Purdue University-West Lafayette  
Aeronautics and Astronautics  
AAE 558: Finite element Methods in Aerospace Structures  
Fall Semester 2018

Time: 01:30 PM -02:20 PM Monday, Wednesday, and Friday  
Location: Seng-Liang Wang Hall 2555

Instructor:  
Vikas Tomar  
3205 ARMS  
Phone: 4-3423 (765-494-3423 for offcampus)  
E-mail: tomarATpurdue.edu (replace AT with @)

Office Hours Begin:  
Friday, August 31 (there is no TA)

Office location for office hours:  
Formal: Fridays 3-4 pm arms 3119 and 4-5 pm arms 3205 (my office)  
Casual: Individual appointment with instructor  
using email OR cell: 317-294-3251 (if I don’t respond, leave me a message stating time when I should call back with number. This has worked very well with distance education students in past).

All E-Mail Attachments must be in PDF format.  
Try to Keep Emails short and to the point. If you need to say or explain something in extreme details then use attachments.

USE PIAZZA for Homework and Exam (one in-class and one take home mid term exam; one final project)

EMERGENCY  
Public announcement from Purdue  
(Please enroll at: http://www.purdue.edu/emergency/)  
PLEASE NOTE THAT Purdue’s home page (www.purdue.edu) is the official source of emergency information.

Pre-requisite/Needed Qualifications: THE COURSE NEEDS HEAVY EXPERIENCE IN MATRIX ALGEBRA AND MATLAB PROGRAMMING. FIRST FEW ASSIGNMENTS REQUIRE HEAVY MATLAB PROGRAMMING

Co-requisite: None

Required text: A First Course in Finite Elements [Paperback] [ Jacob Fish (Author), Ted Belytschko (Author) Wiley; 978-0470035801. (PLEASE NOTE THAT THERE IS ONLY ONE EDITION. However, PLEASE BUY THE LATEST PRINT SINCE THE OLD PRINT HAS A LOT OF TYPOS (especially important if you are using a second hand version). LATEST PRINT WAS DONE IN JANUARY 2012. IF YOU ARE CONFUSED THEN JUST GET THE LATEST NEW VERSION SOLD AT AMAZON.COM)

Necessary Background:

(1) Mechanics of Materials and Structural Analysis  
Review Websites:  
Undergraduate Mechanics  
http://web.mst.edu/~mecmovie/  
Graduate Mechanics  
http://solidmechanics.org/

(2) Linear Algebra:  
Review Website  
http://www.sosmath.com/matrix/matrix.html
MATLAB Tutorial


Goals:
The goal of AAE 558 is to introduce the theory behind finite element calculations of stress, strain, and deformation in structures and materials and describe the role of a commercial finite element package in structural analysis and design. Please note that it’s a 5-level course (senior elective and graduate introductory).

Objectives AND Envisioned Outcomes:
1. Understand the relationship between the finite element shape functions and constitutive behavior and element stiffness matrices
2. Develop the weak form of the equations of mechanics
3. Relate mesh and loading to the assembled stiffness matrix
4. Provide criteria for engineering judgment required to assess the appropriateness of the choice of a finite element model for a particular structure
5. Provide training to understand the equations guiding black-box software such as ABAQUS.

Topics:
1. Introduction—Background and Applications of Finite Elements (Chapter 1-Text Book)
2. Direct Approach for Discrete Systems-One Dimensional Problems (Chapter 2)
3. Direct Approach for Discrete Systems-Two Dimensional and Three Dimensional Problems (Chapter 2)
4. Formulation: Strong and Weak Forms in one dimensional problems (Chapter 3-Text Book)
5. Approximation of Trial Solutions, Weight Functions and Gauss Quadrature (Chapter 4-Text Book)
6. Introduction to ABAQUS (Chapter 11-Text Book)
7. Finite Element Formulation for One-Dimensional Problems and Error Analyses (Chapter 5-Text Book)
8. Finite element formulation for beams (Chapter 10-Text Book)
9. Multi-dimensional scalar field problems (Chapters 6, 7-Text Book)
10. Multi-dimensional vector field problems (Chapter 8, 9-Text Book)
11. Plate and shell bending problems (Class lecture-no textbook coverage)
12. Dynamics using the finite element method (If time permits, class lecture-no text book coverage)
13. Special Topics: Fracture, Bending (plates and shells), dynamics, non-linear material models (If time permits: class lecture-no text book coverage)

ADDITIONS, AMENDMENTS, OR CORRECTIONS TO THIS SYLLABUS MAY BE MADE THROUGHOUT THE SEMESTER VIA IN CLASS ANNOUNCEMENTS, HANDOUTS, OR E-MAIL.

Assessment:
Your performance in this course will be measured by homework assignments, exams, and a Final Project. Each student will complete a final project.

Grading:
- Homework 24%
- exam-1 (in-class) 25%
exam-2 (take-home) 25%
exam-3 (in the form of final class project) 25%
Class Survey 1% (please email me your email proof of having performed this survey in order to get this credit)

Grades scale. I will be aiming for a distribution that looks like this:

100-90 A
80-89 B
65-79 C
50-64 D
49-0 F

The above scale may be adjusted down but not up. For example, 95 is a guaranteed A while 89 may possibly be an A depending upon the curve of grading.

Homeworks:
Your homeworks will be graded and solutions will be posted on the Blackboard website (http://mycourses.purdue.edu).

Homeworks will be returned in class for in-class students and will be scanned and posted on Blackboard for off-campus students.

On-Campus Students: The home work submission deadline time is 1:30 PM before the lecture on the day homework is due for in-class

Distance Students: 11:59 PM the day it is due through email to me.

The schedule for grading and posting homework solutions is given at the end of this handout. ALL SUBMISSIONS MUST BE IN PDF FORMAT.

Late homeworks will not be accepted and zero grades will be given. Depending upon the personal grievance/problem individual exception may be given depending upon the gravity of situation (contact instructor at least one lecture in advance).

Final Exam:
FINAL EXAM IS IN THE FORM OF A PROJECT. THE GUIDELINE FOR PROJECT REPORT EVALUATION IS GIVEN IN THE END OF THIS HANDOUT.

CHOICE OF FINAL PROJECT REPORT DUE, Monday, NOVEMBER, 12: (by the end of day for every students using email to me)-NOT GRADED
✓ You can just scribble on a page. But draw a picture, explain boundary conditions, and explain what is the outcome you are expecting.

FINAL PROJECT REPORT DUE MONDAY, DECEMBER 10 BY EMAIL in PDF FORMAT BY THE END OF DAY (11:59 PM)

PLEASE SEE BLACKBOARD CLASS FOLDER FOR MODEL REPORTS
FORMAT FOR FINAL EXAM PROJECT REPORT:

- Turn in a 10 page maximum excluding the title page and table of contents.
- The 10 page limit also excludes appendix.
- Please submit in acrobat pdf format. No other format is acceptable.
- Please put extraneous information such as codes, long data tables, and data execution etc. in appendix.
- At most 4 figures are allowed in 10 pages (extra plots in appendix ok. At most 2 parts in each figure).
- At the end of this handout more details regarding the report grading are provided.

The report should have:

1. Cover page with title, student name (not counted in the 10 page limit)
2. Table of contents page (not counted in the 10 page limit)
3. An abstract page
4. Objective or introduction: Describe briefly what the reader will see in your report.
5. Setup or procedure: Describe briefly how you create your FEM model.
6. Describe the model. The number elements, type of elements, material properties, type of structural member approximation (such as a tapered cross-section being approximated by uniform cross-sections), section properties, boundary conditions, and the load values (you may create table to present data, take screen snapshots from software..its upto you.)
7. Results and Discussions: Use Figure numbers, Table numbers, and equation numbers in your report to discuss your results. Discuss all the checks (MANDATORY) such as a convergence check made to ensure your results are fine (all research papers on using FEM are outright rejected without convergence checks). Bring relevant observation to the attention of the reader rather that expecting the reader to wade through the information in your report.
8. Conclusion: Brief synopsis of what you have one in previous steps with most focus on your findings.
9. Appendix: (Can be handwritten) Information needed: mechanics of materials equations, formulae, calculations, values of variables in your computations, assumption etc. (not counted in 10 page limit)

Students attending this class have a fair experience in writing the report. However, for uniformity, the following layout must be followed in report outline. Suggested format is US-Letter sized page with 1” margin on all side, Times New Roman 12 sized font with single spacing.

IMPORTANT INFORMATION REGARDING EXAM AND CHOICE OF PROBLEMS:

The apparent difficulty of the task that you undertake is of course strongly dependent on your choice of problem. The amount of credit given will depend upon the problem difficulty, but the grade will also strongly depend on you convincing me that your analysis is proper. Thus the supporting documentation might include a convergence study and perhaps some simpler related problems in which you have compared the finite element solution to solutions available in the literature or to a solution derived analytically. Else, you might choose a problem that has been solved previously and compare your FEM solution to the previous solution. Convince me that you have verified your solution. (Validation needs experiments and therefore not covered in this class).

Software:

You can use any software of your choice, but class presentations and training documents will focus on ABAQUS. I encourage using ABAQUS. Student version of ABAQUS is available with book. We will also work on MATLAB software available with book on companion site. In that case they can use any of
the available free FEM software. An example of software available is at:
http://www.freebyte.com/cad/fea.htm

The School of Aeronautics and Astronautics has agreed to provide access to Abaqus on-campus. I’ll
give those details separately when I provide training.

Policies:

The University Regulations Handbook reads: "Students are expected to be present for every meeting
of the classes in which they are enrolled." Regular attendance will not be taken, but if you must miss
a class, you are responsible for the lecture material, assignments and / or announcements made.

Late homework will generally not be accepted except in the case of illness or serious emergency.
Contact the instructor before the due date (if possible) to arrange an acceptable due date.

Illnesses and emergencies should be documented with an appropriate authority (such as a doctor etc.)

Grading corrections:

Any disputes over grading should be brought to the instructor.


- Syllabus statement. “Academic integrity is one of the highest values that Purdue University holds.
Individuals are encouraged to alert university officials to potential breaches of this value by either
emailing integrity@purdue.edu or by calling 765-494-8778. While information may be submitted
anonymously, the more information that is submitted provides the greatest opportunity for the
university to investigate the concern.”

- Purdue Honors Pledge. “As a boilermaker pursuing academic excellence, I pledge to be honest and
true in all that I do. Accountable together - we are Purdue.”

- Commercial Websites.
  - In general, notes are “considered to be ‘derivative works’ of the instructor's presentations and
    materials, and they are thus subject to the instructor's copyright in such presentations and
    materials.” As such, they cannot be sold or bartered without your express written
    permission. See the policy with regard to commercial note taking in classes that you may
    wish to include in your syllabus (see part J of the Purdue student misc. conduct regulations).
  - Course materials may NOT BE posted anywhere due to copyright issues.

Diversity & Inclusion

- Purdue University is committed to maintaining a community which recognizes and values the inherent
worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect
among its members; and encourages each individual to strive to reach his or her own potential. In
pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The
University believes that diversity among its many members strengthens the institution, stimulates
creativity, promotes the exchange of ideas, and enriches campus life. Purdue’s nondiscrimination
policy can be found at: http://www.purdue.edu/purdue/ea_eou_statement.html.

- When interacting with colleagues (on campus or off-campus), please conduct yourself in a
  professional, respectful manner
• Please help to ensure that we have a positive working environment
• We want to have fun, but not at the expense of others
• No jokes or comments that are insensitive with regards to gender, race, religion, sexual orientation, etc.
• No wall art or white board graffiti that may be considered insensitive
• No social media posting that portrays anyone associated with AAE in a less than positive manner

Mental Health Syllabus Statement

CAPS Information: Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at (765)494-6995 and http://www.purdue.edu/caps/ during and after hours, on weekends and holidays, or through its counselors physically located in the Purdue University Student Health Center (PUSH) during business hours.

Students with Disabilities

• The Disability Resource Center (DRC) is a resource for students and instructors. Students may present a “Letter of Accommodation” to you at any point in the semester. Should you have questions about accommodations, please contact the DRC at: 494-1247 or drc@purdue.edu. In many cases the DRC can partner with you to develop inclusive teaching strategies that benefit all students in your class.

• Accessibility and Accommodations Syllabus Statement: Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let me know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at: drc@purdue.edu or by phone: 765-494-1247.” http://www.purdue.edu/drc/faculty/syllabus.html

Emergency Procedures

• Emergency notification is vital!
  o Keep your cell phone on to receive a Purdue ALERT text message. (in this case our common text system)
  o Log into a Purdue computer connected to the network…will receive any Desktop Popup Alerts.
  o If you have a “no cell phone” in class policy allow one or two students who have signed up for Purdue ALERT to keep their phones on to receive any alerts.
EMERGENCY PREPAREDNESS – A MESSAGE FROM PURDUE

To report an emergency, call 911. To obtain updates regarding an ongoing emergency, sign up for Purdue Alert text messages, view www.purdue.edu/ea.

There are nearly 300 Emergency Telephones outdoors across campus and in parking garages that connect directly to the PUPD. If you feel threatened or need help, push the button and you will be connected immediately.

If we hear a fire alarm during class we will immediately suspend class, evacuate the building, and proceed outdoors. Do not use the elevator.

If we are notified during class of a Shelter in Place requirement for a tornado warning, we will suspend class and shelter in [the basement].

If we are notified during class of a Shelter in Place requirement for a hazardous materials release, or a civil disturbance, including a shooting or other use of weapons, we will suspend class and shelter in the classroom, shutting the door and turning off the lights.


Wang Hall Emergency Procedures

A comprehensive listing of all Armstrong Hall emergency procedures and other information is available in the Building Emergency Plan (BEP). Click the link below to access the ARMS BEP.

- WANG Building Emergency Plan (Draft Version)

The two most common emergency situations encountered at Purdue at fire alarms and severe weather alerts. The evacuation/shelter-in-place locations for these two types of emergencies are below (as described in the BEP):

**Fire Alarm:** The evacuation location for the ENE spaces in WANG is the grassy area to the north of the rear parking lot (shown in the photo below). Use the nearest stairwell to exit the building. Do not use the elevator.
Severe Weather Shelter-In-Place: The severe weather shelter-in-place location for WANG is any space on the first floor that is away from windows and other glass. Ideally, the first floor stairwell, restrooms, and janitor area are to be used. An alternate shelter-in-place location is the tunnel underneath the Northwestern Parking Garage. This location should only be used if it is safe to briefly travel outdoors.

An ENE emergency response plan for WANG will be developed in the coming months.
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<thead>
<tr>
<th>DATE</th>
<th>TOPIC</th>
</tr>
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<tbody>
<tr>
<td>8/20</td>
<td>Introduction-Background And Applications of FEM</td>
</tr>
<tr>
<td>8/22, 8/24, 8/27, 8/29, 8/31, 9/5, 9/7, 9/10</td>
<td>Direct Approach for Discrete Systems</td>
</tr>
<tr>
<td>9/10</td>
<td>Homework 1 is due</td>
</tr>
<tr>
<td>09/12, 9/14, 9/17, 9/19, 9/21, 9/24</td>
<td>Approximation of Trial Solutions, Weight Functions and Gauss Quadrature, Finite Element Formulation for One Dimensional Problems</td>
</tr>
<tr>
<td>9/24</td>
<td>Homework 2 is due</td>
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<tr>
<td>EXAM 1 ON October 10</td>
<td>IN CLASS (SEPARATE ARRANGEMENT FOR DISTANCE STUDENTS)</td>
</tr>
<tr>
<td>9/26, 9/28; 10/01, 10/03, 10/05, 10/12, 10/15</td>
<td>Finite Element Formulation for Beams, Formulation: Strong and Weak Forms in 1-D</td>
</tr>
<tr>
<td>10/22</td>
<td>Homework 3 is due</td>
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<tr>
<td>EXAM 2 ON OCTOBER 29</td>
<td>NOVEMBER 05 Take Home</td>
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<tr>
<td>10/17, 10/19, 10/22, 10/24, 10/26, 10/29, 10/31, 11/2</td>
<td>ABAQUS Training-Part 1, Strong and Weak Forms in Multidimensional Problems</td>
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<td>11/5, 11/7</td>
<td>ABAQUS training</td>
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<tr>
<td>11/9, 11/12, 11/14, 11/16</td>
<td>Finite Element Formulation for Multidimensional Scalar Field Problems Including Linear Elasticity</td>
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<tr>
<td>11/12</td>
<td>Preliminary report is due (see discussion in syllabus) by email PDF</td>
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<tr>
<td>11/19</td>
<td>Homework 4 is Due</td>
</tr>
<tr>
<td>11/19, 11/26, 11/28</td>
<td>Error Estimation Convergence</td>
</tr>
<tr>
<td>12/10</td>
<td>FINAL PROJECT REPORT IS DUE (see discussion in syllabus)</td>
</tr>
<tr>
<td>11/30, 12/03, 12/05, 12/07</td>
<td>Three Dimensional Finite Element Analyses, Beam and plate bending problems, Modeling Considerations and Software Use, Special situations such as fracture mechanics</td>
</tr>
<tr>
<td>ABAQUS Guest Lecture</td>
<td>12/07</td>
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</tbody>
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**Holidays**: September 04 (Labor Day), October 09-10 (Fall Break), November 22-24 (Thanksgiving)

**Note**: Dates FOR EXAMS, HOMEWORK DUES, AND REPORTS can be changed by in-class announcements
REPORT WRITING GUIDELINES

GENERAL COMMENTS
• FOLLOW THE REPORT WRITING GUIDELINES WHICH ARE IN THE SYLLABUS

IMPORTANT ITEMS TO BE INCLUDED IN EXAMS:
• FORM FE EQUATIONS AND SOLVE
• EXPERIMENT WITH DIFFERENT NUMBER OF ELEMENTS TO MAKE SURE SOLUTION IS CORRECT (CONVERGENCE STUDY)
• COMPARE WITH ANALYTICAL SOLUTION
• ASSESS ERROR (DIFFERENCE BETWEEN FE SOLUTION WITH DIFFERENT SUBDIVISIONS VS. ANALYTICAL SOLUTION)

POINT DIVISION DURING REPORT GRADING (OUT OF 100)

FORMATING HAS 10 POINTS DIVIDED AS:
IS NUMBER OF PAGE GUIDELINES FOLLOWED PROPERLY: 3 POINTS
AT MOST 5 PLOTS WITH PROPER ILLUSTRATION: 3 POINTS
ARE ALL REQUIRED REPORT SECTIONS PRESENT: 4 POINTS

TECHNICAL CONTENT CARRIES 90 POINTS DIVIDED AS:
1. FE MODEL: 20 POINTS
   1.A. IS PROBLEM MATHEMATICALLY AND FIGUATIVELY SPECIFIED WITH BOUNDARY CONDITIONS PROPERLY? AND ELEMENT PLACEMENT DESCRIBED (10 POINTS)
   1.B. IS PROBLEM OBJECTIVE SPECIFIED MATHEMATICALLY IN A WAY AS DISCUSED IN CLASS (5 POINTS)
   1.C. ARE LIMITATIONS OF SOLVING THE PROBLEM WITH GIVEN ELEMENT SIZE AND TYPE DISCUSSED (5 POINTS)
2. RESULTS: (15 POINTS)
   2.A DO RESULTS SUPPLY QUANTITATIVE DATA TO SUPPORT OBJECTIVE ACHIEVEMENT (7.5 POINTS)
   2.B HOW WELL IS DATA REPRESENTED USING ANALYSES AND PLOTS (7.5 POINTS)
3. FE EQUATIONS: (20 POINTS)
   3.A IS WEAK FORM AT ELEMENT LEVEL GIVEN? (10 POINTS) (NEEDS TO BE PROBLEM SPECIFIC)
   3.B IS A DESCRIPTION OF HOW GLOBAL FE EQUATIONS RELATED TO LOCAL FE EQUATIONS PROVIDED? (10 POINTS)
4. CONVERGENCE ANALYSES: (20 POINTS)
   4.A HOW IS THE STUDY PERFORMED (SYMMETRIC VS. RANDOM; ASPECT RATIO USE, ELEMENT SHAPES DISCUSSION) (10 POINTS)
   4.B ARE ELEMENT SHAPES DISCUSSED AND ANALYSES CORRECTNESS JUSTIFIED? DID ONE USE RIGHT PARAMETERS TO JUSTIFY CONVERGENCE? (10 POINTS)
5. ANALYTICAL SOLUTION COMPARISON (15 POINTS)
   5.A WHAT PART OF FE CHOSEN TO COMPARE WITH ANALYTICAL SOLUTION..HOW THE CHOICE IS JUSTIFIED? HOW WELL IS THE COMPARISON POSED (10 POINTS)
   5.B IS THERE A DIRECT CORRESPONDENCE BETWEEN ANALYTICAL MODEL AND MODEL SOLVED? (5 POINTS)