16.20 - STRUCTURAL MECHANICS

Course Information and Policies

Fall, 2002

Instructors: Professor Paul A. Lagace

Lectures:

There are four one-hour lectures each week. It is expected that students will be present at these lectures:

M T W F

Lectures will generally be devoted to presentation of new material. However some lecture time will be used to address questions and specifically to discuss practice questions given to allow students to put to work the material presented in the previous lecture. This will be made possible by the means of lecture presentation that will be via projection of computer charts. Student participation in class is not only encouraged but necessary to maximize the learning opportunity. Copies of the computer charts used in lecture presentation are available on the course website (see later) from where they can be downloaded and printed, if desired. Students who prefer to directly obtain paper copies should contact the Course Administrative Assistant. These will be made available for such students prior to the material being addressed in class.

Recitations

There is one weekly recitation scheduled for the entire class on Tuesday from 3 to 4. However, if we find this to be too many students in one recitation, we will work to schedule an additional section.

Recitations are meant to respond to <u>your</u> questions on the material covered in lectures, home assignments, and the exams. However, some new material, especially worked examples, will be presented in recitation.

Goals and Objectives

The primary goal of 16.20 is to give students an understanding of the essential elements necessary to analyze aerospace (and other) structures. Basics are emphasized rather than mathematical manipulation. Through Unified Engineering, the students are to have acquired the basic tools for analyzing structural problems (elasticity equations, equilibrium concepts, etc.). In 16.20, it is intended that the students be shown how to extend and apply these basic tools to typical structural problems (torsion, shell beams, columns, etc.). This includes real-life considerations for two-dimensional and three-dimensional cases. The students are to come away with a "*working familiarity*" with the various approaches and typical problems. Throughout the course, the structural problems are relatively simple and straightforward although some real-life (but watered-down) examples are given via home assignments.

A second goal of 16.20 is to extend understanding and capability that the students acquired in Unified. This is the understanding of and capability to use the fundamental skills, knowledge and sensitivities that are the traits of a successful engineer. As noted in Unified, these include the skills necessary to work successfully in a group, to self-educate, and to communicate properly questions, answers, and approaches. Professional engineers have the knowledge and confidence to make estimates of poorly known parameters, create conceptual models of systems, and design new solutions to meet technical challenges. Engineers in positions of leadership are sensitive to the interaction of technical solutions with the economic, political, social and environmental needs, and constraints of society.

The working objective throughout the course is to teach students to "ask the right questions," "challenge the assumptions," and figure out what analysis really applies in a particular situation.

Things students are expected to know when they arrive: Students need a basic statics and mechanics background as provided in Unified. This includes the ability to use and/or perform the following:

- free body diagrams
- tensor notation
- the concepts of stress and strain
- basic equations of elasticity: equilibrium, stress-strain, strain-displacement
- orthotropic constitutive relations
- transformation of stress and strain
- beam theory
- basic concepts of structural instability
- (basics of) structural failure analysis

Although many of these concepts will be reviewed and built upon, students should review the material from Unified early in this term and again when particular material is presented in 16.20 (see the handout on “Topics Covered: Materials & Structures Section of Unified” as well as the summary items handed out each term in Unified.)

For the benefit of the students, there will also be an Assessment Exercise and a recitation devoted to this. This will be in the form of a number of "PRS questions" from Unified Engineering as provided by the teacher of the M&S Section of Unified. There are three major objectives to this exercise. The first is to provide each student with a tool to assess their capability in the material from Unified Engineering that is built upon in 16.20. Students can review and work with the teaching staff as necessary to help fill any gaps. A second is to allow the staff of 16.20 to understand the overall background of the 16.20 Learning Community to better orient the lectures with regard to the material that is assumed as previously learned. The third is to provide feedback to the Professor as to the retention of material from the M&S portion of Unified. Individual student results will not be compiled or recorded in any way with only the responses across the class on each quest--ion used by the 16.20 staff.

(Additional) things students are expected to know when they leave:

- design considerations for aerospace structures
- anisotropic constitutive relations and engineering constants
- environmental stresses and strains
- alternate coordinate systems
- stress potentials

- torsion theory
- analysis of general shell beams
- how to perform failure analysis
- structural instability
- beam-column
- structural dynamics

The specific **learning objectives** are that students graduating from 16.20 will be able to:

- **use** the one-dimensional and two-dimensional structural idealizations of beams, columns, rods, and shell beams to **determine** stress and deformation states.
- **apply** such structural idealizations to **model** general structural configurations under specified loading in order to **determine** the stress and deformation states.
- **assess** the applicability of such structural idealizations and **judge** the errors introduced in their use.

The specific **measurable outcomes** are that students graduating from 16.20 will be able to:

- **explain** the basic considerations of structural design.
- **explain** the basic assumptions underlying the idealizations of: general elasticity, torsion theory, general beam theory, shell beams, beam-columns, dynamic lumped-mass systems.
- **apply** a basic physical intuition for the function and sizing of structural elements as noted in the previous item.
- **calculate** the stress and strain state at simple structural details, such as holes and fillet radii, using stress function solutions and standard handbooks.
- **calculate** the stress and strain distributions and deformation of arbitrary structural idealizations (such as those previously listed).
- **design/specify** a structural configuration using basic structural elements (as previously listed) in order to meet specified loading and deformation criteria.
- **assess** the applicability of the structural idealizations (as previously listed) for specific applications.

Thoughts on teaching and learning

The teaching staff of 16.20 is committed to helping you learn. However, we cannot, by ourselves, make this happen. Learning is a partnership -- a partnership amongst the teachers and the learners. A teacher can only “provide” the material, the explanation, the context, and other associated items. It is the learner (i.e. the student) who “receives” and must work to receive and to understand how they best receive and learn. Working with the teacher(s) to align the “providing” and “receiving” is the key in maximizing learning. A great teacher cannot cause learning without contribution from the learner. We need your help!

Furthermore, this partnership goes a step beyond the teacher(s) and the individual student. There are numerous students in this course and together we all form the “16.20 Learning Community.” We can all help each other and be helped by each other so that the entire community learns and all members of the community learn. We therefore encourage Study Groups and students working with each other (see later). It is the objective of this teaching staff to maximize the learning of each individual in 16.20. We hope you join us in that objective.

Office Hours and Assistance

Prof. Lagace will *generally* be available after lecture from 11-11:30. For other times, please make an appointment. It is easiest to contact Prof. Lagace and to make such appointments via email.

There is a Q&A section on the 16.20 website where students can post questions for answering by the teaching staff. It is the intent of the teaching staff to answer posted questions within 24 hours except in the case of holidays and unforeseen circumstances. Details as to the operation of this are still being worked out and will be noted in an announcement.

A course T.A. is not available for this course since the Department did not allocate resources to provide for such. This limits the capability to provide support for students. This may include timely grading, with needed feedback, of home assignments; available help for current work and questions; answering questions posted on the website Q&A section in a timely manner; and generally timely upkeep of the website. The instructors apologize for any difficulties this may cause students and will do their best to address such, but are limited in their capability in this regard when sufficient resources are not allocated for the course.

Syllabus/Schedule

The specific syllabus for the course is another handout. The same is true for a day-by-day schedule. Note that these are the *planned* schedule and the *planned syllabus. Updates will be made on the* syllabus.

We will cover six major topics in 16.20: 1. (Review of) Design Considerations; 2. General Elasticity; 3. Torsion; 4. General (Shell) Beams; 5. Stability; and 6. Structural Dynamics. As noted earlier, we will rely on the material taught in Unified. Your Unified notes are thus very valuable. Please see the earlier section on "Goals and Objectives" to see the exact knowledge you should have from Unified as applicable to this course and reference to handouts.

The two term-time exams will be held after Lecture 21 and Lecture 35 respectively. These two exams will be nighttime exams beginning at 7:30 and scheduled to last one hour. However, students will have until 9:30 to complete the exam. The final exam will be during the final exam period as scheduled by the Registrar. There will be no formal class on the days of the exams.

Unit/Lecture Notes

The material covered in class does not correspond to any one available text book. It is therefore particularly likely that you will find that the most important and valuable reference you will have for this class is your CLASS NOTES. To aid you in this regard, all equations, derivations, worked examples, key statements and conclusions, and the general outline for such are captured on unit/lecture notes. These will be made available for such students prior to the material being addressed in class.

It is essential to understand that these printed notes **cannot** in any way capture the opportunity to learn that occurs when a student participates in a class (see earlier section on "Thoughts on teaching and learning"). Such notes do not even capture the opportunity to self-learn that one has when one works with a book since a book has substantially greater explanatory text. These unit/lecture notes are provided in an attempt to allow students to spend more time in the class learning and less time copying material from the blackboard or screen. It also allows the teacher to spend more time teaching, rather than transcribing notes. It does, however, very much require each student to use the notes in a manner that fits the way in which **that individual student best learns**. Think about this and try to maximize this learning opportunity.

(DEAR STUDENTS:

It is important to say that this mode of teaching continues to be an experiment for us. We had great success using this mode in 16.20 last year. We strongly believe that together we can build on this success and improve our learning via this mode. However, we need your help to tell us how you can and do make best use of it. We are the teachers and can provide, but we need to hear from you the learner to understand and know how you receive. Only by working together will we be able to adapt our providing to best align with your receiving and thereby maximize our learning.

-Thank you,
Paul Lagace & Raul Radovitzky)

Textbooks

Although it is possible to follow the course by using the extensive class notes and any additional notes taken by students, it is suggested that students learn to refer to alternate sources. In many cases, a different presentation may spark or enhance understanding. Thus, the following list of books is provided to serve this purpose. Specific readings from some of these books are recommended for the units taught in this course and are noted in the syllabus and unit notes. Furthermore, these books serve as more permanent and referencable material than class notes:

1. Theory and Analysis of Flight Structures, Rivello, McGraw-Hill, 1969.
2. Theory of Elasticity, Timoshenko and Goodier, McGraw-Hill, 1970.

3. Aircraft Structures for Engineering Students, Megson, Halsted Press, 1990.
4. Statics of Deformable Solids, Bisplinghoff, Mar and Pian, Addison-Wesley, 1965. (also: Dover, 1990)
5. An Introduction to Aerospace Structural Analysis, Haisler, Wiley, 1985.
6. Aircraft Structures, Perry, McGraw-Hill, 1950.
7. Mechanics of Composite Materials, Jones, McGraw-Hill, (also: Hemisphere, 1988).
8. Understanding Aircraft Structures, Cutler, Granada, 1981.
9. Theory of Elastic Stability, Timoshenko (and Gere), McGraw-Hill, 1961.
10. Mechanics of Materials, (4th Edition) Gere (and Timoshenko), PWS, 1997.
11. Elements of Vibration Analysis, (2nd Edition), Meirovitch, McGraw-Hill, 1986.

The first text (Rivello) has been a primary text but is now unfortunately out of publication. Copies of it will be on reserve in the Aero/Astro library. The second text (Timoshenko and Goodier) is a (the?) classic text on elasticity with lots of examples. A few copies may be available if people are interested. The third text is a relatively new text which helps to reinforce many of the ideas taught in 16.20 and is now a primary text. Copies of such can be purchased and a group purchase can be arranged if there is sufficient interest. The other eight texts (4-11) are good background references and reading assignments will be given in these (as background) from time to time. Text 11 is particularly pertinent as general background for Section VI on "Structural Dynamics." All texts are also on reserve in the Aero/Astro Library. In addition, Barker has an extensive set of references on structural mechanics including these texts. You are encouraged to seek out additional reading material to supplement lectures and reading assignments from the primary texts. In addition, the two books from the Materials & Structures section of Unified are good sources for information, particularly in reviewing material learnt in Unified.

Please note that most of the texts (except for No. 7) deal almost exclusively with isotropic materials. With the widespread use of composites and the use of metals and special metal alloys with directionality, we no longer deal exclusively with isotropic materials.

Handouts

There will be occasional handouts in lectures including outlines/summaries of each of the major topics covered in 16.20. It is expected that regular attendance in lecture will offer the opportunity to pick up these handouts. All handouts will be posted on the website on the day that the handout is distributed in class. Students who miss handouts may obtain these handouts from the Administrative Assistant of the course for one week after the date of the handout. At that point, extra copies will be discarded.

Home Assignments

There will be four types of home assignments given in this course. Three of these will be given on a weekly basis, generally Wednesdays, and the parts that are to be submitted generally will be due one week later. There will be four design problems distributed throughout the term. Due dates for these will be clearly indicated and provide sufficient time to address the complexity of the problem.

As noted, the **weekly home assignments** will be of three types. Together they give the student the opportunity to further their learning by applying the concepts and methods presented in the unit/lecture material and as found in the textbooks.

The first type is referred to as *warm-up exercises*. These require direct use of equations and methodologies in very simply posed problems. One can think of these as the stretching and warming up that one would do prior to engaging in a physical sporting event. Solutions to these will be posted on the 16.20 website shortly after the assignment is handed out. Students are encouraged to work on these individually. Students can do the work and check their results, study the results together with doing the work, ask questions of the teaching staff and in recitation, or use whatever technique they find maximizes their learning. **These are not to be handed in**.

The second type is referred to as *practice problems*. These require applications of the concepts and methodologies, mainly from the past week of lecture material, but also building on previous items. The problems will have limited complexity requiring students to utilize more than one concept and methodology in their solution. However, the needed concepts and methodologies generally will be apparent. One can think of these as the practice plays one would run in a team sport either in practices or before engagement in a game. Solutions to these will be posted one week after they are handed out (on the due date for that weekly set). Students are encouraged to work with others in study groups in solving these problems and understanding the key concepts and methodologies involved. Questions to the teaching staff and in recitation are encouraged as some of these problems may be worked there. Students will be able to check their solutions via the posting on the website. **These are not to be handed in**.

The third type is referred to as *application tasks*. These require judgement of the concepts and methodologies to be used. These will focus on the material from the past week of lectures, but will also require the use of and coupling with material previously addressed in order to solve these more complex problems. These can be thought of as applications of the material of the past week in the context of general problems in the area of Structural Mechanics including the “Materials and Structures” as presented in Unified. Judgement will be required for a number of reasons including that the problems may be “imperfectly posed.” Students are encouraged to work with others in study groups in determining and understanding the key concepts and methodologies involved and as to how these work together in an overall approach to a solution. Questions can be asked and approaches discussed with the teaching staff. However, each student is to submit an individual solution to the problem that represents their expression of their understanding of that solution. (see section on “Academic Honesty”). **These are to be handed in by the noted due date**. Solutions to these will be posted on the website after the due date.

The fourth type of home assignment is **design problems**. There will be four of these. *Tentative* handout dates and due dates are on the schedule. These are intended to be realistic exercises similar to those encountered by a junior engineer in the area of structural mechanics. These will be slightly “watered-down” to account for the realities of the academic environment. These problems will be realistically posed and will ask you to provide preliminary designs, or judgements thereof, of realistic structures. You will also be asked to present solutions in realistic means such as with written reports or cover executive summaries supported by the actual work in appendices (specifics will be requested in each case). The problems will require judgement, use of multiple concepts and methodologies and an overall *systems thinking* to arrive at a solution. Such problems do not have one single solution and it is the judgements, the skillful use of methodologies, and the communication thereof that is important and will be considered in grading. These problems will be **team problems and are to be handed in by the noted due date**. Only one solution is required per team. Teams are to be of three students. Teams will be formed in cooperation with students during the first week of the term. The teaching staff approach to these problems will be posted on the website after the due date.

All solutions will remain posted throughout the term.

A Note on Submission of Work

The manner in which you present your work can be just as important (and in some cases more so) than the final answer. Be sure to delineate each step along the way. Show a clear and logical approach to your solution. That makes your problem sets a better reference to you and easier for us to give you partial credit (if so deserving). That is also the way a good engineer works (by properly communicating), so it is an excellent habit to acquire. Remember, in this course the solution is an essay, not a number.

"Pop Quizzes"

There will be occasional "pop quizzes" held in classes. These will take on the order of five minutes and allow both the student and the teaching staff to quickly check understanding of fundamental principles soon after they are taught. The answers to these pop quizzes will be discussed immediately following the pop quiz. Generally, these pop quizzes will be based on items presented over the past few lectures or potentially related to a practice problem as recently given.

Assessment of student performance on pop quizzes will be used to better understand a student's overall understanding of and capability to use the course material and is thus most likely to improve a student's grade (i.e. "extra credit").

Exams

Two term-time exams will be given. These two exams will be nighttime exams beginning at 7:30 and scheduled to last one hour. However, students will have until 9:30 to complete the exams. In addition, a final exam scheduled to last three hours will be given during finals week.

Exams will be "open notes." This includes anything you produced by hand or otherwise, including "summary sheets," and any material produced by the teaching staff of the course including handouts and the material available on the 16.20 website. It does not include notes produced by other students, "bibles" from previous years, or material from other faculty. The exams are also "closed book" implying no printed material either as available in paper or via the web.

Students who use a laptop computer as their "notebook" are allowed to use the laptop during exams for retrieval of information **only**. Students will be trusted to comply with such. Any violations of such will be treated accordingly. Calculators, including programmable calculators, are allowed for performing calculations. The same can be done with laptop computers. In these cases, it is up to the student to not program any material into the programmable machine prior to the exam. The integrity of each student with regard to academic honesty is key here (see section in that regard). Exams will be written such that calculating power beyond simple calculators will not be necessary. Furthermore, as noted in the section on "Submission of Work", although it is important as an engineer to properly conduct numerical work, it is the description of such (the essay) that is key in assessing the student's knowledge of the material. It is important to note that the setting of an exam, with time constraints and other items, is artificial and one that is seldom encountered in the work life of an engineer, but is necessary in the assessment process in a course for both teachers and students.

Solutions to the exams will be posted generally on the day after the exam. The staff will work to return the graded exams during the following recitation where they will be discussed.

Late Policy and Exam Attendance/Absences

Late submission of home assignments is not allowed. Exceptions may be granted at the discretion of the course staff if advance notice is given or if emergencies occur. Weekly home assignments will generally be given out on Wednesdays and due one week later. There will be no such assignment the week of exams. There will also be four design problems during the term. The *tentative* days that these will be given out and the respective due dates can be found in the schedule. There is sufficient time in all cases, particularly the design problems, for students to seek help as needed prior to the night before the due date and to proportion their time such that "night before" intensive work is not necessary. Thus, extensions are not allowed. It is left to the judgement of students as to how to best proportion and use their time.

Students are expected to take the exams at the scheduled times. Exams take precedence over other items such as medical appointments, travel plans, and personal activities. Missed exams will receive a grade of F unless excused by Prof. Lagace ***prior*** to the exam. As a general guideline, excuses will be granted only for a verifiable illness. Other *unavoidable* situations should be discussed with Prof. Lagace as far in advance of the scheduled date as possible. Special cases involving emergency situations are exempt from these rules and will be handled on an individual basis. Contact should be made with Prof. Lagace in such situations by any means as soon as possible (e.g. note, phone/voicemail, email).

Grading

The final grade will be calculated approximately as follows:

Home Assignments	40%
Exams (including final exam) (NOTE: final exam has 1.5 relative value versus term-time exams)	60%
	100%
"pop quizzes" (extra credit)	(up to) +10%
General evaluation	±5%

The letter grades are based on absolute performance and are not subject to a curve. Subjective exceptions to strict grading may be made in cases close to grade division lines. Since the answers to engineering questions are actually essays, all problems (except pop quizzes) will be graded on a letter basis according to the MIT definition of grades:

A - Exceptionally good performance, demonstrating a *superior* understanding of the subject matter, a foundation of extensive knowledge and a skillful use of concepts and/or materials.

B - Good performance, demonstrating capacity to use the appropriate concepts, a *good* understanding of the subject matter, and an ability to handle the problems and materials encountered in the subject.

C - Adequate performance, demonstrating an *adequate* understanding of the subject matter, an ability to handle relatively simple problems, and adequate preparation for moving on to more advanced work in the field.

D - Minimally acceptable performance, demonstrating at least *partial familiarity* with the subject matter and some capacity to deal with relatively simple problems, but also