Department of Mechanical and Aerospace Engineering

(www.mae.buffalo.edu)

GRADUATE MANUAL

(Revised 12/4/2012)

State University of New York at Buffalo
School of Engineering and Applied Sciences

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I. General Academic Information

The department offers separate programs in Mechanical and Aerospace Engineering. In each program, the Master of Science, M.S., and the Doctor of Philosophy, Ph.D., degrees are granted. Students are accepted for Spring or Fall admission. Subject to certain limitations, students may undertake their program on a full- or part-time basis.

1.1. Admission Requirements

The Department of Mechanical and Aerospace Engineering offers Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees. A B.S. in Mechanical or Aerospace Engineering, or the equivalent, with a quality point average of at least 3.0/4.0, is normally required for admission to all programs. Prospective students may apply for either the M.S. or the Ph.D. program. Students with B.S. degree (i.e., without a M.S. degree) can apply for Ph.D. program directly or may choose to first obtain M.S. degree and then enter the Ph.D. program. Students who complete UB's M.S. program and wish to continue for Ph.D. must re-apply for admission to the Ph.D. program.

All Ph.D. students are required to have GRE's taken before admission to the program. All M.S. students who have not obtained an undergraduate degree in the United States are also required to have GRE's taken before admission to the program.

1.2. Student Classifications

a) Degree Student: Graduate students who have been accepted by the department with an undergraduate quality point average of 3.0/4.0 or better.

b) Non-degree Student: Students with appropriate academic qualifications who do not wish to pursue a degree program.

c) Non-Matriculated Student:

i) Graduate credit earned by non-degree students may be applied toward a degree program by petition to the Director of Graduate Studies after acceptance as a degree student.

ii) Students who are admitted to a particular course on a no-credit basis at the discretion of the Department and the instructor of the course. No transcripts or other supporting papers are required, but an online application must be completed.

iii) *Provisional Admission*: Students admitted on a provisional basis do not qualify as degree students and must demonstrate their ability to perform satisfactorily at the graduate level before being admitted to degree candidacy. **A grade of B or higher is required in each of the first three graduate courses**. Otherwise, the student will be dropped automatically from the program with no further probationary period possible.

1.3. Application Dates for Admission

These dates can be found at http://www.mae.buffalo.edu/admissions/admission_dates.php.

1.4. Student Status

a) Full-Time: A student who carries 12 credit hours (equivalent to four approved courses) of work is considered a full-time student by the department. Research assistants (RAs), teaching assistants (TAs) and graduate assistants (GAs) are considered full time at 9 or more credit hours. The following students must be full time: *university fellows, department fellows, TAs, RAs, GAs, veterans* (supported by the Veteran's Administration), and ***all foreign students with a student visa***.

Students who are within 12 credit hours of fulfilling their Masters or Ph.D. degree requirements (9 credit hours in the case of RAs, TAs and GAs) should submit the Certification of Full-Time Status Form to the Graduate School for full-time status if registering for fewer than 12 (9 for RAs, GA and TAs) credits. Forms are available at http://www.grad.buffalo.edu/forms/students/certfts.pdf. All supported students and all foreign students falling into this category must file the petition. Note that an Application to Candidacy (ATC) form (see http://www.grad.buffalo.edu/forms/students/atc.pdf) must be submitted and approved ***before*** a petition for full-time status will be approved by the Graduate School. Supported students should also be aware that the number of tuition scholarship credits that will be allowed will be limited to only those credit hours required for a particular degree (30 credit hours for the M.S. or 72 credit hours for the Ph.D., less any transfer credits).

b) Part-Time: A student who carries less than the equivalent of four approved courses and has not filed a petition for full-time status is considered a part-time student by the department.

1.5. Advisement

As early as possible in their first semester, students should meet with MAE department faculty members to find a common area of research or technical interest with the purpose of deciding a preference for a thesis/dissertation topic and advisor. Upon reaching mutual agreement with a faculty member on thesis advisement the student should so notify the department graduate office. The advisor must be a member of the Graduate School Faculty. Prior to selection of an advisor, the Director of Graduate Studies will serve as advisor.

Students should select an advisor by the end of their first semester if at all possible. Students are encouraged to actively seek an advisor.

Students should discuss regularly with their advisors, who must approve all course selections as well as provide thesis or project supervision. In unusual circumstances, students may change advisors only with permission of the Director of Graduate Studies.

Advisement by non-MAE faculty: Non-MAE faculty can serve as committee members, provided they have a Graduate School appointment. If a non-MAE faculty member is to serve as the principal advisor, this must be approved in advance by the Director of Graduate Studies, and in accordance with MAE policy. In such a case, the other committee members must be MAE faculty. If appropriate to the research effort, additional members beyond the minimum number may be added.

1.6. Registration

Every student is required to register every semester; registration options include courses, research, thesis, or dissertation work. Schedules should be planned as early as possible at the beginning of each semester. The latter may be undertaken only under the direct supervision of a

faculty member. No credit will be allowed for work done without proper registration. Proper registration is important for determination of the residence requirements. "Residence" implies the pursuit of advanced study or research while registered at UB-SUNY under the supervision of the Graduate School Faculty.

Normally, a minimum registration period of one year on a full-time equivalent basis is expected for the M.S. degree, and two years on a similar basis is expected for the Ph.D. A Ph.D. candidate must also fulfill the Ph.D. residency requirement of at least two semesters as a full-time student.

Students are required to register continuously during their period of graduate study until all requirements for the degree are completed. Students who, for one reason or another, cannot maintain continuous registration must request a Leave of Absence (using the Graduate Student Petition Form available at http://www.grad.buffalo.edu/forms/students/pet_loa.pdf before the start of the semester for which the leave is being requested. For this purpose, the student must petition the Dean of the Graduate School and obtain the approval of the Director of Graduate Studies. A leave of absence will only be granted to students in good academic standing. If the student is enrolled for less than 12 credits (less than 9 credits for TAs, GAs or RAs, and for all international students), the Certification of Full-Time Status form should be completed; see the page http://www.grad.buffalo.edu/forms/students/certfts.pdf.

Leaves of absence will normally be granted for only one (1) semester at a time. Leaves of more than one (1) semester may require additional justification and documentation from the student and the student's advisor. Documented cases of financial hardship, illness, or compulsory military service constitute valid justification. Students who leave the program after completion of some graduate work, but have not been given an approved leave of absence, must reapply and be readmitted as a new student. Continued leaves of absence beyond two (2) semesters will not be granted.

1.7. Paperwork Deadlines for M.S. and Ph.D. Conferral

It is the responsibility of the student to meet all deadlines specified by the Department and by the Graduate School. Students should consult the ***Graduate School Policies and Procedures*** (http://www.grad.buffalo.edu/policies) and the ***Graduate Newsletter*** published each Fall and Spring semester as a supplement to ***The Reporter***, for the most up-to-date information on these matters.

Degree conferral deadlines are available at http://www.grad.buffalo.edu/policies/deadlines.php and are subject to change. Check at least three months before expected conferral. Allow time for internal processing.

It is the **responsibility of the student** to check with the Graduate School prior to the various deadline dates to be sure that all the requirements and paperwork for the degree have been completed.

* **IMPORTANT NOTE ON APPLICATION TO CANDIDACY FORM**: In order to be in compliance with tuition verification policies of the University and other requirements, all full-time students should submit their Application to Candidacy forms before the end of the second semester of full-time graduate study in the case of M.S. (no new enrollment) students and before the end of the sixth semester beyond the B.S. degree in the case of the Ph.D. students. Students transferring to the University with an M.S. degree should submit the Application to Candidacy form no later than the end of the fourth semester of full-time study for the Ph.D.

1.8. Transfer Credit

a) From Another School: Transfer credit will be allowed only for graduate work with a grade of "B" or better. Graduate work done at other institutions may be offered in partial fulfillment of the requirements for a degree if the work is of acceptable quality and appropriate to the student's program. Credits earned in correspondence courses may not be transferred.

A student desiring to transfer graduate credits should consult with his advisor at the earliest opportunity after admission. When the student's Application to Candidacy is submitted, it must list the credits to be transferred.

For the M.S. program, this transfer is limited to a maximum of 20% of the degree requirements (or 6 credit hours total).

A student entering the Ph.D. program may transfer up to 30 total credit hours of previous graduate course work. Previous project or thesis work may **not** be transferred.

b) From another Department within UB: Graduate work done in another department within UB may be offered in partial fulfillment of the degree requirements if the work is of acceptable quality and appropriate to the student's program and to the satisfaction of the advisor.

1.9. Graduate Credit

Graduate credit is granted only to degree students who:

i) have been accepted into the department prior to registration in any course, seminar, research program, or other type of study.

ii) are seniors close to graduation with at least a 3.0/4.0 grade point average during their last three semesters and who do not need the course credit to complete the B.S. requirements. (Petition forms are available in the Student Advising Services office. Exception registration is done within the department, by the assistant to the chair, with instructor's permission.)

Graduate credit is earned for approved courses consisting of a minimum of 3 semester hours (1 semester hour of credit is equivalent to 15 hours of class work per semester) and registration in thesis/dissertation which is under the direct supervision of the advisor.

Graduate credit is granted for 500, 600 and 700 level courses, provided the advisement and registration requirements are met. Graduate courses from outside the School of Engineering and Applied Sciences or Natural Sciences and Mathematics must receive prior approval from the student's advisor and the Director of Graduate Studies.

Informal Courses

Informal courses usually include Individual Problems and Special Topics courses, which are taught on an informal basis. These courses require a complete narrative description on a special form designed for this purpose, which includes the signatures of the student, instructor, and the Director of Graduate Studies. A copy of this form, available at http://www.mae.buffalo.edu/files/special_topic.pdf, should be submitted to the MAE graduate secretary during registration time (the beginning of the semester) along with the student's Application to Candidacy form.

A maximum of six (6) credit hours of individual problems may be applied toward the minimum 30 credit-hour requirement for the Masters degree.

Excluding those credits applied towards the Masters degree, a maximum of 6 additional credit hours of informal course work may be applied towards the minimum 72 credit-hour requirement for the Ph.D. degree.

Distance Learning for Part-time Students

For degree programs not offered completely online less than 50% of student's credit hours can come from distance learning (e.g.: EngiNet). Full time students are generally discouraged from taking EngiNet courses, and must discuss with advisor and Director of Graduate Studies.

Graduate Credit from Undergraduate Courses

Students wishing to use an undergraduate course for graduate credit ***must*** submit a petition (http://registrar.buffalo.edu/forms/documents/OutsideofCareerPeition111111_003.pdf) along with a statement or syllabus from the instructor showing the additional work required for graduate credit to the MAE graduate office during the first week of classes to receive approval. Copies of these petitions must be included along with the Application to Candidacy form. ***Retroactive approval will not be granted*.**

Such courses must be limited to a maximum of 2 advanced undergraduate courses at the 400 level. This maximum limit applies to the entire M.S. or Ph.D. degree program.

Undergraduate courses which carry 4 or more semester hours of credit will receive a maximum of 3 semester hours of graduate credit. Graduate students taking a 4 credit hour course must register and pay tuition for the full 4 credits.

Other

The following courses may **not** be employed to fulfill degree credit requirements:

i) undergraduate courses in which a grade of C or lower is obtained. Credit for such courses will not be applied to the total program, but the grades will be counted in the overall average.
ii) a graduate course already used to fulfill the requirements of an undergraduate degree program; repeat of graduate course already taken at undergraduate level
iii) graduate courses in which a grade of D, F or U is obtained.

1.10. Scholastic Requirements (General)

a) Grades: A minimum average of B (3.0/4.0) must be maintained during all graduate work. This requirement takes effect after 3 courses, and all work taken for graduate credit which could be applied to the degree is used in calculating the grade point average. Courses should not be taken using "S/U" grading unless approval is obtained ahead of time from the Director of Graduate Studies.

Accordingly, courses taken in excess of that which is applied toward the degree credit requirements will be included in the computation of the student's grade point average. Students whose averages fall between 2.5 and 3.0 at the end of any grading period may be permitted, upon

the recommendation of their advisors and approval of the Director of Graduate Studies, to make up the grade point deficiency within a specified period.

A student will be considered for dismissal from the program when:

i) the grade of F is earned in any course;

ii) more than two grades are earned from among, C, D, and U;

iii) probation status has not been removed;

iv) the grade point average falls below 2.5 at the end of any grading period;

v) the student is found guilty of academic dishonesty according to existing regulations.

Incomplete grades (I) are not counted in the program average while they are on the student's record. However, after no more than two additional semesters, all requirements for such courses must be completed and a letter grade assigned. If this is not done, the '**I**' grade will **automatically** be changed to a U (unsatisfactory), which cannot be used to satisfy graduation requirements. The program average is not affected by grades received for thesis, dissertation and seminar.
The grade L is normally to be used for Thesis, Project, Dissertation or Departmental Seminar courses.

Graduate students are permitted to resign from a course without academic penalty if this is done prior to the last day for dropping a course without penalty. The student must resign officially by use of a Change of Registration slip which is available in the Student Response Center office. The student must consult with his advisor before returning the slip. Students who are required to keep full-time status must also receive approval of the Director of Graduate Studies prior to dropping a course.

It is important that the student resign officially from a course in the manner described, otherwise a grade of **F** will be recorded.

b) Time limits for full-time degree students

The time limit for the M.S. degree is four years, measured from the first registration as a graduate degree student. For *part-time* students a time limit of 6 years from the first registration in the graduate program may be permitted. At the end of 4 years, a graduate student petition form must be submitted to request an extension beyond the fourth year. The limit for the Ph.D. degree is five years from the date of the first Ph.D. registration, and seven years from the date of first graduate registration. The time spent on an approved leave of absence is not included in these time limits.

Time limit extensions may be granted for adequate reasons by petition to the Executive Committee of the Graduate School. The petition must be forwarded with a recommendation from the Director of Graduate Studies. The extension of time limit is normally granted for a maximum period of one year.

c) Other requirements

Any general requirements of the Graduate School or SEAS (see http://www.eng.buffalo.edu/policies.php) must also be satisfied.

1.11. Financial Assistance and Tuition Scholarships

All students are automatically considered for financial aid upon application for admission to graduate studies. There are three main types of financial support: Teaching or Graduate Assistantships, provided by state funds for lines allotted to the department; Research Assistantships, provided by research grants held by individual faculty members; and Graduate Fellowships provided by state funds administered by the Graduate School. In addition to Research Assistantships, potential new graduate students applying for admission are also eligible for Teaching Assistantships on which the decisions are made by the Graduate Studies Committee of the department. For TAs, the general policy of the department is to limit them to two semesters. Ph.D. students as TAs are eligible for support beyond the first two semesters; however the expectation is that the bulk of the support of Ph.D. students is to be provided by Research Assistantships and Graduate Fellowships based on satisfactory performance. The University has imposed a two-year limit on support (TA and GA) of Masters students on a state line; the limit for Ph.D. students is four years.

The duties of TAs, which are assigned by the Department Chair, typically require 15 hours per week and consist of conducting undergraduate laboratories or assisting faculty in recitations or the grading of problems. The stipend and duties of RAs are decided by the Principal Investigator or grant holder. Usually the work of RAs contributes directly to their thesis study or at least is closely related. Graduate or University Fellowships are awarded annually to new students, by the Graduate School on a University-wide competitive basis. The department proposes several of its most promising candidates for these Fellowships every February when applications are solicited by the Graduate School.

Assistantships and fellowships normally include a full or partial tuition scholarship. However, the University has imposed a four semester limit on tuition scholarships for all Masters students and an eight semester limit (beyond the B.S. degree) for Ph.D. students. Extensions of these limits are approved only by petition. For Masters students, it is unusual for the time limit to be extended. For Ph.D. students, no tuition scholarship or remission will be awarded beyond the tenth semester of graduate study. *Tuition Scholarship credit hours will generally be limited only to those credits required for the degree (M.S. or Ph.D.) being pursued*. Continuing students who are eligible for tuition scholarships must complete and submit the necessary forms by the end of May each year for the Fall semester.

Entering students should submit tuition scholarship verification forms before the end of the first week of classes. For exact due dates for these forms please go to http://sarfs.buffalo.edu/office/pdfs/general/waiverInstructions.pdf**.** In cases of late appointments, tuition scholarship forms may be filed until the middle of the **second week of classes each semester. Failure to do this could result in the loss of the tuition scholarship regardless of the initial appointment terms**. Students should also note that tuition scholarships are not granted for courses or thesis/dissertation work undertaken during the summer months. It is therefore necessary that all graduate students register for adequate thesis or project credit during the fall and/or spring semesters in order that tuition scholarships are received for such study. This should be done even though most of the thesis or project work might actually be delayed until a later period. Registration for up to 19 credit hours per semester is permitted without petition.

Supported students in the Ph.D. program must take the Ph.D. qualifying exam, at the first opportunity as described in Sec. 3.2. **Failure to observe these requirements may result in the termination of financial support**.

In the department's view the main purpose of assistantship or fellowship support is to assist the student in completing the objectives and requirements of the degree program. It is mutually

advantageous for the student to complete his program in the shortest period of time consistent with high academic performance. All assistantship appointments are subject to continuous departmental review and require satisfactory progress towards the program objectives as well as satisfactory performance of any assigned assistantship duties.

The granting of a teaching assistantship to a continuing student first requires a nomination by the student's faculty advisor. Students are not permitted to nominate themselves.

Teaching and Research Assistants, as well as Fellows, are expected to pursue their programs vigorously and as a continuing full-time commitment. During the various recesses and periods without classes which occur in the 10-month academic year (September through June) all Teaching and Research Assistants are expected to be present and actively engaged in thesis, project work, or assigned duties. Leaves of absence for time away from the campus must have the prior approval of the student's advisor.

Unfortunately, the department does not have sufficient financial resources to assist all students deserving of support. In fact, only a fraction can be supported. For this reason students should consult the following websites:
http://gse.buffalo.edu/lis/scholarships
http://fellowships.buffalo.edu/
http://www.mae.buffalo.edu/graduate/graduate_scholarships.php

Students are also encouraged to search for competitive awards available from sources outside the department or outside the University.

1.12. Seminar Requirement

All full-time students should register for and attend the departmental seminar series (MAE 503-504). In cases where courses or formal assignments preclude regular attendance at the seminar, students may be excused. It is required that full-time M.S. students sign up for two semesters of seminar during their degree programs and that Ph.D. students take an additional two semesters. All students are encouraged to attend seminars, whether registered or not.

II. Masters Program Information

2.1. Masters Degree Programs

For Master of Science degrees in Mechanical Engineering or Aerospace Engineering the overall credit requirement is a minimum of 30 semester credit hours. Three options exist in each program: a six-credit Thesis plus at least eight courses of three credits each; a three-credit Project plus at least nine courses of three credits each; or, the all-course option which consists of at least ten approved graduate courses of three credits each, plus a final comprehensive examination. Students receiving financial support (TA, RA or GA) through the department are **required** to do the Thesis option, except if they enter the Ph.D. program by passing the Ph.D. qualifying exam and do a dissertation.

The Mechanical Engineering and Aerospace Engineering Master of Science program has no core course requirements. However, at least 50% of the student's program must be MAE courses. Aerospace Engineering Masters students are also required to select at least three courses from

the Aerospace Engineering program courses listed in Sec. 2.2. Exceptions to this require the permission of the Department Chair or the Director of Graduate Studies.

The M.S. programs have no formal core course requirements. However, any student seriously considering a Ph.D. should consider taking the courses required by the Ph.D. qualifier. In general, students specializing in the following areas should consider taking the courses listed below:

Fluid and Thermal Sciences
Fluid Mechanics (MAE 515, 516)
Heat Transfer (MAE 545, 546)

Computational and Applied Mechanics
Advanced Mechanics of Solids (MAE 505/CIE 511)
Finite Elements (MAE 529)

Materials
Advanced Materials (MAE 581)
Thermodynamics of Materials (MAE 570)
Diffraction (MAE 589)

Dynamics and Control
Systems Analysis (MAE 571)
Vibration and Shock (MAE 567)

Design
Optimization in Engineering Design (MAE 550)
Computer Aided Design (MAE 577)

Bioengineering
Cardiovascular Biomechanics (MAE578)
Evaluation of Biomedical Materials (MAE 514)

Students in all areas may also benefit by taking an applied mathematics course (e.g. MAE 507).

Subject to the foregoing requirements, graduate courses may be taken from other departments in Engineering or the School of Arts and Sciences (e.g. Physics, Chemistry, Geology, Biology, Mathematics, etc.), in consultation with advisor.

Graduate courses from other Faculties, such as Health Sciences, for example, may also be taken. However, students should have the ***explicit approval*** of their academic advisor and the Director of Graduate Studies ***before*** taking such courses.

As described in Section 1.9 above, M.S. students may undertake a maximum of two informal courses under faculty supervision, each study counting for a maximum of three credit hours. Also, as noted previously in Sec. 1.9, a maximum of two advanced undergraduate (400-level) courses may be taken for graduate credit for M.S. and Ph.D. degrees upon petition to and approval by the Graduate School at the time of registration. Failure to petition at the time of registration will result in no credit being granted.

Students who have previously completed graduate courses at other universities may, at the discretion of the department, receive transfer credit for a maximum of two three-credit-hour courses or six credit hours. The student should have received a grade of “B” or better to transfer the course(s).

a) Master of Science Degree with Thesis: The minimum requirements consist of at least eight approved graduate courses (24 to 27 credit hours) and 3 to 6 credit hours of thesis registration, for a total of 30 credit hours. One semester before the degree is to be conferred, the student must submit an Application to Candidacy form. Informal courses (section 1.9) listed in the Application to Candidacy must be accompanied by complete narrative descriptions signed by the instructors. The Application to Candidacy is then approved by the Director of Graduate Studies and submitted to the Graduate School for approval by the Executive Committee of the Graduate School.

The department must approve and notify the Graduate School in writing when major changes in the program, such as a change in Thesis title, are made.

The thesis may cover a variety of activities, including theoretical and experimental investigations, practical design projects, and the like. The nature of these activities may vary greatly, but no essential difference should exist in equality and significance as a contribution to engineering. The thesis should be carefully prepared as indicated below. Three people, qualified to render judgment in the area involved, constitute the thesis examination committee: the advisor plus two other faculty members. The candidate makes an oral presentation at which the examination committee is present in addition to other interested faculty and students. Advance notice of the oral defense must be sent to all department members at least one week prior to the presentation.

Following a successful oral defense, the examination committee certifies approval of the thesis by signing the Graduate School "M" form, and the advisor reports the thesis grade (if it needs to be changed).

The typing and detailed format and arrangement of the M.S. thesis as well as the hard-cover binding are to be the same as prescribed for the Ph.D. dissertation in Sec. 3.4. After final corrections have been made, the student submits **one** spiral-bound copy of the thesis to the department and usually at least one bound copy to the advisor. The student also submits the thesis electronically; see http://www.grad.buffalo.edu/etd/ for details. Costs of thesis printing, copying, and binding are paid by the student. The department sends the signed "M" form to the Graduate School. **All materials must be in the Graduate School Office on or before the degree conferral deadlines established each year by the Graduate School**.

b) Master of Science Degree with Project: The minimum requirements consist of nine approved graduate courses (27 credit hours) and 3 credit hours of project registration (under MAE 560) for a total of 30 credit hours. One semester before the degree is to be conferred, the student must submit an Application to Candidacy form (see http://www.grad.buffalo.edu/forms/students/atc.pdf) which includes a summary of courses to be applied toward the degree. Informal courses (section 1.9) listed in the Application to Candidacy must be accompanied by complete narrative descriptions signed by the instructor. The Application to Candidacy is then approved by the department Director of Graduate Studies and submitted to the Graduate School for approval by the Executive Committee of the Graduate School.

The project should be carefully prepared, and must be typed and bound as indicated below. Two people, qualified to render judgment in the area involved, constitute the project examination committee: the advisor plus one other faculty member. The candidate makes an oral presentation at which the examination committee is present in addition to other interested faculty and students. Advance notice of the oral defense must be sent to all department members at least one week prior to the presentation.

The requirements and procedures for the three-credit Project are as follows:

i) The Project must be done under the supervision or advisement of a Mechanical and Aerospace Engineering Department graduate faculty member, although it can be initiated by a student.

ii) A typed report of substantial length is required, written to a satisfactory standard as judged by the faculty advisor, with one spiral-bound copy to be submitted to the MAE department (for retention). The detailed format and arrangement of the report should be the same as prescribed for the M.S. thesis.

Following a successful oral presentation, the advisor certifies approval of the project by signing the Graduate School "M" form.

c) All-Course Master of Science Degree with Comprehensive Examination: The requirements of this option are at least ten approved graduate courses of three credits each, plus a final comprehensive examination. The general regulations and guidelines governing program course content are the same as for the M.S. Thesis and Project options.

The comprehensive exam for the All-Course option is an oral exam in the area of the student's specialization conducted by a committee of at least two faculty members of the department. Upon approval from the Director of Graduate Studies the student forms the examination committee, and arranges for notice of the exam to be sent to all faculty members of the department at least one week in advance. Any faculty member may attend the exam. The result of the exam is to be communicated by the examination committee to the Director of Graduate Studies.

d) Dual M.S. Degrees: It is possible for a student to complete a program leading to two M.S. degrees, for example, the Mechanical Engineering and Aerospace Engineering degrees described, or one of those and a second degree from another engineering discipline and department. The guideline governing such a program is that the integrity of each degree must be observed. This will usually mean that a minimum of 24 semester hours of credit must be completed **for each degree** and that 6 semester hours may be applied to both programs. In some cases the curriculum will contain prescribed courses which are common to both programs. Such common courses may be counted for both degree programs. See also information on the Graduate School site at http://www.grad.buffalo.edu/academics/combined.php.

e) Deadlines: In order that students receive their degrees when expected it is necessary that certain deadlines be met in their programs (see http://www.grad.buffalo.edu/policies/deadlines.php). It is the student's responsibility to be cognizant of these deadlines and ensure that they are met.

III. Doctoral Program Information

3.1. Ph.D. Degree Programs

The minimum requirements for both the Mechanical Engineering and the Aerospace Engineering Ph.D. programs consist of a minimum of 48 credit hours of graduate course work and 12-24 credit hours of dissertation work, for a total of 72 credit hours. A maximum of six credit hours of the 48 credit hour course requirement may be fulfilled by M.S. Thesis (six (6) credit hours) or M.S. Project (three (3) credit hours) completed at the University at Buffalo. Transfer credit policy for students entering with an M.S. degree from outside the Department was stated previously in Sec. 1.8. Effective Fall 2007, all PhD students must have taken the Graduate Record Exam (GRE).

Normally, at least three academic years of full-time graduate study, beyond the baccalaureate degree, are required to complete the Ph.D. degree requirements. The selection of the program of courses and the student's dissertation research are under the supervision of a Ph.D. program committee chaired by the student's advisor.

Students Entering Ph.D. Program With M.S. degree

Students who already have a Masters degree, an outstanding academic background and highly interested in research can pursue their Ph.D. degree by entering the Ph.D. program. All applicants to the Ph.D. program must take the GRE before their application to the program can be assessed.

Students Entering Ph.D. Program Without M.S. degree

Students with outstanding undergraduate studies and a high level of interest in research can pursue their Ph.D. degree by directly entering the Ph.D. program. During this pursuit, if the student wishes to take M.S. instead of Ph.D. for special reasons, they need to first seek for the approval from their advisor. The request needs to be submitted by the advisor to Graduate Studies Committee for final approval.

Ph.D. Program for Continuing Students

Students completing the M.S. program in UB's MAE department who wish to proceed to the Ph.D. program must re-apply following the standard admission procedure. All applicants to the Ph.D. program must take the GRE before their application to the program. This requirement holds even if the applicant previously earned an M.S. degree or equivalent at UB or elsewhere and had not taken the GRE.

Qualification for the Ph.D. programs is through a qualifying examination. Details of this examination, the Ph.D. program committee, and the final dissertation examination (oral defense by the student) are described below.

The Ph.D. qualifier format has recently changed.

See 3.2.a and 3.2.b for details of each format. The exam will still be given at the end of the Spring semester. Note that under the new format outside courses are no longer required, although specific areas still have required courses. Many students may have already taken some outside area courses to meet the old format requirements. Therefore, we are allowing every Ph.D. student to decided which format to take for the next exam (offered in 2013), whether you have taken outside area courses or not. If you can't decide which format to take then please consult your Ph.D. advisor.

3.2.a Qualifying Examination - OLD FORMAT

Each student desiring to become a Ph.D. candidate in the department must pass a Ph.D. qualifying examination. The qualifier will be given at the end of the academic year, in May. **The date will be announced at the beginning of the Spring semester.** Qualifier tests normally last 3-4 hours, and details depend on the specific focus area, as described in detail below. Students should take the exam at their first opportunity after having been accepted by the department into

the Ph.D. program. Students entering the Ph.D. program with a M.S. degree should take the qualifying exam at the end of their first year of Ph.D program. However, students who enter the Ph.D. program without M.S. degree can take qualifying exam either at the end of their first year of Ph.D program or at the end of the second year, as advised by the advisor.

The qualifying exam in each focus area is organized and administered by an ad hoc examination committee of department faculty members. The committee consists of a chair who has overall responsibility for the exam, and at least two faculty members from that focus area in which a specialty exam is given. The qualifying examination is the same for Mechanical Engineering and Aerospace Engineering students.

The subject level of the exams may include undergraduate and introductory graduate level material. Students will be asked to declare their exam areas prior to the qualifying exam. Students are strongly advised to review the exam contents (courses, topics, references) provided below.

Following completion of the written and oral exams the examination committee reaches a decision as to whether each candidate has passed or failed. In the case of a failure, the committee decides whether or not the candidate should be permitted a second opportunity, which is limited to retaking the entire exam, both written and oral. Candidates who fail without being granted a second try, or those who fail twice, must necessarily be dropped from the program.

a) <u>Focus Areas:</u>

The student, in advisement with advisor, will select the focus area. Students will be asked to identify their focus area at the start of their PhD program. There are five focus areas as listed below:

Bioengineering **(BIO)**
Computational and Applied Mechanics **(CAM)**
Fluid and Thermal Sciences **(FTS)**
Materials **(MAT)**
Dynamics/Control and Design **(DCD)**

b) <u>Qualifying Exam Format:</u>

i) Course requirements for qualifying exam: Each focus area of MAE lists courses as their fundamental/core courses.
<u>Courses by area</u>:

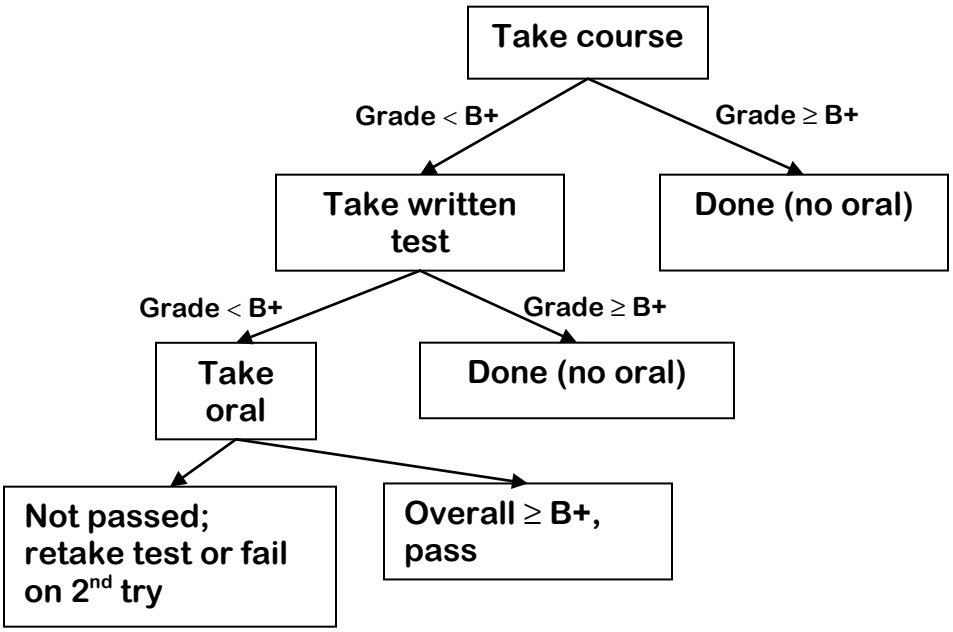
BIO: MAE 514 Evaluation of Biomaterials, MAE 578 Cardiovascular Biomechanics
CAM: MAE 505/CIE CIE 511 Advanced Mechanics of Solids, MAE 529 Finite Elements
FTS: MAE 515 Fluids 1, MAE 545 Heat Transfer I
MAT: MAE 581 Advanced Materials, MAE 589, Diffraction, MAE 570 Thermodynamics, MAE 538 Smart Materials, MAE 587 Solid State Materials
DCD: MAE 550 Optimization in Eng'g Design, MAE 571 Systems Analysis I

Students who select BIO, CAM, FTS, or* DCD *as a focus area take all the courses in their focus area listed above. In addition, the student selects one listed course from any 2 of the remaining areas listed above. In addition, all students will take MAE 507 Eng'g Analysis I. This means that each student will take a total of 5 of the listed courses (2 from their Focus area and 2 from other listed areas, plus a mathematics course). ***For students who select Materials (MAT)***

as a focus area, they are required to take three of the five courses listed above in MAT. In addition, MAT students will select one course from among the remaining areas listed above.

For any Focus Area, if a specified course is not available in a given year, the group will propose a substitute. This will be announced before the beginning of the Fall semester.

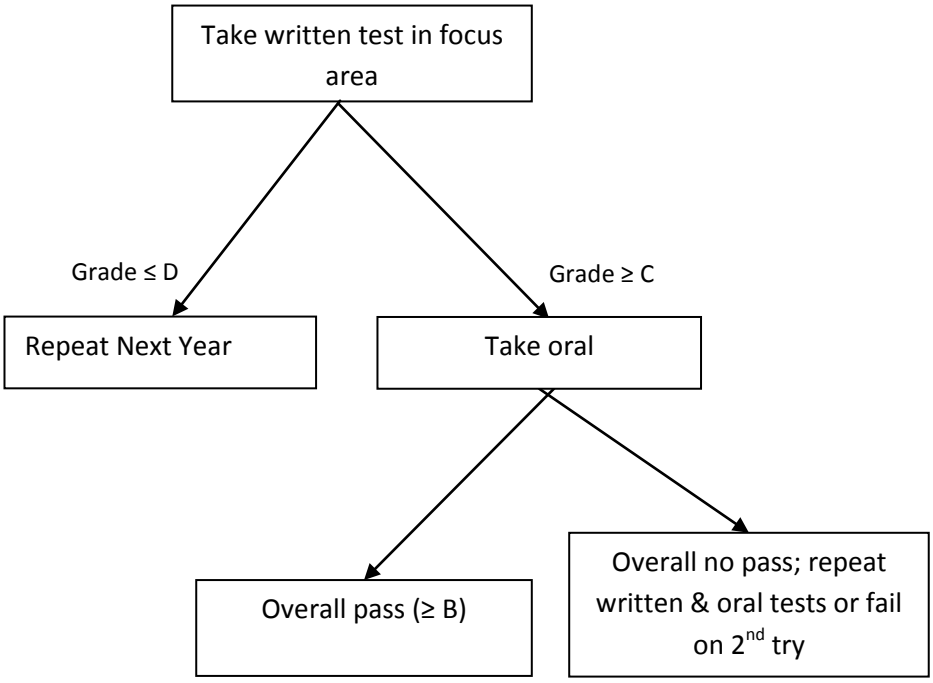
ii) Grade requirements for courses taken outside the focus area, including the mathematics course: Students must earn a B+ or better grade in the required course they have selected outside their focus area. If they get a B+, they have completed their responsibility in that course. If they do not, they will be given an additional written test. This test is to be given within approximately 2 weeks after the end of the semester in which the course is offered, and given by the instructor of that course. If the student does not achieve a B+ overall in that course, he/she will be given an oral exam. Should this fail, the student will repeat the test the following year. If the student fails to achieve a B+ in the following year, he/she has failed the qualifier and will be dismissed from the program. This can be summarized by the figure below.



Figure—Sequence for courses taken outside the focus area

iii) Qualifier Procedure: The student takes required courses in the focus area, plus any additional materials that focus area requires. There is both an oral and a written component to the qualifier exam. If the student does not pass on the first try, he/she will repeat the qualifier exam the following year. If the student fails again, the student will be dismissed from the program. The significance of the written grades is as follows: A – superior, B – pass, C - fail, but make sure with an oral exam, D - fail, no oral (repeat next year, if first fail). **All students with a grade of C or better take an oral exam.** For a grade of C on the written qualifying exam, a pass would require a strong performance on the oral. At least two faculty members would administer the exam. The advisor is invited to attend the oral exam but is not an active examiner or participant. It is not required that the advisor attend. The examiners decide whether a student passes or fails based on the written and the oral exams. The examination committee can prescribe additional written or course work as conditions for the student to pass the qualifier test

The working of the qualifier in the focus area can be summarized by the figure below.



Figure—Qualifier Procedure

If the student fails to achieve a B in the following year, he/she has failed the qualifier and will be dismissed from the program.

iv) Transfer students: Students who have earned a M.S. or equivalent degree from outside MAE at UB and then are admitted to the Ph.D. have the same qualifier requirements as described above. If they have already taken and performed satisfactorily in one or more of the non-focus area courses, they will simply take the written test in those non-focus areas, administered by the faculty member who has taught that course in the year of the test. If they have already taken and performed satisfactorily in their focus area, they need not repeat these courses but must pass the qualifying exam.

v) <u>Qualifying Examination Detail Requirements (by area):</u>

<u>Bioengineering (BIO):</u>

<u>Required Courses:</u>

Cardiovascular Biomechanics (MAE578)
Evaluation of Biomedical Materials (MAE 514)

<u>Topics from MAE578:</u>

- Cardiovascular system and physiology of the heart
- Physical principles of circulation
- Properties and rheology of blood
- Mechanical properties of blood vessels
- Steady flow models

- Unsteady flow models
- Interaction of wall shear stress with endothelial cells
- Vascular remodeling
- Flow and vascular pathology

Topics from MAE 514:

- Characteristics of specific polymer, metal, ceramic, and engineered tissue materials used for various types of medical, dental and diagnostic devices;
- Selection criteria based on intended biological functions and longevity;
- Performance testing *in vitro* and *in vivo*;
- Evaluation of material breakdown in biological media, and potential toxicologic consequences; (5) design of animal and clinical trials;
- Surgical considerations; and
- Ethical, regulatory, and legal issues.

Suggested Text: Handbook of Biomaterials Evaluation: Scientific, Technical, and Clinical Testing of Implant Materials, AF von Recum (editor), MacMillan Publishing Co., 1986.

Computational and Applied Mechanics (CAM):

Required Courses:

CIE 511/MAE 505, MAE 529

Suggested course:

MAE 415

Topics/subtopics:

- Cartesian Tensors: operations; integral theorems; invariants
- Stress: transformation, equilibrium, traction (Cauchy)
- Strain: infinitesimal displacement gradient, rotation, and strain; compatibility (simply connected); transformation
- Constitutive Relations: Hooke's law for isotropic and anisotropic materials; relation of constants; engineering constants; thermal effects; yield surfaces (von Mises, Tresca)
- Boundary Value Problems: posing and solving basic problems (exact solutions)
- Structural Elements (approximate solutions): Euler Bernoulli beam theory, plane strain/plane stress, buckling
- Energy Methods: Castigliano 2nd theorem; virtual work; minimum potential energy; derivation of differential equation and admissible boundary conditions from minimum potential energy; approximate methods (Rayleigh-Ritz)
- Finite Element Methods: Spatial discretization and element definitions; assembly and solution algorithms; isoparametric element formulations; mixed formulations; temporal discretization and transient solution algorithms; natural frequency analysis; error analysis for static and dynamic problems

Suggested Texts/chapters:

- I.H. Shames, F.A. Cozzarelli, *Elastic and Inelastic Stress Analysis* (1992 or revised printing 1997), Chapters 1-5, 9-10, 12-13.
- A.C. Ugural, S.K. Fenster, *Advanced Strength and Applied Elasticity*, 4th ed. (2008), Chapters 1-4, 8, 10-11.
- J.R. Vinson, *The Behavior of Thin Walled Structures* (1989), Chapters 1-3, 7, 9.
- T.H.G. Megson, *Aircraft Structures*, 4th ed. (2007), Chapters 1-2, 4.
- T.J.R. Hughes, *The Finite Element Method* (2000), Chapters 1-4, 7-10.
- K.-J. Bathe, *Finite Element Procedures* (1996), Chapters 1-5, 8-11.

Fluid and Thermal Sciences (FTS):

Required Courses:

MAE 515, Fluid Mechanics I
MAE 545, Heat Transfer I

Suggested courses:

EAS 204, MAE 422, MAE 431, MAE 335, MAE 336, MAE 516, MAE 519, MAE 546

Required texts/chapters:

I Shames, "Mechanics of Fluids"
I.G. Currie, "Fundamental Mechanics of Fluids", 3rd edition
Incropera, Dewitt, Bergman, and Lavine, "Introduction to Heat Transfer", 5th ed.
Moran and Shapiro, "Fundamentals of Engineering Thermodynamics"

Additional suggested texts:

S. Kakac and Y. Yener, "Heat Conduction", 4rd edition
S. Kakac and Y. Yener, "Convective Heat Transfer", 2nd edition
Alexander J. Smits, "A Physical Introduction to Fluid Mechanics"

Topics/subtopics:

Fluid Mechanics:

- Fundamentals: flow kinematics, conservation equations
- Ideal flow: basic theory, elementary solutions, superposition, complex potential
- Viscous flow: Navier Stokes equations, exact solutions, low-Reynolds number flows, boundary layer flows
- Compressible flow: Shock waves, expansion waves, one dimensional flows
- Turbulent flow: Statistical description of turbulent flows, governing equations, free shear flows, scales of turbulent motion, wall flows

Heat Transfer:

- Fundamentals: physical origins, rate equations, 1st Law, control volume analysis
- Conduction: steady, transient, multidimensional, approximate techniques

- Convection: natural, forced, laminar and turbulent boundary layers; integral techniques; mathematical solution or developing internal flows; dimensionless groups, correlations
- Radiation: blackbody, view factor, spectral intensity, spectral and total properties, diffuse-gray enclosures
- Phase change: latent heat, condensation, boiling, physics of various regimes; exact, similarity solutions; Nusselt condensation analysis

Thermodynamics:

- Energy forms: potential, kinetic and internal; energy transfer - work and heat, equivalence; properties of ideal gases - concept; equation of state; pressure, temperature, internal energy specific heat
- Energy conservation: first law for closed and open systems (control volume); enthalpy and flow work; unsteady and steady state
- First law for ideal gas-closed systems: constant T, p or v processes; adiabatic reversible processes; polytropic processes; Carnot cycle; open system steady flow processes; unsteady or transient flow processes
- Entropy and second law: definition of entropy; entropy change of ideal gases; isentropic processes of ideal gases; the TdS relations; irreversible effects and entropy production; statement of the second law of thermodynamics; availability
- Gas power and refrigeration systems

Materials (MAT):

Required Courses*:

Advanced Materials Science (MAE 581)
Smart Materials (MAE 538)
Thermodynamics of Engineering Materials (MAE 570)
Diffraction, Microscopy and Spectroscopy Techniques (MAE 589)
Solid State Materials Physics (MAE 587)

Topics from MAE 581:

- CRYSTAL STRUCTURE: lattice and basis, types of lattice, index system for crystals.
- CRYSTAL BINDING: Van der Waals, Covalent, ionic, and metallic, equilibrium lattice constants.
- DEVIATION FROM IDEAL CRYSTAL STRUCTURE: point and line defects, point defects in ionic crystals, equilibrium point defect density.
- NUCLEATION AND GROWTH: first principle calculations of embryo and nucleus during phase growth and resulting microstructure.
- PHASES IN n-COMPONENT SYSTEM: phase and phase diagrams for a n-component system (n = 1, 2, or 3), solid solutions, phase rule, thermodynamics for materials.

In addition, MAE 381 or equivalent is the pre-required course.

Topics from MAE 538:

This course covers the science and applications of smart materials, which include functional and multifunctional materials. Emphasis is on materials that enable a structure to be smart, e.g.,

having the ability to sense and respond appropriately. The attributes sensed include strain, stress, damage and temperature. The response includes actuation. In relation to sensing, nondestructive evaluation will be covered. Other functions include electromagnetic interference shielding, deicing, energy conversion, etc. The fundamentals of composite materials will also be covered. The course assumes a prior course on introductory materials science. The topics include:

- Composites and carbon fibers
- Intrinsically smart polymer-matrix structural composites
- Intrinsically smart cement-matrix composites
- Materials characteristics including Electrical behavior, Electromagnetic, Dielectric, Magnetic and optics
- Shape memory
- Nondestructive evaluation
- Vibration damping

Topics from MAE 589:

This course covers experimental methods for the study of engineering materials. The objective is for the students to understand the array of methods that are available, thereby becoming able to choose a suitable method for the study of a particular aspect of a given material. The topics include:

- Reciprocal lattice
- Diffraction theory and methods
- Microscopy concepts and techniques
- Scientific concepts behind spectroscopy techniques involving electromagnetic radiation, electrons and ions.

Topics from MAE 570:

- First and Second Laws of Thermodynamics; Entropy generation
- General framework of classical thermodynamics
- The required interrelationships between variables and their derivatives
- Expression of thermodynamic functions in terms of arbitrary sets of variables
- Consideration of various types of work (energy): fluid, solid, chemical, surface, electric, magnetic, EM waves;
- Interactions between the various types of work (energy)
- Equilibrium in pure (unary) and multicomponent systems: phase stability, metastability, and instability; construction and interpretation of phase diagrams.
- elementary principles of statistical thermodynamics and atomic/molecular mechanics; prediction of thermodynamic properties from first principles.

Topics from MAE 587:

- Quantum Mechanics principles for functional materials
- Energy band structure and electron transport theory
- Crystal vibration and phonons: heat capacity and thermal conductivity
- Electronic, optical, and magnetic properties of metals, semiconductors, and insulators materials
- Nano-material synthesis and dimensional effects on nanosystems: thin film, nano-wire, and nano-dots
- Materials principles for modern devices development

** All five courses may not be available each year. However, course availability will be announced each April for the following academic year. The requirements for the Qualifying Exams will reflect the courses offered in that year.*

Dynamics/Control and Design (DCD):

The qualifying exam for the Dynamics/Control and Design area is structured so that all students will have to be familiar with areas A and B below. Typically, there will be two questions each from **A** and **B** plus one or two questions each from areas **C** and **D**, as described below. Normally students will be required to answer a total of four questions.

A. All topics covered by MAE 550 Optimization

B. All topics covered by MAE 571 Systems Analysis

C. Dynamic Systems Topics:

C.1. Kinematic and dynamic modeling of multibody systems

e.g. 1, 2 and higher # of d.o.f. systems such as the inverted pendulum, double pendulum, linkages etc.

Specific subtopics include:

a. Deriving kinematic and dynamic equations-of-motion

b. Linearization/Taylor Series Approximations

c. Equilibrium and stability analysis

Courses covering these topics: EAS 208 Dynamics, MAE 412/512 Machines and Mechanisms II or MAE 493/593 Mathematical Methods in Robotics

C.2. Analysis of systems of ordinary differential equations

d. Time-domain/analytical solution methods (1^{st} order and 2^{nd} order, free/forced systems)

e. Numerical solution methods (via conversion into state-space form)

f. Frequency domain methods (via Laplace transform)

Courses covering these topics: MAE 340 System Dynamics or MAE 467/567 Vibrations or MAE 443/543 Control Systems

C.3 Control system design and analysis

g. Stability analysis (poles/zeros)

h. Controller characteristics and design (PD/PID)

i. Analysis (Bode/Root locus)

Courses covering these topics: MAE 443/543 Control Systems

D. Design Topics:

D.1. Matrix-based computations, e.g. as applied to Computer Graphics

a. Fundamentals of 2-D and 3-D Graphics: translations and rotation

b. Representation of solids, coordinate system transformations

c. Curve and surface generation (Bezier and B-Spline approaches)

Courses covering these topics: MAE 473/573 Graphics in CAD or MAE 474/574 Virtual Reality or MAE 493/593 Mathematical Methods in Robotics

D.2. Computational functional analysis as applied to design

Concepts of FEM: stiffness matrices for elements and systems, basics of variational approach, solution concepts for deflections, stress, etc., von Mises failure concepts

Courses covering these topics: MAE 529 Finite Element Structural Analysis or MAE 541 Topics in Finite Element Analysis

Please note that you do not have to take these courses noted in sections C & D if you have previously taken equivalent courses. However, it is suggested that you review syllabi from these UB courses and plan your course-of-study to make sure that you are familiar with the topical materials C-D prior to the qualifier.

vi) Examples of the previous qualifying exams in all areas can be found at: http://www.mae.buffalo.edu/current/phd_exams.php.

3.2.b Qualifying Examination - NEW FORMAT

Each student desiring to become a Ph.D. candidate in the department must pass a Ph.D. qualifying examination. The qualifier will be given at the end of the academic year, in May. **The date will be announced at the beginning of the Spring semester.** Qualifier tests normally last 5-6 hours, and details depend on the core and specific focus areas, as described in detail below. Students should take the exam at their first opportunity after having been accepted by the department into the Ph.D. program. Students entering the Ph.D. program with a M.S. degree should take the qualifying exam at the end of their first year of Ph.D. program. However, students who enter the Ph.D. program without M.S. degree must take qualifying exam either at the end of their first year of Ph.D. program or in rare cases at the end of the second year with the explicit permission of the advisor and graduate chair.

The qualifier exam is made up of two parts. The qualifying examination is the same for Mechanical Engineering and Aerospace Engineering students and all students are required to take both parts. The first part tests the student's knowledge in 3 basic areas: 1) statics/dynamics, 2) thermodynamics, and 3) solid mechanics. The material for each is based on sophomore level courses found in most Mechanical and Aerospace Engineering programs.

The second part tests the student's knowledge in his/her specific focus area. The qualifying exam in each focus area is organized and administered by an ad hoc examination committee of department faculty members. The focus area committee consists of a chair, who has overall responsibility for the exam, and at least two faculty members from that focus area in which a specialty exam is given. The subject level of the focus area exam may include undergraduate and introductory graduate level material. Students will be asked to declare their focus area prior to the

qualifying exam. Students are strongly advised to review the exam contents (courses, topics, references) provided below.

Qualifying Exam Format:

a) Part I Core MAE Requirement: Each student will be required to take the core MAE requirement part of the qualifier exam, which consists of 3 basic areas: 1) statics/dynamics, 2) thermodynamics, and 3) solid mechanics. Students choose 2 out of the 3 areas at the time of exam to be tested on, but it is highly suggested that students prepare for all 3 basic areas before the exam is administered (i.e., it is desired that students be knowledgeable in all 3 areas but he/she can choose which 2 areas to take during the exam). **Students must obtain a B or higher in each of the 2 chosen areas to pass Part I**. For example, if a student obtains an A on one portion and a C on the other portion then the student has still failed Part I of the qualifier exam. If the student is allowed to retake the exam the following year then the entire Part I exam is retaken, not just portions of it. No oral exam is required for Part I. Specific topics for each area are listed below.

i) Statics/Dynamics Topics

- Statics
  - Elements of Vector Algebra
  - Equivalent Force Systems
  - Equations of Equilibrium
  - Introduction to Structural Mechanics
  - Friction Forces
  - Properties of Surfaces
  - Moments and Products of Inertia
  - Methods of Virtual Work
  - Stationary Potential Energy
- Dynamics
  - Kinematics of a Particle
  - Particle Dynamics
  - Energy Methods for Particles
  - Methods of Momentum for Particles
  - Kinematics of Rigid Bodies
  - Kinetics of Plane Motion of Rigid Bodies
  - Energy and Impulse-momentum Methods for Rigid Bodies
  - Dynamics of General Rigid-Body Motion
  - Vibrations

Suggested Texts:

Engineering Mechanics: Statics and Dynamics, Bedford and Fowler

Engineering Mechanics: Dynamics, Meriam and Kraige

Vector Mechanics for Engineers: Statics and Dynamics, Beer and Johnston

Engineering Mechanics: Statics and Dynamics, Hibbeler

Engineering Mechanics: Statics and Dynamics, Plesha, Gray, and Costanzo

ii) Thermodynamics Topics

- First and Second Law of Thermodynamics
  - Mass, Energy, and Entropy Balance
  - Kelvin-Planck and Clausius Statements of Second Law of Thermodynamics
  - Carnot Heat Pump, Refrigerator, and Heat Engine
- Determination of Properties of a Pure Substance
  - Using a Table
  - Equations of State
- Analysis of Open and Closed Systems
  - Boundary Work
  - Efficiency
  - Isentropic Relationships
- Analysis of Cycles
  - Power Cycles: Carnot, Otto, Diesel, Gas-Turbine
  - Net Work
  - Thermal Efficiency

Required texts/chapters:

Thermodynamics: An Engineering Approach by Cengel and Boles, Chapters 1-7 and 9

Additional suggested texts:

Fundamentals of Engineering Thermodynamics by Moran, Shapiro, Boettner, and Bailey

iii) Solid Mechanics Topics

- Axially Loaded Members
- Torsion Shear Forces and Bending Moments
- Stresses in Beams (Basic Topics)
- Pure Bending and Non-Uniform Bending
- Curvature of a Beam
- Longitudinal Strains in Beams
- Normal and Shear Stresses in Beams
- Stresses in Beams (Advanced Topics)
- Composite Beams
- Bending of Unsymmetric Beams
- The Shear Center Concept
- Analysis of Stress and Strain: principal values and directions, constitutive equations
- Deflections of Beams
- Statically Indeterminate Beams
- Columns

Required texts/chapters:

Mechanics of Materials, Beer, Johnston, DeWolf, Mazurek, 6th ed, McGraw-Hill (2011) entire text, except for sections dealing with plasticity or energy methods (Chapter 11).

Additional suggested texts:

Egor Popov, Engineering Mechanics of Solids 2nd ed (1998) all chapters except 17-20 (except energy methods and plasticity).

b) Part II Focus Area Requirement: The student, in advisement with his/her advisor, will select the focus area. Students will be asked to identify their focus area at the start of their Ph.D. program. There are six focus areas as listed below:

Bioengineering **(BIO)**
Computational and Applied Mechanics **(CAM)**
Design and Optimization **(DO)**
Dynamics and Control **(DC)**
Fluid and Thermal Sciences **(FTS)**
Materials **(MAT)**

There is both a written and oral component to the focus area exam. If the student does not pass on the first try, he/she will repeat the focus area exam the following year. If the student fails again, the student will be dismissed from the program. The significance of the written grades is as follows: A – superior, B – pass, C – fail, but make sure with an oral exam, D – fail, no oral (repeat next year, if first fail). **All students with a grade of C or higher take an oral exam.** For a grade of C on the written focus area exam, a pass would require a strong performance on the oral. At least two faculty members would administer the focus area exam. The advisor is invited to attend the oral exam but is not an active examiner or participant. It is not required that the advisor attend. The examiners decide whether a student passes or fails based on the focus area written and the oral exams. The requirements for each focus area are given below.

i) Bioengineering **(BIO)**

Required Courses:

MAE 578 Cardiovascular Biomechanics
MAE 514 Evaluation of Biomedical Materials

Topics from MAE578:

- Cardiovascular system and physiology of the heart
- Physical principles of circulation
- Properties and rheology of blood
- Mechanical properties of blood vessels
- Steady flow models
- Unsteady flow models
- Interaction of wall shear stress with endothelial cells
- Vascular remodeling
- Flow and vascular pathology

Topics from MAE 514:

- Characteristics of specific polymer, metal, ceramic, and engineered tissue materials used for various types of medical, dental and diagnostic devices;
- Selection criteria based on intended biological functions and longevity;
- Performance testing *in vitro* and *in vivo*;
- Evaluation of material breakdown in biological media, and potential toxicologic consequences; (5) design of animal and clinical trials;
- Surgical considerations; and

- Ethical, regulatory, and legal issues.

Suggested Text: Handbook of Biomaterials Evaluation: Scientific, Technical, and Clinical Testing of Implant Materials, AF von Recum (editor), MacMillan Publishing Co., 1986.

ii) Computational and Applied Mechanics **(CAM)**

Required Courses:

CIE 511 Advanced Mechanics of Solids
MAE 529 Finite Element Structural Analysis

Suggested course: MAE 315 Analysis of Structures or equivalent

Topics/subtopics:

- Cartesian Tensors: operations; integral theorems; invariants
- Stress: transformation, equilibrium, traction (Cauchy)
- Strain: infinitesimal displacement gradient, rotation, and strain; compatibility (simply connected region); transformation
- Constitutive Relations: Hooke's law for isotropic and anisotropic materials; relation of constants; engineering constants; thermal effects; yield surfaces (von Mises, Tresca)
- Boundary Value Problems: posing and solving basic problems (exact solutions)
- Structural Elements (approximate solutions): Euler Bernoulli beam theory, plane strain/plane stress, buckling
- Energy Methods: Castigliano 2nd theorem; virtual work; minimum potential energy; derivation of differential equation and admissible boundary conditions from minimum potential energy; approximate methods (Rayleigh-Ritz)
- Finite Element Methods: Spatial discretization and element definitions; assembly and solution algorithms; isoparametric element formulations; mixed formulations; temporal discretization and transient solution algorithms; natural frequency analysis; error analysis for static and dynamic problems

Suggested Texts/Chapters:

I.H. Shames, F.A. Cozzarelli, Elastic and Inelastic Stress Analysis (1992 or revised printing 1997), Chapters 1-5, 9-10, 12-13.
A.C. Ugural, S.K. Fenster, Advanced Strength and Applied Elasticity, 5th ed. (2012), Chapters 1-5, 8, 10-11.
K.-J. Bathe, Finite Element Procedures (1996), Chapters 1-5, 8-11.
J.N. Reddy, Introduction to the Finite Element Method, 3rd ed. (2005) entire text.

iii) Design and Optimization **(DO)**

Required Course:

MAE 550 Optimization in Engineering Design

Topics/subtopics:

- Computer Aided Design and Modeling
  - Matrix-based computations e.g. as applied to Computer Graphics

- Fundamentals of 2-D and 3-D Graphics - translations and rotation
- Representation of coordinate system and transformations
- Curve and surface generation (Bezier, B-Spline approaches, NURB)
- Solid modeling principles: Boundary representation, CSG, Parametric modeling
- Basics of CAD-CAM systems including CNC machines and part programing

Courses covering these topics: MAE 473/573 Graphics in CAD, MAE 474/574 Virtual Reality, MAE 464/564 Manufacturing Automation or MAE 493/593 Mathematical Methods in Robotics

- Design and Optimization
  - Design process fundamentals
  - Requirements development
  - Conceptual and Embodiment Design
  - Mathematical modeling and optimization formulations
  - Zero-, First-, and Second-order methods
  - Constrained and unconstrained methods and optimality conditions

Courses covering these topics: MAE451 Design Process and Methods, MAE 550 Optimization in Engineering Design, MAE551 Advanced Design Theory

Suggested Texts/Chapters:

- Computer Graphics and Geometric Modeling for Engineers, V. Anand, John Wiley and Sons
- The Mechanical Design Process, D. Ullman, McGraw-Hill
- Engineering Optimization: Methods and Applications, A. Ravindran, K. M. Ragsdell, and G. V. Reklaitis, Wiley.

Additional Suggested Texts:

- Systems Approach to Computer-Integrated Design and Manufacturing, N. Singh, Wiley and Sons

iv) Dynamics and Control **(DC)**

Required Courses:

MAE 550 Optimization in Engineering Design
MAE 571 Systems Analysis

Topics/subtopics:

- Kinematic and dynamic modeling of multibody systems (MODELING)
  e.g. 1, 2 and higher number of d.o.f. systems such as the inverted pendulum, double pendulum, planar and simple spatial linkages etc. Specific subtopics include:
  a. Rigid-body motion
  b. Deriving kinematic and dynamic equations-of-motion
  c. Linearization/Taylor series approximations
  d. Equilibrium and stability analysis
- Analysis of systems of ordinary differential equations (ANALYSIS)
  a. Time-domain/analytical solution methods (1^{st}-order and 2^{nd}-order, free/forced systems)
  b. Numerical solution methods (via conversion into state-space form)
  c. Frequency domain methods (via Laplace transform)

- Control system design and analysis (CONTROL)
  a. Stability analysis (poles/zeros)
  b. Controller characteristics and design (PD/PID)
  c. Analysis (Bode/Root locus)

Suggested courses:
MAE 543 Control Systems, MAE 562 Analytical Dynamics, MAE 566 System Identification, MAE 593 Math Methods in Robotics

v) Fluid and Thermal Sciences **(FTS)**

Required Courses:

MAE 515 Fluid Mechanics I
MAE 545 Heat Transfer I

Suggested Courses:

MAE 204 Thermodynamics I, MAE 335 Fluid Mechanics, MAE 336 Heat Transfer, MAE 422 Gas Dynamics, MAE 431 Energy Systems, MAE 516 Fluid Mechanics 2, MAE 519 Turbulent Flow, MAE 546 Heat Transfer II

Required Texts/Chapters:

I Shames, "Mechanics of Fluids"
I.G. Currie, “Fundamental Mechanics of Fluids”, 3rd edition
Incropera, Dewitt, Bergman, and Lavine, "Introduction to Heat Transfer", 5th ed.
Moran and Shapiro, "Fundamentals of Engineering Thermodynamics"

Additional Suggested Texts:

S. Kakac and Y. Yener, “Heat Conduction”, 4rd edition
S. Kakac and Y. Yener, “Convective Heat Transfer”, 2nd edition
Alexander J. Smits, “A Physical Introduction to Fluid Mechanics”
Kundu and Cohen, “Fluid Mechanics”, 5th edition

Topics/subtopics:

Fluid Mechanics:

- Fundamentals: flow kinematics, conservation equations
- Ideal flow: basic theory, elementary solutions, superposition, complex potential
- Viscous flow: Navier Stokes equations, exact solutions, low-Reynolds number flows, boundary layer flows
- Compressible flow: Shock waves, expansion waves, one dimensional flows
- Turbulent flow: Statistical description of turbulent flows, governing equations, free shear flows, scales of turbulent motion, wall flows

Heat Transfer:

- Fundamentals: physical origins, rate equations, 1st Law, control volume analysis
- Conduction: steady, transient, multidimensional, approximate techniques

- Convection: natural, forced, laminar and turbulent boundary layers; integral techniques; mathematical solution or developing internal flows; dimensionless groups, correlations
- Radiation: blackbody, view factor, spectral intensity, spectral and total properties, diffuse-gray enclosures
- Phase change: latent heat, condensation, boiling, physics of various regimes; exact, similarity solutions; Nusselt condensation analysis

Thermodynamics:

- Energy forms: potential, kinetic and internal; energy transfer - work and heat, equivalence; properties of ideal gases - concept; equation of state; pressure, temperature, internal energy specific heat
- Energy conservation: first law for closed and open systems (control volume); enthalpy and flow work; unsteady and steady state
- First law for ideal gas-closed systems: constant T, p or v processes; adiabatic reversible processes; polytropic processes; Carnot cycle; open system steady flow processes; unsteady or transient flow processes
- Entropy and second law: definition of entropy; entropy change of ideal gases; isentropic processes of ideal gases; the TdS relations; irreversible effects and entropy production; statement of the second law of thermodynamics; availability
- Gas power and refrigeration systems

vi) Materials **(MAT)**

Required Courses:*

MAE 581 Advanced Materials Science
MAE 538 Smart Materials
MAE 570 Thermodynamics of Engineering Materials
MAE 589 Diffraction, Microscopy and Spectroscopy Techniques
MAE 587 Solid State Materials Physics

Topics from MAE 581:

- CRYSTAL STRUCTURE: lattice and basis, types of lattice, index system for crystals.
- CRYSTAL BINDING: Van der Waals, Covalent, ionic, and metallic, equilibrium lattice constants.
- DEVIATION FROM IDEAL CRYSTAL STRUCTURE: point and line defects, point defects in ionic crystals, equilibrium point defect density.
- NUCLEATION AND GROWTH: first principle calculations of embryo and nucleus during phase growth and resulting microstructure.
- PHASES IN n-COMPONENT SYSTEM: phase and phase diagrams for a n-component system (n = 1, 2, or 3), solid solutions, phase rule, thermodynamics for materials.

In addition, MAE 381 or equivalent is the pre-required course.

Topics from MAE 538:

*All five courses may not be available each year. However, course availability will be announced each April for the following academic year. The requirements for the Qualifying Exams will reflect the courses offered in that year.

This course covers the science and applications of smart materials, which include functional and multifunctional materials. Emphasis is on materials that enable a structure to be smart, e.g., having the ability to sense and respond appropriately. The attributes sensed include strain, stress, damage and temperature. The response includes actuation. In relation to sensing, nondestructive evaluation will be covered. Other functions include electromagnetic interference shielding, deicing, energy conversion, etc. The fundamentals of composite materials will also be covered. The course assumes a prior course on introductory materials science. The topics include:

- Composites and carbon fibers
- Intrinsically smart polymer-matrix structural composites
- Intrinsically smart cement-matrix composites
- Materials characteristics including Electrical behavior, Electromagnetic, Dielectric, Magnetic and optics
- Shape memory
- Nondestructive evaluation
- Vibration damping

Topics from MAE 589:

This course covers experimental methods for the study of engineering materials. The objective is for the students to understand the array of methods that are available, thereby becoming able to choose a suitable method for the study of a particular aspect of a given material. The topics include:

- Reciprocal lattice
- Diffraction theory and methods
- Microscopy concepts and techniques
- Scientific concepts behind spectroscopy techniques involving electromagnetic radiation, electrons and ions.

Topics from MAE 570:

- First and Second Laws of Thermodynamics; Entropy generation
- General framework of classical thermodynamics
- The required interrelationships between variables and their derivatives
- Expression of thermodynamic functions in terms of arbitrary sets of variables
- Consideration of various types of work (energy): fluid, solid, chemical, surface, electric, magnetic, EM waves;
- Interactions between the various types of work (energy)
- Equilibrium in pure (unary) and multicomponent systems: phase stability, metastability, and instability; construction and interpretation of phase diagrams.
- Elementary principles of statistical thermodynamics and atomic/molecular mechanics; prediction of thermodynamic properties from first principles.

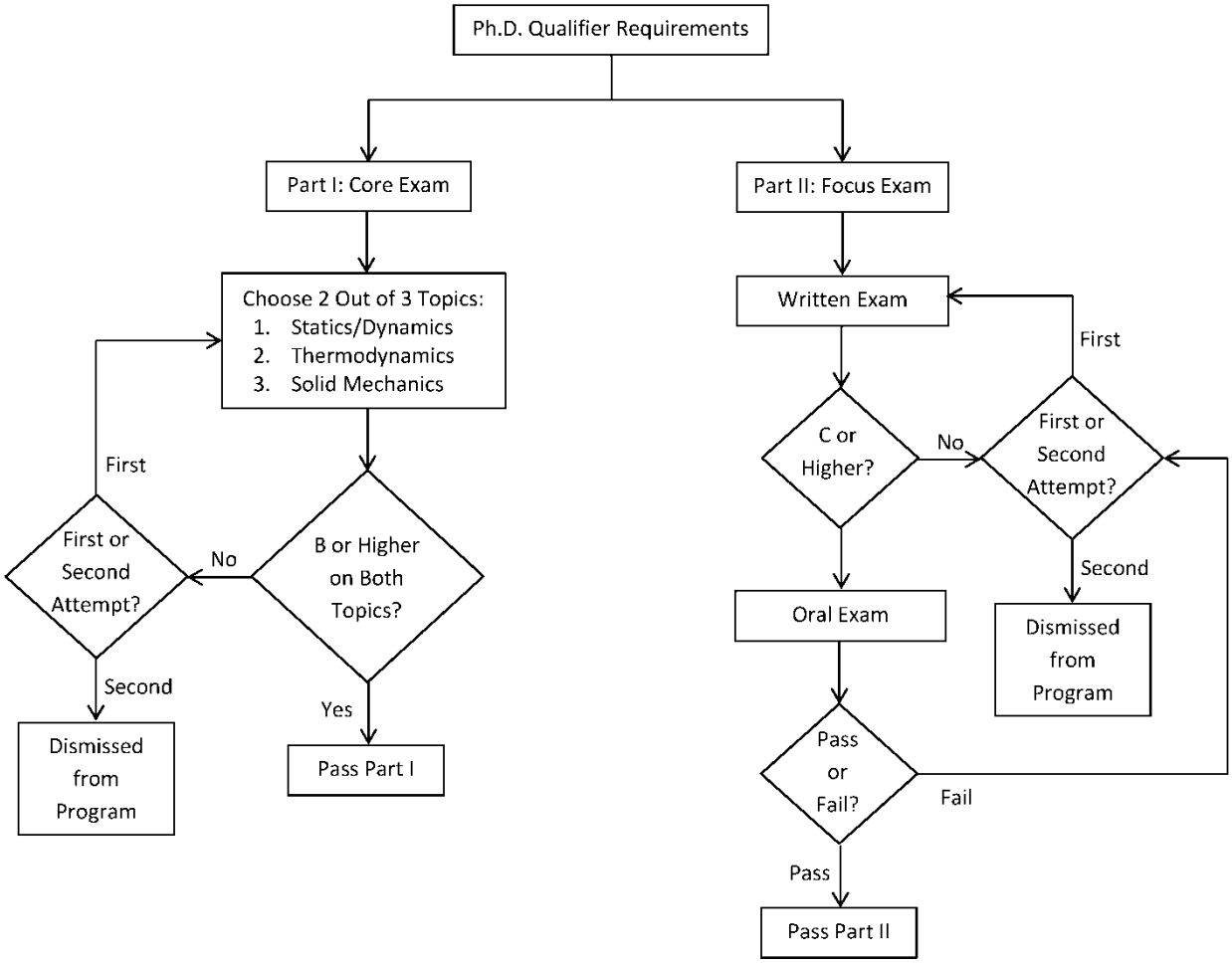
Topics from MAE 587:

- Quantum Mechanics principles for functional materials
- Energy band structure and electron transport theory
- Crystal vibration and phonons: heat capacity and thermal conductivity
- Electronic, optical, and magnetic properties of metals, semiconductors, and insulators materials

- Nano-material synthesis and dimensional effects on nanosystems: thin film, nano-wire, and nano-dots
- Materials principles for modern devices development

Summary of Qualifier Procedure:

The working of the qualifier can be summarized by the figure below:



Following completion of the written and oral exams the examination committee reaches a decision as to whether each candidate has passed or failed. In the case of a failure, the committee decides whether or not the candidate should be permitted a second opportunity for each part. Candidates who fail without being granted a second try, or those who fail twice, must necessarily be dropped from the program.

All students take Part I and Part II of the qualifier exam, which will be given on the same day. For Part I (Core Exam) students choose 2 out of the 3 topic areas during the exam. Students must obtain a B or higher on both topics. If this is accomplished then the student is done with Part I. Otherwise, if the student has taken Part I for the first time, then he/she must retake Part I again the following year. Note that in the following year the student is free to choose 2 topics again, which may be the same or different than the chosen topics from the previous year. If this is the student's second attempt and he/she did not obtain a B or higher on both chosen topics, then the student will be dismissed from the program.

For Part II (Focus Exam) the student first takes a written exam. If the student has achieved a C or higher, then he/she must take the oral exam. If the student passes the oral exam then the student is done with Part II. Should the student not obtain a C or higher on the written exam or should the student fail the oral exam, then if the student is taking Part II for the first time, he/she must retake Part II again the following year. Note that both the written and oral exams must be retaken regardless on how well the student has done on the written exam the previous time. The examination committee can prescribe additional written or course work as conditions for the student to pass the focus area exam, which is left to the discretion of the committee. If the student is taking Part II for the second time and he/she does not pass both the written and oral exams, then the student will be dismissed from the program.

Note that a student does not need to pass both parts in the same year. For example, if a student passes Part I in the first attempt but fails Part II in the first attempt, then only Part II needs to be retaken the following year.

3.3 Other requirements: After successful completion of the qualifying examination, a Ph.D. program committee is formed consisting of three members and chaired by the dissertation advisor. The selection of the program committee members is primarily the responsibility of the candidates and their dissertation advisors.

The student shall prepare a pre-defense presentation to his/her program committee which will include a literature review, research plan, and any preliminary results. This presentation will be given within 12 months after the student successfully passes the Qualifying Exam or within 2 years of being admitted to the Ph.D. program, whichever comes first. The committee will offer written and/or oral comments on the presentation.

The Ph.D. program committee has formal responsibility for the program and guidance of the candidate. During the course of the student's program, one or more progress evaluations should be carried out by the program committee. In the progress evaluation the candidate's course performance will be considered as well as progress made on the candidate's dissertation research. If the committee finds the candidate's progress unsatisfactory, it may recommend corrective action. If the candidate's progress continues to be unsatisfactory, the committee may recommend withdrawal from the University to the Department Chair.

Within one year of passing the qualifying examination, before the completion of eight semesters of graduate study (beyond the B.S.) and no fewer than two semesters (see Section 1.7) before the degree conferral date, the student's Ph.D. program must be approved by the program committee and submitted to the department for approval by the Director of Graduate Studies. The student's Application to Candidacy must include the dissertation title, a 300-400 word dissertation proposal abstract, evidence of full-time residency for at least two semesters, and itemization of at least 72 semester hours beyond the baccalaureate. Courses for transfer credit must be indicated as such on the Application for Candidacy. The approved program is then filed for approval by the Executive Committee of the Graduate School. Approval by the Executive Committee constitutes admission to candidacy. The student notifies the Graduate School by petition when minor changes in the program, such as changes in the dissertation title, or deletion/addition of one or two courses, occur. Major changes in the program, such as research abstract revision, adding or deleting more than two courses or change in major advisor require a petition to be filed through the department graduate office.

All students initially admitted to a Ph.D. program for the Fall 2009 semester or thereafter are required to document successful completion of "Responsible Conduct of Research" (RCR) training when they submit their Application to Candidacy (ATC) for their Ph.D. degree. This training requirement may be fulfilled by either (1.) enrolling in and passing PHI 640 Graduate Research Ethics or RPN 541 Ethics

and Conduct of Research or (2.) completing the Collaborative Institutional Training Initiative (CITI) online Responsible Conduct of Research course with an average score of 80% or higher. Students opting to complete the CITI online course must supply documentation of its successful completion with their Application to Candidacy.

3.4 Dissertation: Each Ph.D. student is required to complete an original dissertation and orally defend his work before the program committee and any other interested parties. Upon completion of the dissertation a draft is submitted to the advisor for comments, corrections, and approval. Graduate School approval of the selection of an outside reader must be obtained before a copy is provided to the outside reader for review. Upon the advisor's approval the student submits copies of the dissertation to the remaining two members of the program committee for their approval and also submits one copy to the outside reader for his/her approval. The outside reader (outside of the department) is selected by the student and his advisor. The outside reader is required to submit his/her approval in writing to the Dean of the Graduate School.

The oral defense consists of a presentation during which the candidates outline the highlights of their work, followed by questions from the program committee or any other interested persons present. Following a successful dissertation defense, the program committee certifies approval of the dissertation by signing the Graduate School M form. The M form must be signed by the Director of Graduate Studies or the Department Chair before being forwarded to the Graduate School.

After the student has made final corrections to the dissertation, the student submits **one** spiral-bound copy to the department and usually at least one bound copy to the advisor. . In addition, the dissertation is submitted electronically; see http://www.grad.buffalo.edu/etd/ for details. This must be done prior to your designated conferral date. ***All materials must be in the Graduate School office on or before the degree conferral deadlines established each year by the Graduate School; see http://www.grad.buffalo.edu/policies/deadlines.php for details***.

The typing and arrangement of Ph.D. dissertations and M.S. theses must meet the requirements of the Graduate School. The Graduate School will accept any self-consistent format which follows the conventions of a recognized discipline. Uniformity is desirable and will be required in the following details:

Pagination: Pages should be numbered consecutively, including not only the principal text but also all plates, tables, figures, etc.

Typing and reproduction: The original of the dissertation must be laser printed, double-spaced, on 8-1/2" x 11", 20-lb. plain white (unlined in any way) bond paper. To allow for binding, the left hand margin must be 1-1/2". Other margins should be 1". Diagrams, photographs, or facsimiles in any form should be a standard page size, or, if large, folded so that a free left-hand margin of 1-1/2" remains and the folded sheet is not larger than the standard page.

The dissertation must conform to permanent record standards. The document submitted to the Graduate School can be either the original or a high quality photocopy. ***Please note: it is illegal to duplicate the University logo/emblem, and therefore, it should not appear anywhere in your body of work.***

The format of the title page (the first page) should be according to the Graduate School web page: http://www.grad.buffalo.edu/etd/etdguide.pdf, p.6.

The dissertation must contain an Abstract, not to exceed 600 words, and a complete table of contents. Bound copies should be bound in hard boards covered with black imitation leather. The title and

author's name should be imprinted on the front in gold. The author's last name, his degree, and the year of conferral of the degree should be imprinted on the spine in gold. The department can provide names of local companies which do satisfactory and economical binding.

Since theses and dissertations represent the joint effort of students and their advisors (if not also other members of the faculty), the student should make no arrangements for publication without consulting his/her advisor. Electronic submission of Ph.D. dissertations, as required by the Graduate School, does not preclude publication by other methods later.

It should be noted that the primary responsibility for the quality of the presentation, organization, grammar and readability of the dissertation, thesis or project lies with the student. Extra effort and outside editorial assistance may be required when the student does not write fluently in the English language.

Deadlines: In order that students receive their degrees when expected, it is necessary that certain deadlines be met in their programs. A summary of these deadlines is given in Sec. 1.7.