle design fits within the above H/D ratio ranges. Consider decreasing the diameter or adding additional buffer heights if the vehicle is below the low end of the acceptable range. Reducing the diameter will require tank, bulkhead and fairing recalculations; also be sure not to decrease the diameter to a value that cannot accommodate the payload. Adding additional buffer heights is acceptable to a small degree; however, the sum of all buffer heights may not exceed 25% of the total vehicle height. If that much buffer height is required, the chosen tank diameters are simply too large and must be reduced.

For a vehicle above the high end of the H/D ranges, consider increasing tank diameters or reducing buffer heights. Again, changing tank diameters requires that the tank, bulkhead and fairing heights and masses all be recalculated. Reducing buffer heights is acceptable; however, some buffer height is required. A minimum of at least 5% of the total vehicle height must be dedicated to buffer height.

7. ON-BOARD PROPELLANT DELIVERY SYSTEM (optional)

The fuel and oxidizer (together known as the propellant) required to propel the launch vehicle can be either liquid or solid. As one of the RFP constraints is that at least one stage of your vehicle be a liquid stage, a delivery system to move the fuel and oxidizer from their respective storage tanks to the engine(s) combustion chamber(s) is necessary. A separate system for each stage that has liquid propellant will need to be designed. The system is comprised of piping, valves, pumps and other miscellaneous fittings such as elbows, reducer and expansion fittings. The piping system will need to be designed and then analyzed to select an appropriately-sized pump.

7.1 Determining Flowrate

The volumetric flowrate of each liquid need not be the same, and in fact, likely will not be the same. Assuming the flowrate to be constant for the entire burntime duration (as is consistent with the assumption that the thrust remains constant), the flowrate calculation is very straight forward:

Eq. 17 $$Q = \text{Volumetric Flowrate} = \text{Total Volume} / \text{Total Pumping Time} \quad (ft^3/s)$$

Where the Total Volume is the volume of either the fuel or oxidizer for whatever stage you are currently analyzing (each tank must have its own piping system since the fuel and oxidizer are kept separate until being mixed in the combustion chamber). The Total Pumping Time is equal to the burntime for that same particular stage. The TRAJECTORY spreadsheet automatically calculates the burntime of each stage for you, which can be used to find the individual fuel and oxidizer flowrates. However, double-checking the calculation is always a good idea. The burntime is calculated assuming a constant thrust and using the following equation:

Eq. 18 $$B = \frac{(I_{sp})(W_P)}{T} \quad \text{(seconds)}$$

Where B is the burntime for a particular stage in seconds
I_{sp} is the specific impulse for the engine for that stage in seconds
W_P is the weight of the propellant for that stage in pounds
T is the thrust for that stage in pounds.

7.2 Designing the Piping System

Designing the piping system is fairly straightforward. Simply lay out piping from the bottom of each liquid storage tank to the top of the engine it feeds (Table 4 in section 11 has standard pipe sizes). If you have multiple engines for a particular stage, you will need to utilize splitters or a manifold to deliver the fuel and oxidizer from their single tanks to the multiple engines. Any good piping system should also include valves for control and safety, as well as at least one flowrate meter. Utilize elbows or other fittings as needed. A table of common fittings is provided in Table 5.

7.2.1. Calculate Elevation Head

Once the size and locations of the tanks are determined for the vehicle, the height that the piping must cover and the overall length of the piping must be calculated. This will require input from the launch vehicle designers. The distance from the bottom of each storage tank to the top of the engine it feeds is known as the elevation head for that tank. For the case of a launch vehicle, gravity assists with the delivery of the propellants since the tanks are located above their engine:

Eq. 19 $$h_{ele} = \Delta h_{\text{bottom of vehicle tank - top of engine}}$$

Where h_{ele} is in feet and represents height difference between the tank and engine (the total -minimum- elevation change that the liquid has to travel)

7.2.2. Calculate Piping Length

The length of the piping, L, can simply be determined by adding the total horizontal and vertical lengths of piping in each system. Keep in mind that the length is for each individual piping system (each tank has its own piping system and pump).

7.2.3. Choose Piping Diameter

The diameter of the piping must be selected. Table 4 provides some standard pipe sizes. The larger diameter pipes will allow higher flowrates for a given pump as compared to smaller diameter pipes. However, the price of piping is almost directly proportional to the pipe diameter; and larger pipes, of course, require more space within the vehicle. You will need to consult with the cognizant engineer responsible for the vehicle fairing and propellant tank designs in order to determine how much space is available between the tanks and vehicle walls for the piping. Piping materials also affect the power requirement of a pump, but the use of stainless steel (vacuum insulated for the cryogenic liquids) is common and will be assumed here and is not a design concern for the preliminary phase.

7.2.4. Choose Fittings

Also required for the piping system are various valves and angled elbows. Normally, a single piping system may also have pipes of different diameters that must be joined together. Devices such as expansions and contractions fittings are required for those situations; however, for our purposes, a single diameter piping system will suffice. Since the pipes are only available in 10ft. sections, it will be necessary to use same diameter couplings to connect the sections together (for manufacturing and maintenance purposes, the customer has indicated that welding the sections together is not an option).

Just as pipe diameter, length and elevation head affect the pumping power requirements and cost, the type and number of fittings will also affect the power requirements and cost. Valves, flowrate meters, elbows and couplings are a necessary part of any system and they certainly add safety and convenience; valves, especially, should be used generously, and at least one flowrate meter should be employed in each line. However, as the amount of fittings increases, they can have an adverse effect on the pumping requirements. As previously mentioned, some useful fittings are provided in Table 5 along with their coefficients of loss and estimated price.

7.3 Pump Calculations and Considerations

7.3.1. Calculate Head Loss and Total Head

Once the piping system is designed, the pumping power requirement can be calculated and an appropriate pump can be selected. Remember to include (or perhaps make) room in the piping system for the pump (it is recommended that the pumps be located right below their respective tanks)! To choose an appropriate pump, the total head required of the pump must be determined. This is done by first determining the head loss of the entire piping system:

Eq. 20 $$h_{Total\ Loss} = h_{Minor\ Loss} + h_{Major\ Loss}$$

The minor head loss ($h_{Minor\ Loss}$) is the energy per unit weight lost due to friction as the fluid moves through the fittings (valves and elbows). The major head loss ($h_{Major\ Loss}$) is the energy per unit weight lost due to pipe friction as the fluid moves through the straight sections of pipe. The equations needed to calculate the major and minor head losses are given below (notice how strongly the diameter affects the major and minor head losses!):

Eq. 21 $$h_{Major\ Loss} = (5E\text{-}4)\ L\ (Q^2 / D^5) \quad \text{(ft)}$$

Where L is the total length of straight pipe (as determined earlier – in feet)
Q is the volumetric flowrate (as found in equation 17 – in ft^3/s)
D is the **INSIDE** pipe diameter (in feet)

NOTE: The units for all h's in the propellant delivery section are in feet. There are units associated with the coefficients in Equations 21 and 22 (so the units will not simplify to feet without knowing those units and including them in your dimensional analysis). As long as the values are substituted in the units as described above and below, the units for h will automatically be correct.

Also note: 5E-4 is another way of writing 5×10^{-4}. Many data tables use this notation, and so it is used here to introduce it to you.

Eq. 22 $$h_{Minor\ Loss} = 0.025\ (Q^2 / D^4)\ \Sigma K_L \quad \text{(ft)}$$

Where ΣK_L = Summation of the Coefficients of Loss (dimensionless)

The minor head loss term accounts for the energy lost for all fittings in the particular system under consideration, so included in the equation is the sum of all coefficients of loss. For example, if the piping system contains five 90° elbows, two gate valves and 50 couplings, the ΣK_L would equal:

Example $$\Sigma K_L = 5(K_{L\ 90°elbow}) + 2(K_{L\ gate\text{-}valve}) + 50(K_{L\ coupling})$$

With the major and minor head losses calculated, the total head loss can be calculated from Equation 20. Again, the head loss represents the amount of power (per unit weight of fluid) that a pump has to provide just to overcome frictional losses, but it is generally only part of the power required of the pump. If the fluid that the pump is moving is to gain elevation, increase in speed or pressure, then the pump has to provide power over and above the power loss due to friction to produce those speed, pressure or elevation increases.

7.3.2. Calculate Total Head, H, Requirement

To calculate the total pumping head required for the propellant delivery system pump, the change in elevation and the pressure change from the storage tank to the combustion chamber must be included. In this case, the elevation change aids in the movement of the propellant (which is why it is subtracted from the total head that the pump must provide):

Eq. 23 $$H = h_{\text{Total Loss}} - h_{ele} + \frac{(P_{chamber} - P_{tank})144}{\rho_{liquid}} \qquad \text{(ft)}$$

Where H is the Total Head required of the pump (ft)

$P_{chamber}$ is the pressure in the engine combustion chamber in psia (this information can be found in Table 2)

P_{tank} is the recommended minimum pressure in the tank, as found in Eq. 24 below (psia)

ρ_{liquid} is the density of whichever liquid is flowing through the system currently being considered. These values for your fuels and oxidizers are found in Table 1 (lbm/ft^3)

The following equation helps to ensure that the liquid propellant will not vaporize as it moves through the piping system. This possibility becomes a concern when liquids move quickly through a piping system, dropping the pressure down to its own vapor pressure. This phenomenon is referred to as cavitation. So to prevent cavitation, the pressure in the tank will be **at least** 5 times the vapor pressure of the liquid plus an amount to account for the pressure drop that occurs when the fluid is accelerated up to speed (based on the volumetric flowrate). Feel free to choose your tank pressure to be larger than this value. The coefficient of 2.238 accounts for unit conversions and other constants that were involved in the derivation of the equation:

Eq. 24 $$P_{tank} = 5P_{vapor} + \frac{2.238(\rho_{liquid})(Q^2)}{A^2} \qquad \text{(psia)}$$

Where P_{vapor} is the vapor pressure of the liquid flowing through the piping system under consideration (psia). This information can be found in Table 1.

Q is the volumetric flowrate for the current system, found earlier (ft^3/s)

ρ_{liquid} is the density of whichever liquid is flowing through the system currently being considered. These values are found in Table 1 (lbm/ft^3)

A is the cross-sectional area of the pipe inside in $inches^2$. This is based on the **INSIDE** diameter of the selected piping.

BE SURE TO PAY ATTENTION TO YOUR UNITS – it is imperative they be plugged in correctly!

7.3.3. Choose Pump

With the total head, H, required for each piping system now known, an appropriate pump (or pumps) can now be selected for each system. A series of pump curves is provided as a separate file.

The pump(s) that is/are selected must produce (within ±10%) the head required as found in Equation 23. If one pump is not sufficient to provide either the flowrate capacity or head (or neither), multiple pumps can be used; however, this should be a rare situation and should be avoided. Similar to electrical circuits, placing pumps in series adds their head, but does not affect the flowrate. Placing pumps in parallel adds their flowrates, but does not affect the head. It is important that if you must place pumps in series or parallel, that they be ***identical*** for maximum efficiency. If pumps must be placed in parallel, it is necessary to use "T" or "Y" splitters and possibly additional 90° or 45° elbows to direct the flow properly. Although this would technically increase the overall head loss (due to the extra fittings and additional lengths of piping that would be required), the multiple pumps will compensate for the fairly negligible increase in head loss (in other words, you do not have to recalculate head loss as a result of adding in parallel lines of piping, elbows and splitters, **but** the additional lines, elbows and splitters DO need to be included in your layout drawing, in the material specification list on the drawing, and in the cost).

To choose a pump (or pumps), use the pump curves (see supplemental document provided by your instructor). Each graph has three individual pump curves for a given "family" of pumps. Pumps with geometrically similar impeller shapes belong to a "family" of pumps; each impeller size has a unique curve and all the curves for a given family are included on the same graph. The differences between the three pumps on any given graph is the impeller diameter, weight and cost. Find the volumetric flowrate on one of the curves and then find the corresponding total head, H. You want this value to match the required total head you calculated in equation 23 within ±10%. The Total Head provided on the curve represents the amount of power (per unit weight of fluid) actually delivered to the fluid in order to move it; the efficiency has already been included. Obviously, pumps are not 100% efficient, so not all of the energy delivered to the pump is delivered to the fluid. Some of the energy is lost to friction as the fluid moves through the pump. If none of the pumps provided in the document, there is guidance in that document on how to estimate the size of a new pump that will meet your needs.

Finally, the final weight allotment verification can be performed with the pumps and piping weights included in the structural weight totals for each stage. The weight of each pump is given on the pump curve. The weight of each standard pipe (per foot) is provided in Table 4.

8. CREATE A DRAWING OF THE RESULTING VEHICLE

You now have sufficient information to draw the launch vehicle that you have designed. Draw a section view (like in Figure 6) and bottom view of the whole vehicle and other stages (showing the engine configurations for each stage) on engineering paper, or using a CAD package. Use a scale which will make it fit the paper without being crowded, yet big enough to see: probably 1/150 or 1/200 scale. You may create your drawing by hand, but it should not be "free-hand"; use only pencil to create (or modify) your drawings, and ensure all lines are drawn with a straight edge (even dimensioning lines) and all curves are created with French curves, stencils or compasses. Make an educated guess at the placement of subsystems: guidance and control, telemetry, and hydraulic/electric power. The format shown in Figure 6 is typical, though Figure 6 is not complete as it has no dimensions; yours must include dimensions. Also, include a border and title block and a summary list of all prominent data which describes the characteristics of the final product (as taught in EGR120 – if no one on your team is taking EGR120, ask a professor of EGR120 for guidance; many of the professors in the Engineering Fundamentals Department teach EGR120). If a CAD program is used, a screen shot of the solid model is not sufficient. A section view drawing revealing the same information as shown in Figure 6 (plus dimensions!) is required. It is acceptable to hand draw labels and dimensions on the CAD drawing if you do not know how to create them in CATIA (or whatever program you use) yet.

9. HOW MUCH WILL THE LAUNCH OPERATION COST

Estimate the cost you would have to charge a customer to pay for the launch service this vehicle could provide. The cost of the manufacturing and assembly of the vehicle and engine is estimated by using cost of similar existing vehicles and engines to generate a value for the cost of that item in dollars per pound, much like buying food at the grocery store. Assume that the costs of the empty vehicle and engines are as given below; the cost of the pumps, piping system and propellants must be tallied by you:

Empty Vehicle = $800/lb (manufacturing/assembly costs) **+** cost of raw materials (use material table data)
Engine = $20/lb of thrust
Propellant = use propellant table data
Pumps = use pump data (cost provided on performance curves)
Piping System = use fittings table data

Example Calculation:

Empty Vehicle: (40,000 lb)(800 $/lb) + (3000 lb)(65 $/lb) + (25,000 lb)(105 $/lb)
(manufacturing/assembly) + (raw stainless steel) + (raw aluminum)

Engines: (514,700)(20 $/lb)
(for all engines)

Propellant: (171,700 lb)(0.96 $/lb) + (28,600 lb)(25 $/lb)
(oxidizer for all stages) + (fuel for all stages)

Pumps: ($29,000 + $22,000) + ($10,000 + $14,000)
(first stage pumps) + (second stage pumps)

Piping Systems: (4)($2500) + (5)($300) + (12)($450) + (3)($600) + (16)($250) + (4)($500)
(venturi meters) + (50 ft of 2" pipe) + (120 ft of 3" pipe) + (30 ft of 4" pipe) + (16 elbows) + (4 valves)

TOTAL COST: $46,094,000

FINAL COST (per lb of payload): $46,094,000/2500 lb of payload = **<u>$18,440 per lb of payload</u>**

Check for reasonableness of your cost answers. Current thought is that putting a payload into low Earth orbit costs several thousand dollars per pound of payload, with $10,000/lb being a commonly quoted number. You can compare your value to this value by taking the full cost you estimate and dividing that by the payload weight as shown in the example on the previous page. The closer to $10,000/lb of payload your cost is, the more competitive it will be. If it is significantly below $10,000 you might have left out some important costs; go back and double-check!

10. PREPARE A REPORT and PRESENTATION DOCUMENTING YOUR DESIGN

Documentation of your design process and its results is always a crucially important part of any engineering effort and is required for this project. Refer to Chapter 3 for guidelines on preparing your design report. Your design report must document all of your calculations, decisions and justifications for the design. It should illustrate the design through the use of dimensioned drawings and simple schematics. Text should explain the calculations and processes used and assumptions made during the design process. Alternate design concepts and iterations should also be summarized, demonstrating that the design being put forward has been compared with other possibilities and has been determined to be the best option by your team.

11. Data Tables

Table 1: Rocket Engine Liquid Propellants

Fuel	Oxidizer	I_{SP} (sec)	Oxidizer /fuel Mass Ratio	Fuel Density (lbm/ft^3)	Oxidizer Density (lbm/ft^3)	Fuel Vapor Pressure (psia)	Oxidizer Vapor Pressure (psia)	Fuel Cost ($/lb)	Oxidizer Cost ($/lb)
LH_2	LOX	390	4.0	4.43	71.3	5.88 *	7.35 **	25.00	0.96
LH_2	LOX	455	6.0	4.43	71.3	5.88 *	7.35 **	25.00	0.96
RP-1	LOX	300	2.56	50.5	71.3	5.08 ***	7.35 **	0.32	0.96
Aerozine-50	N_2O_4	325	1.9	57.9	93	0.73 ++	13.93 ++	10.00	2.70
N_2H_4	LOX	310	0.83	62.4	71.3	0.15 +++	7.35 **	7.50	0.96
JP-4	LOX	263	2.4	48.7	71.3	1.16 +	7.35 **	0.27	0.96
UDMH	N_2O_4	333	2.61	50.9	93	1.99 ++	13.93 ++	11.00	2.70
RP-1	RFNA	263	5.0	50.5	97.2	5.08 ***	0.20 ^	0.32	0.88
JP-4	RFNA	232	4.65	48.7	97.2	1.16 +	0.20 ^	0.27	0.88
N_2H_4	N_2O_4	292	1.33	62.4	93	0.15 +++	13.93 ++	7.50	2.70
LH_2	N_2O_4	279	11.5	4.43	93	5.88 *	13.93 ++	25.00	2.70
Aniline	N_2O_4	221	3.87	63.8	93	3.87 ^^^	13.93 ++	3.68	2.70
LH_2	LF_2	410	7.6	4.43	94.2	5.88 *	7.79 ^^	25.00	25.00

LOX = liquid oxygen
RFNA = red fuming nitric acid
Aniline = $C_6H_5NH_2$
N_2H_4 = hydrazine
Aerozine-50= 50/50 mix of UDMH and Hydrazine
N_2O_4 = nitrogen tetroxide
UDMH = Unsymmetrical Dimethylhydrazine

* at -255.65°C
** at -162.15°C
*** at 10°C
\+ at 15°C
++ at 20°C
+++ at 30.7°C
^ at -17.8°C
^^ at -193.15 °C
^^^ at 140°C

Table 2: Liquid Propellant Rocket Engines

Typical Boosters (First Stage)

Thrust (lbs)	Engine Designation	I_{SP} (sec)	Fuel / oxidizer	Mixture Ratio (oxi to fuel)	Chamber Pressure (psia)	Length (ft)	Dia. (ft)	Nozzle Ratio	Weight (lbs)
12,320	RL-10A-5 (DC-X)	316	LH2 / LOX	6	566	3.51	3.33	4	315
60,500	MC-1 (X-34A)	310	RP-1 / LOX	2.6	624	7	4	40	2010
60,500	LR105-5 (Atlas E, F)	220	RP-1 / LOX	2.25	696	8.80	10	25	1010
163,200	LR89-5 (Atlas booster)	256	RP-1 / LOX	2.25	595	11.1	5	8	1580
200,000	RS-27A (Delta and Atlas)	255	RP-1 / LOX	2.25	700	12.4	3.5	12	2528
205,000	H-1B (Saturn IB)	262	RP-1 / LOX	2.25	696	7.20	2.67	8	2180
213,000	LR87-7 (Gemini Titan 2)	258	Aerozine-50 / N_2O_4	1.9	682	10.3	5	9	1570
408,600	RS-25 (SSME)	363	LH2 / LOX	6	2960	14	5.4	77.5	7000
419,500	MA-5A (Atlas II booster)	263	RP-1 / LOX	2.25	711	11.3	3.9	8	3540
430,000	LR-87-AJ-5 (Titan II)	259	Aerozine-50 / N_2O_4	1.93	783	10.3	3.7	8	1630
548,000	LR-87-AJ-11 (Titan III &)	300	Aerozine-50 / N_2O_4	1.91	857	12.6	3.7	15	1672
650,000	RS-68 (Delta IV EELV)	365	LH2 / LOX	6	1392	17	8	21.5	14,500
1,517,000	F-1 (Saturn V)	265	RP-1 / LOX	2.27	1015	18.5	12.2	16	18,500
1,800,000	F-1A (Saturn V series)	270	RP-1 / LOX	2.27	1015	18.0	11.8	16	17,850

Typical Sustainers and Upper Stages

Thrust (lbs)	Engine Designation	I_{SP} (sec)	Fuel / oxidizer	Mixture Ratio (oxi to fuel)	Chamber Pressure (psia)	Length (ft)	Dia. (ft)	Nozzle Ratio	Weight (lbs)
9,800	AJ10-118K (Delta II and IV small second stages)	321	Aerozine-50 / N_2O_4	1.9	130	11	5.5	65	275
14,800	RL-10A-3 (Centaur)	444	LH2 / LOX	5	406	8.16	5	57	288
20,800	RL-10A-4 (Centaur stage for Atlas II)	449	LH2 / LOX	5.5	566	7.5	3.83	84	370
30,800	LE-5B (H-II second stage)	447	LH2 / LOX	5	522	9.13	8.2	110	593
60,500	MA-3A-B (Atlas sustainer)	220	RP-1 / LOX	2.27	736	7.5	3.6	25	1035
80,000	LR91-AJ -3 (Titan I second stage)	308	RP-1 / LOX	2.6	653	8	3	25	1300
100,000	LR-91-AJ-5 (Titan II second stage)	315	Aerozine-50 / N_2O_4	1.8	826	9.2	5.5	49	1103
105,000	LR-91-AJ -11 (Titan III & IV second stage)	316	Aerozine-50 / N_2O_4	1.86	856	9.2	5.34	49	1300
162,000	Viking 4 (Ariane 1 second stage)	296	UDMH / N_2O_4	1.7	783	12.1	8.5	31	1870
230,000	J-2 (Saturn V second stage)	422	LH2 / LOX	5.5	435	11	6.6	28	3170

Table 2 Sources: Encyclopedia Astronautica at www.astronautix.com, http://www.asi.org, www.aerospaceweb.org, www.engineering.purdue.edu/~propulsi/propulsion/rockets/liquids, www.spaceflight101.com and http://www.b14643.de/Spacerockets_2/Diverse/U.S._Rocket_engines/engines.htm

Table 3: Material Data

Material	Yield Stress, σ_{yield} (lbs/in^2)	Young's Modulus, E (lbs/in^2)	Poisson's Ratio, υ	Density, ρ (lbs/in^3)	Price ($ per lb)
Structural Steel (A36)	36,000	29,000,000	0.303	0.284	55.00
High Strength Steel (A514)	100,000	29,000,000	0.300	0.284	70.00
Stainless Steel (304)	30,000	28,000,000	0.305	0.284	65.00
Aluminum (6063-T5)	21,000	10,000,000	0.330	0.098	75.00
Aluminum (6061-T6)	37,000	10,000,000	0.350	0.098	105.00

Table 4: Standard Schedule 40 Piping

Nominal Size (inches)	Outside Diameter, D (inches)	Wall Thickness (inches)	Weight per foot (lb)	Price ($ per 10 ft. piece)
¼	0.540	0.088	0.42	100
⅜	0.675	0.091	0.57	115
½	0.840	0.109	0.85	130
¾	1.050	0.113	1.13	150
1	1.315	0.133	1.68	175
1¼	1.660	0.140	2.27	200
1½	1.900	0.145	2.72	250
2	2.375	0.154	3.65	300
2½	2.875	0.203	5.79	375
3	3.500	0.216	7.58	450
3½	4.000	0.226	9.11	525
4	4.500	0.237	10.79	600
4½	5.000	0.247	12.54	650

[+]NOTE: Pipes must be bought in 10 ft sections; if a shorter length is needed, the pipe must still be purchased in a 10 ft section and cut to size.

Table 5: Standard Fittings and Valves

Component	Coefficient of Loss, K_L (and reading accuracy for flowrate meters)		Price ($)
Fully Open Globe Valve	10		200.00
Fully Open Gate Valve	1.2		500.00
Fully Open Angle Valve	5		400.00
Fully Open Swing Check Valve	2		400.00
Nozzle Meter	3	±4% error	1000.00
Venturi Meter	0.6	±2% error	2500.00
Turbine Meter	0.4	±0.25% error	4000.00
Ultrasonic Meter*	0	±2% error	9500.00
90° Elbow	0.9		250.00
45° Elbow	0.4		250.00
Two Outlet “Y” Splitter	0.8		500.00
Three Outlet “Y” Splitter	1.3		700.00
Two Outlet “T” Splitter	1.2		250.00
Three Outlet “T” Splitter	1.5		450.00
Same Diameter Coupling	0.08		200.00

*NOTE: Ultrasonic Meter cannot be used on vacuum insulated piping (commonly used for cryogenic propellants) and must be placed directly after a 90° or 45° elbow, pump or valve to work properly.

APPENDIX I: THEORETICAL FREE SPACE ΔV DERIVATION

The following is the brief derivation of a free space ΔV for an orbital vehicle launch.

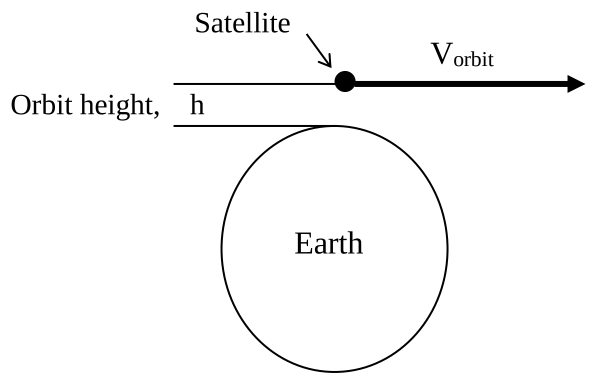


Figure A-1: Orbit Parameters.

As seen in figure A-1, the vehicle will need to reach an orbit height of h with an orbit velocity of V_{orbit}. At this point it will have a kinetic energy proportional to the orbit velocity (squared) and a potential energy proportional to the orbit height. The total energy of the vehicle will be the summation of these two energies.

$$E_{Total} = KE + PE$$

Substituting in the equations for kinetic and gravitational potential energies we get the following:

$$E_{Total} = \frac{1}{2} m V_{orbit}^2 + mgh$$

If the vehicle is starting with some free velocity it has some initial kinetic energy. To find the energy needed to put the vehicle into orbit the initial kinetic energy is subtracted from the total energy.

$$E_{\mathrm{Re}quired} = E_{Total} - KE_{initial}$$

$$E_{\mathrm{Re}quired} = KE + PE - KE_{initial}$$

$$E_{\mathrm{Re}quired} = \frac{1}{2} m V_{orbit}^2 + mgh - \frac{1}{2} m V_{initial}^2$$

If aerodynamic losses are taken into account, the energy required increases by a percentage of the energy due to aerodynamic losses. For a 25% aerodynamic loss the equation becomes:

$$E_{\text{Required}} = 1.25\left(\frac{1}{2}mV_{orbit}^{2} + mgh - \frac{1}{2}mV_{initial}^{2}\right)$$

To find the theoretical energy of which the vehicle is capable, we will model it in deep space. From first stage ignition to the final stage burnout if there are no external forces acting on the vehicle then all the energy the vehicle has will be kinetic: this is the concept of the Free Space Theoretical ΔV.

$$E_{Capable} = \frac{1}{2}m(\Delta V)^{2}$$

To find the most efficient vehicle, we want the net energy the vehicle is capable of producing to equal the energy required for orbit insertion.

$$E_{Capable} = E_{\text{Required}}$$
$$\frac{1}{2}m(\Delta V)^{2} = 1.25\left(\frac{1}{2}mV_{orbit}^{2} + mgh - \frac{1}{2}mV_{initial}^{2}\right)$$

Solving for ΔV we get:

$$\Delta V = \sqrt{1.25\left(V_{orbit}^{2} + 2gh - V_{initial}^{2}\right)}$$

APPENDIX II: ENGINE DESIGN

If the engine is to be a new design so that dimensional data is not available, you can make rough estimates of the size, weight, nozzle ratio, propellant type and chamber pressure of the engine using the following trends.

Height and Diameter

Note: The nozzle is about 2/3 of the total height of the engine. The top portion of the engine is combustion chamber, and control components. The diameter and length of the nozzle are estimated using the trends in the next section (nozzle ratio)

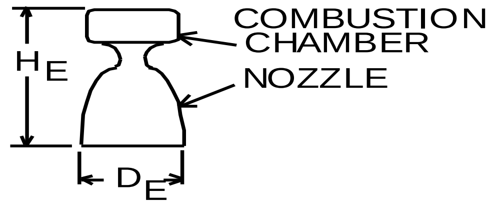


Figure A-2: Simplified Engine

Nozzle Area Ratio

To estimate the nozzle area ratio, NR (or ϵ in the graph), the following graph (Figure A-3) will be used. The dashed line in the plot gives the optimum thrust, and so it should be employed to determine the thrust coefficient, C_F, and the nozzle area ratio. Step 1: Determine the atmospheric pressure at the beginning of the stage for which you are designing the engine (use the TRAJECTORY spreadsheet "altitude at stage burnout" information to aid in this determination); for instance, sea level pressure (14.696 psia) would be used for stage one. Step 2: Estimate a pressure ratio for the engine, P_1/P_3 (where P_1 is the chamber pressure – which is unknown – and P_3 is the atmospheric pressure). At this point, you do not <u>know</u> the chamber pressure, but this will allow you to approximate it; iterations may be necessary in order for the chamber pressure to match with the ranges given in the following section. Typically, first stage engines have lower pressure ratios (100 or lower) and upper stage engines have higher pressure ratios (500 and higher). Step 3: Find where your selected pressure ratio line intersects the dashed line; follow vertically down from the intersection point to the abscissa axis to determine the recommended nozzle area ratio. Follow horizontally to the left to the ordinate axis to find the thrust coefficient. With the thrust coefficient, calculate the throat area using the definition for the thrust coefficient given in Equation A.

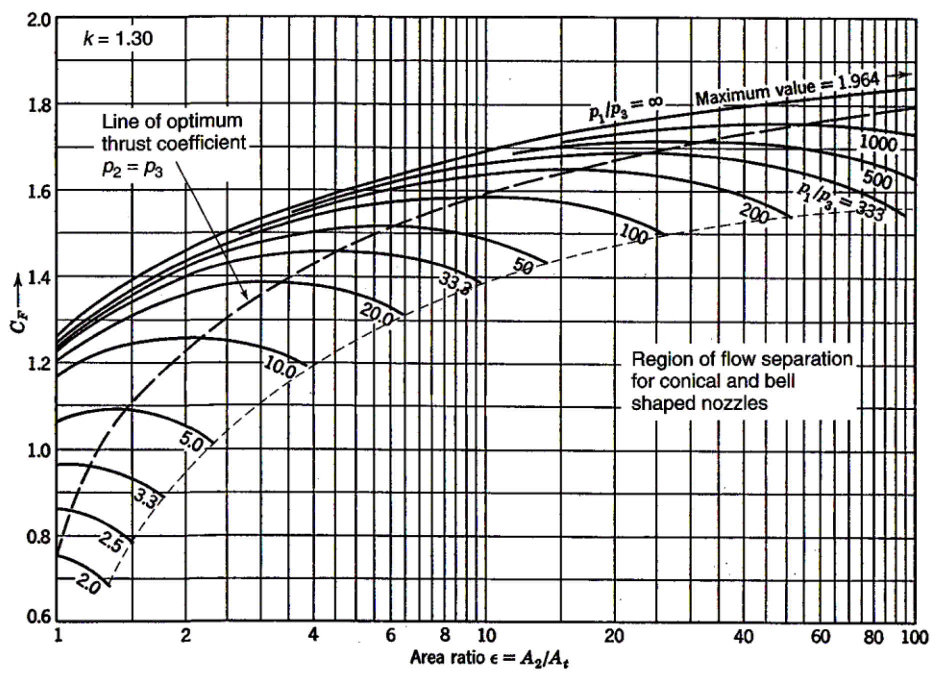


Figure A-3: Plot of Coefficient of Thrust, Nozzle Area Ratio and Pressure Ratio

Source: Sutton, George P., Biblarz, Oscar, *Rocket Propulsion Elements,* 7th Edition, Wiley 2001

Eq. A $$C_F = \frac{T}{A_{throat} P_1}$$

Where T is the desired thrust for the engine you are designing in lb.

P_1 is the chamber pressure in lb/in^2. (P_1 can be found using the pressure ratio, P_1/P_3, you selected and the atmospheric pressure at the start of the stage, P_3. You will need to look up the atmospheric pressure at the altitude; this can be found easily online or in any aerodynamics or fluid mechanics text).

A_{throat} is the cross-sectional area of the throat (the smallest area as seen in figure A-2 above) in in^2.

The exit area of the nozzle can be found by multiplying the throat area by the nozzle area ratio. The diameter, D_E, of the exit plane can then be determined assuming the exit plane to be a circular cross-section.

Figure A-4 can be used to determine the nozzle length. Use the curve associated with the nozzle shape you desire. The corresponding shapes are given in Figure A-5. Finally, with the nozzle length approximated, the full length of the engine, H_E, can be estimated using the rule of thumb given earlier (the nozzle is about 2/3 of the total height of the engine).

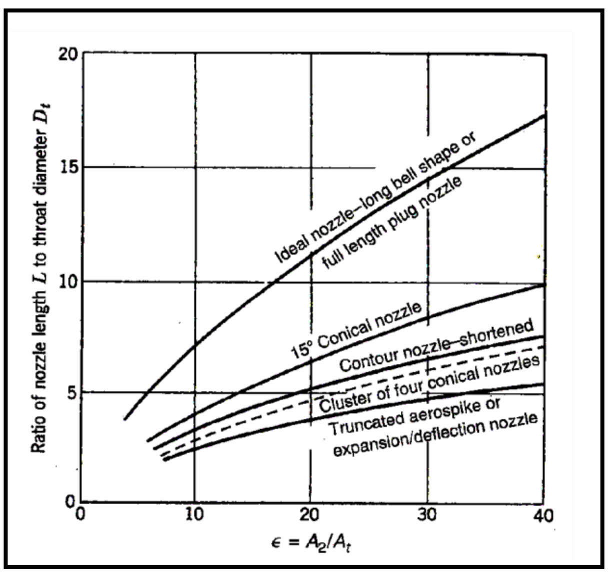


Figure A-4: Plot of Nozzle Length to Nozzle Area Ratio for several nozzle contours
Source: Sutton, George P., Biblarz, Oscar, *Rocket Propulsion Elements,* 7th Edition, Wiley 2001

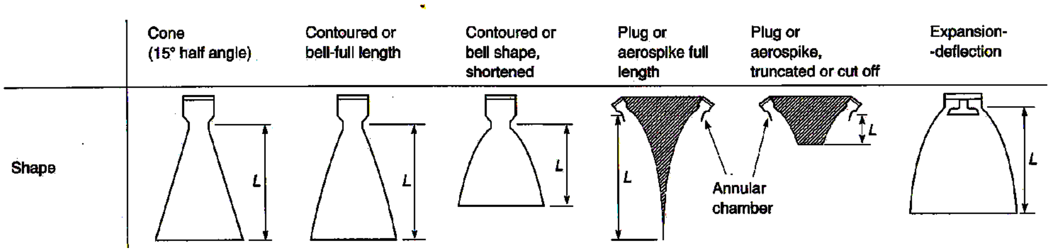


Figure A-5: Illustrations of several nozzle contours
Source: Sutton, George P., Biblarz, Oscar, *Rocket Propulsion Elements,* 7th Edition, Wiley 2001

Chamber Pressure

To validate the chamber pressure selected above for the nozzle ratio, use the following estimates based on existing engine data. Though these values are far from precise – or accurate – they provide a reasonable estimate for the combustion chamber pressure in order to 1) select the best propellant given your pressure ratio selection and 2) design the propellant delivery system (should your team be required to do so). T = thrust of the engine being designed and NR = the nozzle area ratio for the engine. Calculate the product of the desired thrust of the engine and nozzle ratio you found earlier, and then compare your selected chamber pressure with the average values given below. If your selected value is more than ±25% higher or lower than the value given below, you need to go back to the previous section (Nozzle Area Ratio section) and adjust the values. This process may have to be iterated until your pressure values come within ±25% of one another. Note that there are three sets: one for the organic based fuels (RP-1, JP-4 and Aniline), one for the cryogenic fuel (Liquid Hydrogen) and one for the Ammonia-related fuels (Hydrazine, UDMH and Aerozine-50). Check all three. Whichever one is closest to your selected chamber pressure value (again, it must be within ±25%), is the group from which you must select your propellant. Check Table 1 to ensure the specific impulse (I_{sp}) associated with your selected propellant is within ±10% of the I_{sp} value you plugged into MATLAB for that stage. For upper stages with very low atmospheric pressures (and thus fairly low chamber pressures), the allowable difference between the two pressure values can be larger than 25%. Seek advice from your 101 instructor should you require guidance.

<u>For RP-1, JP-4 and Aniline:</u>

If	(T)(NR) < 5E6	then	P = 675 psia
If	5E6 < (T)(NR) < 1E7	then	P = 750 psia
If	1E7 < (T)(NR) < 1.5E7	then	P = 825 psia
If	1.5E7 < (T)(NR) < 2E7	then	P = 900 psia
If	2E7 < (T)(NR) < 2.5E7	then	P = 975 psia
If	2.5E7 < (T)(NR)	then	P = 1050 psia

<u>For LH_2 :</u>

If	(T)(NR) < 5E6	then	P = 500 psia
If	5E6 < (T)(NR) < 1E7	then	P = 1000 psia
If	1E7 < (T)(NR) < 1.5E7	then	P = 1500 psia
If	1.5E7 < (T)(NR) < 2E7	then	P = 2000 psia
If	2E7 < (T)(NR) < 2.5E7	then	P = 2500 psia
If	2.5E7 < (T)(NR)	then	P = 3000 psia

<u>For UDMH, Hydrazine and Aerozine-50: (Note that this trend is not linear)</u>

If	(T)(NR) < 1E6	then	P = 150 psia
If	1E6 < (T)(NR) < 2E6	then	P = 700 psia
If	2E6 < (T)(NR) < 4E6	then	P = 800 psia
If	4E6 < (T)(NR)	then	P = 850 psia

Weight

To estimate your engine weight, W_E , you will need data from Table 2 in section 11. Find two engines with similar specifications as yours (use your best judgment on what parameters to consider, like nozzle diameter, chamber pressure, or specific impulse) between which your engine's thrust fits. Use a linear regression to interpolate your engine's weight between those two values. If you do not know what a linear regression is, do some research first (refer to an online resource, math instructor or library) to learn how to do it. If you still need help, see your EGR101 instructor for further explanation. Item 6 in Appendix 4 at the end of this textbook (not of the project) may be of use to you as well.

APPENDIX III: SYSTEMS INTEGRATION

As a Project Engineer, one of your tasks is to ensure that the design of all of the systems are on schedule and that design decisions which drive other design decisions are recognized and considered critical items. A timeline should be prepared which itemizes the individual tasks for each system, provides the sequence of those tasks along with the approximate start and finish dates and any dependencies between tasks. Not only should the Project Engineer consider the dependency between tasks for a particular system, but also the dependency between tasks of all of the systems. For example, the bulkheads cannot be designed (by the Structural Engineer) until full weight of all the components supported by those bulkheads are known (which is the responsibility of both the Vehicle and Structural Engineers). The volumetric flowrate (needed by the Mechanical Engineer) for any of the fuel or oxidizer delivery lines cannot be known until the volume of the fuel or oxidizer is known, as well as the burntime for that stage (again, determined by the Vehicle Engineer). So it is necessary that the Vehicle Engineer(s) determine these parameters as soon as possible and relay that information to the Structural and Mechanical Engineers so that they may begin their design and meet their deadlines for completion.

Each of the systems of the "Launch Vehicle Project" has been identified below, and the tasks for the complete design of each system are provided in the Gantt Chart. A Gantt Chart provides a graphical illustration of a schedule that helps to plan, coordinate, and track specific tasks in a project. Microsoft Project is a software tool that aids in the creation of a Gantt Chart, as are many other programs and apps. It is your responsibility, as Project Engineer, to ensure that the team members are communicating and meeting deadlines. In general, you will be the liaison between your team members; when a critical item is due for completion, the Project Engineer should ensure that the results of that critical task are delivered to the engineer who requires it.

Launch Vehicle Project systems

- LAUNCH VEHICLE SYSTEM (Vehicle configuration, propellant selection, engines)
    - Vehicle Engineer – sections 1 through 4, Appendix I and potentially Appendix II.
- INTERNAL STRUCTURES SYSTEM (Propellant tanks, Fairing and nosecone, bulkheads)
    - Structural Engineer – sections 5 and 6
- MECHANICAL SYSTEM (On-board propellant delivery system)
    - Mechanical Engineer – section 7
- GROUND SUPPORT SYSTEM (Launch Mount)
    - Ground Support Engineer – Appendix V

Project Engineer Tasks

1) **Become acquainted with the Gantt Chart.**
    a. First recognize that the individual tasks for each system as provided on the Gantt Chart (see the end of this section) come directly from the Launch Vehicle

Project Sections. As each system is assigned to different engineers on your team, one of the first tasks is to determine the specific tasks required to complete the design of their system and develop a schedule; the Gantt Chart will aid them in completing this task.

b. Second, familiarize yourself with the structure of the bar graph portion of the chart. Notice how the tasks depend on one another. Many tasks cannot start until a previous task is completed; this underscores how one design decision drives other design decisions. The critical path is the string of tasks that are the most critical to completing the project on schedule. If any of the critical tasks are not completed on time, the whole schedule from that point on is delayed. On the other hand, non-critical tasks are those tasks that can be started and completed before the results are required.

c. Create a Milestone Schedule. Using the duration predicted by the Gantt Chart, and when your team can begin the project work, estimate when the major milestones will be accomplished, and by whom. The tasks on the Gantt Chart that are represented by diamonds are the milestones. The Milestone Schedule format is provided later in this section and an electronic copy should be provided by your instructor. You do not have to attempt to modify the actual Gantt Chart, the Gantt Chart is simply a resource for you. Use it to aid in producing your Milestone Schedule.

2) **Ensure the schedule is followed**. Again, it is your responsibility, as Project Engineer, to ensure that the team members are communicating and meeting deadlines. You are the liaison between team members, so you should ensure that the results from critical driving design items are given to the appropriate engineers on time. Memos or emails used to accomplish this should be retained and documented. (If you are required to keep a logbook, these memos should be filed there.) **Be advised that you will be required to give status updates in class and/or via email to your instructor, based on your submitted Milestone Schedule. For each milestone deadline you meet on time, your team will earn merit points. Should you miss a scheduled milestone deadline, your team will earn demerit points (you'll lose merit points). These will affect your grade!** You can push back a deadline as soon as you know your team won't meet the deadline, but you can no longer earn merit points for that milestone; you can, however, still earn a demerit if you still fail to meet the new deadline. For these reasons, be sure to make the Milestone Schedule reasonable; you are NOT allowed to put all of the deadlines on the project due date. This would not be feasible anyway as much of the work cannot even be started until some other tasks are completed.

3) **Produce milestone status reports.** A status report should be provided to your instructor each time your team has completed a milestone. This status should include the name of the milestone that is completed and the result of that milestone (i.e., "Determine thrust required" is one of the milestones for the Vehicle Engineer. The actual required thrusts (for each stage) calculated by your team should be included in

that report). The transmission of these reports is at the discretion of the instructor and could include such means as email, hardcopy, logbook, or in-class oral status report. In the case of a hardcopy status report, the format employed should be that of a memo (see example at end of this section – this can be found as a template within Microsoft Word). These status reports not only keep you on schedule and let your instructor know you're on schedule, the content of the reports allows your instructor to verify that you are on the correct track, or if there may be errors in your calculations. It is possible that your instructor may request additional information related to the milestone; if so, be sure to provide it in a timely manner, as he/she is likely just trying to verify that your calculations are sound.

4) **Update the schedule as necessary.** The schedule will likely change as your team progresses through the design process, so you should also reflect changes and handout revisions to your teammates when necessary. If milestone dates are changed as a result, be sure to notify your instructor. Depending on how far out the deadlines are, you may or may not lose the ability to earn merit points for meeting the new deadlines.

5) **Evaluate systems interface.** At the completion of the project, it is your task to evaluate how well your systems will interface. For example, will the payload fit into the launch vehicle? Will the vehicle interface with the launch mount properly? Were all the weight allotments verified? Was there anything that your team did not consider? These are just a few of the questions you should ask yourself. This evaluation should be included in the final report for the Launch Vehicle Project under the heading of Systems Integration; there is likely a specific section on the grading rubric for systems integration. Be sure to discuss these points in this section of your final report (given below). Also, the allowable tolerances between initial estimates and actual values are summarized below for your convenience.

6) **Perform Other Tasks.** Just because you are the Team Leader and Project Engineer does not mean you have no calculations to perform or tasks to complete. You are responsible for sections 8-10 and Appendices III (the one you're reading right now) and IV (the launch mount drawing for ensuring proper interface between the launch mount and vehicle). Additionally, you should help your teammates wherever they are getting stuck or need guidance.

<u>Systems Integration Report Section:</u> (You must show that the values of the parameters listed are within the allowable tolerances, will not interfere with each other, or will match up, as the case may be)

<u>Tolerance Values</u>

- Required Theoretical Free ΔV and Achievable Delta V
- V_{orbit} and V_final
- I_{sp} of actual selected engine and I_{sp} inputted into MATLAB
- Required thrust of engine(s) and Actual thrust of engine(s)
- Structural weights (per stage) and Allotted structural weights (per stage)
- Total buffer heights are within the range described in Section 6 (and below)

- Require pump head and available pump head
- Vehicle H/D ratios (for each stage) are within the range provided in Section 6
- T/W ratios for each stage

Non-Interference Values

- Actual payload bay space envelope and payload required space envelope
- Interface between bulkheads, tanks, pipes, fairing and engines
- Available space between tanks and vehicle fairing and propellant delivery piping
- Fairing diameter (per stage) and tank diameters (per stage)
- First stage engine nozzle diameter and inside open space of launch mount
- Length of engine nozzle outside of vehicle and clearance height to launch pad surface

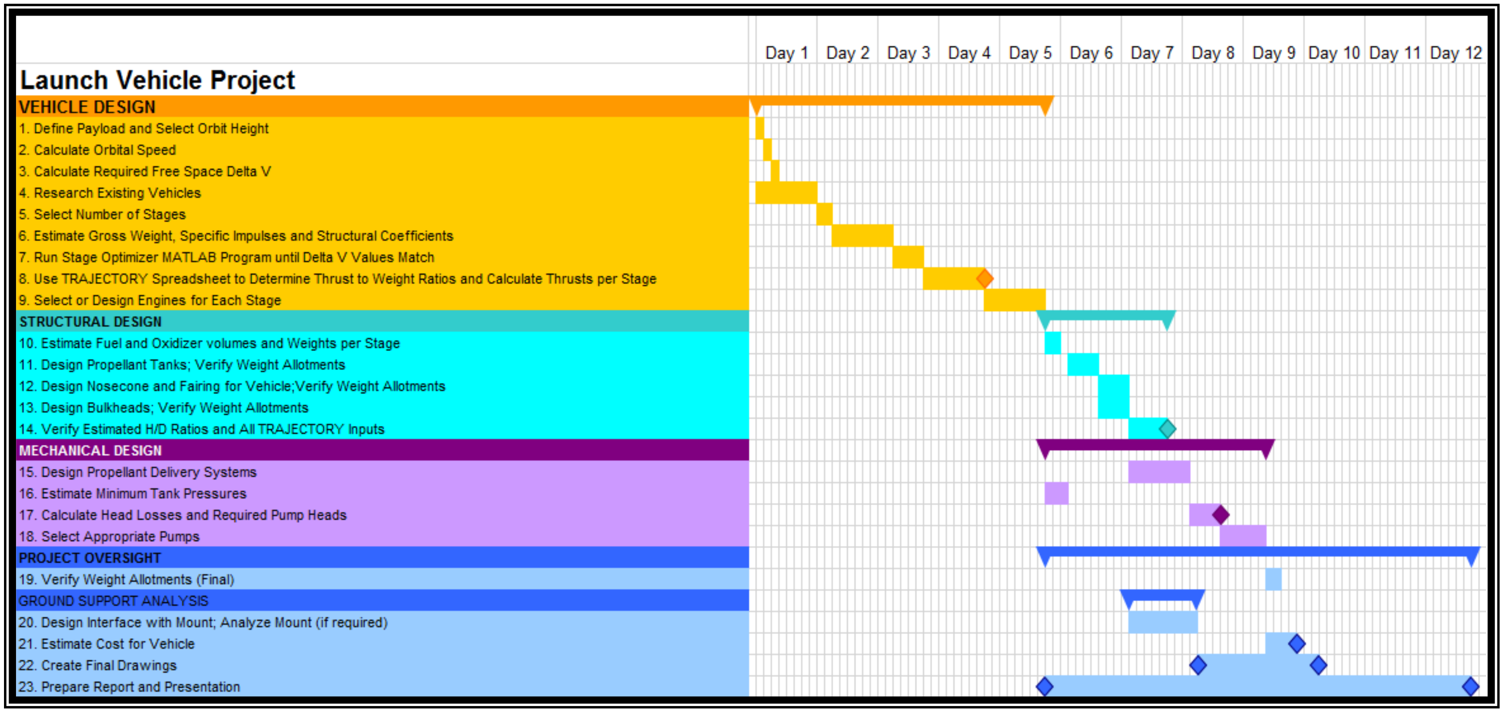
Matching Values or Designs

- Propellants used for each stage are consistent throughout report
- Burntime (per stage) in TRAJECTORY spreadsheet and in propellant flowrate calculation
- Drag coefficient & frontal area (per stage) in TRAJECTORY spreadsheet and in vehicle fairing calculation
- Attachment points on vehicle and on launch mount

Allowable Tolerances:

Parameters	Tolerance	
Required Theoretical Free ΔV and Achievable Delta V	±1%	
V_{orbit} and V_final	±5%	
I_{sp} of actual selected engine and I_{sp} inputted into MATLAB	±10%	
Required thrust of engine and Actual thrust of engine	±10%	
Diameter of Tanks and Vehicle Diameter for given stage	$D_P \leq \sim 85\% \ D_V$	
Actual Pump Head and Required Pump Head	±10%	
Parameters	**Allowable Ranges**	
Total of all Buffer Heights	no more than 25% of no less than 5% of	Total Vehicle Height
Actual Structural Weight	no more than 10% over at least 60% of	Allotted Structural Weight (MATLAB output)
T/W ratio for any stage	greater than 1.0	less than or equal to 3.0

GANTT CHART


Launch Vehicle Project
Day 1
Day 2
Day 3
Day 4
Day 5
Day 6
Day 7
Day 8
Day 9
Day 10
Day 11
Day 12
VEHICLE DESIGN
1. Define Payload and Select Orbit Height
2. Calculate Orbital Speed
3. Calculate Required Free Space Delta V
4. Research Existing Vehicles
5. Select Number of Stages
6. Estimate Gross Weight, Specific Impulses and Structural Coefficients
7. Run Stage Optimizer MATLAB Program until Delta V Values Match
8. Use TRAJECTORY Spreadsheet to Determine Thrust to Weight Ratios and Calculate Thrusts per Stage
9. Select or Design Engines for Each Stage
STRUCTURAL DESIGN
10. Estimate Fuel and Oxidizer volumes and Weights per Stage
11. Design Propellant Tanks; Verify Weight Allotments
12. Design Nosecone and Fairing for Vehicle;Verify Weight Allotments
13. Design Bulkheads; Verify Weight Allotments
14. Verify Estimated H/D Ratios and All TRAJECTORY Inputs
MECHANICAL DESIGN
15. Design Propellant Delivery Systems
16. Estimate Minimum Tank Pressures
17. Calculate Head Losses and Required Pump Heads
18. Select Appropriate Pumps
PROJECT OVERSIGHT
19. Verify Weight Allotments (Final)
GROUND SUPPORT ANALYSIS
20. Design Interface with Mount; Analyze Mount (if required)
21. Estimate Cost for Vehicle
22. Create Final Drawings
23. Prepare Report and Presentation

Fill out and hand in the following table. An electronic copy is available from your professor.
Please either type or print using ENGINEERING LETTERING

Milestone Table

Milestone Number	Milestone Name	Cognizant Engineer	Expected Date of Completion
1	Determination of Required Stage Thrusts		
2	Verification of H/D ratios and TRAJECTORY inputs		
3	Calculate Propellant Delivery System Head Losses and Required Pump Heads		
4	Estimation of Vehicle Cost		
5	Begin Draft of Report		
6	Finish Draft of Report		
7	All Team Members Review/Edit Report		
8	Begin Draft of Presentation		
9	Finish Draft of Presentation		
10	All Team Members Review/Edit Presentation		
11	Finalize Report/ All Members Sign Off		
12	Finalize Presentation		

Group Name Here

Milestone Status Report

To:

From:

CC:

Date:

Re:

APPENDIX IV: LAUNCH MOUNT DRAWING

Modular Launch Pad System
US Patent 6321631 B1

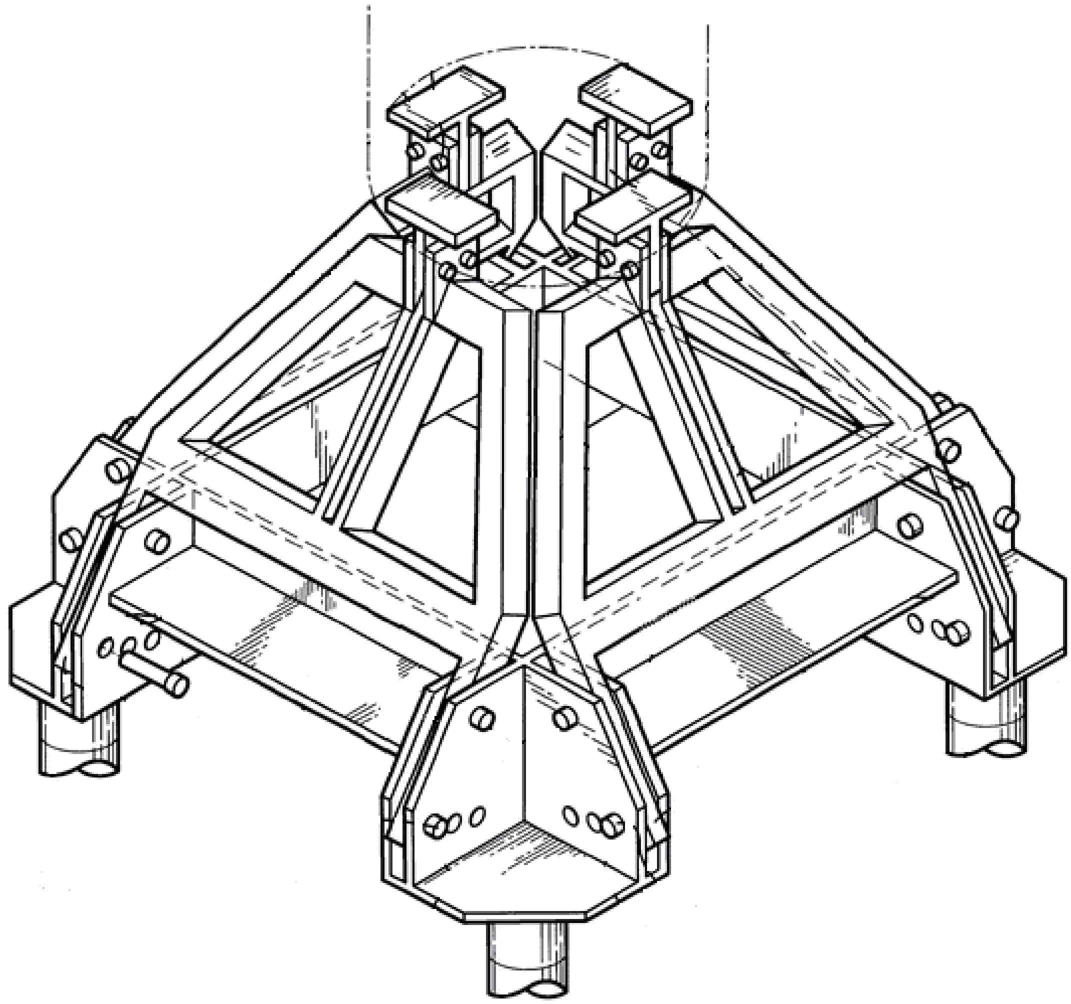
Summary

The launch mount shown here can be configured for three different mounting diameters. The mounting system includes a mounting frame and four arms (columns) pivotally interconnectable to the mounting frame for supporting launch vehicles of different sizes. There are three positions that the arms can be located, as can be seen in the isometric and side views. The three different configurations are achieved using the three pin-lock holes in each of the pivoting plates of the main mounting frame. A locking pin is inserted into the same position hole at each corner pivoting plate (8 pins). To ensure the mounting brackets remain level, the four brackets are also pivotally connected and have three associated positions as can be seen in the side view drawing. Analysis must be performed to ensure the brackets, pins and pivoting arms can support the launch vehicle. The three possible center-to-center distances between adjacent brackets are 54 inches, 99 inches and 145 inches. The mount material is structural steel. The mounting bracket material is high strength steel. The pin material must be selected by the user.

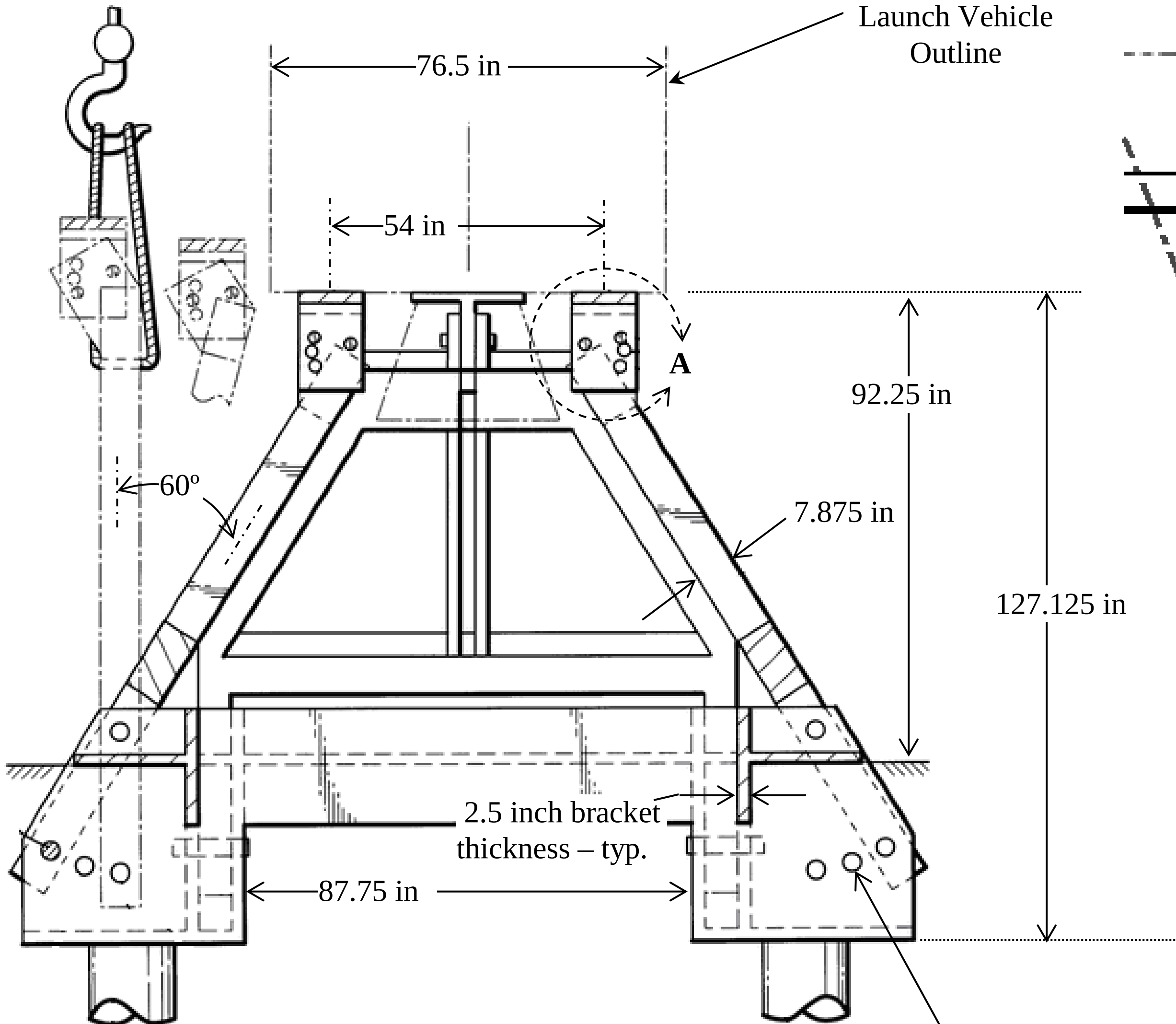
Publication number	US6321631 B1
Publication type	Grant
Application number	US 09/420,913
Publication date	Nov 27, 2001
Filing date	Oct 20, 1999
Priority date ⓘ	May 2, 1994
Fee status ⓘ	Lapsed
Also published as	US5845875, US5974939
Inventors	Gary G. Deel
Original Assignee	Lockhead Martin Corporation
Export Citation	BiBTeX, EndNote, RefMan

Patent Citations (7), Referenced by (2), Classifications (13), Legal Events (8)

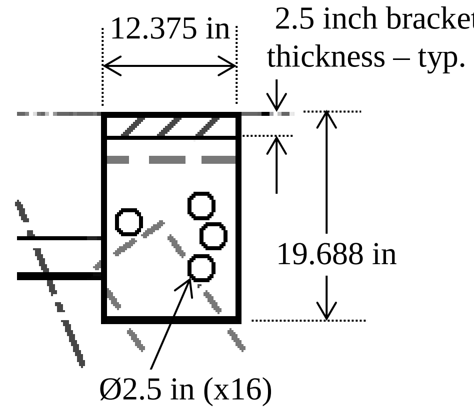
External Links: USPTO, USPTO Assignment, Espacenet



ISOMETRIC VIEW
SCALE 1:40



SIDE VIEW
SCALE 1:36



Detail A
1:18 scale

APPENDIX V: LAUNCH MOUNT ANALYSIS - OPTIONAL

Introduction

The ***launch mount*** is a civil engineering ground support structure that is designed to serve several purposes, each of which is critical for the success of the mission. The launch mount must be designed to:

1. Support the rocket in an upright position during ground operations;

2. Position the rocket at the proper elevation and location over the "flame bucket";

3. Provide the means by which the rocket can be leveled during assembly;

4. Restrain the rocket on the launch pad using locks or explosive bolts until the required engine thrust has been generated.

Failure of the launch mount would lead to catastrophic failure of the rocket and launch pad, possibly resulting in the loss of life and billions of dollars in flight and ground hardware. Given this possibility, aerospace firms spend millions of dollars for the design, development, construction, and testing of launch mount structures.

There are several different operationally successful launch mount configurations in the world today. Some launch mounts are static with no moving parts, while others are hydraulically actuated to swing the mount clear of the passing engine bell. There are even launch mounts that are spring supported to isolate the rocket from ground movements caused by earthquakes or nearby nuclear detonations!

For this project, you are required to use the provided launch mount (drawing in Appendix IV). It is important that the mount be analyzed to ensure it can support the weight of your launch vehicle. The following describes that analysis in simplified terms. Modification is allowed to ensure proper interface with your launch vehicle. The drawings in Appendix IV should be referenced for all dimensions required for the following analyses. If dimensions are missing, estimate the needed dimensions off of the drawing using the appropriate scale.

Loading Analysis and Geometry

To verify that the existing mount will support your launch vehicle, you will need to determine the cross-sectional area that supports the vehicle, A_C, provided by the columns (or pivoting arms), $A_{B,}$ provided by the tangs of the brackets, $A_{hold\ down\ hardware}$, provided by the hardware used to secure the vehicle to the mount bracket surfaces and $A_{locking\ pins}$, provided by the bracket locking pins (the smaller pins). Additionally, the bearing area of the locking pins, $A_{bearing}$, must also be determined (this area will be defined in the bearing stress analysis section. For simplicity, approximate the columns as made up of simple, square columns, ignoring any additional members and embellishments. The cross-sectional area, as shown in the figure below, is the area that is resisting the compression and tension loads from the vehicle.

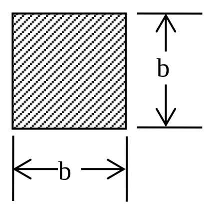


Figure 1: Cross-section of mount column

The bracket tang is a thin rectangle (the vertical structure of the bracket); the Detail A view in App. IV provides the dimensions needed for the tang cross-sectional area. The bracket thickness given can be assumed for the tang as well.

Before getting started in the analysis, the following variables representing the loading conditions are defined:

W = maximum operational weight of the rocket and payload;

T = Maximum thrust developed by the main engines;

From both the symmetry of the loads and the structure, it can be safely assumed that each column supports an equal load, so the total cross-sectional area supplied is the sum of the cross-sectional areas of each column.

W is a downward load, referred to as a ***gravity load*** in civil engineering, and will cause the launch mount to be shortened, or compressed. This type of loading is referred to as ***compressional loading*** in structural analysis. There are two concerns when dealing with compression loadings. First, as with tension loading, we do not want the material to permanently deform (i.e. 'yield') under the stresses developed. And, second, we do not want the structure to buckle under the load. For each of these concerns we will determine the smallest launch mount size that guarantees that it will not fail by either yielding or buckling. In this case, the gravity load will be the largest load that the structure will experience and will serve as the 'controlling design load.'

In contrast, T is pulling the launch mount upward, causing it to stretch. This type of load is called a ***tension load*** and is a transient (temporary) load. When designing a structure for tension loads the engineer must ensure that stresses developed in the structure do not exceed the maximum capacity of the material itself. The maximum stress ***(stress is defined as the force divided by the area over which the force is applied)*** that a material can take before undergoing permanent deformation is referred to as the ***yield stress*** **(σ_{yield})**. The net tension load is the difference between the thrust and weight, as the weight of the vehicle is still acting downward.

Eq. 1 $\mathbf{T_{net} = (T - W)}$

The first step in structural design is determining the loading. For the launch mount, the loading is the result of the design of the rocket itself so the launch mount analysis cannot commence until a reasonable estimate of W and T is made available from the launch vehicle engineers. We can, however, proceed with the initial structural analysis since we know the geometry of the structure.

Only a fraction of W will cause compression in the launch mount. To find the amount of W that will need to be considered we can use basic trigonometry and the known geometry of the launch mount. To determine how much of the total load is actually causing compression or tension, break the W vector into its two vector *components*, $W_{//}$ which is parallel to the columns (when viewed from the side as in the side view of the mounting system), and $W_{\perp}$ which is perpendicular to the columns as shown in Figure 2. The example given assumes a vertical height, h, of 8 feet and a column length, L, of 10 feet.

Note that the triangle formed by W, $W_{//}$ and $W_{\perp}$ is similar to the triangle formed by the launch mount and its vertical and horizontal dimensions. Thus, by the laws of similar triangles,

Eq. 2 $\mathbf{W_{//} / W = h / L}$

Similarly for the tension load, T_{net} and $T_{net, //}$ are related in the same way:

Eq. 3 $\mathbf{T_{net, //} / T_{net} = h / L}$

So for this example only, where h = 8 and L = 10:

(example) $W_{//} = 0.8\ W$ and $T_{net, //} = 0.8\ T_{net}$

NOTE: The value of 0.8 is only valid for the below example where h = 8 ft and L = 10 ft.

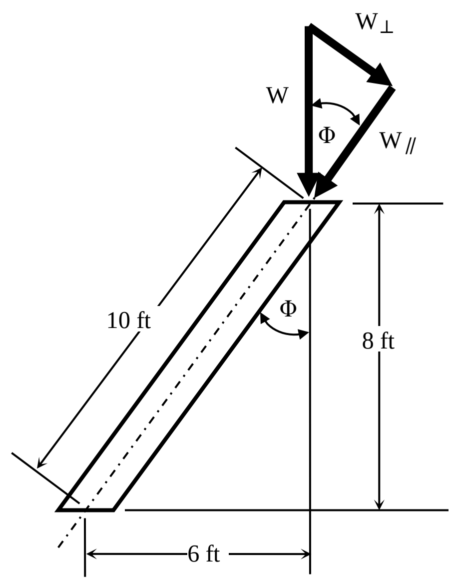


Figure 2: Detail of Launch Mount Column viewed from the side

The perpendicular component of the W and T_{net} vectors ($W_{\perp}$ and $T_{\perp}$) cannot be ignored by the engineer, but frequently the engineer will design a compression ring to resist the perpendicular load vector components, and is generally not the point of failure. Consequently, we will consider only the compression and tension load components ($W_{//}$ and $T_{net,//}$, respectively) for the analysis of the launch mount support pipe. Also, the civil engineer would need to make sure that the support reaction loads on the concrete do not exceed material limits for the concrete material. Our analysis will be restricted to the mounting system as described in the next section, however.

Structural Analysis

Compression and Tension – Columns, Tangs and Bolts

As mentioned earlier, we must ensure that the compression or tension forces resisted by the launch mount do not induce permanent deformation in the structure, or worse, allow for catastrophic failure. Consequently, we must ensure that the stress applied to the structure is less than the yield stress of the material. The materials of the mount, tangs and brackets are fixed and provided in the descriptive paragraph in Appendix IV (tangs and brackets are made out of the same material). The hold down hardware and locking pin materials must be selected. A factor of safety, *f*, will help to ensure that:

$$\sigma_{applied} < \sigma_{allowed}$$

Incorporating the factor of safety, *f*, allows us to redefine $\sigma_{allowed}$ as $(\sigma_{yield})/f$.

The structural engineer must determine if the contact area, A_C, that is provided by the launch mount columns is large enough to ensure the above condition. This is accomplished by ensuring the inequality given below is satisfied. Remember the term A_C represents the cross-sectional contact area of all of the launch mount columns (of which there are eight) added together. Substituting the weight divided by the column cross-sectional area in for the applied stress ($\sigma_{applied}$), we can then rewrite the condition in terms of parameters that are known:

Eq. 4 (Check) $$\sigma_{yield} > f\,(W_{//}) / A_C$$

(NOTE: The factor of safety for structures can be quite high; some research is encouraged to determine a reasonable factor of safety for ground operation structures, like a launch mount.)

Recall that $W_{//}$ is the parallel component of the weight of the rocket on the columns, and σ_{yield} is the yield strength (or sometimes called yield stress) of the material of the mount.

In a similar manner, if you are using explosive bolts (or some other hardware) to hold down the vehicle, the area shown in the below equation is the total minimum required cross-sectional area of the **bolts** (or whatever hardware used to attach the vehicle to the mount) to prevent failure under tension (elongation and necking). You must ensure that the total cross-sectional area of all of the **bolts** combined is at least:

Eq. 5 (Check) $$A_{hold\ down\ hardware} > f\,T_{//}^{*} / \sigma_{yield}$$

Again, the area in the equation above (Eq. 5) is NOT the area used in Equation 4, but rather, is the total cross-sectional area of all the bolts -or other hardware holding attaching the vehicle to the launch mount- summed together. Also, keep in mind that you are determining the size and number of bolts needed (or the size and number of whatever hardware you choose to use); the brackets are of fixed size and may not be enlarged. The bolt material is to be selected by you.

Finally, the bracket tangs also must support the weight of the vehicle. The equation is identical to Equation 4; however, the cross-sectional area is different (find the cross-sectional area of the tang that *supports* the vehicle – remember to multiply by four since there are four brackets!). Also the bracket material is different, so be sure to update the yield stress value too.

Eq. 6 (check) $\sigma_{yield} > f\,(W_{//}) / A_B$

Buckling - Columns

The structural engineer must also ensure that the launch mount columns will not ***buckle*** under the compressional load, $W_{//}$. The fundamental equation for buckling is known as the Euler Buckling Equation. A simplified form appropriate for the provided launch mount states that to prevent buckling the following must be true:

$$F_{applied} < (\pi^2 E I) / f (L)^2$$

Where:

- f = factor of safety
- L = Length of the structural column
- E = "Young's Modulus," a value indicating a material's resistance to deformation under load.
- I = the moment of inertia about an axis in the plane of the cross-sectional area

Using our terms and for our conditions:

Eq. 7 (Check) $W_{//} < (\pi^2 E b^4)/(12 f L^2)$

Where the moment of inertia for a square cross section has been substituted: $I = \frac{1}{12} b^4$

and where b is the dimension of the square cross-section shown in Figure 2.

Be sure that all units are in pounds and inches; i.e. E is in lb/in^2, b is in inches, L is in inches and $W_{//}$ is in lb.

Shear and Bearing Stress – Locking Pins

As the locking pins transmit the load from the support brackets to the columns, it is necessary to ensure they are large enough to support the full load of the launch vehicle. The pins must be analyzed for two failure modes: from shear stress and from bearing stress.

Shear

The pins are in double shear (the pins go through three plates like a clevis and tang). This means that when calculating the cross-sectional area of the pins, the final value should be doubled as the weight is supported by two shear faces, not just one. The actual stress check is very similar to that of the compression and tension analysis, however, materials are generally much weaker in shear (in fact, only about half as "strong"), thus an extra factor of 2 must be included to account for that.

Eq. 8 (Check) $\sigma_{yield} > 2 f\,(W_{//}) / A_{locking\ pins}$

Just as in Equations 4, 5 and 6 the area that should be plugged in must account for all of the pins (so all four). And because the pins are in double shear, that area should then be doubled before plugging it into Equation 8. As you may realize, the pins must be made of very strong material to support the vehicle since that cross-sectional area is so small. Unlike the mount, you may choose the material type for the locking pins to suit your needs.

Bearing Stress

The outside surface of the locking pin that is in physical contact with the tang must also be analyzed to ensure it does not fail in compression. Though the equation looks like Equation 4, it is termed bearing stress as the pin is not acting like a column, but rather more like a beam that is simply supported on both ends; the area over which the force is distributed is very different for bearing stress compared to the area used in Eqn. 4. Any pivoting joint like the one seen with the locking pins must be analyzed for bearing stress.

Eq. 9 (Check) $$\sigma_{yield} > f(W_{//}) / A_{bearing}$$

Here the area is the projected area of the contact between the tang and the locking pin. The area is a rectangle with one dimension equal to the diameter of the locking pin and the other equal to the flange thickness. Remember to plug in the correct yield stress – in this case whichever is smaller between the mounting bracket material and locking pin material.

Conclusion

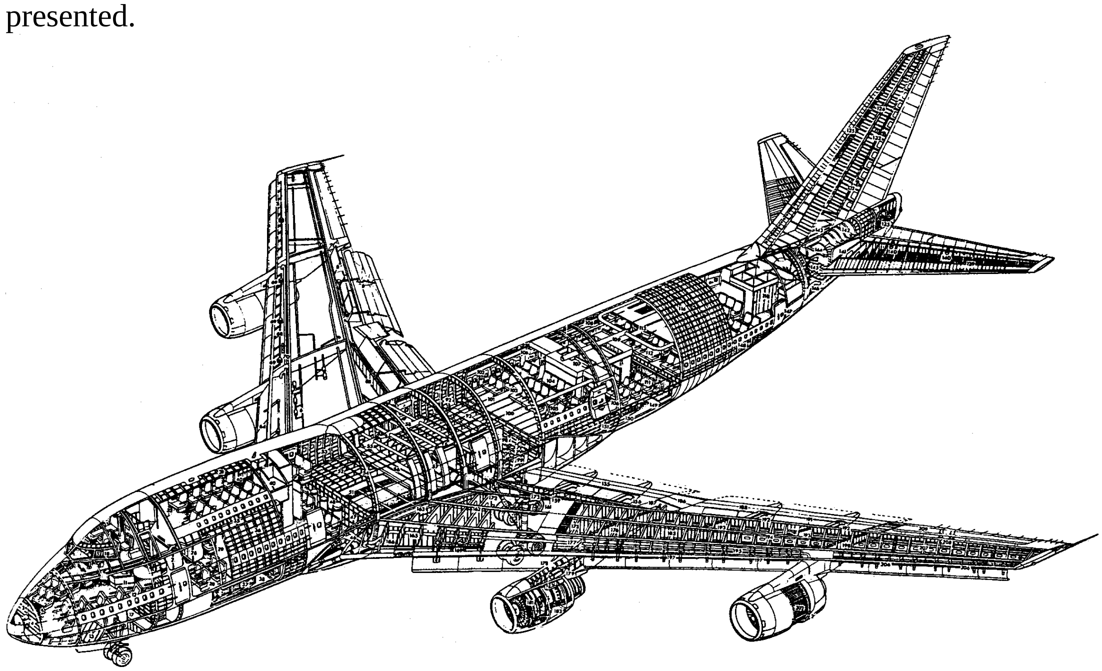
If all of the checks are met, then the launch mount and attachment method will be successful! Show the calculations in the report to prove the launch mount is appropriate for the launch vehicle. Don't forget to ensure there is room for the vehicle and first stage engine nozzle(s) when attached to the mount, and that the attachment method to the vehicle is illustrated on the vehicle drawing(s) as well.

Aircraft Design Project

Introduction

You have designed a launch vehicle to insert a satellite into orbit. You now need a means to transport that satellite from your factory to the launch site. A cargo jet aircraft is the most likely candidate, though it may have to be unusual in size and shape because of the weight and shape envelope of the satellite design. Speed is not critically important but range is. Since the aerospace industry has become truly an international business it would be advisable to have a delivery aircraft with the ability to fly across the Atlantic Ocean, say New York to London or New York to Paris. This requires a range of about 2500 nautical miles. That is also roughly the coast-to-coast distance across the U.S., so delivery from within the U.S. to a coastal launch site would probably be convenient as well.

This aircraft design portion of the project is a very simplified version of the preliminary design process which will be undertaken by some of you in AE420. It requires only algebraic calculations. In several cases, rule-of-thumb estimations are used to avoid having to do analysis which is beyond the current technical background of the typical first year college student. These estimations are explained at the fundamental concept level when they are presented.



The general nature of any type of design project is summarized in Figure 1. The specific sequence of steps to be followed in this project is depicted in Figure 2. The equations presented in the following discussion presume that the aircraft is subsonic. Supersonic flight over land is not currently allowed in any heavily populated country because the sonic boom irritates people on the ground.

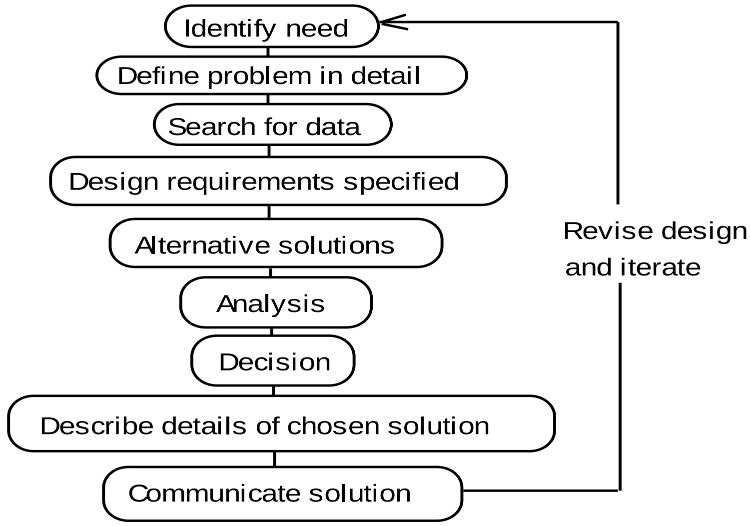


Figure 1. The Design Process

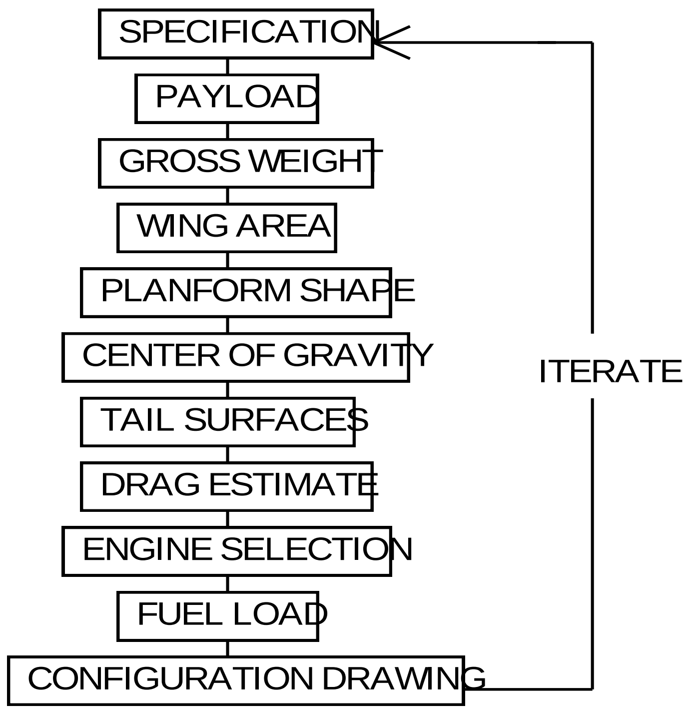


Figure 2. Sequence of Aircraft Design Calculations

Details of the Design Calculations

1. FIND THE PAYLOAD THE AIRCRAFT WILL CARRY

(1) $W_{payload} = (170)\ N + W_{cargo}$

where $W_{payload}$ (lbs) = weight of people and cargo to be carried
N = number of passengers and crew
170 = weight of one person (lbs), specified by Federal Aviation Regulations
W_{cargo} (lbs) = weight of the spherical mirror satellite

2. ESTIMATE THE GROSS (TOTAL) WEIGHT OF THE AIRCRAFT

Gross weight, W_G, is the sum of empty weight, W_E, payload weight, W_P, and fuel weight, W_F.

(2) $W_G = W_E + W_P + W_F$

A precise calculation is quite complicated and can only be done in later design stages as the structural design is completed. General statistically derived values as shown in the table below are used in preliminary design.

Type of aircraft	Empty weight, W_E	Fuel weight, W_F
Light aircraft, piston engine	$.57\ W_G$	Eq. 3
Light aircraft, turboprop	$.55\ W_G$	Eq. 3
Small transport	$.55\ W_G$	Eq. 3
Large transport	$.50\ W_G$	Eq. 3

Aircraft are designed with large variations in range, so fuel weights are harder to describe with simple averages. Plotting the data from 21 aircraft illustrates a trend that we can use as an estimate. Curve fitting a straight line to the data gives the equation below.

(3) $W_F = [0.15 + 3.33 \times 10^{-5}\ (R - 1000)]\ W_G$

Example: For a large transport aircraft with a range of 5000 miles we would estimate W_G as
$W_G = W_E + W_P + W_F = .50\ W_G + W_P + .283\ W_G$ or $W_G\ (1-.50-.283) = W_P \Rightarrow W_G = 4.608\ W_P$

3. FIND WING PLANFORM AREA REQUIRED TO MEET DESIRED LANDING SPEED

Lift, $L = W_G$, at any time the aircraft is in level flight. An important definition, which will be rearranged and used to calculate the wing Planform area is:

(Definition - 4) Lift coefficient, $C_L = \dfrac{L}{0.5\rho V^2 S}$

where ρ = air density (.002377 slugs/ft^3 at sea level standard (SLS) conditions, good to assume for landing)

V = aircraft velocity (ft/sec) ; Note: the FAA uses only knots. Knots x 1.688 = ft/sec.
S = wing planform area (ft^2)

Minimum speed possible, called stall speed, V_{STALL}, occurs when the wing is at $C_{L_{MAX}}$. $V_{LANDING}$ is usually (V_{STALL} x 1.1). Making all these substitutions and **solving Eq. (4) for S, gives:**

(5) $$S = \frac{2W_G}{C_{L_{MAX}} \rho V_{STALL}^2} = \frac{2.42 W_G}{C_{L_{MAX}} \rho V_{LANDING}^2}$$

$C_{L_{MAX}}$ depends on the type of flaps used. The table below gives some approximate values. For jets, $V_{LANDING}$ varies from about 135-240 ft/sec (80-140 knots), with higher speeds requiring longer runways. The ground facilities required to handle your airplane, often called infrastructure, cannot be overlooked, however, even in the beginning of the design process. Runways cost money. Other aerodynamic calculations can be used to derive an approximate relationship between stall speed and runway length required.

(6) L (feet) = .5664 V_S^2, using V_S in knots

Flap type	$C_{L_{MAX}}$
None	1.4
Plain flaps	1.8
Double slotted flaps	2.4
Double slotted flaps plus leading edge flaps	2.7

4. ESTIMATE THE DRAG OF THE AIRCRAFT AT CRUISE SPEED AND ALTITUDE

Drag is the sum of two contributions which we calculate separately: induced drag and zero-lift drag.
Induced drag is drag of a lifting wing which can be attributed to the presence of wing tip vortices. To perform these drag calculations, you will need to choose your cruising speed and altitude if you have not already done so. As travel at the speed of sound is unauthorized over land due to the sonic boom emitted, the speed you choose must be verified to not exceed the speed of sound at that altitude. In addition, without modifications to the design of the engine, many of the engines provided are not designed to handle air entering at sonic or supersonic speeds. To maintain efficiency, the Mach number at which your aircraft cruises must be below 0.8. The speed of sound and air densities at various altitudes are given in CHARACTERISTICS OF THE STANDARD ATMOSPHERE table provided at the end of this document. Mach number for an aircraft is defined as the cruising speed of the aircraft divided by the speed of sound at the cruising altitude.

(7) Induced drag coefficient, $C_{D_i} = \frac{(C_{L\,CRUISE})^2}{\pi A}$

where (8) $C_{L\,CRUISE} = \dfrac{W_G}{.5\rho_{CRUISE} V^2_{CRUISE} S}$

ρ_{CRUISE} = air density at selected cruise altitude (slugs / ft^3)
V_{CRUISE} = selected cruise velocity (ft / sec)
A = aspect ratio as defined below

Aspect ratio, A, = (span / average chord) = b^2 / S. Typical values for subsonic aircraft are 6 to 9. The higher the aspect ratio, the longer and thinner the wings will be (like commercial aircraft). For shorter and stouter wings, the aspect ratio is smaller (like wings on some fighter aircraft). Given the objective of this project (cargo/transport aircraft), a larger aspect ratio is more appropriate. Aspect Ratio is a design choice; you choose it, do not calculate it.

The coefficient of lift that is calculated above in equation 8 is the CRUISING coefficient of lift; this is the coefficient of lift required of your aircraft while cruising (constant velocity and level flight). It is important that the required $C_{L,\,CRUISE}$ not be too big – in fact it should be around 0.2 or 0.3. The lower the better (this means you're flying at a lower angle of attack); of course, it must be greater than 0.

Zero-lift drag, C_{D_O} , is mostly skin friction. It is that portion of the drag which exists whether the wing is producing lift or not. It is another fairly complex calculation, but we can use approximate values here. For retractable gear aircraft, for a sleek jet use C_{D_O} = .020 and for a more typical shaped light aircraft use .025. For fixed gear aircraft use .035. Since we might have an unusually big fuselage on our satellite carrier (12 feet in diameter is typical for a narrow body passenger jet), it would be appropriate to elaborate on the typical value of .020 by using

(9) C_{Do} = .012 + .000667(d), where d = fuselage diameter in feet.

Then (10) $C_D = C_{D_o} + C_{D_i}$

and (11) Cruise Drag (lbs) = $D_{CRUISE} = 0.5\rho C_D V^2 S$

It is required that the fuselage diameter be chosen for evaluating equation 9. Keep in mind there must be enough room for the satellite, the passengers, and any other amenities you have chosen to include. Suggested values are:

minimum w_f = 5 feet for two side-by-side seats with aisle, like executive jets
typical w_f = 12 feet for single aisle airliner, known as a "narrow body"
typical w_f = 17 feet for double aisle airliner, known as a "wide body"

5. SELECT AN APPROPRIATE ENGINE

In unaccelerated flight, thrust equals drag.

(12) $(T_{CRUISE}) = D_{CRUISE}$ where T_{CRUISE} is the cruising thrust at altitude.

An engine at altitude is capable of producing much less thrust than it can produce at sea level. Also, jet aircraft generally cruise at a throttle setting which is about 90 % of the maximum. Manufacturers of engines provide entire books of tabulated engine thrust available as a function of altitude and flight Mach number, but for typical speeds and altitudes it is reasonably accurate to use the simple approximations given below.

$$(13)\qquad T_{RATED} = (T_{MAX})_{SLS} = \frac{(T_{CRUISE})}{.90\sigma}, \text{ where } \sigma = \frac{\rho_{CRUISE}}{\rho_{SLS}}$$

Maximum thrust available at sea level and zero forward velocity is called sea level static (SLS) thrust. This is the value that most manufacturers quote to briefly describe their engine, so it is often called rated thrust. Once equation 13 has been used to calculate the value you need, it can be used to select an engine. A representative collection of engines suitable for a medium to large size subsonic jet aircraft is summarized in Table 1. You could, of course, go to the library or the internet and find others on your own.

So, select an engine or engines that provide a total thrust slightly larger than what equation 13 says you need, and calculate the fuel load required to complete your mission. To calculate the fuel load we use specific fuel consumption, SFC, which is defined as:

$$\text{(Definition - 14)}\qquad SFC = \frac{\text{fuel flow}}{\text{thrust}} = \frac{(\text{lb / hr})\text{ of fuel}}{\text{lb of thrust}}$$

Use the values for SFC for your selected engine in Table 1. Fuel load can be estimated as that required for cruise plus a 45 minute reserve, as given below.

$$(15)\qquad \text{Cruise fuel weight (lbs)} = (SFC)\,(T_{CRUISE})\,(hr_{CRUISE})$$

NOTE a common misunderstanding at this point in the calculations. In equation 15, cruise thrust at altitude is the **total required**, and IS NOT multiplied by the number of engines used to provide the thrust.

Cruise time, $(hr)_{CRUISE}$, can be specified or can be calculated from the range requirement.

$$(16)\qquad (hr)_{CRUISE} = \frac{\text{Range (miles)}}{V_{CRUISE}\ (\text{miles / hr})}$$

Reserve fuel is an arbitrary extra amount to allow for delays caused by bad weather or heavy traffic at the destination of the trip. It can be estimated as:

$$(17)\qquad \text{Reserve fuel weight (lbs)} = (45/60)\,(SFC)\,(T_{CRUISE})$$

And finally (18) Total fuel weight (lbs) = Cruise fuel weight + Reserve fuel weight

The best engine selection is the one for which the sum of the engine weight plus the fuel weight is the least. That is, an engine which is heavy or has more thrust than you need might still be the best choice if it has low SFC. Keep in mind that you probably want to select an engine that is somewhat larger than that required for level flight at cruise speed, so that your aircraft can climb or do other maneuvers. This is the reason for the .90 factor in the denominator of equation 13.

As a very rough check for consistency of design parameters, see whether total fuel weight from equation 18 is about the same as the percent of gross weight which you assumed in Section 2 with equation 3. If it is not, at this point you must EITHER adjust your fuel weight to reflect the value found from equation 18, adjust your gross weight as a result and reiterate through the calculations (equations 5-18) OR adjust your range in equation 16 to reflect your original fuel weight allowance. If you want (or must) maintain your range due to customer requirements, then you must iterate through equations 5-18 until the total fuel weight in equation 18 is within ±10% of the value found from equation 3. This iteration cycle may require changing your engine choice as well, however, choosing an engine that produces at least 15-20% more thrust than you require will give you a "buffer" within which your engine will still meet your thrust requirements even as you increase the total weight. If, through the process of iterating, your estimated fuel weight (eqn. 3) and actual fuel weight (eqn. 18) do not tend to converge (get closer in value), then you may need to consider decreasing your range, cruising speed, or choose an engine with a lower SFC if possible.

6. DEFINE THE SHAPE OF THE WING PLANFORM

Once you have achieved agreement (within ±10%) between the estimated and actual fuel weights, you are now in a position to begin designing your wing planform as the wing area is finally set. As part of the Planform shape design, the designer chooses aspect ratio, taper ratio and sweep angle. The aspect ratio was required to be chosen in section 4 for the induced drag calculation. The remainder of these characteristics can be chosen to satisfy the designer's artistic sense of what he/she wants the aircraft to look like, or they can be based on analysis of what has worked well on other airplanes similar to the current design. (See "Jane's All the Worlds Aircraft" for more information on current existing aircraft; this book is available in an online format through the ERAU online library.)

Taper ratio is defined as, λ = tip chord / root chord. It is usually about 0.5. This value approaches the optimum aerodynamic efficiency, which can be realized with an elliptical planform shape. Elliptical shapes are seldom used because they are very complex to manufacture.

Sweep angle, Λ, is usually defined as the sweep angle of the quarter chord line. Below a flight Mach number of about 0.6, roughly 400 mph depending on cruising altitude, there is little or no advantage to be gained from wing sweep. Subsonic wings are generally swept about 30-35°, if they are swept at all.

With the previously chosen aspect ratio, A, and previously calculated Planform area, S, the wing span, b, can be calculated.

(19) $\quad \text{Span, b (ft)} = \sqrt{(A)(S)}$

Span is the distance from wing tip to wing tip, so a portion of the wing planform area is inside the fuselage and thus not really there in terms of lift production. Including this hidden area is a rough way of accounting for the lift created by the fuselage. Fuselage width, w_f, should be selected now. Suggested values are:

minimum w_f = 5 feet for two side-by-side seats with aisle, like executive jets
typical w_f = 12 feet for single aisle airliner, known as a "narrow body"
typical w_f = 17 feet for double aisle airliner, known as a "wide body"

Now the root chord, C_{ROOT}, and the tip chord, C_{TIP}, can be calculated and the planform drawn to scale like that shown in Figure 3. The equations used to calculate these chord lengths are as follows.

(Definition - 20) General trapezoidal geometry: $b(\frac{C_{ROOT} + \lambda C_{ROOT}}{2}) = S$

(20a) Solving for root chord: $C_{ROOT} = \frac{2S}{b(1+\lambda)}$. (For λ = .5, C_{ROOT} = 4S/3b.)

(21) $C_{TIP} = \lambda\ C_{ROOT}$.

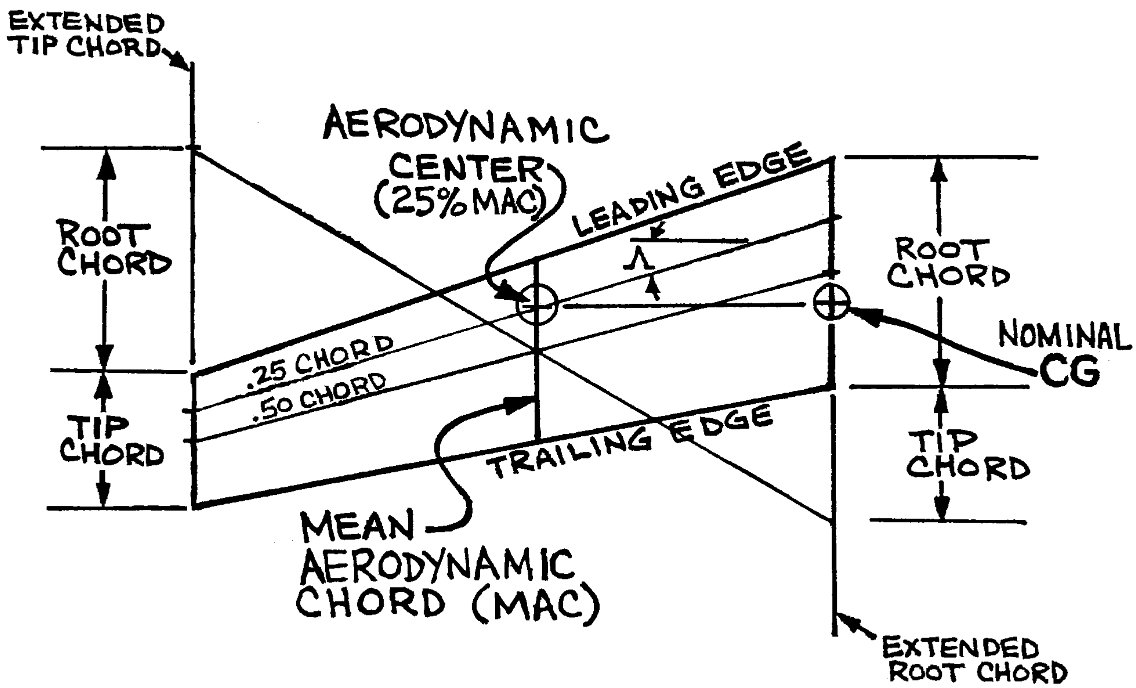


Figure 3. Geometric determination of mean aerodynamic chord (MAC)

Once Figure 3 is drawn, the mean aerodynamic chord, MAC, can be found by the graphical procedure illustrated in the figure. The quarter-chord point on the MAC is called the aerodynamic center. Projecting this point inward to the centerline of the aircraft locates the nominal center of gravity, CG, position. To ensure adequate controllability and stability, the center of gravity generally will need to be kept between about 15 and 35 % of the MAC, measured aft of the leading edge of the MAC.

7. ESTIMATE HORIZONTAL AND VERTICAL TAIL SIZE

Accurate calculation of tail sizes required is the material covered in detail in AE413, Aircraft Stability and Control, and is too lengthy for this project. Reasonable assumptions for the vertical tail planform area, S_{VT}, and aspect ratio, A_{VT}, as well as the horizontal tail planform area, S_{HT}, and aspect ratio, A_{HT}, and respective taper ratios, are:

(22) $S_{VT} = (.15)\ S,\ \ A_{VT} = 1.5,\ \ \lambda = 0.667$

(23) $S_{HT} = (.25)\ S,\ \ A_{HT} = 3,\ \ \lambda = 0.5$

Equations 19, 20a, and 21 can be used to calculate span and chord length of the tails in a manner similar to that used for the wing. But draw the tail areas as exposed area, with none hidden inside the aft fuselage.

NOTE: Whatever reasoning was used to select Λ and λ for the wing applies also to the tails.

Positioning of the tails is estimated using a term called tail length, L_T, which is the distance from the aerodynamic center of the wing to the aerodynamic center of the tail. It applies to both the vertical and the horizontal tail. It is simply 2.5 - 3 times the length of the wing's mean aerodynamic chord.

(24) Minimum L_T = 3 MAC, and longer is OK if it looks better

Data is now sufficient to add the horizontal tail to the wing planform, making a top view of the aircraft, and to begin a side view showing the wing root chord, CG, and vertical tail.

8. COST

Cost is never very far from the thoughts of a designer. A vehicle that no one can afford to buy or operate is not an admirable engineering accomplishment, even though it might be incredibly fast or really beautiful looking. The customer's budget is always an important consideration in the design process. For a jet of conventional design it is reasonable to expect it to cost $600 per pound of the empty weight we estimated earlier. Airplanes with unusual shapes or unusual performance characteristics may cost more. And a composite airplane is more expensive than a traditional aluminum one.

(25) Cost = W_E x ($600 / lb)

9. MAKE A DRAWING OF YOUR DESIGN

The information is now available to draw a configuration sketch of the aircraft you have designed. The fuselage shape is a streamlined fairing around the payload and must be simply sketched out using your "calibrated eyeball". Because of the payload shape for this design, it may have to be fatter than you are accustomed to seeing. Keep in mind that each seated person requires a space roughly 24 inches wide, 50 inches high, and 40 inches long. Figure 4 shows a "95th percentile standard male aviator" and a typical cockpit side view. This standard size person is a brief way of considering human factors engineering in the design. He comes from a government standard (Military Standard 1472), stands 6 feet 2 inches tall, and 95 percent of the population are this size or smaller. You should copy this onto your drawing to ensure that proper interior volume is provided by your fuselage shape. The same document also defines a "standard female" who is quite a bit smaller and, if used, would leave insufficient space for male occupants, a possibility which might be proper for a specialized design.

Where you choose to place the engine(s) is entirely up to you for this project. In reality, your placement of passengers, crew, fuel and engines would have to be determined by lengthy calculations which verify that they produce an acceptable CG location, consistent with that discussed in Section 6. The procedure for locating the CG will be discussed in class.

The configuration definition drawing should now be completed by including all information shown in Figure 5. This is the document which communicates your ideas to the rest of the world, so it should be as clear and complete as possible. It normally includes key dimensions and a summary of the design and performance specifications. In addition to a top and side view, a front view should also be provided in your drawings. All three views should be drawn using the same scale so that size and location of features are consistent between views. Each view can be provided on it's own sheet if necessary.

Additionally, the drawing must:
1. Be on A-size paper (8-1/2 by 11), using whatever scale fits.
2. Have a 1/2 inch border and a title block like Figure 5 (Use your own title and name).
3. Be drawn with drafting instruments or CAD. No hand sketched curves.
4. Show engine and people in top and side view; show cockpit in side view.
5. Show landing gear, ground reference line, and ground reference line rotated to a 12 degree take-off angle to show that the tail won't drag on the runway.
6. Show the Center of Gravity location
7. A reasonable location for the cargo door, and the cargo itself

10. PREPARE A REPORT DOCUMENTING YOUR DESIGN

Documentation of your design process and its results is always a crucially important part of any engineering effort. Since several related projects are now integrated into the EGR 101 system design, a separate document will be provided that spells out the details of the report format requirements.

11. THE END

At this point you have acquired a feeling for how aerodynamics, propulsion, weight, and stability fit together in the design and analysis of an aircraft. This would be the starting point for another design and analysis cycle (iteration) in a real design project, hopefully producing a more detailed and more accurate result with each cycle until a final design is reached.

Table 1: Turbofan Engines

Sea level static thrust (lbs)	SFC @ cruise alt. (lb/hr/lb)	Manufacturer	Model	Weight (lbs)	Dia. (in.)	Length (in.)
3000	.70	Williams International	FJ44-3	445	23	48
5000	.80	Honeywell	TFE731-60	988	43	72
6575	.573	Pratt&Whitney, Canada	PW 308A	1317	37	96
7500	.845	Honeywell	ALF502L	1311	50	66
9275	.605	General Electric	TF34-400A	1478	52	100
15,400	.69	Rolls Royce	Tay 651	3380	45	95
17,000	.65	Rolls Royce	BR710	3520	53	87
18,500	.567	General Electric	CF34-10E	3800	57	90
19,500	.632	CFM International	CFM56-7B18	5235	65	98
21,000	.567	Rolls Royce	BR715	4597	60	102
21,700	.778	Pratt & Whitney	JT8D-219	4515	49	154
22,100	.54	Pratt & Whitney	PW 6122	5050	56	108
25,000	.558	Int'l Aero Engines	V2500-A1	5210	63	126
25,000	.596	CFM International	CFM56-5A1	4860	72	99
32,000	.574	Int'l Aero Engines	V2533-A5	5210	64	126
34,000	.596	CFM International	CFM56-5C4	5670	77	103
38,250	.513	Pratt & Whitney	PW 2037	7300	85	147
41,500	.583	General Electric	CF6-6D1A	8966	105	188
42,000	.65	Rolls Royce	RB211-22B	9195	85	119
50,000	.519	Pratt & Whitney	JT9D-7R4E3	8905	97	132
53,000	.54	Rolls Royce	Trent 553	10660	97	155
54,000	.642	General Electric	CF6-50C2	8966	105	183
60,000	.57	Rolls Royce	RB211-524H	9470	86	125
60,000	.548	Pratt & Whitney	PW 4060	9213	97	133
65,800	.644	General Electric	CF6-80E1A2	11225	114	168
74,600	.56	Rolls Royce	Trent 875	13100	110	172
77,000	.52	General Electric	GE90-77B	17240	134	286
90,000	.52	General Electric	GE90-90B	17240	134	286
95,000	.56	Rolls Royce	Trent 895	13100	110	172
98,000	.537	Pratt & Whitney	PW 4098	16500	120	195
115,300	.52	General Electric	GE90-115B	18850	135	287

Typical values for SFC if no specification is available:

Turbojet	1.0 (lb/hr)/lb
Turbofan	0.5 (lb/hr)/lb
Afterburning turbojet	2 - 4 (lb/hr)/lb

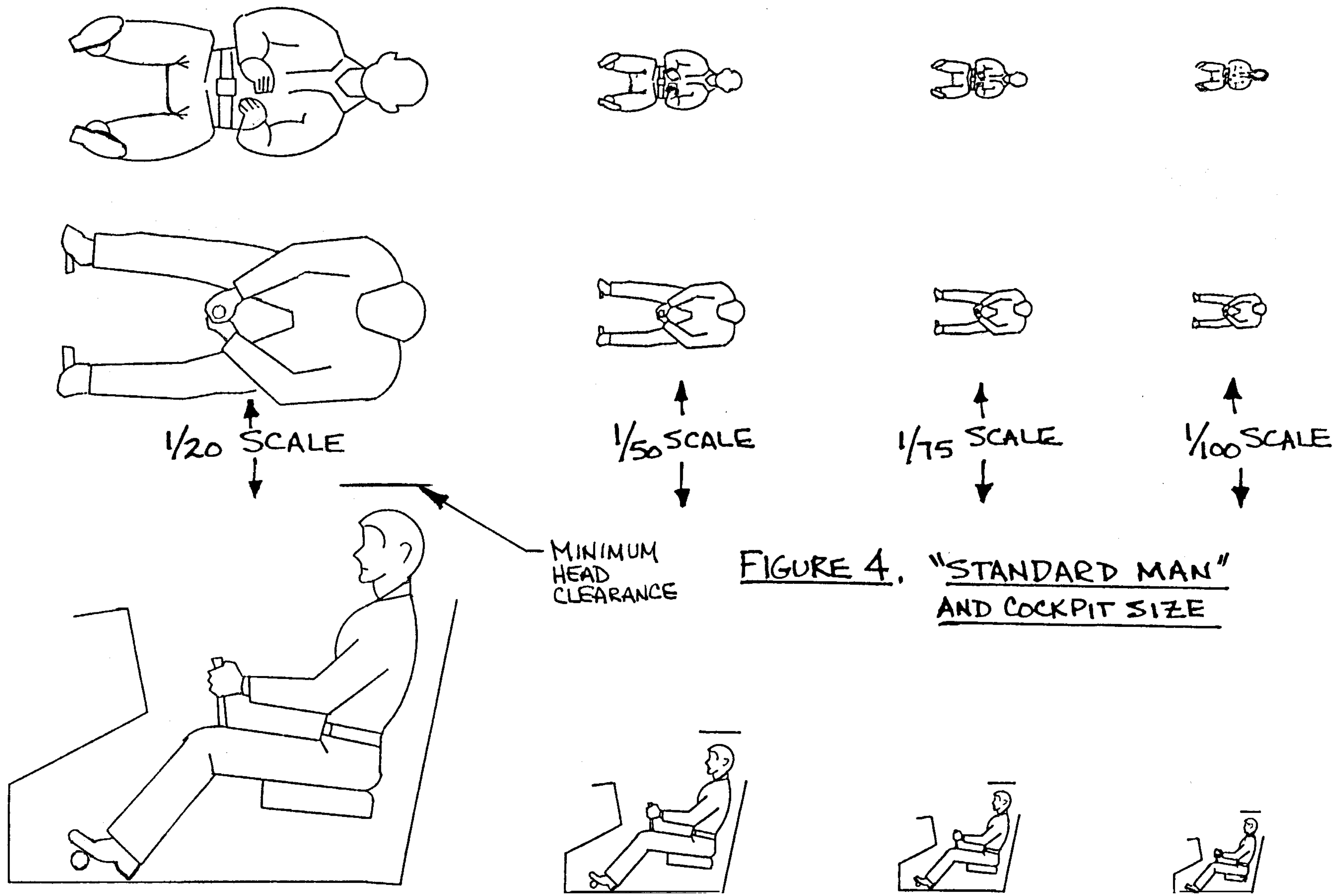


FIGURE 4. "STANDARD MAN" AND COCKPIT SIZE

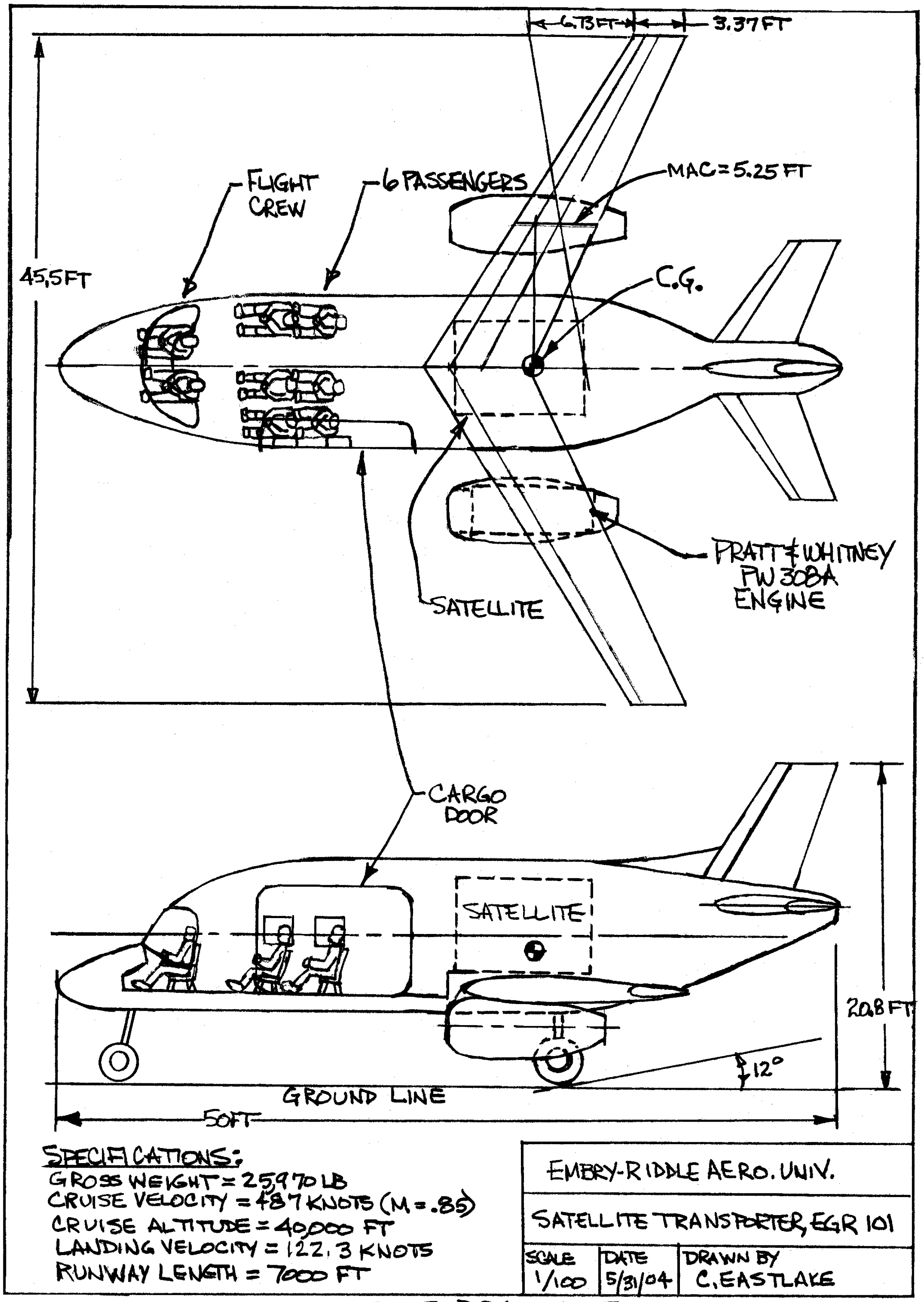


FIGURE 5. DRAWING FORMAT

CHARACTERISTICS OF THE STANDARD ATMOSPHERE (ENGLISH UNITS)

Altitude ft	**Temperature T, ^{O}R**	**Pressure p, lb/ft^2**	**Density ρ, lb s^2/ft^4**	**Speed of sound ft/sec**	**Kinematic viscosity ft^2/sec**
0	518.69	2116.2	2.3769 E-3	1116.4	1.5723 E-4
1,000	515.12	2040.9	2.3081	1112.6	1.6105
2,000	511.56	1967.7	2.2409	1108.7	1.6499
3,000	507.99	1896.7	2.1752	1104.9	1.6905
4,000	504.43	1827.7	2.1110	1101.0	1.7324
5,000	500.86	1760.9	2.0482	1097.1	1.7755
6,000	497.30	1696.0	1.9869 E-3	1093.2	1.8201 E-4
7,000	493.73	1633.1	1.9270	1089.3	1.8661
8,000	490.17	1572.1	1.8685	1085.3	1.9136
9,000	486.61	1512.9	1.8113	1081.4	1.9626
10,000	483.04	1455.6	1.7556	1077.4	2.0132
11,000	479.48	1400.0	1.7011 E-3	1073.4	2.0655 E-4
12,000	475.92	1346.2	1.6480	1069.4	2.1196
13,000	472.36	1294.1	1.5961	1065.4	2.1754
14,000	468.80	1243.6	1.5455	1061.4	2.2331
15,000	465.23	1194.8	1.4962	1057.4	2.2927
16,000	461.67	1147.5	1.4480 E-3	1053.3	2.3541 E-4
17,000	458.11	1101.7	1.4011	1049.2	2.4183
18,000	454.55	1057.5	1.3553	1045.1	2.4843
19,000	450.99	1014.7	1.3107	1041.0	2.5526
20,000	447.43	973.27	1.2673	1036.9	2.6234
21,000	443.87	933.26	1.2249 E-3	1032.8	2.6966 E-4
22,000	440.32	894.59	1.1836	1028.6	2.7724
23,000	436.76	857.24	1.1435	1024.5	2.8510
24,000	433.20	821.16	1.1043	1020.3	2.9324
25,000	429.6.4	786.33	1.0663	1016.1	3.0168
26,000	426.08	752.71	1.0292 E-3	1011.9	3.1044 E-4
27,000	422.53	720.26	9.9311 E-4	1007.7	3.1951
28,000	418.97	688.96	9.5801	1003.4	3.2893
29,000	415.41	658.77	9.2387	999.13	3.3870
30,000	411.86	629.66	8.9068	994.85	3.4884
31,000	408.30	601.61	8.5841 E-4	990.54	3.5937 E-4
32,000	404.75	574.58	8.2704	986.22	3.7030
33,000	401.19	548.54	7.9656	981.88	3.8167
34,000	397.64	523.47	7.6696	977.52	3.9348
35,000	394.08	499.34	7.3820	973.14	4.0575
36,000	390.53	476.12	7.1028 E-4	968.75	4.1852 E-4
37,000	389.99	453.86	6.7800	968.08	4.3794
38,000	389.99	432.63	6.4629	968.08	4.5942
39,000	389.99	412.41	6.1608	968.08	4.8196
40,000	389.99	393.12	5.8727	968.08	5.0560
41,000	389.99	374.75	5.5982 E-4	968.08	5.3039 E-4
42,000	389.99	357.23	5.3365	968.08	5.5640
43,000	389.99	340.53	5.0871	968.08	5.8368
44,000	389.99	324.62	4.8493	968.08	6.1230
45,000	389.99	309.45	4.6227	968.08	6.4231
46,000	389.99	294.99	4.4067-4	968.08	6.7380 E-4

Appendix 1

SAMPLE CODES from former teams

Note the different approaches to including the consequences for not meeting the expectations; the last example is a poor example of including consequences in the code. The consequences should be explicit and well defined, not ambiguous or simply "decided at a later time" for all offenses. An occasional "will be determined", as in the first example, is satisfactory.

Team Alpha Zulu Code of Cooperation

1. EVERY member is responsible for the team's progress and success.
   a. A poor attitude will be penalized on the peer eval. For each major disruption caused by negative comments, unconstructive arguments or rude behavior, 1 point will be deducted from the attitude column of the peer eval. **If more than three disruptions occur by any one teammate, that teammate will be removed from the team.**
2. Attend ALL classes and team meetings and be on time.
   a. First missed meeting is a freebee, but for every missed meeting (without reasonable excuse) thereafter, 0.5 points will be removed from the participation column of the peer eval.
3. Come prepared.
   a. Coming to a meeting unprepared (without logbook, not having read what you were supposed to, not having done what you promised to by that meeting) will be reflected in the contribution column of the peer eval.
   b. For forgetting your logbook, the first time is excused, but for every other time, 0.5 points will be deducted
   c. For not reading what you were supposed to, 0.5 points will be deducted, even the first time (there's no excuse).
   d. For not doing what you promised to have done, 0,5 points will be deducted for the first offense, and 1 point for any additional offenses. **A fourth offense will result in that teammate being removed from the team.**
4. Carry out assignments ***on schedule***.
   a. See part d above in item 3 for consequences. This is the same thing.
5. Listen to and show respect for the contributions of other members; be an active listener.
   a. Being disrespectful and interrupting is an attitude issue. See part a of item 1 for consequences.
6. CONSTRUCTIVELY criticize *ideas,* not persons.
   a. See part a of item 1 for consequences
7. Resolve conflicts constructively.
   a. If teammates are not able to resolve conflicts, the peer mentor will be consulted as a mediator. If the peer mentor sees fit, (or if they're unavailable), the professor will be consulted to help resolve the conflict in a positive manner.

8. Avoid annoying side conversations.
    a. If the team begins to recognize a pattern of disrupting behavior with side conversations by any one particular member, that member will be confronted and expected to modify their behavior. If they do not, they will be penalized in the participation column of the peer eval. The team (minus the disrupting member) will decide the appropriate amount to deduct at that time. The teammate can counteroffer another solution or punishment (like bringing food to meeting or doing extra work to make up for it), and the team (including the disrupting teammate) will vote.
9. Only one person speaks at a time.
    a. This is similar to item 8. This type of behavior will be handled in a similar manner to part a of item 8.
10. Everyone participates, no one dominates.
    a. This too is like item 8, except disruptive member is "taking over" rather than just talking too much. This type of behavior will also be handled in a manner like part a of item 8.

Team "The Riddlers"

1. Attend meetings regularly
2. Come prepared
3. Participate in the discussion
4. Do assignments on time
5. Listen and show respect to all members
6. Pay attention
7. Share all ideas regardless of how insignificant you think it may be
8. Allow for constructive criticism
9. Resolving Conflicts:
    a. Express what is causing the conflict in a respectful manner.
    b. Discuss what is bothering each person and try to reach some type of compromise with each party.
    c. Keep a positive attitude at all-times - and it may avoid conflicts.
    d. Conflicts relating to design ideas will be resolved by a group vote 3 out of 5 (person must state facts to substantiate their vote).
    e. If one has a personal conflict, they should speak to the lead engineer and try to resolve the problem within the group first. If the matter does not get resolved then it should be referred to the professor (All discussions will be kept confidential).

Team Icarus

Each Member of the EGR101 Team Icarus shall agree to the following terms listed below.

1. I will always put forth my best effort and fair share of work on the design project.
2. I will attend and participate fully in every meeting inside and outside of class time. If cannot attend, a team member will be notified before the meeting unless there are emergency circumstances.
3. If I plan to be late (more than 15 minutes) to a meeting, I will bring some form of food or drinks for the team to enjoy.
4. If at any point if I am having trouble, I will seek immediate help from the lead engineer, another team member or the instructor.
5. When a task is assigned or taken on, I will complete the task to the best of my ability and in a timely manner (before the due date!).
6. I, as a team member, will be a team player and will abide by a majority wins rule
7. I will not let my personal life, in any way, effect my design team.
8. I will do my best to help other members of my team when they are in need.
9. I will help my team to complete each task by the specified dates on the master schedule, especially the critical points.
10. I will try very hard to NOT do 90% of the work in 10% of the time.
11. Consequences for not adhering to our team code of conduct are listed below:
    - Late to a meeting – one freebee, bring food/drinks to next meeting for each additional unexcused tardy
    - Missed a meeting – if unexcused (didn’t tell anyone ahead of time) automatic 5% deduction from peer evaluation from all other members – 10% more for each additional unexcused missed meeting
    - Didn’t complete task – automatic 40% deducted from peer evaluation for each incomplete task (if someone is having trouble on a task – they can just ask for help and won’t get penalized!! The deduction will occur if the responsible member never gets his/her work done and never tells anyone about it until it’s due, causing the rest of the team to scramble to get the project done)
    - Did not contribute at all – 0% on peer evaulation from all other team members

Team Awesome Code of Cooperation

1. Don't interrupt. Allow people to finish speaking.
2. Be punctual. You are allowed three times tardy before being punished.
3. Aid group members when they need help.
4. Stay on topic/task, and don't slack off.
5. Use good time management and follow the schedule.
6. Use constructive criticism, when you have a difference of opinion.
7. Don't point fingers, and don't bicker.
8. Pull your own weight.
9. Be enthusiastic. Enjoy the work and make it fun.
10. Hold yourself accountable for your actions.
11. No procrastination.
12. Penalties will be discussed at the time of the offense.

EMBRY RIDDLE
AERONAUTICAL UNIVERSITY

EGR101 LOG BOOK

TEAM MEMBERS:

____

____

____

____

____

TEAM #________________________

INSTRUCTOR: ____

SCHOOL TERM

This team log is intended to be used by the members of an EGR 101 Team for recording:

- the identity of the persons assigned to the team roles for each activity
- all decisions agreed to by the team
- any agreed to work responsibilities
- minutes of meetings conducted by the team in and out of class
- brainstorming notes
- affinity process notes
- work assignments accepted by any team member
- any appropriate comments on the activity/project progress
- additional information needed as determined by the team members dealing with matters technical, philosophical or interpersonal.
- ALL of MY INDIVIDUAL WORK PERFORMED ON THIS PROJECT.

This log is to be submitted to any of your course facilitators upon request during the term and for grading either at the end of the term or completing of the project.

Appendix 2

George Armstrong

Permanent Address
5408 Main St.
San Antonio, TX 77584
Cell #: (713) 555-1212
georgeArmstrong@yahoo.com

Current Address:
Mail # 140000
600 Clyde Morris Blvd
Daytona Beach, FL 32114
Dorm #: (386) 226-6000

OBJECTIVE

To obtain an internship at an aircraft engineering firm. Enabling me to gain experience and utilize my technical skills and my hardworking, persistent personal strengths.

EDUCATION

Pursing Bachelor of Science degree in Aerospace Engineering with a Computer Science minor at Embry Riddle Aeronautical University. Expected graduation date 12/2010.

COMPUTER SKILLS

Software: Word, Excel, Access, Power Point, CATIA, and Maple
Languages: C, MATLAB, and HTML

PROJECT EXPERIENCE

Rocket Launch System
Four person team project to research and design a rocket that would take a payload of 5000 lb to the International Space Station. Analyzed and sized the support structures for a launch mount for the rocket. Sized and designed a fuel delivery system for the rocket. Created a code in C to optimize the project costs, and used CATIA for all drawings for the rocket and the launch mount.

Aircraft Sizing Program
Designed and built a 500 LOC C program to automate the calculations for aircraft sizing. Program interacted with user and read a library of files to output wing span, gross weight, engine requirements, and list of potential engines for a specified range, number of passengers, and payload requirements.

WORK EXPERIENCE

Assistant Manager Pizza Hut Summer 2006 Pearland, TX
Responsibilities included: opening and closing store, money management, scheduling staff, ordering supplies, and supervising 8 employees.

Instructor, The Pride of Pearland Marching Band Summer 2006 Pearland, TX
- Worked with 250+ high school marching students daily
- Taught students how to read marching coordinate sheets

AWARDS

National Honor Roll, ERAU Scholarship, AP Scholar

ACTIVITIES

American Society of Civil Engineers (ASCE)
American Institute of Aeronautics and Astronautics (AIAA)
Task Force One (TFO) Freshman Student Government Division

INTERESTS

Clarinet, Piano, Marching Band, Jazz, Civil Engineering

Appendix 3

Commonly Under-Developed Mathematical, Scientific and Computer Skills

1. Summation and Product notation:

$$\sum_{i=1}^{n} x_i \quad \text{and} \quad \prod_{i=1}^{n} x_i$$

The summation given by the first item tells you to add all the values from 1 to n where i represents the index (which values from the list to add). For instance if you had ten values as listed below, and you wanted to add the first five values, "i" would begin at "1" and end at "5", so n would equal five since that is where you want to end. But if you only wanted to add the last five, then i would go from 6 to 10.

1. 5
2. 15
3. 4
4. 16
5. 3
6. 17
7. 2
8. 18
9. 1
10. 19

$$\sum_{i=1}^{5} x_i = 5 + 15 + 4 + 16 + 3 = 43$$

$$\sum_{i=6}^{10} x_i = 17 + 2 + 18 + 1 + 19 = 57$$

Likewise, the product symbol means to multiply all of the values represented by the index. Perhaps you wanted to multiply the middle four values in the above list, then the notation and result would look like the following:

$$\prod_{i=4}^{7} x_i = 16 \cdot 3 \cdot 17 \cdot 2 = 1632$$

2. Weighted Average:

$$W.A. = \frac{\sum w_i v_i}{w_i} \quad \text{where } w_i = \text{weight of item and } v_i = \text{value of item.}$$

An application of the above would be the computation of your grade for a course. Typically, projects are weighted more than homework assignments, and exams may be weighted the most of all. If a course has three exams, each worth 20% of your grade, one project worth 30%, and the homework average is worth the final 10%, and your grades were as follows, then your final grade for the course would be computed as shown below:

Exam 1 = 65
Exam 2 = 86
Exam 3 = 82
Project = 95

Homework average = 78

$$W.A. = \frac{\sum w_i v_i}{w_i} = \frac{(0.2)(65)+(0.2)(86)+(0.2)(82)+(0.3)(95)+(0.1)(78)}{(0.2)+(0.2)+(0.2)+(0.3)+(0.1)} = 82.9......B$$

Another application of the above is computing the center of mass for a composite object. This will be explained further in your statics and solids classes.

3. Vocabulary:

Modulus = remainder

4. Percentage as decimal:

To convert a percentage to a decimal, simply divide by 100. To convert a decimal to a percentage, simply multiply by 100.

5. Parts Per Million (PPM) as a percentage:

Percent Concentration (%) = PPM/10,000

For example, if the concentration of a particular chemical dissolved in water is given as 3000 PPM, then the concentration percentage is 3,000/10,000 or 0.3%

This is identical to taking the 3000 and dividing it by 1,000,000 (as you might expect for finding the parts per million ratio) to get the decimal and then multiplying by 100 to get into a percentage (as explained in #4)

6. Linear Interpolation / Extrapolation – Find an unknown value from two known points:

Suppose there exists known points (x_1, y_1), (x_2, y_2), and known value x_3 such that (x_3, y_3) lies on the line connecting (x_1, y_1) and (x_2, y_2)

Then,

$$y_3 = \left[\frac{y_2 - y_1}{x_2 - x_1}\right](x_3 - x_1) + y_1$$

An application of this can be found in the Launch Vehicle Project of this text. If you find yourself sizing your own launch vehicle engines, you will need to use linear interpolation to determine the engine's weight based off the weight of similar existing engines.

7. Linear Normalization:

Suppose there exists a known value $V_0 \in [LO_o, HI_o]$, then to find V_n such that $V_n \in [LO_n, HI_n]$, with proportional fit then (the symbol $\in$ means "is an element of the set":

$$V_n = \left[\frac{HI_n - LO_n}{HI_o - LO_o} \right] (V_o - LO_o) + LO_n$$

8. Running Total:

A running total is the summation of values to which new values are being added as they are acquired. This is a common programming concept.

```
total + value -> total
```

9. Concept of a “Prompt” (as in “prompt the user”):

The “prompt” is generally used in programming (or coding). A prompt is simply a question posed to the user of the program in order to acquire an input. An example is shown below.

```
What number would you like? (0-100)
```

10. Memory slots can hold only a single value (overwriting of memory)