

E14 - Statics: Class and lab information

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Class location/time (A)	Bldg 370 Room 370	(M)WF 12:50-2:05		
Class location/time (B)	Bldg Gates Room 312	(M)WF 3:15-4:45		
Lab location/time	MERL 126	Sign up		
Web site	www.stanford.edu/class/engr14	(Webmaster: Ezra Schiff)		
Holidays	Monday May 25 (memorial day)			

Textbook

Statics: Analysis and Design of Systems in Equilibrium, by Sheri Sheppard

Course description and prerequisites

Modeling, analysis, and experiments of civil, mechanical, biological, and aeronautical systems. Numerical and analytical solutions of linear and nonlinear algebraic equations governing the behavior of system in static equilibrium. Requires familiarity with geometry, physics, and vectors (addition, negation, dot-products, and cross-products). 3 units, Spring (Mitiguy).

Course objectives

Statics is required for Biomechanical, Civil, Mechanical, and Aeronautical Engineering and Architectural Design majors and fulfills a general engineering requirement. Statics is a prerequisite for dynamics (E15), mechanics of materials (ME80), and mechanical design (ME112), and is useful for biomechanics of human movement (BioE281), and finite element analysis (ME309). The course objectives are to:

- Acquire fundamental engineering processes and skills
- Model, introduce mathematical identifiers, analyze, and interpret systems in static equilibrium
- Gain physical insights into basic principles with experiments
- Understand the role of analytical methods and computational tools, with professional software.
- Develop a hands-on, minds-on, can-do attitude

The Accreditation Board of Engineering & Technology program outcomes are (in order of relevance):

- Ability to identify, formulate, and solve engineering problems
- Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
- Graduates have the ability to apply knowledge of mathematics, science, and engineering
- Ability to design and conduct experiments, as well as to analyze and interpret data
- Ability to design a system, component, or process to meet desired needs

Learning by design

The word *educate* is from the Latin *educare* - “to draw out” (not “to stuff in”). Please provide suggestions, comments, criticism, ideas, and creative brainstorming about lectures, labs, homeworks, classroom interaction, office hours, software, hardware, etc. With 150⁺ classes of experience and a significant financial investment in your education, you are both learning experts and customers. **We appreciate your input!**

³Paul prefers meeting students in office hours, scheduling a weekend or evening appointment, or talking on the telephone rather than corresponding by e-mail. Do not expect a technical discourse via e-mail.

Topics covered

History of math & mechanics	Math review	Computation in mechanics
Vector review	Dot-products and cross products	Rotation matrices
Position vectors	Vectors in geometry	Forces
Moment of a force	Modeling forces & torques	Static equilibrium
Torque	Equivalence and Replacement	Free-body diagrams
Connections/constraints	Machines	Trusses and frames
Biological structures	Indeterminate structures	Shear force & bending moment
Computational tools	Statics laboratory and equipment	MIPSI (defining your own problem)
Design	Failure (compress/tension/bending)	Quasi-static equilibrium*
Dyadics*	Stress*	Stress & eigenvalues/eigenvectors*
Application to structures, robotics, biomechanics, machines, aerospace, ...		

Course conduct and the Stanford University Honor Code and Fundamental Standard

Students are required to uphold Stanford University's Honor Code and Fundamental Standard. Makeup exams are not given without university authorization. Exam grades are non-negotiable and exams will not be regraded. Exams, homework, labs, and other submitted material may be photo-copied by an instructor. Other than with an instructor, there is to be **no** class-related communication (no exchange of electronic devices, notes, homework, written material, or other information) during exams. Although you are *encouraged* to work with other students on homework and lab problems, it is expected that each student pass in his/her own homework and lab. Copying other students' homeworks or labs is a violation of the Honor Code.

Grading

- **Homework: 25%** Weekly homework is due at the **start** of class on the schedule specified in the syllabus. Homework is graded with a $\sqrt{++}$ (100), $\sqrt{+}$ (93), $\sqrt{}$ (85), $\sqrt{-}$ (78), $\sqrt{--}$ (70), or no credit (0).
 - Late homework that is passed in less than one lecture day late and before the end of Paul's office hours is penalized **15 points**. Late homework that is passed in less than two lecture days late and before the end of Paul's office hours is penalized **30 points**, and is not thoroughly examined - only checked for completeness by an instructor.
 - To accommodate ill or overtired students, or students who need an extension for *any* other reason, *one class lecture* homework extension is permitted during the quarter. For example, a homework due Wednesday may be passed in on Friday without penalty.
Note: The late day for homework due Friday is **Monday!**
 - Homework that is more than two lecture days late is not graded.
 - Homework is not accepted after the last day of class.
 - **Patricia Ho** is the grader intermediary. Consult **Patricia** for questions about homework/lab/test scores. Verify your scores with **CourseWork** <https://coursework.stanford.edu> before the final exam to ensure none of your homeworks were overlooked.
 - Submit your work and answers on separate sheets of paper (not on homework assignments).

Homework solutions are not posted. Ask your friends and instructors for help. Homework is practice, not a trade secret, and you are *encouraged* to work with your classmates and instructors. There is a strong correlation between high homework scores and high exam scores - and few reasons to do poorly on homework. **Please staple and submit all the homework problems.**

- **Synthesis & Hardware Laboratory: 15%** The description of each lab is included in the course syllabus. Associated with each laboratory are pre-lab and post-lab questions. There are three elements in the laboratory grade, and each is graded with a $\sqrt{++}$, $\sqrt{+}$, $\sqrt{}$, $\sqrt{-}$, $\sqrt{--}$, or no credit.
 - 5% Completing the pre-lab questions **before** the lab session
 - 5% **On-time** participation in your *regularly* scheduled lab session
 - 5% **On-time** completion of post-lab questions

Labs are conducted in groups of 3 students, depending on the size of the class. Each lab session is less than 1 hour and has approximately 4 groups. Some labs may be done in class. Lab write-up

consists of writing short answers to a few questions. The labs are intended to be *fun*. We hope you enjoy playing with the concepts you've learned in class and get an intuitive feel for static systems.

- **Midterm: 25%** The midterm exam is an in-class, open-book, open-note exam, and requires a calculator. **No makeup exam** will be given for the midterm.
- **Final: 35%** The final exam is open-book and open-notes and requires a calculator. No makeup exam will be given without university authorization.
- **Graded material:** Student → Adrit Lath (alphabetize) → Graders → Dan Jacobs (Coursework/Excel) → Adam Leeper (Photocopy, ABET) → Student (in class or outside Paul's office).

Dan Jacobs is the grader intermediary. Consult **Dan** for questions about homework/test scores.

Verify your scores at <https://coursework.stanford.edu> *each week* to ensure no grades were overlooked.

When **you** choose to use computational tools (e.g., **MotionGenesis**, Matlab, C, etc.) to **avoid tedious calculations**, make sure **you** know what the computer is doing (it is not magic). Print out and submit the appropriate computational files (e.g., .all files) and include both input and *output*.

Class participation and grader questions

Class participation is facilitated by **Nick Liao** (Section A), **Ezra Schiff** (Section B), and the instructor team who will ask students to participate in demos, answer questions, and work out problems on the board. Music selections are made by **Ezra Schiff**.

Computer facilities

The symbolic manipulator **MotionGenesis** is used for various homework problems. e.g., **generating** and **solving** equilibrium equations. Alternately, you may choose to do numerical analysis with C, Fortran, or Matlab. The plotting capabilities in **MGPlot**, Matlab or Excel are useful for generating graphs. Student PC (Windows) and MAC (OSX) versions of **MotionGenesis** and **MGPlot** are available on the class website. Instructions for using these computer programs will be distributed in class. The software Working Model 2D may be used in several lab and in-class experiments.

Statics Syllabus

Date	Who	Assignments	Topic
04/02 Wed	P	Hw1 assigned Lab groups	Music: TBD. Course introduction. Course roadmap: $\mathbf{F} = m\mathbf{a}$. What is “statics”: What are the forces - and where is it. MIPSI problem solving methodology. Demo: Beam balance with hardware, Working Model, and MotionGenesis. <i>Install MotionGenesis and MGPlot from course website.</i> Demo: Solving nonlinear algebraic equations with MotionGenesis.
04/04 Fri	P		Music. Math review: trigonometry (circles, triangles, sine, cosine). The importance of definitions: the definition of π ; how to calculate a value for π ?. Definitions of sine/cosine to complete blank in notes. Philosophy on applied mathematics - C oncepts, C alculations, C ontext. Demo: Student/class solution of nonlinear algebraic equations. Solve $x^2 - \cos(x) = 0$. (solution is $\approx \pm 0.824$). Reminder: Nonlinear = computer (e.g., Homework 2.17). Questions of the day: Who invented vectors, when, and where? (a short history of Gibbs); What is a unit vector? What is the magnitude and direction of a zero vector? Vectors: magnitude and direction, notation for a vector (arrows, hats, boldface, and strike-through). Demo: Magnitude and direction of a vector with a bike pump. Differences and similarities between an engineer’s vector and a mathematician’s vector (column matrix). Kane’s 2 nd theorem “Everything is equal to everything else”. Question of the day: When are two vectors equal? (differences between equal position vectors equal force vectors, and equal vectors). Vectors: scalar multiplication, negation, addition (and units). Helpful hints for Hw 2.
04/09 Wed	P	Hw2 assigned	Music. Vector dot-products: Concepts, Calculation, Context. Demo: Calculating dot-products with a tape-measure and framing square (calculating dot-products from lengths and angles - without “ i, j, k ” or “ x, y, z ” unit vectors). Student calculation of a dot-product with an orthogonal basis. Usefulness of a dot-product for calculating an angle (see Homework 2.8), magnitude of a vector (e.g., distance calculation in Homework 2.9), perpendicularity (e.g., Homework 2.4), unit vectors (e.g., Homework 1.15), and vector exponents. Various properties of dot-products. Vector cross-products: Concepts, Calculation, Context. Demo: Calculating cross-products with a tape-measure and framing square (calculating cross-products from lengths, angles, and the right-hand rule - without “ i, j, k ” or “ x, y, z ” unit vectors). Practice with calculating cross-products of unit vectors in an orthogonal basis directly with the right-hand rule and via the “ i, j, k clock”. Student calculation of a cross-product with an orthogonal basis (directly and via an engineer’s “twisted” use of determinants). Usefulness of a cross-product for calculating moment of a force and area (see Homework 2.12). Various properties of cross-products including $\mathbf{b}(\mathbf{a} \cdot \mathbf{c}) - \mathbf{c}(\mathbf{a} \cdot \mathbf{b})$. Scalar triple products: $\mathbf{a} \cdot \mathbf{b} \times \mathbf{c} = \mathbf{a} \times \mathbf{b} \cdot \mathbf{c}$. Usefulness of scalar triple-product for cut-and-fill mass/volume calculations.

04/11 Fri	P	Hw 2.2-15 due	Music. Rotation matrices: Calculation and Concepts. The right-hand rule as a universally accepted convention? How to remember a basis, dude. Student demo of efficiency of transpose versus inverse for rotation matrices. Helpful hints for Hw 3. SohCah(Toa). Matrix multiplication. Multiplying simple rotation matrices. Successive rotations and the babyboot in Section 4.3. MotionGenesis: RigidBody, Rotate, SetRotationMatrix.
04/16 Wed	P	Hw2 due Lab due Hw3 assigned	Music. Rotation matrices: Context (how are they useful). Demo: Rotation matrices on white board. Demo: Expressing one rotating vector in terms of $\mathbf{a}_x \mathbf{a}_y$. Given $ \mathbf{v} = 5$ and $\theta = 30^\circ$, express \mathbf{v} in terms of $\mathbf{n}_x, \mathbf{n}_y, \mathbf{n}_z$ and form $v_x \triangleq \mathbf{v} \cdot \mathbf{a}_x = 4.3301$, $v_y \triangleq \mathbf{v} \cdot \mathbf{a}_y = 2.5$, $v_z \triangleq \mathbf{v} \cdot \mathbf{a}_z = 0$. Given $v_x = 3, v_y = 4, v_z = 0$, find θ . Introduction to atan2 . Given $v_x = -3, v_y = -4, v_z = 0$, find θ . Expressing three vectors $\mathbf{b}_x, \mathbf{b}_y, \mathbf{b}_z$ in terms of $\mathbf{a}_x, \mathbf{a}_y, \mathbf{a}_z$. Expressing $\mathbf{a}_x, \mathbf{a}_y, \mathbf{a}_z$ in terms of $\mathbf{b}_x, \mathbf{b}_y, \mathbf{b}_z$ using SohCah(Toa). Using the table to skip the previous step. What are all the reasons the rotation table is useful.
04/18 Fri	P		Music. Review of class road map. Philosophy on vectors to supplement/replace geometry/trigonometry in high-school. Definition of position vectors revisited: Notation (it must be two points!). Calculating position vectors via vector addition. Position vectors: Notation and calculating with negation and vector addition. Definition of distance between two points, point and line, point and curve, point and plane, two lines, ... Draw examples of unit vectors as sign posts in Section 2.4. Unit vectors as the "I" in MIPS. Finding contact - and finding normals to surfaces - tangents and gradients. Geometry, the Greeks, Gibbs, and Hw 6.???. Demo: Two link manipulator position vectors on white board. Question: Find position vector of end-effector (Point E) from origin point N_o . Sensor information for θ_A and θ_B , Lengths of links are L_A and L_B (naming them is the I in MIPS). Find mixed-basis representation of \mathbf{r}^{E/N_o} . Find rotation matrices ${}^N R^A, {}^A R^B$ with SohCah(Toa) and find rotation matrix ${}^N R^B$ via matrix multiplication. Determine $x \triangleq \mathbf{r}^{E/N_o} \cdot \mathbf{n}_x$ and $y \triangleq \mathbf{r}^{E/N_o} \cdot \mathbf{n}_y$. Now do inverse problem - find θ_A and θ_B from numerical values of x and y . Lastly, form unit vector from N_o to point E . Calculate the force in the rubber band from N_o to E . MotionGenesis: Express command.
Lab	DBEP	Prelab due Go to lab	Moment balance on scaled crane.
04/23 Wed	P	Hw3 due Lab due Hw4 assigned	The Summary of Equations Toolbox . Question of the day: ? Question of the day: What is an engineer? What is an engineer? Newton and thermodynamics. Design engineers and analysts. Center of mass demonstrated by both statics and dynamics. Explore the trajectory of several points on the body. The c.m. has a nice parabolic trajectory. Demonstrate Piston or 4-bar linkage problem since they are both 1 DOF
04/25 Fri	P		Units, unit conversions, NIST, and unit conversion failures.

Lab	DBEP	Prelab due Go to lab	Create your own 2D or 3D vector geometry problem. Examples: Forward kinematics, inverse kinematics, parallel mechanics, serial mechanism, intersection of line and line, line and curve, curve and curve, line and plane, etc.
No lab		No lab	Prepare for midterm.
04/27 Sun	DBEP	Review	Midterm exam review in Terman 556, 6:30-8:30 p.m.
04/30 Wed	P	Hw4 due Lab due	Midterm exam. Exam room is Terman 556 for last names starting with A-M.
05/02 Fri	P	Hw 5 assigned	Midterm solutions. CPCC Salary survey summary. Engineers are in their professional training now. Cost of attending professional schools for Pre-Med, Pre-Law, and Pre-Business majors. Cost of missing an engineering class (\$150 - \$200/class). Inflation costs of education. State spending on education (1/2 the budget). Importance of engineering to solve global problems with energy, food, and medicine. Statics - a gateway to engineering. If nothing else, statics can help direct you towards or away from engineering. Regardless, we hope it is a great experience - and let us know what we can do to improve. Mathematical foundation to replacement of sets of forces with equivalent sets.
Lab	DBEP	Prelab due Go to lab	Hardware/software to be announced.
05/07 Wed	P		Demo: Static analysis and FBD of Solitary balance. Introduction to free-body diagrams: (a) Identify <u>your</u> system; (b) Identify the contact/distance forces on <u>your</u> system. Various FBD for solitary balance (also used on homework).
05/09 Fri	P		Review of replacement of <u>distance</u> (gravity) forces by an equivalent set. Replacement of <u>contact</u> forces by an equivalent set. Modeling replacement of contact force systems for various joints. Analogy between <u>restricting</u> translation and <u>reaction</u> forces. Analogy between <u>restricting</u> rotation and <u>reaction</u> torques. Insights into replacement of forces into equivalent set for roots supporting a tree (homework problem). Review of methods for static analysis: (a) replacement of contact/distance forces by an equivalent set; (b) free-body diagrams: (identity <u>your</u> system then identify the contact/distance forces on <u>your</u> system; (c) Write static equations $\mathbf{F}^s = \mathbf{0}$ <small>(statics)</small> and $\mathbf{M}^{S/O} = \mathbf{0}$.. Demo: Static analysis and multiple FBD of triple pendulum.
Lab	DBEP	Prelab due Go to lab	Create a MIPS statics problem with Working Model.

05/14 Wed	P	Hw5 due Lab due Hw6 assigned	Demo: Working Model for MIPSI. Forces: Gravity, translational springs and dampers, and linear actuators (motors). Demo: Slinky with numbers, ruler, scale, and stop watch. Demo: Bike pump as nonlinear spring/damper. Springs in parallel and series. Demo: Slinky. Torques: rotational springs/dampers, DC motors. Demo: Metronome, rotational spring. Demo: Moment of gravitational forces on gyroscope. Demo: Center of mass of rattleback. Torque motors and linear actuators. Generators. Demo: Generator radio and generator flashlight. Electric voltage in quartz to create force. Question of the day: Is God an EE, ChemE, ME, or CE?
05/16 Fri	P		
Lab	DBEP	Prelab due Go to lab	MIPSI on a dynamic system - counts as two labs. Model, introduce identifiers, simplify, solve, and interpret a dynamic system of your own choosing.
05/21 Wed	P	Hw6 due Lab due Hw7 assigned	Least-square solution for indeterminate problems. Demo: Normal forces for ?? car.
05/23 Fri	P		Review of matrix algebra: Determinants, inverse, solving sets of linear algebraic equations. Picking a major.
No lab		No lab	Memorial day Holiday - Have Fun.
05/28 Wed	P	Hw7 due Hw8 assigned	Music: Go Stanford. Eigenvalues and eigenvectors. Demo: Wilbur force pendulum.
05/30 Fri	P		Eigenvalues/eigenvectors.
Lab	DBEP	Prelab due Go to lab	Hardware/software to be announced.
06/04 Wed	DBEP	Hw8 due Lab due	Course review. Final exam review. Course evaluations. Computer programs, e.g., MotionGenesis, Matlab, Working Model, MSC.Adams, Nastran, and their use in statics systems. Next classes: E15 Dynamics; ME80 Mechanics of Materials; ME281 Biomechanics of Human Movement (Delp); ME331B Advanced Dynamics (Mitiguy); ME309 FEA (Sheppard). Demo: Static structures in Cirque Sol.
06/06 Fri	P	Final exam	Final exam 12:15-3:15 p.m.
06/10 Tues	P	Final exam	Final exam 8:30-11:30 a.m. Exam room is Terman 556 for last names N-Z.