

A Comprehensive Term Project for Materials Science Course

Dr. Hui Shen, Ohio Northern University

Dr. Vishal R. Mehta, Ohio Northern University

B.S. Metallurgical Engineering, Maharaja Sayajirao University of Baroda, India, 1995 M.S. Materials Science and Engineering, New Jersey Institute of Technology, 2002 Ph.D. Materials Science and Engineering, New Jersey Institute of Technology, 2010 1995-1996: Quality Assurance Engineer, Keystone Valves (I) Pvt. Ltd., Vadodara, India. Lead engineer of assembly, functional testing, third party inspection and certification of safety relief valves. 1997-2000: Process Engineer, Hindalco Industries, Dahej, India. Shift in-charge of daily smelter operations at primary Copper plant. 2000-2010: Research Assistant, New Jersey Institute of Technology (NJIT), Newark, NJ, USA. Fabricated and characterized High k dielectrics in semiconductors. 2004-2006: Graduate Teaching Assistant, New Jersey Institute of Technology (NJIT), Newark, NJ, USA. Taught applied physics lab to first year and second year students. 2010- 2013: Post-doctoral Fellow National Renewable Energy Laboratory (NREL), Golden Colorado, USA. Fabricated and characterized Photovoltaic/Solar cells and mentored graduate students. 2014-2016 (spring): Assistant Professor-College of Engineering and Technology, Northern New Mexico College (NNMC), Espanola, NM, USA. Taught courses in Basic math for engineering applications, Intro to math for engineering applications, General engineering design, Applied Metallurgy, Photovoltaic Devices, Mechanics of Materials, Solar Thermal Applications, Electric Energy Storage Devices, Materials and Devices and Capstone 2016 (Fall): Assistant Professor of Mechanical Engineering, Ohio Northern University, taught statics, engineering materials science and renewable energy courses. Activities: Sophomore academic advisor.

A Comprehensive Term Project for Materials Science Course

Abstract

At Ohio Northern University (ONU), Materials Science is a required course for freshmen in Mechanical Engineering and an elective for other engineering majors. The course is the first engineering course for most engineering students in the college and therefore it is challenging to explain some concepts and discuss the application of course materials in their future study and career. It is well known that project based learning activities motivates the students to learn new concepts faster. To help students engage in the class, a comprehensive term-long project was developed, which combines material testing, simple design for engineering applications, material selection for the design, and testing of the failure of the designed structure. In this project, students were required to select materials for the major components of an aircraft used for SAE Aero Design Competition. Students selected materials with certain dimensions for five major components of the airframe, including rib, body spar, engine mount, payload box, and wing spar. Each component has different loading conditions and design requirements. The project includes three steps: 1) Material selection was based on mechanics calculation of the material properties from online database to satisfy design constraints. Then design criteria were used to decide the best option using decision matrix. 2) Testing of the mechanical properties of selected materials. The material selections were verified and modified based on the test results. 3) Bending test of the selected component and presentation of the project. A formal final project report was optional for students to earn extra points. From this project-based learning experience, students not only learned the theory, but also gained hands-on experiences. This project changed the passive learning style of the material tests and calculation to active learning style. Students had more questions than just following instructions, as they had to think about how to do the experiments and solve the problem primarily by themselves. While the project was group work with a group of three students, all students contributed to the work based on their own strength. Within each group, leadership roles were rotated among group members for different task. A few assessments were implemented including memos on labs and material selection calculations, formal final project report, presentation, teamwork evaluations, and a survey. Student feedback indicates that overall students enjoyed the experience and believed it should be continued in the future.

Introduction

This paper discusses a comprehensive term project for Materials Science course, which is a required course for freshmen in Mechanical Engineering and an elective for other engineering majors at ONU. The Ohio Northern University is a teaching-focused private university. The college of engineering at ONU, with a student population of around 500 undergraduate students, offers bachelor degrees in five accredited programs: civil, mechanical, electrical and computer engineering, as well as computer science. This course is offered in both fall and spring semesters serving a total of roughly 100 students with about 70 mechanical engineering freshmen. Materials Science course offered in the engineering college aims to introduce fundamental physical and microstructural characteristics of materials and discusses how these relate to their mechanical properties. A major purpose of this course is to help the engineering students learn

how to select materials in the engineering design. Offering this course to mechanical engineering freshmen is challenging because freshmen, especially in their first semester, lack engineering background and it is difficult for them to understand the application of the course knowledge. While the students come from different high schools in different areas, the background of students is also very different. It would be ideal to offer this course in the junior year when the students already learned mechanics and design. However, due to the difficulty of the curriculum scheduling of mechanical engineering at ONU, this course has to be offered in the first year. A comprehensive term-long project was therefore developed, which combines material testing, simple design knowledge for engineering applications, and material selection for the design.

Project based learning (PBL) as an instructional tool has been widely used in the engineering curriculum.^{1, 2, 3} In this methodology, a question or problem is used to drive the students learning activities to produce a product that can be used in real world. The PBL is used to prepare students with skills such as leadership, team building, ethical behavior, creativity, critical thinking, problem solving, and entrepreneurial skills.⁴ PBL has been implemented as part of the curriculum⁵ or as a replacement of traditional classroom.⁶ There has been study where it has been applied in multiple universities simultaneously where students from different degrees were given PBL based materials science course.⁷ For the specific field of materials sciences, PBL has been implemented mostly for sophomores, juniors but rarely in a freshman classroom. In an increasingly complex modern world, engineers are regularly challenged both technically as well as socially to solve multifaceted problems. Material science course is a highly interdisciplinary course, which is related to design, mechanics analysis, testing, etc. PBL can help students engage in the class and understand the course content.

For the term project in this paper, an aircraft for the SAE Aero Design Competition was used as a hook to attract students' attention. Students were required to select materials with certain dimensions for five major components of the airframe, including rib, body spar, engine mount, payload box, and wing spar. Each component has different loading conditions and design requirements which were described in each assignment. The project includes totally three assignments: 1) Material selection based on mechanics calculation of the material properties from online database to satisfy design constraints. Then design criteria were used to decide the best option using decision matrix. 2) Testing of the mechanical properties of selected materials. The material selections were verified and modified based on the test results. 3) Bending test of the selected component and presentation of the project. A formal final project report was optional for students to earn extra points. From this project-based learning experience, students not only learned the theory, but also gained hands-on experiences. While this project can be used in the course for the first year engineering students, it can be also used for higher-level engineering students enrolled in this course.

Project Plan

The Materials Science course is offered during a 16-week semester. The project includes three assignments. Students in the class were aware of the project from the first day of class when discussing the syllabus. The project was also mentioned during the lectures on the mechanical properties of engineering materials starting from the fourth week of the semester. The first assignments started right after the lectures of mechanical properties and a tension experiment,

which was a regularly scheduled lab. At this point, students already knew some concepts of material properties and how to do the tension test. The last (third) assignment was due the last week before finals week. The students in class were given two weeks, three weeks, and three weeks for the first, second, and the third assignment, respectively. The three assignments are attached as appendices in this paper. Students worked on the project in groups of three, and each student took a leading role in turn for the three assignments. The instructor appointed the leader for each assignment for a group. The estimated contributions of group members and the amount of work performed by each group member along with meeting information were logged for each work.

1) Assignment 1

The SAE Aero Design Competition was used as the hook for this project. The competition is to “design, manufacture, and successfully fly a remote controlled aircraft capable of carrying a large payload, while adhering to the SAE Aero Design competition requirements”.⁸ While there are many requirements, the requirements that are most relevant to material selection are the weight of the aircraft is less than 55 pounds with payload and “all aircraft components must remain attached from takeoff to landing”.⁸ These requirements were then used as the selection criteria for weight and strength of the materials. The airframe made by the 2015 SAE Aero Design Competition team at ONU is shown in Figure 1. The ribs and spars were made of balsa wood and the engine mount and payload box were made of plywood. The students in the class were asked to verify the selection of the old design and also evaluate the possibility to use new materials for the components of airframe in the 2017 competition. That is, the goal for this project is to help SAE Aero Design Competition team at ONU to make a decision on the material selection for the airframe components for the next year.



Figure 1: The airframe of the 2015 aircraft for the SAE Aero Design Competition⁸

The five major components of the airframe are rib, body spar, engine mount, payload box, and wing spar. There were totally ten groups in the class. Every two groups were assigned to work on the material selection for one component. The dimensions and loads for components were given based on the approximate real loading condition and the design of the airframe. The material selection constraint and criteria were also given based on the airframe design. The constraint for the material selection is that the maximum stress must be less than or equal to the failure strength divided by the safety factor. The criteria are cost, weight, and strength. The weighting factor for each criterion used for the material selection depends on the design. For example, because there

is relatively low loading applied on the rib and there are many ribs in the airframe, the weighting factor is 80% for the component weight and 10% for the material strength as the weight of the rib is a key factor to achieve lightweight of the aircraft. The wing spar, which supports the entire wing, should be more critical on the strength of the material than the weight and therefore has a weighting factor of 60% for strength. The students would understand that the material selection would be different for each component from the various design requirements.

Totally seven candidate materials, including balsa wood and plywood, with two thicknesses for each material, were provided as candidate materials. For Assignment 1, students first selected three candidate materials from the candidate material pool and did the calculation to ensure these materials to satisfy the constraint. All the material properties were obtained by searching online material property database. Then used a decision matrix to make the final selection based on the criteria and the weighting factors. The first assignment was a typewritten group memo on the material selection according to the design considerations. Students were supposed to state the task and their three selections of the materials and how they made their decision. Teamwork was required to be recorded.

2) Assignment 2

In the previous assignment, Assignment 1, the calculation and material selection were based on the information obtained from database of some material property websites such as matweb.com.⁹ However, the material properties are statistical in nature. That is, the material properties can be affected by many factors, especially for balsa wood and plywood. So there are two parts for this assignment. In the first part of Assignment 2, the students were required to perform a self-designed experiment to measure the material properties including strength and density. At this point, the students had already performed a tension test in the regular lab, in which students simply followed the instructions provided by a lab instructor. For this part of the project, the students complete the test on their own, including procedure design, test setup, data collection, and result analysis. Then they discussed how their results were compared with the data from other websites. An experiment memo summarizing the results was required. Each group was assigned one task as shown in Assignment 2 in the Appendices. The results from each group were then compiled by the instructor and provided to the students for the second part of the project assignment. For the second part of Assignment 2, student group revised and resubmitted the material selection memo from Assignment 1 using the properties obtained from the student experiments and also based on the feedback from the instructor on their first memo.

3) Assignment 3

There are required and optional parts for this assignment. The required part is a PowerPoint presentation from each group to present their results in the class at the end of the semester. Grading of this assignment was based on presentation skills and the content. The optional part is for the students to make extra points. It is an ambitious plan to ask first semester freshmen to write a formal project report and do a test that they have never done before. For this last part of the project, only those students who feel confident and interested to earn extra points would do this part. A bending test was asked to be performed in the material lab to find the failure load of the component, and then to compare the test result with the calculation result of failure. A

formal report template was offered in detail including abstract, introduction, mechanics analysis, material selection, experiment result and discussion, conclusion, acknowledgments, and references as well as the format of figures, tables, and equations. This would offer the students a chance to learn and practice technical writing of a formal technical report.

Student Work Reflection

Teaching Material Science to engineering freshmen is challenging due to the limited engineering background of the students. This application driven PBL combines the material selection with the material tests and incorporates simple design ideas. Students not only learned the theory, but also gained hands-on experiences. Overall, the process of the project was carried out in the class successfully.

For Assignment 1, the students learned to search material properties from various resources. Then they did a mechanics calculation and a decision matrix using Excel spreadsheet. Finally, they summarized the result in a memo. It seems that the students had no problem obtaining the information they needed from online resources. It was a little surprising that 3 out of the 10 groups did wrong on the maximum stress calculation. The calculation was just to plug in numbers in the mechanics equation. It seems that students were good at online searching and excel calculation, but not hand calculation. None of the groups did well on the format of tables, figures, and equations. This is understandable due to the limited technical writing training for the students. All the mistakes were marked on the students' work and returned to the students. They were aware that their next assignment of the project would refer to the feedback from this work.

For Assignment 2, the strength and density of the candidate materials were measured by the students and compared with the data obtained from data on websites. The test samples were made by the students with the assistance of the machinist in the machine shop in the engineering college. The results are reasonable and they analyzed what might cause the difference between their results and the published ones. Through this self-designed lab, the student learned to apply the experiment skills to obtain material properties by themselves. They also realized the statistical nature of the material properties. The students then revised their first material selection memo based on the test results and the feedback from their first memo. The writing of the second memo was greatly improved by eliminating the format errors such as missing figure caption and table titles and with better organization and writing. They also fixed the calculation errors and made the final selections on the material for the component. Therefore, the students selected and tested materials for the airframe of the aircraft for the 2017 SAE Aero Design Competition for the ONU.

For Assignment 3, all the groups presented in class the whole process and results of the project. The presentation lasted about five to ten minutes for each group. The students were required to discuss background, objective, theory of calculation, constraint and criteria, initial and revised analysis and material selections, 3-point bending test results and calculation results (optional), conclusion, and future work. The grading rubrics of the presentation were discussed in class before the presentation to teach presentation skills. Most groups did well on the presentation by following the detailed instruction in Assignment 3 (as attached in Appendices).

For the optional bonus part of Assignment 3, 8 out of the 10 groups did this part including the 3-point bending test and a formal report. The bending tests went smoothly for all the groups. The bending test allowed the students to observe how the material behavior under bending which is similar to the real application. Some groups started to critique about their selection after observing how material samples behaved under bending. For example, one group chose polycarbonate for the wing spar component. While the sample had a large deformation under bending, they started to question if it was reasonable to choose the material ignoring stiffness and deformation. Before the material reach the ultimate strength, large deformation would already affect the integrity of the whole structure. This critique is valuable for the students to validate their own selections. Students were also encouraged to review and criticize the material selection criteria given by the instructor in the project.

For the report, as aforementioned, it is challenging to ask freshmen to write a formal report and therefore this part is a bonus part. A 1-6 scale was used as grading rubric to evaluate the sentence structure, organization, figures, tables, format, and reference etc. As the training of technical writing is limited, only one group got 5 out of 6 and other group got 2-4. It was not uncommon to see missing table titles, figure captions, using “the first person” instead of “the third person” in their report, etc. However, it is still a valuable experience for the students to have a technical writing training at the early stage.

Assessment and Discussion

An anonymous survey of the outcomes of the comprehensive term project for Materials Science course was conducted by the instructor. 27 out 30 students enrolled in the course submitted their responses. The level of agreement was rated for 7 outcomes, including 3 on material science knowledge skills and 4 on the communication skills. Students were asked to rate each outcome on a scale of 1 (strongly disagree) to 5 (strongly agree). 2 questions were also asked regarding the continuation of this project and suggestions on improvement.

Material Science knowledge skills

Table 1 presents the data of the ratings given by the students for outcomes on the material science knowledge skills. The outcomes on the survey are shown in the first row. For the outcome about the project being a motivator for learning material properties, 7.4% strongly agreed, 55.6% agreed, while 7.4 % disagreed. For outcome about improving ability for the material selection for specific application, 37% strongly agreed, 48.1% agreed, and 3.7% disagreed. It should be noted herein that “select the proper material for a specific application” is also a course outcome for the Material Science course. The rating of the course outcome changes from 3.96/5.00 from last year to 4.25/5.00 from this year based on course outcome evaluation from students in the class. That is, the project improves the rating on course outcome on this aspect. When the students were asked about how the term project has helped them to be aware about current technical trends, 62.9% agreed while 11.1% disagreed. Based on the feedback from the students, the project motivated them to learn the material property and applications. More generally, it helps them prepare for their future curriculum. The material testing gave them training necessary to be successful in other similar group projects in senior years. For example, one student commented “will probably do something like this in the future”.

Table 1 Survey results for Material Science knowledge skills.

Outcome	This project has motivated me to learn material properties	This project improved my ability to select the proper material for a specific application based on the relevant properties	This project helps me be aware of current technical trends in material selection
Average rating	3.59/5.00	4.15/5.00	3.70/5.00
Detail Answers	Percentage	Percentage	Percentage
Strongly Disagree 1	3.7	3.7	0.0
2	3.7	0.0	11.1
3	29.6	11.1	25.9
4	55.6	48.1	44.4
Strongly Agree 5	7.4	37.0	18.5
Total	100.0	100.0	100.0

Communication skills

Table 2 presents the data of the ratings given by the students for communication skills. The outcomes on the survey are shown in the first row. When students were asked if the term project improved their technical skills, 29.6% strongly agreed, 29.6% agreed while 3.7% disagreed. Technical writing is very challenging for engineering freshmen and engineering students seemed to not like writing anyway. The revised memo in the second assignment was greatly improved compared with the first memo. But technical writing is still some area that the students did not feel confident in.

Table 2 Survey results for communication skills

Outcome	This project improves my technical writing skills	This project improves my presentation skills	This project improved my information searching skills on material properties	This project improves my teamwork skills
Avg. rating	3.63/5.0	3.56/5.0	3.96/5.0	3.96/5.0
Detail Answers	Percentage	Percentage	Percentage	Percentage
Strongly Disagree 1	3.7	3.7	0.0	3.8
2	18.5	3.7	11.5	11.5
3	18.5	48.1	3.8	7.7
4	29.6	22.2	61.5	38.5
Strongly Agree 5	29.6	22.2	23.1	38.5
Total	100.0	100.0	100.0	100.0

On a question regarding improving presentation skills 22.2% strongly agreed, 22.2% agreed while 48% somewhat agreed and 3.7% disagreed. This relatively low rating on improvement of presentation skills because the students were asked to present their results in the last week of the

semester. While the last week is a relatively busy week, the students didn't have enough time to prepare. Moreover, there was not enough time to give students feedback on their presentation skills. This can be improved next time by assigning the project early and allow more time for the presentation preparation. If possible, two presentations can be assigned for the project and students can use the feedback on their first presentation to prepare for their second presentation. Technical writing and presentation are crucial soft skills that undergraduate engineering students are expected to learn. Despite the relatively low rating, the project activities still helped the students improve their writing and presentation skills. One student commented "This project helped me improve my writing and presenting skills dramatically which is helpful for other classes too".

On an outcome regarding the term project improving information searching skills, 23.1% strongly agreed, 61.5% agreed, 3.8% said somewhat agreed while 11.5% disagreed. Based on the feedback from the students, the project-based learning activities encouraged them to look for the resources to gather the information they need. For example, one student commented "discovered matweb.com to search for material information". Another wrote "I was unaware of the tools available for finding material properties before doing this project". The information searching skills would be useful for them in other classes and even in their future career.

The table also shows that 38.5% strongly agreed and 38.5% agreed that the term project improves their teamwork skills. While the project was completed by groups of three students, they were required to log teamwork information and take leading roles in turn. This helped them learn to work in teams. Their final grade was also based on their contribution to the team.

Feedback on the continuation of this project

For question regarding the project, "Do you think we should do this lab again next year?" 23 of the 27 students answered "Yes", three students answered "No". One student commented "good freshman level project", other commented "I enjoyed it and learned a lot about experimental processes". It seems that overall the students enjoyed the experience and believed it should be continued in the future.

Suggestions on improvement

The students suggested improving the project on a few aspects including assignment timing, candidate materials, and variation of project tasks between groups. A few typical comments are listed herein as examples:

- Project timing: - "give the students the project at the very beginning of the semester instead of 5-6 weeks into the semester" (5 responses)
- Variation of project between groups: "more project types, so all presentations are not the same". (4 responses)
- Candidate materials: - "having more materials" (3 responses)
- Project execution; "perhaps streamline some of the directions and tasks of the overall project. At times, writing the memos and performing the test was tedious". (2 responses)
- Material testing: "have it set up so that a group tests all of the materials for each specific project of the airplane, instead of having groups rely on provided/other's data"

Based on the above suggestions, some modifications will be made to improve the comprehensive term project: 1) The project will be introduced earlier in the semester (e.g. fourth week). 2) A wider variety of project assignments and more candidate materials will be made available to

students to make sure that the students have more options in tasks and materials for testing. 3) Project execution direction will be improved by improving the student instructor interaction/communication. 4) Have the students test all the candidate materials that they are interested to use for their material selection for the aircraft design. 5) Students will be introduced to a writing center and will be asked to get help of this valuable resource for their technical writing.

Conclusion

This paper describes a comprehensive term project conducted in a Materials Science course. In this project, students selected and tested materials for the airframe of aircraft for the SAE Aero Design Competition. The student's results will serve as a reference for the 2017 SAE Aero Design Competition team at ONU to make decisions on their design. The students also did an oral presentation in class and a few write-ups. Based on the students' feedback on the assessment, the authors believe the project was a success. It not only trains the students in material sections, testing, property searching, but also helps students on teamwork skills and communication. This meaningful and enjoyable experience would help the students succeed in their future courses and career development. It should be mentioned that although this project was designed for low-level engineering students in Material Science course, the project could also be used for relatively high-level engineering students in the course by eliminating some specific step-by-step details, which aimed to help freshmen to get started.

Acknowledgments

The authors acknowledge the financial support of 2016-17 KEEN Pedagogy mini-grant as well as the help from Mr. Scott Cottle, the machinist at Ohio Northern University.

Bibliography

- [1] Núñez J. S., Lascano S. F., Esparragoza, I. E. A project-based learning approach for a first-year engineering course, Eleventh LACCEI Latin American and Caribbean Conference for Engineering and Technology (LACCEI'2013), Cancun Mexico, August 14 - 16, 2013.
- [2] McLoone, S.C., Lawlor, B. J., and Meehan, A. R. The Implementation and Evaluation of a Project-Oriented Problem-Based Learning Module in a First Year Engineering Program. *Journal of Problem based learning in Higher Education*, 4(1), 2016.
- [3] Anwar, S and Granlund, E. Enhancing a Freshman Level Engineering Design Course through Project Based Learning. *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition, Nashville, Tennessee, June 2003.*
- [4] Lee, J. S., Blackwell, S., Drake, J., and Moran, K. A. Taking a Leap of Faith: Redefining Teaching and Learning in Higher Education Through Project- Based Learning. *Interdisciplinary Journal of Problem-Based Learning*, 8(2), 2014.
- [5] Hadim, H. A. and Esche, S. K. Enhancing The Engineering Curriculum Through Project-Based Learning. *32nd ASEE/IEEE Frontiers in Education Conference, Boston, MA, November 6 - 9, 2002.*

- [6] Mills, J. E. and Treagust, D. F. Engineering Education – Is Problem based or Project-Based Learning the Answer? Australasian Journal Of Engineering Education, Jan 2003
http://www.aee.com.au/journal/2003/mills_treagust03.pdf
- [7] Lidón, M.M. et al. Acquisition of transversal skills through PBL: a study of the perceptions of the students and teachers in materials science courses in engineering. Multidisciplinary Journal for Education, Social and Technological Sciences, 2 (2), 2015.
- [8] 2015 SAE Aero Report, ONU 2015.
- [9] www.matweb.com
- [10] <https://www.quora.com/What-is-a-simply-supported-beam-Is-it-possible-to-make-it-by-hinging-both-ends>

Appendices

The three assignments of the project are attached in this appendix. It should be noted that there are many details on mechanics calculation in the assignments because the students are freshmen that have a limited mechanics background. Students don't have technical writing training either. Therefore, many details regarding mechanics calculation and writing requirements were given in detail. For high-level engineering students, some details may be not necessary.

Appendix 1: Material Selection Term Project Assignment 1

1. Project Background

The goal of the SAE Aero Design Competition is to “design, manufacture, and successfully fly a remote controlled aircraft capable of carrying a large payload”, while adhering to the SAE Aero Design Competition requirements including that the weight of the aircraft is no more than 55 pounds with payload and “all aircraft components must remain attached from takeoff to landing”.⁸ The design philosophy of the 2017 aircraft is to make a lightweight airframe that is easy to construct, while remaining simplistic and fulfilling the competition requirements. It is therefore very important to select the right materials for components of the airframe.

The airframe made by the 2015 SAE Aero Design Competition team at the author’s ONU is shown in Figure a1 (a1= Figure a in Appendix1). The ribs and spars are made of balsa wood and the engine mount and payload box are made of plywood. The 2017 SAE team will design the new airframe using the old design as a reference, while looking for a new material to improve the design. That is, they will verify the selection of the old design and also evaluate the possibility to use new material for the components.



Figure a1: The airframe of the 2015 aircraft for the SAE Aero Design Competition⁸

2. Project Goals

The goal for this project is to help SAE Aero Design Competition team at the authors ONU to make a decision on the material selection for the airframe components. The job of selecting the right material for an engineering component in a design can be overwhelming due to the large variety of commercially available engineering materials. Based on the understanding of the design requirements, first, the students need to identify 3 candidate materials and evaluate the cost, strength, and weight of the structure materials. Then make a decision to select a material for the component design. While the bending moment is the major load for most components of the airframe, students will use a simply supported beam (Figure b1) to simulate the loading condition for the component in the airframe. Finally, the students will test the beam to verify their material selection for the component.

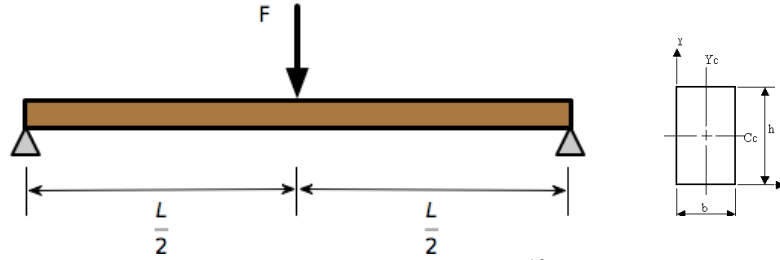


Figure b1: A simply supported beam.¹⁰

3. Theoretical Background

The maximum stress in the beam is:

$$\sigma_{\max} = \frac{3FL}{2bh^2} \quad (1)$$

where load F , span length L , and the side length of the cross-section of the beam are different for each type of components which will be given for each lab group in the next section.

The failure strength for this design is the yield strength of ductile materials or the fracture strength of brittle materials. The maximum stress σ_{\max} should be less than or equal to the failure strength divided by the safety factor (F.S.), i.e.

$$\sigma_{\max} = \frac{\sigma_y \text{ or } \sigma_f}{F.S.} \quad (2)$$

The safety factor is 2.5 for this design.

4. Analysis and Material Selection

A systematic approach based on the understanding of the design requirements and the properties of materials should be adopted to make an optimum selection for each type of components. While each group needs to select three materials for each type of components, the first two types of material each group needs to consider are balsa wood and plywood with available thicknesses of 1/8 in and 1/4 in (Table a1), unless they can't satisfy the constraints. The other materials can be a metal and/or a polymer material from the candidate listed in Table a1 (Where Table a1= table a in appendix1).

Table a1 Candidate materials for the airframe design.

Candidate Material	Thickness (in)
Balsa wood (must be considered)	1/8 or 1/4
Plywood (must be considered)	1/8 or 1/4
Aluminum 6061	1/16 or 1/8
Aluminum 1100	1/16 or 1/8
Chemical-Resistant PVC	1/8 or 1/4
Antistatic Polycarbonate	1/8 or 1/4
Easy-to-Machine Polystyrene	1/8 or 1/4

Design Constraint:

For the load condition of each type of component, a relatively small load would apply on the ribs, medium load on body spars, large load on the engine mount and payload box, and

extremely large load on the wing spars. The constraint for the material selection is that the maximum stress σ_{\max} must be less than or equal to the failure strength divided by the safety factor. The safety factor is 2.5 for this design. The dimensions for each type of components are listed in Table b1. For the failure strength, adopt yield strength for metals and tensile strength for all other materials.

Design Criteria:

The design criteria for the material selection include cost (the lower the better), strength (the higher the better), and weight (the lower the better). The load, span length, and width for each type of components and criteria with the corresponding weighting factor are listed in Table b1.

Table b1: Dimensions and material selection criteria for each type of components.

Component	Load F (lb.)	Span Length L (in)	Width b (in)	Cost (%)	Strength (%)	Weight (%)
Rib	0.25	6	1/2	10	10	80
Body Spar	1	8	1/2	10	30	60
Engine Mount	2	6	1	15	40	45
Payload Box	2	6	1	10	40	50
Wing Spar	3	8	1/2	10	60	30

5. Project Assignment - 1

In total, three tasks will be assigned for this term project. The first assignment should be a typewritten group memo on the materials section for the beam according to the design consideration. The memo should contain 3 viable materials including material thickness that was selected. All the material properties should be obtained from online material property database. Check the design constraint for the selections and then use decision matrix to determine the final selection. Finally, make conclusions.

6. Teamwork

Each student will take a leading role in turn in the whole semester and the leader will be the one in charge of the paperwork for that period. Please state contributions of group members. Estimate the amount of work (percentage of the total work) performed by each group member. Also please log meeting information.

Format of the log:

Group leader for Assignment 1:

Contributions of each group member:

Estimate the amount of work (percentage of the total work) performed by each group member:

Meeting information:

7. Memo Report Content

1. Heading:

To:

From: Your names

Date: Submission date

Title:

2. **Problem Outcome:** State the task that is assigned to your group.
3. **Analysis:** Identify the three selections of the materials. Please present the calculation about how you check your selections that satisfy the design constrain for the component. Then use a decision matrix to make the final selection.
4. **Conclusions:** Discuss your findings.
5. **Teamwork:** State who is the group leader for this assignment and state the contributions of each group member. Estimate the amount of work (percentage of the total work) performed by each group member. Log the activities of group meeting. State the reasons for any significant imbalance in the work effort.
6. **References:** In the memo report, you must include the information of the resources from where you obtain material's information. References should be provided as needed, using the format specified for a formal report.
7. **Attachments:** Any information or calculation related to the memo report.

Appendix 2: Material Selection Term Project Assignment 2 – Part I

1. Material Experiment

In Assignment 1, the calculation and material selection you made were based on the information obtained from some websites. However, the material properties are statistical in nature. That is, material properties can be affected by many factors, such as manufacturing processes, suppliers, and testing equipment. In Assignment 2 – Part I, your group will be expected to perform a self-designed experiment to measure the material properties in Table a2 (where Table a2 = Table a in appendix 2). Each group will be assigned one task.

Table a2: Candidate materials for the airframe design.

Task	Material to Be Tested	Property
1	Balsa wood	Tensile strength
2	Plywood	Tensile strength
3	Aluminum 6061	Yield strength
4	Aluminum 1100	Yield strength
5	Chemical-Resistant PVC	Tensile strength
6	Antistatic Polycarbonate	Tensile strength
7	Easy-to-Machine Polystyrene	Tensile strength
8	Balsa wood and Aluminum 1100	Density
9	Plywood and Chemical-Resistant PVC	Density
10	Antistatic Polycarbonate and Easy-to-Machine Polystyrene	Density

2. Experiment Memo (The memo must be **typed**, not hand-written.)

To:

From: Your names

Date: Submission date

Title:

Objective

A brief explanation of the task your group was assigned.

Equipment

A complete, specific list of the equipment was needed to perform the experiment.

Procedure

Detailed procedures that were accomplished.

Results

Draw a table to list the properties that you measured for at least three samples and find the average of the values.

Discussion

Discuss how your result is compared with the data from other websites.

References

Include citations as needed in the main body of the memo.

3. Teamwork

Each student will take a leading role in turn in the whole semester and the leader will be the one in charge of the paperwork for that period. Please state contributions of group members. Estimate the amount of work (percentage of the total work) performed by each group member. Also please log meeting information.

Format of the log:

Group leader for Assignment 1:

Contributions of each group member:

Estimate the amount of work (percentage of the total work) performed by each group member:

Meeting information:

Assignment 2 – Part II

For this Assignment 2 – Part II, your group will revise the material selection using the properties obtained from the experiments and based on the feedback on your memo of Assignment 1. This revised memo should follow the following format:

1. **Heading:**

To:

From: Your names

Date: Submission date

Title: Revised ...

2. **Problem Outcome:** State the task that is assigned to your group (please briefly mention the constraint and criteria).
3. **Analysis:** Identify your three candidate materials.
 - Please present the calculation on how you check your selections that satisfy the design constraint for the component.
 - List information of the candidate materials.
 - Finally, use a decision matrix to make the final selection.
4. **Conclusions:** Discuss your findings.
5. **Teamwork:** State who is the group leader for this assignment and state the contributions of each group member. Estimate the amount of work (percentage of the total work) performed by each group member. Log the activities of group meeting. State the reasons for any significant imbalance in the work effort.
6. **References:** In the memo report, you must include the information of the resources from where you obtain the material's information. References should be provided as needed, using the format specified for a formal report.
7. **Attachments:** Any information or calculation related to the memo report.

Appendix 3: Material Selection Term Project

Assignment 3 – Part I

Group Presentation (5-10 minutes)

A PowerPoint presentation is required for each group to present your results in the class at the end of the fall semester. Grading of this assignment will be based on presentation skills and PowerPoint slides. In the group presentation, you should address the following aspects of the project:

1. Project background
2. Objective
3. Theory of calculation (maximum stress calculation)
4. Constraint and criteria
5. Initial analysis and material selections
 - Candidate materials and their cost, weight, and strength based on online data
 - Decision matrix and the final selection
6. Revised material selections based on our test results
 - Candidate materials and their cost, weight, and strength from test results
 - Any change for the decision matrix and the final selection
7. (Optional - extra points) 3-point bending test results and calculation results
8. Conclusion
9. Future work
 - The current technical trends on material selections. For example, computer-aided systems for material selections could reduce cost and design rework.

The presentation evaluation rubrics are as following:

- Introduction
 - Topic/purpose clear
- Organization
 - Main points clear
 - Points thoroughly explained
 - Transitions between points
- Visual aids
 - Clear, easy to see
 - Effectively used
- Delivery
 - Eye contact
 - Posture/poise/Gesture/movement
 - Volume
 - Rate
 - Articulation/Pronunciation
 - Inflection/Variety/Enthusiasm/Energy

Assignment 3 – Part II: Bending test and a formal report

1) Bending test:

- A bending test needs to be performed in the material lab to find the failure load of the beam.

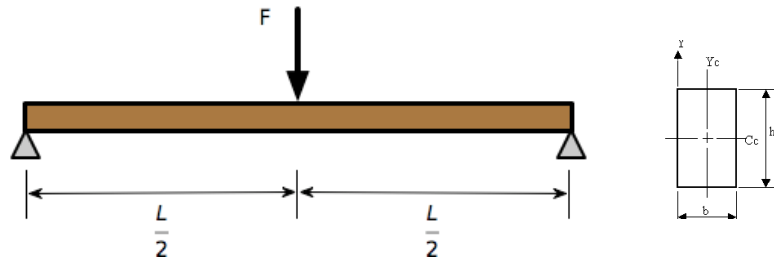


Figure a3: A simply supported beam.¹⁰

- Then compare the test result with the calculation result. The equation to calculate the failure load is:

$$F_f = \frac{2bh^2\sigma_f}{3L}$$

where b is the width and h is the thickness of the sample; L is the span length, σ_f is the failure strength; adopt yield strength for metals and tensile strength for all other materials.

2) Formal report template

Title of the Paper

First Author, Second Author, Third Author
Academic Affiliation 1, City, State, Zip Code

Abstract

The abstract is one paragraph (not an introduction) and complete in itself (no reference numbers). It should indicate subjects in the paper and state the objectives of the investigation. Then state the three candidate materials and the final selection. Readers should not have to read the paper to understand the abstract.

Introduction

This section is an opportunity to present the background and motivation behind the project, and the objective of the project. A brief summary of the project constraint, criteria, procedures and the results you obtained should also be presented here.

Mechanics Analysis

This section is to present the theory to calculate the maximum stress and the failure load of the component.

Material Selection

This section should include the three candidate materials that satisfy the constraint and the final selection. State the candidate material properties, and the final selection based on the constraint and criteria. Discuss the result of the decision matrix. Reflect the difference between the online data you used for the first time and the test results for the revised one.

Experiment result and discussion

State the result of the bending test and compare the test result with calculated failure load. Then reflect on the results.

Conclusion

This section contains the overall conclusions drawn from the analysis. The conclusions should be clear, concise, and should wrap up the project so the reader can easily determine the overall summary of the project. Any recommendations for future/follow-on work should go here.

Acknowledgments

In this section, acknowledge the assistance of all who helped with the project.

References

This is the section in which you list all sources referenced in the text. Of course, the reference number should appear in the text in the section in which it is referenced. Examples would be:

[1] *Cobalt 2.0 User's Manual*, Cobalt Solutions, LLC, Dayton, OH, 2003.

[2] Shang, J.S., and Scherr, S.J., "Navier-Stokes Solution for a Complete Re-Entry Configuration", *AIAA Journal of Aircraft*, Vol. 23, No. 12, December 1986, pp. 881-888.

Teamwork (include in the report, only for grading purpose)

Each student will take a leading role in turn in the whole semester and the leader will be the one in charge of the paperwork for that period. Please state contributions of group members. Estimate the amount of work (percentage of the total work) performed by each group member. Also please log meeting information.

The following is for information only, and should be removed from your paper!

If you want to insert tables and figures within your document, you must explain the figure and table before you insert them. The examples of a table with a table title and a figure with a figure caption are shown in Figure b3 and Table a3 (where Table a3 = Table a in appendix 3).

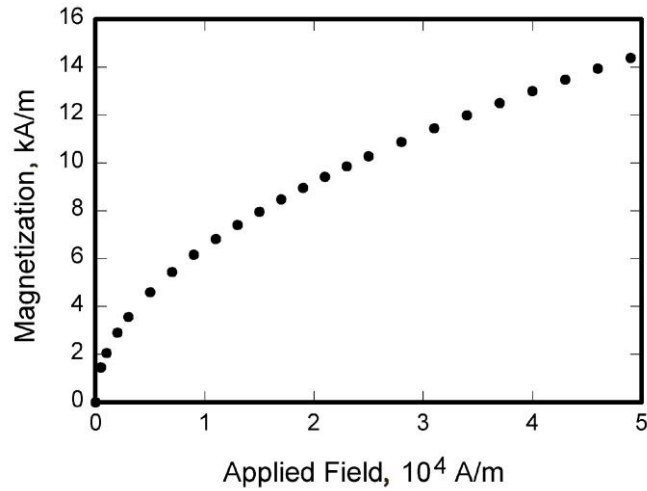


Figure b3 Magnetization as a function of applied fields.

Table a3 Transitions selected for thermometry

Line	Transition		J''	Frequency, cm^{-1}	FJ, cm^{-1}	Gv, cm^{-1}
	ν''	P_{12}				
a	0	P_{12}	2.5	44069.416	73.58	948.66
b	1	R_2	2.5	42229.348	73.41	2824.76
c	2	R_{21}	805	40562.179	71.37	4672.68
d	0	R_2	23.5	42516.527	1045.85	948.76

A sample equation (1) is shown below:

$$\sigma_{\max} = \frac{2FL}{2bh^2} \quad (1)$$

where F is load, L is the span length, ...