Caltech 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 PhD. Candidacy exam
Date: May 8, 2020

The Ph.D. candidacy examinations in AM, CE, and ME have two components, one based on coursework - subject component, and one based on research - research component. The subject component of the examination is given at the end of the summer term of the first year. The research component of the examination is given in the winter and spring terms of the second year.

I. Subject component of the candidacy examination

Each student is required to select a major area for the examination from the following list:

Control and Robotics: CDS 131, CDS 232, CDS 233
Fluid Mechanics: Ae/APh/ CE/ME 101abc
Solid Mechanics: Ae/AM/CE/ME 102abc

The list is updated every year. A student may petition the mechanical and civil engineering faculty to add a major area in mechanical or civil engineering that is not on the list and is not a sub-specialty of one of the listed areas. The approval is not automatic; such petitions are submitted rarely and some of them have been denied in the past.

The examination is offered during a single time window of 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.

The subject-component examination will consist of two separate sixty-minute oral exams:

Course-based exam: This part examines the basic knowledge in the student's major area, with written problems given to the student at the beginning of the exam and presented by the student to the panel orally. The same problems are given to all students in a given major area. While the exam in each major 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. 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 the 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.

Specialized- study exam: This part examines the student's ability to apply the knowledge in the major area to understand and critically analyze a more specialized study described in a research paper or papers. The student chooses the paper(s) in consultation with the advisor; the choice is approved by the group of faculty administering exams in the major area of the student. During the exam, the student orally presents to the faculty panel the contributions of the paper(s), the prior work to place the contributions in context, the overview and pros/cons of the technical approach and methodology, and the remaining research questions. The student gives a relatively short, 20 minutes or less, uninterrupted presentation, followed by discussion with the faculty panel. The discussion may refer to the presentation but would mostly require the student to answer questions orally with the help of writing on the board.

The Result

The examination outcome is based on the performance in both oral examinations. The outcome is determined at the MCE faculty meeting at the end of the examination period. The potential outcomes are:

1. Pass. This recommendation is made if the student demonstrates sufficient knowledge in the chosen major area.

2. No Pass. This recommendation is made if the student has substantial deficiencies in their knowledge. A retake of the exam may be offered if it is the judgement of the faculty that the deficiencies can be remedied by additional short-term study. If the retake is offered it must be completed before the end of the fall term following the exam.

After the faculty meeting, the result of the exam is communicated to students orally by their advisors and in writing by the Option Office.

The student is encouraged to discuss the exam with the examining panel 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.

II. 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.

Scope of Examination

The scope of this examination is to demonstate that the student has the ability and is adequately prepared to undertake PhD 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 subject-based 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) can be obtained online via REGIS
2. Copy of Research Report

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.

The Result

The examination committee makes one of the following recommendation 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 outcomes 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 review 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 timetable 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 PhD. 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.

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

CONTROL & ROBOTICS

Basic system concepts; state-space and I/O representation. Properties of linear systems, including stability, performance, robustness in both state space and frequency domain. Reachability, observability, minimality, state- and output-feedback. Fundamental limits of performance for feedback systems.

Feedback linearization, stabilization of feedback linearizable system. Control Lyapunov functions, constructing control Lyapunov functions and Lyapunov analysis of nonlinear systems. Optimization based controllers, including those utilizing on control barrier functions and multi objective control. Continuity and explicit closed for solutions for optimization based controller. Adaptive control and input to state stability. Stability and stabilizability of periodic orbits, potentially including Poincare maps. Application of nonlinear controllers to robotic systems.

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.

SOLID MECHANICS

1. **Fundamentals:** Tensors and Tensor calculus, deformation mappings, finite deformation, deformation gradient, 3-D displacements, small strain theory, compatibility, balance laws, traction, stress, boundary conditions, Elastic potentials, basic continuum thermodynamics, constitutive equations.

2. **Linear elasticity:** Basic governing 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. **Theory of elastic rods.**

4. **Structural theorems:** virtual work, strain energy, complementary energy, stationary total potential energy) with applications to statically indeterminate structures, energy bounds, wrinkled membranes, beams on elastic foundation, Rayleigh-Ritz method, stability of equilibrium, buckling.

5. **Theory of plates and shells**

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