Course information: Advanced Dynamics & Computation ME331A
Advanced Dynamics, Simulation, & Control ME331B

Instructors	Paul Mitiguy 113 Peterson (Building 550 - d.School) **650-346-9595**
Software	MATLAB®, **M**otion**G**enesis™, . . . (**M**otion**G**enesis™ is a MATLAB® connections partner)
Website	www.MotionGenesis.com ⇒ Textbooks ⇒ Advanced Dynamics
Course elements	Lecture, **computation/office hours**, colleagues, homework, MIPSI, book.

Course material
Distributed in class

***Advanced Dynamics & Motion Simulation** (by Mitiguy)* **$145**
For Professional Mechanical, Aerospace, and Biomechanical Engineers

$\vec{\mathbf{F}} = m\vec{\mathbf{a}}$ computation/simulation lab and office hours

Day	Time	Location	Instructor
Sunday (ME331B)	6:30-8:45$^+$	Peterson 550-126/Atrium	Team
Monday	6:30-8:45$^+$	Peterson 550-126/Atrium	Team
Tuesday (ME331A)	6:30-8:45$^+$	Peterson 550-126/Atrium	Team
After class	Until 6:30$^+$	Peterson 550-126/Atrium	Paul

Office hours start Sun. January 15 and restart Sun. April 9

Note: Instructors facilitate interactive classroom participation, peer-networking, computation, and MIPSI simulation projects.
Note: ME 492 (ME TA Training) is required for first-time CA/TAs (can be taken for 0 units).
Note: Students are expected to help each other. **Cookies provided on occasion**.

Course description: ME331A, Advanced Dynamics & Computation

Vector algebraic/differential geometry for kinematic analysis. Formulation of equations of motion for **3D multibody systems** with: Newton/Euler equations; angular momentum principle; and D'Alembert principle (MG road-maps); Symbolic and numerical computational solutions to linear/nonlinear algebraic and differential equations governing the configuration, forces, and motion of multiple degree of freedom systems. Training for advanced research and professional work.

Course description: ME331B, Advanced Dynamics, Simulation, & Control

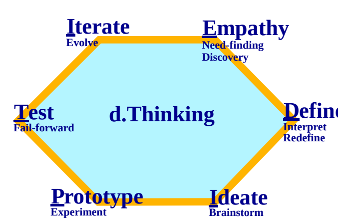
Formulation of equations of motion for **constrained 3D multibody systems** with: D'Alembert principle (MG road-maps); power, work, and energy; Lagrange's equations; and Kane's method. Euler parameters/quaternions, **specified motion**, constraint force/torque calculations, feed-forward control, inequality constraints and/or intermittent contact. Tensors and mass property calculations. Symbolic and numerical computer skills for geometry/kinematic analysis, mass/inertia calculations, forces and motion, and simulation of multi-body dynamic systems. Training for advanced research and professional work.

Skills and training for advanced research and professional careers

Advanced Dynamics focuses on efficient formulation and solution of equations of motion for complex 3D multibody dynamic systems. The course facilitates advanced graduate research and professional work. The "big picture" is $\vec{\mathbf{F}} = m\vec{\mathbf{a}}$. This course is ***detail-oriented*** with focus on details of $\vec{\mathbf{F}}$, m, $\vec{\mathbf{a}}$, the equals (=) sign, definitions, equations, words, precise notation, descriptive language, efficiency of formulation, computational solution, simulation, visualization, MATLAB®, **M**otion**G**enesis, etc.

Learning by design - we appreciate your feedback.

"Educate" is from Latin ***educare*** - "to draw out" (not "stuff in"). Please provide constructive suggestions, content, and creativity about lectures, labs, computation, homework, demos, classroom interaction, office hours, software, etc. With 150$^+$ classes of experience and a significant investment in your education, you are both learning experts and customers.



[3]Paul prefers meeting you (e.g., in office hours) or talking by phone rather than conversing by e-mail.

Interactive participation and peer/professional networking

Class participation is facilitated by the instructor team who ask students to engage in peer instruction, participate in demos, answer questions, and work problems on the board.

Computation and visualization tools (MATLAB®, MotionGenesis, Simwise, Working Model, ...)

This course provides training for computational tools for **generating** and **solving** equilibrium equations. Plotting capabilities in MATLAB® or **M**otion**G**enesis are useful for generating graphs.

Graded material: Student → Box → Instructors (alphabetize/grade/Coursework) → Student (in class). Consult **TAs** for questions about homework/computation/test scores.
Verify your scores at https://coursework.stanford.edu ***each week*** to ensure no grades are overlooked.

When **you** choose to use computational tools 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., MATLAB® `.m` files, **M**otion**G**enesis `.all` files, or WolframAlpha screen-shots) and include both input and ***output***.

Grading

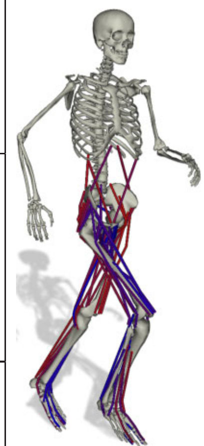
- **Homework & Computation/Simulation Labs: ME331AB 33%**
  - Work is only accepted in the box at the **start** of class (not by instructors or under office doors)
  - Work submitted one lecture day late is penalized **15 points**. Work submitted two lecture days late is penalized **35^+ points**, and is not thoroughly examined. Work submitted more than two lecture days is penalized **55^+ points** and is not thoroughly examined.
  - Homework is not accepted after the last day of class.
  - To accommodate ill or overtired students, or students who need an extension for ***any*** other reason, ***two class*** homework extensions are permitted during the quarter. For example, a homework due Wednesday may be submitted on Friday without penalty.
  - Submit your work and answers on separate sheets of paper (not on homework assignments).
  - Communicate clearly, write neatly, and use only one side of the paper.
  - Use detailed **notation** e.g., ${}^{N}\vec{\mathbf{v}}^{P}$. Use $\triangleq$ for **definitions**, e.g., ${}^{N}\vec{\mathbf{a}}^{P} \triangleq \frac{{}^{N}d\,{}^{N}\vec{\mathbf{v}}^{P}}{dt}$
  - Homework marked **optional** does not need to be submitted (no extra credit).
  - Work must be **stapled** (not paper clipped, dog-eared, origami, or bubble-gummed)
  - Work is graded: $\surd^{++}$ (100), $\surd^{+}$ (93), $\surd$ (85), $\surd^{-}$ (78), $\surd^{--}$ (70), or no credit (0).
  - To maximize office hours, your work is examined – but with deep analysis of few (1-3) homework/computational problems. In-depth feedback of your work is available in office hours.
  - Homework solutions are not posted. Ask 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.
- **Midterm & Computation: ME331A = 22% / ME331B = 20%(in-class) + 10%(take-home)**
  In-class portion is open-book/note. **No electronic devices permitted** (e.g., no cell phone, computer, calculator, etc.). No makeup exam given. Your computation/simulation questions must be done ***solo***.
- **Final & Computation/Simulation: ME331A = 35% / ME331B = 20%(collaboration)**
  In-class portion is open-book/note. **No electronic devices permitted** (e.g., no cell phone, computer, calculator, etc.). No makeup exam without university authorization. Your computation/simulation questions must be done ***solo*** – no communication of **any** class-related material (lectures, notes, homework, labs, exams, questions, etc.) with **anyone** other than ME331 instructors or designees.
- **MIPSI - Team-based Simulation Project: ME331A = 10% / ME331B = 17%**

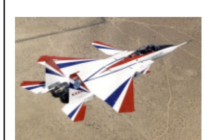
10%	**Cover-page**: Ask, answer, and present (question, system picture, team picture, result).
15%	Detailed modeling assumptions and comprehensible schematics (preferably with photo). Precise description of all physical objects and unit vectors.
10%	Concise accurate tabular description of all **scalar** symbols.
10%	Correct MG road-map or high-level summary of calculations.
30%	Correctness of analysis. **Short (2-3 pg.)**, solid report. Appendix of calculations.
15%	Interpret: Relevant text interspersed with relevant plots.
10%	On-schedule. Met with instructor. Technical difficulty, demo/video, interesting problem.

Communicate!

ME331A: Advanced Dynamics & Computation

Week	1^{st} meeting of week	2^{nd} meeting of week
01/09	Concepts assigned.	Concepts **due**.
01/16	Hw 1 **due**. Basis independent vectors Hw 2 **due**. Vector computation + - · × $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$	**Computation Lab:** Mathematics, evaluating expressions, matrices, solving linear/nonlinear algebraic equations. 3D microphone problem. Saving/running .m and MG files.
01/23	Hw 4 **due**. Vector bases: Rotation matrices I Hw 5 **due**. Vector differentiation $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ R $\vec{r}$ $\vec{\omega}$ $\vec{v}$ $\vec{\alpha}$ $\vec{a}$	**Computation Lab:** Vector computation (+ - · × , magnitude), position vectors, rotation matrices, vector geometry (measurements of distance, area, volume, angles).
01/30	Hw 6 **due**. Angular velocity/acceleration **Direct feedback** homework grading - sign up for in-class time-slot to meet with an instructor. $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ R $\vec{r}$ $\vec{\omega}$ $\vec{v}$ $\vec{\alpha}$ $\vec{a}$	**Computation Lab:** Symbolic differentiation, computer solutions to nonlinear ODEs, SI/US unit conversions. ODEs, simulation, plotting for precessing gyro and torque-free satellite. Auto-generating .m files.
02/06	Hw 8 **due**. Points: Velocity/acceleration I $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ R $\vec{r}$ $\vec{\omega}$ $\vec{v}$ $\vec{\alpha}$ $\vec{a}$	**Computation Lab:** Kinematics, angular velocity/acceleration, velocity/acceleration. Trim solution of aircraft. Phugoid mode simulation.
02/13	Hw 9 **due**. Points: Velocity/acceleration II Inverse kinematics for neuromuscular biomechanics $\vec{\mathbf{r}} \Rightarrow \theta,\ \vec{\mathbf{v}} \Rightarrow \vec{\boldsymbol{\omega}}$.	**Midterm & Computation**
02/20	Hw 11 **due**. Particles: $m\,\vec{\mathbf{v}}$, $\frac{1}{2}\,m\vec{\mathbf{v}}^2$, $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ Projectile motion (baseball with/without air-resistance). FBD, vibration/resonance of mass/spring systems. Rolling and gears: $v = \omega\,r$. $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ R $\vec{r}$ $\vec{\omega}$ $\vec{v}$ $\vec{\alpha}$ $\vec{a}$	**Computation Lab:** Computer-generated equations of motion ($\vec{\mathbf{F}} = m\vec{\mathbf{a}}$). Accuracy (closed form vs numerical solution) of ODEs. Simulation, plotting, and visualization of projectile motion and rocket-sled.
02/27	Hw 10.1 - 10.4 rolling. Hw 12 **due**. Mass/inertia I	**Moment of inertia baton lab** **Dynamic Celt Lab**
03/06	Hw 14 **due**. Rigid body momentum, energy, motion MG road-maps/D'Alembert's method. MIPSI instructions & sample MIPSI.	**Simulation Project: MIPSI** Consulting – submit question, model, system picture, identifier table.
03/13	Hw 17 **due**. Translation: Laws of motion. Hw 18 **due**. Systems: MG road-maps/DAlembert MG conservation of momentum checklist. **Computation:** Coast-guard helicopter rescue. $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$	**Simulation Project: MIPSI** Presentation - submit 1 power-point slide with: (a) question, (b) picture of system, (c) picture of team, (d) results (answer to question).
03/20	**Final exam. MIPSI Project - Team Simulation Report** Grades in Axess. Course evaluations.	
	Spring break	

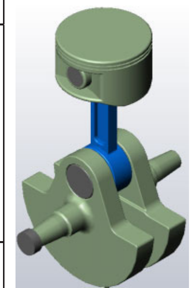



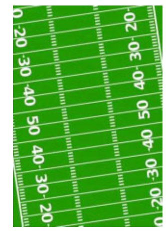



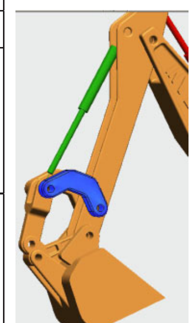


ME331B: Advanced Dynamics, Simulation, & Control

Week	1^{st} meeting of week	2^{nd} meeting of week
04/03	Advanced position vectors and geometry. Review ME331A final exam. Loops for laser/4-bar.	MG road-maps with constraints. 4-bar and linkage demos.
04/10	Hw 3 **due**. Advanced vector geometry, vector loops. Hw 21.4 **due** (Skip $\mathcal{F}_{\dot{q}_A}$. Instead form **3** MG road-maps and **2** position constraint equations **by hand** and solve with a computer). Four-bar linkage statics/dynamics (holonomic constraints/closed-chains). Efficiency of MG road-maps vs. single FBDs.	**Simulation Lab:** Computer generated static/dynamic equations for constrained multibody system. Initial values from nonlinear algebraic equations. Constraint stabilization. MIPSI.
04/17	Hw 10.5-12 **due**. Constraints I (do Optional) Position/velocity scalars/constraints (holonomic/nonholonomic). Degrees of freedom. Hw 21.5 **due** (do with **M**otion**G**enesis with **3** MG road-maps and **2** position constraint equations).	**Simulation Lab:** DAEs. Continuous solutions to nonlinear algebraic equations. Linkage analysis/design. SkyCam. piston. **Carmichael** optimization MIPSI.
04/24	Hw 7, 10.16, 10.17 **due**. Euler parameters & quaternions. Poisson & Rodrigues parameters, rotational ODEs	**SimTools:** MATLAB®, , ...
05/01	Hw 21.3, Hw 21.11 **due** (use FBD/road-maps only)	**Midterm & Simulation**
05/08	**Midterm Simulation due** Efficient formulation and solution for $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$.	Kane/Lagrange methods. Forces and motion, muscles, indeterminate systems. Inverse/forward dynamics for neuromuscular biomechanics.
05/15	Hw 20 **due**. Kane/Lagrange I – unconstrained. (do optional problems - but skip optional sub-parts). Generalized coordinates/speeds. Partial velocity, virtual displacement. Kinetic energy, effective force.	**Simulation Lab:** Nonholonomic constraints. Rolling disk, spinning rattleback. gears, ropes/contact
05/22	Hw 21 **due**. Kane/Lagrange II – with constraints (skip optional). Feed-forward model-based control of multi-body systems (with/without constraints).	**Simulation Lab:** Feed-forward model-based control 2D/3D helicopter dynamics (PID/feed-forward). MIPSI.
05/29	Hw 22 **due**. Feed-forward control **Optional:** Hw 12. Advanced mass & inertia.	**Simulation Project: MIPSI** Consulting – submit question, model, system picture, identifier table.
06/06	**Simulation Project: MIPSI.** Selection for exam - submit 1 power-point slide with: (a) question, (b) picture of system, (c) picture of team, (d) answer.	**Final exams start**
06/13	**Final simulations (3). MIPSI Project - Team Simulation Report** Grades in Axess. Course evaluations.	
June 18 Graduation ⇒ Jobs/Ph.D. Research		







Per funding: Menu of topics/projects for ME331C – Subject-Specific Advanced Dynamics

- Robotics: Microprocessor dynamics and controls, redundancy/singularities, path planning.
- Skilled integration with CAD, FEA, and controls (SolidWorks, MATLAB®, Simulink, ...).
- Dynamics and control of systems with flexible bodies (constraints and Order-N).
- Kane^{+}: Constraint forces, augmented (simulation) and embedded (controls) methods.
- Linearization of equation of motion for control-system design.
- Integrals of equations of motion (generalized principles of conservation of energy/momentum).
- Numerical methods: Integrators, inequality constraints, event-handling, matrix switching.
- Efficient equations of motion for systems with gyrostats (rotors, wheels, propellers, etc).
- Contact detection, collisions, contact response, friction, event-handling.