MCE Option Office
Department of Mechanical and Civil Engineering
Division of Engineering and Applied Science

To: Students planning to earn a Ph.D. in AM, CE, or ME
From: Nadia Lapusta, MCE Option Representative
Subject: MCE Ph.D. Candidacy exam
Date: June 27, 2016

The Ph.D. candidacy examinations in AM, CE, and ME are taken by PhD students in their second year of graduate study at Caltech and have two components, one based on coursework - quals, and one based on research - candidacy. The qualifying component of the examination is given at the beginning of the fall term. The candidacy component of the examination is given in the winter and spring terms.

Qualifying Examination

Each student is required to select three of the areas listed in the table below for the examination, one of the three areas must be mathematics. The exam in each area will include common questions to be asked of all students who have selected that area, regardless of students' individual fields of specialization. In addition, for each student, the examination will extend beyond the common questions in one of the areas that the student has designated as his or her major area of interest. The pre-approved areas are as follows:

Mathematics (required; see page 6)	ACM 100ab, ACM 104 ACM 113 AM/ACM 127
Fluid Mechanics (see page 7)	Ae/APh/CE/ME 101abc
Solid Mechanics (see page 8)	Ae/AM/CE/ME 102abc
Thermal Sciences (see page 9)	ME 119ab or ME 117 + ME 120ab
Dynamics and Vibrations (see page 10)	AM /CE 151ab
Dynamical Systems (see page 11)	CDS 140 and CDS240
Mechanical Systems (see page 12)	ME 115ab
Control Theory (see page 13)	CDS 110 and CDS 112
Seismology (see page 14)	CE 181ab/Ge162

A student may petition the mechanical and civil engineering faculty to replace one of the specified areas (other than mathematics) with an area that is not on the list and is not a sub-specialty of one of the listed areas.

While the exam in each subject area need not be limited to the content of any particular course, the nominal level of preparation for the exam is suggested by the Caltech course or courses appearing opposite each area listed above. The attached subject area descriptions indicate the topics from which exam questions will be drawn.

The examination is offered during a single time window in the first term of the academic year. This window is approximately a week in length, depending on the number of candidates. This year the exams will be conducted the week before the fall term begins. A fixed set of examiners conduct the exams, all of which are oral. Exams in each area are approximately forty-five minutes in length, and each will be preceded by a fifteen-minute period during which the student will be allowed to review the written questions for that exam. The fifteen-minute period is for the student to collect their thoughts and there will be no consultation of reference material. The student may write some notes during this time to bring into the exam. In the exam in the student's designated major area, the examiners will probe more deeply into the issues raised in the questions.

Students must notify the Options Manager in writing of their math choices and the other two subject areas (other than Mathematics) for the exam, and which of these is the major area. A student who intends to petition for an area not on the pre-approved list should seek and obtain approval of the mechanical and civil engineering faculty of the area to be substituted at least three months prior to the exam.

Research component of the candidacy examination

It is the responsibility of the student to (1) find a research advisor by the end of the third term of their first year of graduate study at Caltech, and (2) in consultation with this advisor, identify a research topic that is appropriate and adequate for a doctoral thesis in Applied Mechanics, Civil Engineering, or Mechanical Engineering.

<u>Scope of the Examination</u>
The scope of this examination is to demonstrate that the student has the ability and is adequately prepared to undertake Ph.D. level research in the proposed area. This preparation includes necessary knowledge of the chosen subject, a review of the literature, identification of promising directions to pursue for the rest of the PhD study, and

preparatory theory or experiments as applicable. It is not necessary to have conclusive results or the final thesis outline.

Eligibility

Students who are in good standing in the Ph.D program and who have passed the course-work component of the candidacy examination are eligible to take this examination.

Examination Committee

The membership of the examination committee is usually the same as the Ph.D. dissertation supervision committee. The committee shall elect a chair other than the research advisor who is an MCE faculty member.

The student shall propose the committee in consultation with the advisor in writing to the Option Office (Holly Golcher) by the end of the fourth term of their first year of graduate study at Caltech. The student is to seek the consent of the members in writing before proposing them.

Any changes must be approved by the Option Representative, at least one week prior to the exam.

Scheduling

The examination shall be scheduled to occur before June 7, of the student's second year of graduate study at Caltech. The time should be acceptable to the committee. The faculty members will make every reasonable effort to make themselves available for the examination. The student is responsible for reserving the room and necessary equipment.

The examination date, time and place must be communicated to the Option Office (Holly Golcher) by April 1. Exceptions must be approved by the faculty and the Option Representative by April 1.

The Examination

The student shall submit a 5-10 page written Candidacy Report to the Option Office (Holly Golcher) and to the three members of the committee at least one week before the examination. The candidacy report should describe the proposed topic of research, relevant survey of the literature, and any preliminary results or laboratory preparation. The report cannot be longer than 10 pages (excluding references but including figures).

The student shall bring the following to the exam:

1. Current Caltech Transcripts (unofficial)

2. Current Agreement to Serve as Academic and Research Advisors
3. Candidacy Form For The Degree of Doctor of Philosophy

Item 1 can be obtained on-line via REGIS and items 2 and 3 can be picked up from the Options Manager Office, a few days after your report has been submitted.

The student shall make a half-hour oral presentation of the research proposal, followed by questions from the committee consistent with the scope of the examination. The examination is expected to last for approximately one hour.

<u>The Result</u>

The examination committee makes one of the following recommendations to the MCE Graduate Studies Committee. The final decision shall be made by the MCE Graduate Studies Committee in consultation with the examination committee.

1. Pass. This recommendation is made if the student satisfies the criteria that form the scope of this examination.

2. Pass subject to remedial action. This recommendation is made if the student satisfies the criteria that form the scope of this examination except for an isolated deficiency. No further examination is required. The examination committee shall propose the remedial action, specify criteria to demonstrate that the student has taken this action and a time-table to complete this action. Examples include but are not limited to (a) taking an additional course or (b) conducting additional literature survey in a specified area.

3. No Pass. This recommendation is made if the student fails to satisfy the criteria that form the scope of this examination. (A re-examination may be allowed by the MCE Graduate Studies committee as discussed below.)

The chair of the examination committee shall communicate the recommendation (1) orally to the student at the end of the examination and (2) in writing to the Option Representative through the Option Office (Holly Golcher).

The student is encouraged to discuss the exam and recommendation with the examination committee members to get any additional feedback. Such discussions are especially important if the recommendation is “No Pass,” in which case the student should also discuss the exam with the Option Representative.

Based on the recommendation and in consultation with the examination committee, the MCE Graduate Studies Committee determines the final outcome of the exam from the following options:

1. Pass. The student shall be admitted to candidacy on fulfillment of the remaining requirements.

2. No Pass subject to remedial action. The student shall be admitted to candidacy on fulfillment of remaining requirements and the remedial action. The MCE Graduate Studies committee reviews and approves the remedial action and the timetable to complete it. If the remedial action is not completed in time, the outcome of the exam changes to "No Pass."

3. No Pass with an option for re-examination. This determination is made if the MCE Graduate Studies committee judges that the student may be able to pass the examination in the near future with additional study. The committee shall specify the time-table for the re-examination; the re-examination cannot be later than six months from the time of the examination. Further, the committee will suggest a faculty member (chair of the examination committee, thesis advisor or another faculty member, as appropriate) to counsel the student regarding the re-examination. The result of any re-examination can only be a pass or no pass (with no second re-examination).

4. No Pass. This determination is made if the MCE Graduate Studies committee judges that the student is unlikely to be able to pass the examination in the near future. The student shall not be allowed to continue in the Ph.D program.

The MCE Graduate Studies committee decision is communicated to the student in writing by the end of the examination period (June 7) or within two weeks from the examination date, whichever is later.

<u>Honor Code</u>

The faculty and the students are reminded that the examination is administered under the Caltech Honor Code.

MATHEMATICS

There are four areas as defined below. The student should be prepared to answer questions from two areas of their choice. Each area contains a list of topics and a list of courses to indicate the depth of these topics. However, the exam is not intended to be a final exam in any of these courses; instead the exam evaluates the general mathematical understanding of these areas.

1. **Linear spaces** (ACM 104)
   Finite dimensional vector spaces, linear transformations and matrices, canonical forms, spectral theory, operators on infinite dimensional spaces, applications to differential and integral equations.

2. **Complex variables** (ACM 100)
   Analyticity, Laurent series, contour integration, residue calculus.

3. **Ordinary differential equations** (ACM 100)
   Linear initial value problems, linear boundary value problems, Sturm-Liouville theory, eigenfunction expansions, transform methods, Green's functions.

4. **Partial differential equations** (ACM 100)
   Heat equation, separation of variables, Laplace equation, transform methods, wave equation, method of characteristics, Green's functions.

FLUID MECHANICS

1. **Kinematics**: Eulerian and Lagrangian description, fluid deformation, rate of strain, shear, dilatation, vorticity, circulation, material path lines, streaklines, streamlines.

2. **Conservation laws** (control volume, differential form) for mass, momentum, energy.

3. **Euler equations of motion.**

4. **Constitutive relations**: Newtonian fluids, Navier-Stokes equations.

5. **Potential flow:** velocity potential, Kelvin's theorem, d'Alembert's paradox, Bernoulli's equation, complex potential, Blasius' theorems, airfoils, Kutta condition, lift.

6. **Boundary layers:** scaling, laminar boundary layers on flat plates and wedges, thin free shear layers (mixing layers, wakes, and jets).

7. **Stability:** general concepts, instabilities of parallel shear flows (viscous and inviscid).

8. **Turbulent flow:** general characteristics, Reynold's averaging, transition, scaling of turbulent boundary layers (e.g. law of the wall)

9. **Flow over bluff bodies:** drag, separation, wakes.

10. **Gasdynamics:** stagnation conditions/properties, normal/oblique shocks, Prandtl-Meyer expansions, simple waves, quasi-one-dimensional flow.

11. **Free surfaces:** surface tension, small amplitude surface gravity waves, dispersion.

SOLID MECHANICS

1. **Fundamentals**: Finite deformation, deformation gradient, 3-D displacement, small strain theory, compatibility, balance laws, traction, stress, boundary conditions, constitutive equations.

2. **Linear elasticity**: Basic equations, generalized Hooke's law, plane strain and plane stress, axisymmetric problems, 3- dimensional problems, reciprocal theorem, transformation of stress and strain, St.Venant's principle, thermal effects, thick tubes, Kelvin's point/line load problem, stress concentration, torsion of non-circular and thin-walled cross sections, theory of beams, rods, cables.

3. **Energy methods**: Principle of virtual work, theorem of potential energy, basics of the finite element method, discretization, concepts of nodal degrees of freedom and shape function, stiffness matrix and boundary conditions.

4. **Theory of rods, plates and shells**: Kinematics of rods, equilibrium of rods, Kirchhoff and von Kármán theories of plates, buckling of columns and plates, geometry of shells, theory of shells.

5. **Stress wave propagation**: 1-D theory, method of characteristics, boundary and initial value problems, 3-D equations of motion, reflection and refraction of plane waves, Rayleigh wave, wave guides, dispersion relations.

6. **Composites**: Theory of fiber reinforced composite, micromechanical models, effective moduli, ply and laminate mechanics.

THERMAL SCIENCES

I. **Heat & Mass Transfer** (ME 119ab)

- Conduction heat transfer (steady-state and transient conduction, fins, thermal resistances).
- Forced convection heat transfer (internal and external flows, laminar boundary layers, similarity solutions, integral method)
- Natural convection (Boussinesq approximation, boundary layer flow, internal flow).
- Mass transfer (Fick's law and binary diffusion, evaporation),
- Thermal radiation (basic radiation laws and concepts, radiation circuits, multi-surface grey diffuse exchange).

II. **Nano-to-macro Transport** (ME 117)

- Basic kinetic theory for gases
- Simple solutions of the Schrodinger equation
- Reciprocal space for electrons and phonons; density of states
- Statistical mechanics and partition function
- Fermi-Dirac and Bose-Einstein distributions; specific heat of electrons and phonons
- Boltzmann equation (derivation of macroscopic transport laws, classical size effects)

Combustion (Ae/ME 120ab)

- Basic chemistry (thermodynamics, kinetics, hydrocarbon chemistry, pollutants formation)
- Ignition (thermal and radical) & detonations (Rayleigh & Hugoniot lines, ZND model)
- Transport equations (species and temperature)
- Premixed flames (flame structure, scaling arguments, flame sheet model, G equation)
- Diffusion flames (flame structure, flamelet equations, S-curve, extinction, ignition)
- Flame stretch and flame instabilities (Darrieus-Landau & thermo-diffusive)
- Turbulent combustion (regime diagrams)

DYNAMICS AND VIBRATIONS

1. **Dynamics of discrete systems:** Equilibrium concepts, conservative and dissipative systems, Lagrange's equations, differential equations of motion for discrete single and multi degree-of-freedom systems, natural frequencies and mode shapes of these systems.

2. **Phase plane analysis of vibrating systems and concepts stability**

3. **Energy dissipation**: Forms of damping and energy dissipated in damped systems.

4. **Forced Vibration**: Response of dynamical to simple force pulses, harmonic and earthquake excitation, response spectrum concepts.

5. **Random Vibrations and introduction to the nonlinear vibrations**

6. **Dynamics of continuous systems**: Hamilton's principle, axial vibration of rods and membranes, transverse vibration of strings, beams (Bernoulli-Euler and Timoshenko beam theories), and plates, traveling and standing wave solutions to motion of continuous systems.

7. **Approximate methods of analysis for oscillatory systems:** Rayleigh quotient and the Raleigh-Ritz method to approximate natural frequencies and mode shapes of discrete and continuous systems.

DYNAMICAL SYSTEMS

1. Lagrangian formulation of mechanics
2. Hamiltonian formulation of mechanics
3. Flows and critical points; linearization
4. Small oscillations; normal modes
5. The stable manifold and Harman-Grobman theorems
6. Equilibrium points in planar systems
7. Center manifold theory; normal forms
8. Lyapunov stability theory
9. Hamiltonian and gradient systems
10. Periodic orbits, limit cycles, and separatrix cycles
11. Stability of periodic orbits
12. Nonlinear oscillations and parametric resonance
13. Poincare-Bendixon theory
14. Structural stability
15. Hopf bifurcations
16. Perturbation theory
17. Method of averaging
18. Homoclinic and heteroclinic connections

MECHANICAL SYSTEMS

1. Kinematics of multi-body systems and linkages. Orientation representations, such as Euler's angles, quaternions, etc. Spatial representation, including homogeneous coordinates and dual quaternions. Screw theory. Linkage mobility.

2. Dynamics of lumped parameter and rigid multi-body systems. Frequency and time-domain analysis of linearized mechanical systems.

CONTROL THEORY

1. **Modeling and analysis of feedback systems:** use of ordinary differential equations for modeling mechanical systems. Stability of equilibrium points and linearization. Input/output modeling and performance specifications (frequency and step response).

2. **Classical control theory:** control of single-input/single-output systems. State space control and state feedback, including controllability and observability. Loop analysis of feedback systems using Nyquist and Bode plots. Design of feedback compensators using loop shaping techniques, including PID control.

3. **Modern feedback control design:** stability and performance analysis in frequency and time domain. Optimal control and linear quadratic regulators.

4. **Estimation theory:** random processes and state estimation in the presence of noise. Kalman filters and observer-based control.

ENGINEERING SEISMOLOGY

1. **Seismic wave propagation**: Navier's Equation, P-waves, S-waves, Rayleigh waves, Plane-wave reflection and transmission, Plate waves, Love waves, Strain and stress associated with waves, Q.

2. **Seismic sources:** Moment tensor, earthquake magnitude, radiation pattern, directivity, time-functions, Gutenberg-Richter relationship, stress drop, spectral representations.

3. **Seismometry**: Derivation of ground motion from seismograms, instrument poles and zeroes, dynamic range and bandwidth, linear filters.

4. **Building response:** Modal excitation, response spectra, traveling wave solutions, nonlinear phenomena.

5. **Seismic hazards:** Performance based earthquake engineering, Ground motion prediction equations, log-normal and power-law probabilistic hazard.