DECLARATION ADDENDUM

I, Robert J. Abend, declare and state the following:

I. Dr. Walter Hollister and Dr. Larry Brock Class Notes

1. In his 23 May 2000 letter "To whom it may concern" Dr. Walter Hollister states that his attached class notes discussing gravity assisted trajectories on 21 and 23 March 1960 were notes he took during Dr. Battin's lectures in course 16.46T "Astronautical Guidance" taught at The Massachusetts Institute of Technology (MIT). This data provided by Dr. Hollister is intended to support Dr. Richard Battin's claim that he had developed the concepts of gravity assisted trajectories prior to Dr. Minovitch's paper on the same topic published 23 August 1961.
2. During his 7 May 2001 Deposition, Dr. Larry Brock provided, as Exhibit 1, his set of lecture notes reportedly provided by Dr. Battin during the 1960 – 1961 term at MIT. Those were reported by Dr. Brock to be class notes provided by Dr. Battin to students in his class on "Astronautical Guidance". In reviewing those prepared notes, I find them to be similar or the same as data published in Dr. Battins 1964 book "Astronautical Guidance". The prepared notes are dated August 1961.
3. I obtained excerpts from the MIT Bulletin which describes courses taught during the 1959 – 1960, 1960 – 1961, and 1961 – 1962 class years in the Aeronautics and Astronautics Department. Those excerpts are attached to this Addendum.
4. During the 59-60 class year, the MIT Bulletin shows, on Page 262, that the Astronautical Guidance course is being taught by an instructor with the last name

of Wrigley. Page 78 of the same document lists Walter Wrigley as an MIT Aeronautics and Astronautics Department Professor. Dr. Battin is not referenced anywhere in the 59-60 documentation I received from MIT.

5. During the 60-61 class year, the MIT Bulletin shows on Page 258 that the Astronautical Guidance course is being taught by an instructor with the last name of Wrigley. Page 84 of the same document lists Walter Wrigley as an MIT Aeronautics and Astronautics Department Professor. Dr. Battin is not referenced anywhere in the 60-61 documentation I received from MIT.
6. During the 61-62 class year, the Bulletin shows on Page 264 that the Astronautical Guidance course is being taught by Dr. Battin. Page 84 of the same document lists Walter Wrigley as an MIT Aeronautics and Astronautics Department Professor. Dr. Battin is also listed on Page 84 as an Aeronautics and Astonautics Department Lecturer.
7. The course description for the 61-62 class year, on Page 264, is fairly detailed and lists "one way" and "round trip" trajectories to the moon and planets, but does not discuss multi-planetary, dual reconnaissance, or gravity assisted trajectories.
8. The course description also changed significantly when Dr. Battin became the instructor in 1962. This change seems to correlate with Dr. Battin taking over the course in 1962.
9. The Astronautical Guidance course is given a G (2) designation for all three MIT Bulletins indicating that it was a graduate course taught during the Spring Semester.

II. Conclusions:

1. Since Dr. Battin is not listed as an Aeronautics and Astronautics Department member for the 59 – 60 and 60 – 61 class years, and he is not listed as the Astronautical Guidance course instructor, it does not appear he taught the course during those years.
2. Since Dr. Battin is listed as an Aeronautics and Astronautics Lecturer, and the instructor for the Astonautical Guidance course during the 61 – 62 class year, and the course was only taught in the Spring, the documentation shows that he taught the course in the Spring of 1962. Since multi-planetary gravity assisted trajectories would have been at a level of import equal to or greater than those topics listed in the course description, it is surprising they were omitted, and Dr. Battin may not have addressed that topic during his Spring 1962 class.
3. Based on the MIT documentation discussed above, it does not appear that the description of 1960 class notes given By Dr. Hollister, nor the similar description for the 1961 prepared lecture notes provided by Dr. Larry Brock are accurate. It is not clear what those documents really are.
4. In his 9 February 2005 deposition, Dr. Battin states on Page 59 Line 13 that the lecture notes identified by Dr. Brock were also the substance of his 1963 Draper Anniversary Volume, which was later published by McGraw Hill as the "Astronautical Guidance" book in 1964. Dr. Battin states that those class notes were used in his new course at MIT taught for the first time in 1961. Since, based on MIT documentation, his new course was taught during the Spring Semester in 1962, Dr. Battin's accounting does not appear to be accurate. This finding may

also bring into question the accuracy of the August 1961 date on Dr. Battin's lecture notes.

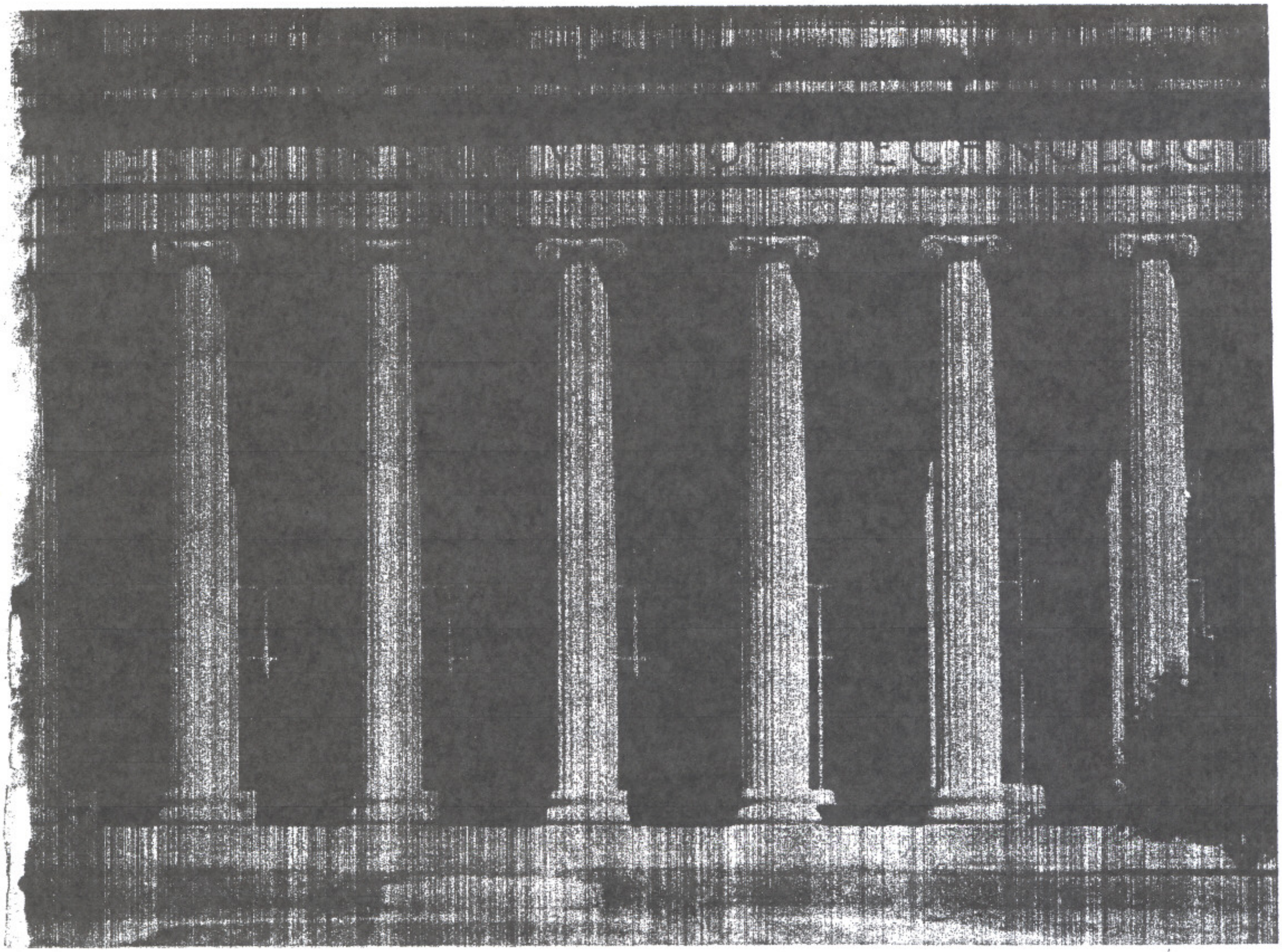
5. Since the Astronautical Guidance course was always taught during the Spring Semester, class notes completed in August 1961 would have been available too late for the Spring Semester in 1961. Even if the publication date of August 1961 were accurate, the notes could not have been used for the Astronautical Guidance course in 1961.

III. DECLARATION

I declare under penalty of perjury that to the best of my knowledge the foregoing is true and correct.

____
Robert J. Abend, PE

____
Date



THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY BULLETIN

1959

THE GENERAL CATALOGUE ISSUE

1960

Course Cat. 1959-60

Department of Aeronautics and Astronautics

CHARLES STARK DRAPER, SC.D.
Professor of Aeronautics and Astronautics; Head of the Department; Director of the Instrumentation Laboratory

RAYMOND LEWIS BISPLINGHOFF, SC.D.
Professor of Aeronautics and Astronautics; Deputy Head of the Department

ROBERT LOUIS HALFMAN, S.M.
Associate Professor of Aeronautics and Astronautics; Executive Officer

JEROME CLARKE HUNSAKER, SC.D., ENG.D.
Professor of Aeronautical Engineering, Emeritus

OTTO CARL KOPPEN, S.B.
Professor of Flight Vehicle Engineering

EDWARD STORY TAYLOR, S.B. (*Absent*)
Professor of Flight Propulsion

JOHN RAYMOND MARKHAM
Professor of Aeronautical Engineering

SHATSWELL OBER, S.B.
Professor of Aeronautical Engineering, Emeritus; Lecturer

HORTON GUYFORD STEVER, PH.D., SC.D.
Professor of Aeronautics and Astronautics

WALTER WRIGLEY, SC.D.
Professor of Instrumentation and Astronautics

RENE HARCOURT MILLER, M.A.
Professor of Flight Vehicle Engineering

BENJAMIN SCOVILL KELSEY, S.M.
Jerome Clarke Hunsaker Professor of Aeronautical Engineering (*Visiting*)

WALTER McKAY, S.M.
Associate Professor of Aeronautics and Astronautics

WALTER HENRY GALE, S.M. (*Absent*)
Associate Professor of Aeronautics and Astronautics; Special Assistant

JOSEPH BICKNELL, S.M.
Associate Professor of Aeronautics and Astronautics

PAUL EDWIN SANDORFF, S.B.
Associate Professor of Aeronautics and Astronautics

ROBERT KARL MUELLER, SC.D.
Associate Professor of Aeronautics and Astronautics

HOLT ASHLEY, SC.D.
Associate Professor of Aeronautics and Astronautics

YAO TZU LI, SC.D.
Associate Professor of Aeronautics and Astronautics

MORTON FINSTON, PH.D.
Associate Professor of Aeronautics and Astronautics

ERIK LEONARD MOLLÖ-CHRISTENSEN, SC.D.
Associate Professor of Aeronautics and Astronautics

LEON TRILLING, PH.D.
Associate Professor of Aeronautics and Astronautics

MARTEN TEODOR LANDAHL, DR.TECHN.
Associate Professor of Aeronautics and Astronautics

JAMES WAH MAR, SC.D.
Associate Professor of Aeronautics and Astronautics

THEODORE HSUEH-HUANG PIAN, SC.D.
Associate Professor of Aeronautics and Astronautics

HENRY PHILIP WHITAKER, S.M.
Associate Professor of Aeronautics and Astronautics

FRANK KINGSLEY BENTLEY
Assistant Professor of Aeronautics and Astronautics

ELMER EUGENE LARRABEE, S.M.
Assistant Professor of Aeronautics and Astronautics

MYRON ARNOLD HOFFMAN, SC.D.
Assistant Professor of Aeronautics and Astronautics

JUDSON RICHARD BARON, SC.D.
Assistant Professor of Aeronautics and Astronautics

JOHN DUGUNDJI, SC.D.
Assistant Professor of Aeronautics and Astronautics

WINSTON ROSCOE MARKEY, SC.D.
Assistant Professor of Aeronautics and Astronautics

WALLACE EARL VANDER VELDE, SC.D.
Assistant Professor of Aeronautics and Astronautics

JAMES LEE STOCKARD, S.B.
Assistant Professor of Aeronautics and Astronautics

GORDON CEDRIC OATES, PH.D.
Assistant Professor of Aeronautics and Astronautics

Lecturer

JOHN HOVORKA, S.M.

Research Associates

MYRON JACQUES BLOCK, B.S.

JIRO SUHARA, D.ENG.

Professor Emeritus

JEROME CLARKE HUNSAKER, SC.D., ENG.D.
Professor of Aeronautical Engineering, Emeritus

SHATSWELL OBER, S.B.
Professor of Aeronautical Engineering, Emeritus; Lecturer

AERONAUTICS AND ASTRONAUTICS

Aeronautics and astronautics deal with the problems of manned or unmanned vehicles that operate above the earth's surface. These include fixed-wing aircraft, helicopters, ballistic missiles, guided missiles, and space vehicles. Successful realization of systems based on such devices requires that solutions be found for the static and dynamic problems of sustentation, fluid resistance to motion, propulsion, strength and elasticity of minimum-weight structures, and measurements under difficult environmental conditions. In addition it is necessary to understand and use the theory of rapid, precise, and reliable manual and automatic control of the direction and speed of massive bodies moving in space with many degrees of freedom under driving forces from very powerful and complex engines. It is the primary objective of the Department of Aeronautics and Astronautics to give a clear understanding of all the basically important problems that occur in aeronautics and to provide students with a broad background of education in the art and science of applying sound judgment in achieving acceptable solutions for practical situations.

More than any other, the factor which influences the educational climate of the Department is the extensive, vigorous participation by every faculty member in the activities of one or more of the several departmental research laboratories. The Department is outstanding in the volume of sponsored and unsponsored research carried out by its staff. Except for flight testing and similar activities, all this work is done either on or in the immediate vicinity of the campus. Because all faculty members are actively interested in teaching, the aeronautical research problems of one day can and often do become the classroom examples or assignments of the next. Many undergraduates and a majority of graduate students find that part-time employment in one of the laboratories gives a source of income while providing experience that is an invaluable supplement to formal courses. Such experience commonly suggests thesis projects which place fundamental emphasis on a working relationship with the current problems of aeronautics and astronautics. The Department is proud that all of its extensive research facilities are available to its student body for thesis work or instruction, and that the utilization is high for both of these purposes. Of the many basic contributions to aeronautical science in such areas as automatic control, inertial navigation, turbojet engines, aeroelasticity and aerodynamic heating, a large proportion had their origins in student-faculty collaboration on thesis projects.

Major departmental laboratories are listed below, with a brief description of their activities:

AEROELASTIC AND STRUCTURES LABORATORY

Here a wide variety of investigations are conducted on the interrelation between aerodynamic and elastic forces. Model construction facilities are available, as are wind tunnels and a shock tube for low-speed or high-speed dynamic testing. The structural test facility contains equipment for static or dynamic loading of aircraft components and material samples. Electro-thermal furnaces permit study of high-temperature gradients and transient effects.

AIRCRAFT INSTRUMENTS LABORATORY

The Aircraft Instruments Laboratory operates extensive equipment for studying the performance of measuring and control systems, with particular emphasis on instructing students in the fundamentals of such systems and providing thesis facilities. Items available include an electronic simulator, harmonic synthesizer, environmental facility, and apparatus for measuring vibratory characteristics of instruments.

GAS TURBINE LABORATORY

The facilities of this Laboratory are devoted to the study of fluid-dynamic phenomena in turbines, compressors and combustion chambers, boundary-layer flow and mixing of jets. The Laboratory includes an 8 by 8 inch supersonic wind tunnel for testing turbine components, along with other experimental apparatus of all types related to aircraft propulsion research.

INSTRUMENTATION LABORATORY

The Instrumentation Laboratory is a defense research organization devoted to research and development on fire control and navigation systems. Its equipment includes several digital and analog computers as well as an extensive facility at Hanscom Air Force Base near Boston. Research projects are organized in such a way that students may obtain advanced professional experience, similar to an internship, in instrumentation and weapons systems. Valuable sources of thesis material are provided in these fields. Results of current research are being applied directly to graduate academic subjects and ultimately to undergraduate teaching in the Department. The weapons systems curriculum provided for Air Force officers, Navy officers, and civilians is very largely based on the work of the Instrumentation Laboratory.

NAVAL SUPERSONIC LABORATORY

Here basic research is carried on in problems of high-speed flight — for example, loads on supersonic wings and bodies, aerodynamic heating, and hypersonic gas dynamics. The Laboratory centers on a 10,000-horsepower wind tunnel, with rectangular test section 18 by 24 inches, ambient pressures 1/4 to 4 atmospheres, and velocities up to four times sonic speed. Associated facilities include a small tunnel capable of operating above 10 times sonic speed.

WRIGHT BROTHERS WIND TUNNEL

Here there is a 2,000-horsepower low-speed wind tunnel, with elliptic throat 7½ by 10 feet and operating pressures 1/4 to 4 atmospheres. This tunnel also serves as the reservoir for an intermittent transonic wind tunnel with a 22-inch slotted-wall test section, and for an intermittent supersonic tunnel with continuously variable Mach number between 1.2 and 2.0. The latter facility is particularly adapted for the measurement of oscillatory air loads and aeroelastic stability.

OTHER RESEARCH GROUPS

The Fluid Dynamics Research Group is not directly associated with any one facility but takes advantage of the staff and equipment of any and all departmental laboratories that are able to make contributions to its research.

THE UNDERGRADUATE PROGRAMS

Aeronautics and Astronautics (Course XVI)

Building on the firm grounding in basic science and mathematics provided by the first two years of Institute work, the undergraduate Course in Aeronautics and Astronautics adds the advanced subjects required to apply engineering science in working out optimum designs for aeronautical systems. The program is broad and flexible, with education not only in peculiarly aeronautical sciences such as three-dimensional gas dynamics but also in the areas of generalized rigid-body mechanics, elasticity, structures, thermodynamics, vector field theory, complex linear systems, applied electronics, measurements, stability of physical systems, servomechanisms, and automatic controls.. The essential unity of the curriculum formed from these subjects is emphasized by sequences of coordinated subjects that bridge the gap between basic science and mathematics and the comprehensive subjects in the principles of aeronautical and astronautical engineering.

These comprehensive subjects are taken in the senior year and include the major steps required for a preliminary study of a chosen manned or unmanned aeronautical vehicle. In the course of this work, essential subsystems and components are considered and integrated into an over-all design. Methods of checking the expected performance of a vehicle based on such a design are studied by laboratory tests on aerodynamic performance, structural behavior, and the operation of various subsystems including automatic control components. During parts of the fourth-year program students work together in teams similar to those commonly used by industry for large projects. As a result, each student receives interesting and rewarding experiences in the technical aspects of his chosen profession, and he also becomes aware of the great importance of personal relationships in modern engineering. In his professional work with comprehensive problems, the student has continuous contacts with a number of senior faculty members who are familiar with current practice in the aeronautical industry. Each student is given personal attention, since it is the Department's aim to prepare him for his first job with the breadth of vision and ability required of potential chief engineers. In addition, his qualifications in basic science, mathematics, and applied science give him an excellent preparation for starting advanced study toward a career in research.

The curriculum not only provides the coordinated education described above but offers the flexibility of choice among several advanced professional electives in many fields. In addition, subjects in the regular curriculum may be replaced by equivalent subjects, if the substitutions are approved by the Registration Officer.

The Course leads to the degree of Bachelor of Science in Aeronautics and Astronautics. The curriculum for the first year is shown on page 77; the curriculum for the second, third, and fourth years is shown on the next page.

SECOND YEAR[1]

First Term

2.01	APPLIED MECHANICS I	3	0	5
8.03	PHYSICS	4	1	5
16.70	AIRCRAFT DETAIL DESIGN	3	5	0
16.82	INTRODUCTORY AERONAUTICAL ENGINEERING	3	0	3
18.03	CALCULUS	3	0	6
21.03	HUMANITIES	3	0	5
			49	

Second Term

2.40	HEAT ENGINEERING	4	0	5
8.04	PHYSICS	4	1	5
16.00	FLIGHT DYNAMICS	3	1	5
18.04	DIFFERENTIAL EQUATIONS	3	0	6
21.04	HUMANITIES	3	0	5
			45	

THIRD YEAR

First Term

2.38	MECHANICAL BEHAVIOR OF MATERIALS	3	2	4
6.18	FUNDAMENTALS OF ELECTRICAL ENGINEERING	3	1	6
16.01	FLIGHT DYNAMICS	4	1	5
16.02	AERODYNAMICS	4	2	6
	[2]*Humanities*	3	0	5
			49	

Students registered in the third year, first term, 1959–60: omit 2.38 and 16.02. Add 2.40 HEAT ENGINEERING (4–0–5) and 16.11 AIRCRAFT PERFORMANCE AND STABILITY (4–0–8).

Second Term

16.11	AIRCRAFT PERFORMANCE AND STABILITY	4	0	8
16.20	STRUCTURES	4	0	6
16.30	PRINCIPLES OF AUTOMATIC CONTROL	3	0	9
16.53	AIRCRAFT PROPULSION	3	0	6
	[2]*Humanities*	3	0	5
			51	

Students registered in the third year, second term, 1959–60: omit 16.11. Add 16.02 AERODYNAMICS (4–2–6).

FOURTH YEAR

First Term

16.302	AERONAUTICAL SYSTEMS	3	0	6
16.71T	AERONAUTICAL ENGINEERING	2	10	0
	[2]*Humanities*	3	0	5
	Laboratory elective subject		10	
	Professional elective subject or humanities (see next column)		8	
			47	

Second Term

16.72	AERONAUTICAL ENGINEERING	0	9	3
	THESIS OR PROJECT		9	
	[2]*Humanities*	3	0	5
	Professional elective subject (see next column)		9	
	Professional elective subject or humanities (see next column)		8	
			46	

[1] Students who have not already completed the 12-unit elective requirement for the first two years must finish it during the second year; these elective subjects will be in addition to the regular curriculum shown here.

[2] 14.01 ECONOMIC PRINCIPLES I (3–0–5) is a requirement for graduation and must be one of the humanities subjects taken. The humanities requirement is described in Section 2 of this Catalogue.

PROFESSIONAL ELECTIVE SUBJECTS

Electives may be chosen from any of the areas of aeronautics and astronautics or from associated fields, in consultation with the Registration Officer.

The Honors Course

Students who wish to pursue a coordinated schedule of studies through their senior and graduate years may apply for the Honors Course group; a limited number of students of superior ability are selected each year for the group by the Department. A member of the Department aids each member in planning the senior and graduate schedules which are best suited to his individual interests. The program requires completion of all unit and humanities requirements for the Bachelor's degree and for either the Master's degree or the degree of Engineer in Aeronautics and Astronautics, but only a single thesis of not less than 30 units in the graduate program.

The Honors Course leads to the degree of Bachelor of Science in Aeronautics and Astronautics and either the degree of Master of Science in Aeronautics and Astronautics or the degree of Engineer in Aeronautics and Astronautics, awarded simultaneously at the end of the graduate program.

Aeronautics and Astronautics (Cooperative Course) (Course XVI-B)

The cooperative program for Aeronautics and Astronautics undergraduates provides the opportunity for about six months of experience in an industrial organization before the professional work of the senior year. Continuous contact with industrial problems enables students to discover and develop their aptitudes and interests to better advantage than would be possible with shorter periods of employment. The program does not interfere with the student's academic progress nor with his extracurricular activities in association with his classmates.

The cooperating companies of the aircraft industry pay the students at prevailing rates during their period of employment. The students pay their own transportation and living expenses while away from the Institute.

Students who are interested in the program should apply to Department Headquarters for a set of Personnel Record Forms prior to December 1 of their sophomore year. These forms should be completed and returned by December 15, with an added statement specifying the location where the student prefers to work.

Representatives of the cooperating companies come to the Institute to interview interested students and to determine, together with the Department representative, the distribution of those selected for employment. Students who are thus selected become regular employees during their period of employment in an aircraft plant and are subject to the regulations of the company. They are expected to carry the Course through to completion unless exceptional circumstances intervene.

A list of the companies cooperating in this program is available at the Headquarters of the Department of Aeronautics and Astronautics.

Juniors in the Cooperative Course are also eligible for the Honors Course described above.

The Cooperative Course leads to the degree of Bachelor of Science in Aeronautics and Astronautics. The curriculum is shown below.

FIRST YEAR

Same as Aeronautics and Astronautics (Course XVI)

SECOND YEAR

First Term

Same as Aeronautics and Astronautics (Course XVI)

Second Term

2.37	MECHANICAL BEHAVIOR OF MATERIALS	3	2	4
8.04	PHYSICS	4	1	5
16.00	FLIGHT DYNAMICS	3	1	5
18.04	DIFFERENTIAL EQUATIONS	3	0	6
21.04	HUMANITIES	3	0	5
			45	

THIRD YEAR

Summer

	At M.I.T., first 6 weeks:			
2.40	HEAT ENGINEERING	4	0	5
16.01	FLIGHT DYNAMICS	4	1	5
			19	
	Vacation, approximately 2 weeks			
	At plants, remainder of summer:			
16.851	INDUSTRIAL PRACTICE	40 h.p.w.		

First Term

	At plants:	
16.852	INDUSTRIAL PRACTICE	40 h.p.w.

Second Term

	At M.I.T.:			
6.18	FUNDAMENTALS OF ELECTRICAL ENGINEERING	3	1	6
16.02	AERODYNAMICS	4	2	6
16.20	STRUCTURES	4	0	6
16.30	PRINCIPLES OF AUTOMATIC CONTROL	3	0	9
	[1]*Humanities*	3	0	5
			52	

Students registered in the third year, second term, 1959–60: omit 16.20. Add 16.53 AIRCRAFT PROPULSION (3–0–6).

FOURTH YEAR

Summer

	At M.I.T.:			
16.11	AIRCRAFT PERFORMANCE AND STABILITY	4	0	8
16.53	AIRCRAFT PROPULSION	3	0	6
	[1]*Humanities*	3	0	5
			29	

Students registered in the fourth year, summer, 1960: omit 16.53. Add 16.20 STRUCTURES (4–0–6).

First and Second Terms

Same as Aeronautics and Astronautics (Course XVI)

[1] 14.01 ECONOMIC PRINCIPLES I (3–0–5) is a requirement for graduation and must be one of the humanities subjects taken. The humanities requirement is described in Section 2 of this Catalogue.

GRADUATE STUDY IN AERONAUTICS AND ASTRONAUTICS

Graduate students in the Department of Aeronautics and Astronautics study and conduct research in the engineering and scientific aspects of many problems of flight transportation. Fields of endeavor may be fairly general; programs may be oriented to aeronautical or astronautical engineering or to aeronautics or astronautics, in which case there will be less emphasis on engineering applications. Major fields of specialization include vehicle design and operation, aerodynamics or gas dynamics, space mechanics, structures, aeroelasticity, propulsion, instrumentation, and automatic control. For successful graduate work in any of these fields, strong preparation and aptitude in applied mathematics and physics are necessary foundations. Students may elect subjects in other departments which bear a useful relation to their program.

Advanced study in the Department leads to the degrees of Master of Science in Aeronautics and Astronautics, Engineer in Aeronautics and Astronautics, and Doctor of Science or Doctor of Philosophy.

Entrance Requirements for Graduate Study

In addition to the general requirements for admission to the Graduate School, all applicants must have completed strong fundamental undergraduate subjects in thermodynamics, mechanics, electrical engineering, and automatic control. Additional undergraduate preparation is a prerequisite for specialization in particular fields. Some prerequisites may be completed early in a graduate program.

The Graduate Degrees

MASTER OF SCIENCE IN AERONAUTICS AND ASTRONAUTICS

For this degree, at least one year of an approved graduate program is required, including thesis. Two terms of advanced mathematics beyond DIFFERENTIAL EQUATIONS (18.04) or its equivalent must be included. This degree is awarded simultaneously with the Bachelor of Science in Aeronautics and Astronautics upon successful completion of the five-year Honors Course program.

Although excessive specialization is undesirable, it is expected that most candidates for this degree will concentrate in a single professional field, not seeking the same breadth of educational background implied by the Engineer degree.

ENGINEER IN AERONAUTICS AND ASTRONAUTICS

For this degree the student must satisfactorily complete at least two years of an approved graduate program, including thesis. Subjects in a variety of professional specialties are required, so as to provide a broad foundation in both aeronautical and astronautical science and their engineering applications.

Requirements for admission to candidacy for the degree of Engineer in Aeronautics and Astronautics are more rigorous than for the degree of Master of Science in Aeronautics and Astronautics.

DOCTOR OF SCIENCE (OR PHILOSOPHY) IN AERONAUTICS AND ASTRONAUTICS

To be recommended for this degree by the Department of Aeronautics and Astronautics, the student must complete an approved program, including thesis. Such a program probes more deeply into a special field than the program for the Engineer degree and does not necessarily include the same breadth of engineering applications. Competence must be demonstrated by a General Examination consisting of written and oral parts. The thesis must demonstrate the student's ability to carry out independent original research of high quality on a problem of aeronautical or astronautical science or engineering.

DOCTOR OF SCIENCE WITH SPECIALIZATION IN THE FIELD OF INSTRUMENTATION

For the Doctor's degree in this field, the student is required to complete an approved program, including thesis, in the interrelated professional fields of instrumentation. This work involves the cooperative effort of the Departments of Aeronautics and Astronautics (Instrumentation and Weapons Systems Divisions), Electrical Engineering, Mechanical Engineering, Mathematics, and Physics. The program is administered, for registration purposes, by the Department of Aeronautics and Astronautics. The General Examination includes both written and oral parts. The thesis must demonstrate the ability of the student to do original research of high grade on a problem of instrumentation or weapons systems engineering.

Language Requirement

No language requirement is made for candidates for the Master of Science or Engineer degrees. A candidate for the Doctor of Science degree must demonstrate competence in reading two foreign languages in his major field. Each student's choice of languages must be approved by his Graduate Registration Officer.

Financial Assistance for Graduate Study

The Department offers several fellowships for full-time study in aeronautics and astronautics; these are described in Appendix A of this Catalogue. In addition, graduate students may earn part or all of their expenses as part- or full-time assistants. These duties, concerned with either teaching or research, provide valuable educational experience.

DESCRIPTIONS OF SUBJECTS

The subjects and descriptions given in this Section are subject to change. The final list of subjects to be given in 1959–60 will be published with the class schedules prior to the beginning of each term.

(A) following the name of a subject indicates that it is given primarily for graduate students.

(R) following the name of a subject indicates that it is restricted to special groups because of content; all subjects open only to special groups are so noted at the end of the description of the subject.

The information given below the number and name of the subject is as follows:

1. The number(s) of prerequisite subjects, if any. Numbers in italics indicate subjects which may be taken simultaneously with the subject described.
2. The year (and term) for which the subject is normally scheduled in one or more curricula.
3. The time distribution of the subject, showing in sequence the units allotted to: recitation and lecture; laboratory, drawing, or field work; and preparation. Each unit represents 15 hours of work. The total unit credit for a subject is obtained by adding together all the units shown. One unit of recitation or lecture credit, and two units of laboratory or drawing credit, are each equivalent to one semester hour.

   Arr. indicates that time units are specially arranged.
4. The name of the instructor(s) in charge, when known at press time.

15.951 ***Special Studies in Management*** **(A)**
Prereq.: ——
Year: G (1) *Arr.*

15.952 ***Special Studies in Management*** **(A)**
Prereq.: ——
Year: G (2) *Arr.*

For graduate students who desire to do advanced work or to carry out some special investigation of a management problem not specifically covered elsewhere and not qualifying as a thesis. Readings, conferences, laboratory and field work, and reports. *T. M. Hill*

15.96 ***Administrative Theory and Practice*** **(A)**
Prereq.: 15.312, 15.412, 15.712, 15.812
Year: G (1) 3–0–6

Especially designed for graduate students who look forward to ultimate responsibilities in the top management of industry. Initial problems confronting the new business administrator. Formulation of methods of approach to administrative problems. Techniques of negotiation, mediation and group deliberation. Relationships of top management to subordinates, investors, vendors, customers, associates, community, government, and the public. Underlying principles leading to long-term continuity and tenure. Evening conferences with business administrators and industrialists. *Schell*

15.971 ***Seminar in Research Management***
Prereq.: ——
Year: G (1) 2–0–7

Graduate seminar dealing with several aspects of managing research laboratories: organization, economics, human relations. Case discussions, guest speakers, readings and reports. Participation by research supervisors from local laboratories. (*Generally restricted to graduate students who have worked in research or development laboratories. Permission of instructor required.*) *Rubenstein*

15.972 ***Management of Research and Development***
Prereq.: ——
Year: G (2) 3–0–6

Organizational and economic aspects of managing research laboratories. Lectures, readings, discussions, field studies, reports. Subject intended for graduate students with little or no previous experience in research management. *Rubenstein*

15.98 ***Seminar in Administration*** **(A)**
Prereq.: 15.18
Year: G (1) 3–0–6

15.99 ***Seminar in Administration*** **(A)**
Prereq.: 15.18
Year: G (2) 3–0–6

Study of fundamental economic, financial, organizational and administrative relationships analyzed and discussed by experienced leaders in business, labor and public administration. Examination of managerial philosophies and practices in the field and in seminar discussions. (*Restricted to Sloan Fellows.*) *Wynne*

16.

Aeronautics and Astronautics

16.00 ***Flight Dynamics***
Prereq.: 2.01, 18.03
Year: 2 (2) 3–1–5

Dynamics, with applications to aeronautical and astronautical problems. Kinematics of a point and of plane motion of a rigid body. Relative motion as seen by accelerating and rotating observers. Dynamics of particles, groups of particles, and rigid bodies in planar motion. Work and energy, impulse and momentum in relative motion. Particles of variable mass. *Halfman*

16.01 ***Flight Dynamics***
Prereq.: 16.00, *18.04*
Year: 3 (S, 1) 4–1–5

Dimensional analysis. Kinematics of a rigid body in general motion. Mass properties of rigid bodies, ellipsoid of inertia, geometric and mass symmetries. Dynamics in general motion of a group of particles, a rigid body, a body of variable mass. Euler's dynamical equations, gyroscope equations, rocket equations with application to aircraft, spacecraft and their components. Linear systems, free and forced oscillations, multiple degrees of freedom, classical and operational methods of analysis. System performance and stability. Examples of nonlinear systems. *Halfman*

16.02 ***Aerodynamics***
Prereq.: 2.40, *16.01*
Year: 3 (1, 2) 4–2–6

Description of gaseous environment of vehicles in flight, considered as a continuous medium and from viewpoint of kinetic theory. Application of the conservation laws of mass, momentum and thermodynamic energy to real and perfect fluids in motion. One-dimensional flow of a perfect gas, with simple aeronautical and astronautical illustrations. Fundamentals of three-dimensional fluid motion; applications, with special reference to nonviscous incompressible flow; airfoil and wing theory. Elementary examples of viscous flow; boundary layer. *Ashley*

16.041 ***Aerodynamics — Viscous Fluids*** **(A)**
Prereq.: 16.02, *18.05*
Year: G (1) 3–0–9

Introduction to viscous flows. Basic flow equations; exact solutions; low Reynolds number cases; boundary layer flows; brief discussion of stability; transition; turbulent boundary layers. Lectures to be supplemented by occasional demonstrations. *Bicknell, Finston*

(A) indicates a subject given primarily for graduate students. (R) indicates a subject restricted to special groups because of content. Other notations are described on the first page of this Section.

16.042 ***Aerodynamic Heating* (A)**
Prereq.: 16.041, *18.06*
Year: G (2) 3–0–9
Extension of discussion in 16.041 to include thermodynamic aspects. Kinetic heating at high speeds; heat transfer through boundary layers; discussion of methods of reducing surface temperatures. Application to hypersonic aircraft and re-entry bodies, including real gas effects at high temperatures. *Finston*

16.051 ***Aerodynamics of Compressible Fluids I* (A)**
Prereq.: 16.02, *18.05*
Year: G (1) 3–0–9
Gas dynamics equations. Rotational and irrotational flow. Subsonic, transonic, supersonic and hypersonic flow regimes. Similarity and area rules. Nozzles, diffusers, and unsteady flows. Conical flow. Hodograph and characteristic methods. Experimental techniques. Some real gas effects. *Baron*

16.052 ***Aerodynamics of Compressible Fluids II* (A)**
Prereq.: 16.051
Year: G (2) 3–0–9
General solutions of the Prandtl-Glauert equation. Flow past inclined axisymmetric bodies. Supersonic wing theory. Distributed sources and conical field techniques. Wing-body interference. Reverse flow theorems. Blunt bodies. *Baron*

16.065 ***Physics of High Speed Gas Flows* (A)**
Prereq.: 16.02
Year: G (1) 3–0–9
Review of statistical mechanics as basis for the equations of motion of a gas. Physical nature of transport phenomena. Mechanism of vibrational excitation, dissociation, ionization, radiation and relaxation effects. Free molecule and slip flows. Introduction to magnetohydrodynamics and plasma flows. *Trilling*

16.07 ***Aerodynamics and Dynamics of Missiles* (A)**
Prereq.: 16.02, 16.11
Year: G (1) 3–0–6
Introduction to aerodynamic techniques useful for predicting performance and stability of slender vehicles in high-speed flight at all altitudes in planetary atmospheres. Flow of compressible fluid past bodies, wings, and more general configurations. Slender-body methods, Newtonian theory, other approximate techniques and their limitations. Estimation of forces and moments at subsonic, transonic, supersonic, and hypersonic speeds. Similarity laws and area rules. Some quasi-linear and nonlinear dynamic problems peculiar to slender vehicles. *Ashley*

16.081 ***Advanced Gas Dynamics* (A)**
Prereq.: 16.052, 18.06
Year: G (1) 3–0–9

16.082 ***Advanced Gas Dynamics* (A)**
Prereq.: 16.081
Year: G (2) 3–0–9
Two-semester subject for advanced graduate students. Fundamentals of gas dynamics of continua with examples from widely diverse fields such as boundary layer theory, acoustics, rotary flows, potential flows, and jet and wake flows. Discussion of unsolved as well as solvable problems. Free use of mathematical tools. *Mollö-Christensen*

16.10T ***Space Flight Dynamics* (A)**
Prereq.: 16.01
Year: G (2) 3–0–6
Satellite librations and some effects of nonspherical gravitational fields. Elementary inertial navigation and the Schuler pendulum. Calculus of variations in flight engineering with applications to dynamic aircraft performance and interplanetary rocket flight; classical minimum principles. General motion of "rigid" bodies of variable mass. Relativity and space flight. *Halfman*

16.105 ***Applied Aerodynamics* (A)**
Prereq.: 16.02, 16.11
Year: G (1 or 2) 3–0–6
Further studies of airplane performance, including the effects of variations of propeller, type of power plant, and Mach number at trans- and supersonic velocities. *Ober*

16.11 ***Aircraft Performance and Stability***
Prereq.: *16.01*, 16.82
Year: 3 (1, 2); 4 (S) 4–0–8
Application of aerodynamic theory to aircraft performance and stability. Presentation of general theory of aircraft stability. *Bicknell*

16.15 ***Advanced Stability and Control of Aircraft* (A)**
Prereq.: 16.11
Year: G (1) 3–0–6
Various features of stability and control of aircraft, including airplane motion with free controls; rotary derivatives; airplane frequency response to control motion; controls and control forces. *Larrabee*

16.20 ***Structures***
Prereq.: 2.37 or 2.38
Year: 3 (2); 4 (S) 4–0–6
Fundamental theory and methods for static strength analysis and design of airplane components. Elasticity relations and practical two-dimensional plasticity. Properties and failure modes of ductile materials, including combined stresses, fatigue, and elevated temperature effects. Solid sections, simple shells, and stiffened-skin structures under shear, bending, torsion, and compression; both elastic and plastic effects. *Mar*

16.21 ***Theory of Structures***
Prereq.: 16.20
Year: 4 (1) 4–0–6
Introduction to the energy theorems in structural analysis. Influence coefficients and statically indeterminate structures. Flight vehicle shell structures; load distribution in multi-cell and tapered stiffened shells, analysis of fuselage rings, general stability problems. Introduction to plate theory, small and large deflections. *Pian*

16.22 ***Shell Structures* (A)**
Prereq.: 16.21
Year: G (2) 3–0–6
Advanced topics in aircraft structural theory. Theory of elasticity applied to the stress and stability analyses of plates and shells including variational methods. Approximate solutions including finite difference techniques and relaxation methods. Plastic effects in stress and stability analyses. Thermal effects. *Pian*

16.23T ***Flight Vehicle Structures and Materials***
Prereq.: 16.20
Year: G (1) 3–0–9
Selected analysis and design problems for advanced structures of aircraft, missiles, rockets, and space vehicles. Considerations of hypervelocity impact, high vacuum and radiation environment, on materials. *Bisplinghoff*

16.25 *Advanced Theory of Structures* (A)
Prereq.: 16.21
Year: G (1) 3–0–6
Varying content from year to year as new methods for analysis of all-metal aircraft become available for examination. Investigation and development of methods involving stability criteria or applications of elastic theory and of probable effects on structural analysis methods to be expected from new trends in design. *Mar*

16.30 *Principles of Automatic Control*
Prereq.: 6.18, 16.01
Year: 3 (2) 3–0–9
Analysis of automatic control systems, including analytical, graphical, and analog methods. Formulation of control system performance equations leading to solutions for transient and steady state inputs. Non-dimensionalized treatment of simple linear systems and extension to more involved automatic control loops. Selected aeronautical and astronautical control problems. *McKay*

16.302 *Aeronautical Systems*
Prereq.: 16.30
Year: 4 (1) 3–0–6
Application and extension of the basic techniques for control system analysis (root locus, frequency response, computer utilization) to feedback control systems in aircraft, missiles, and space vehicles. Case studies of aeronautical and astronautical control systems. *McKay*

16.31 *Principles of Instrumentation and Control* (A)
Prereq.: 16.30
Year: G (1) 3–0–9
Generalized concepts of system performance analysis based on frequency, transient and error coefficient methods. Combined use of feedback and programmed control systems for improving adaptive capability of systems under adverse environmental changes. Principles of system synthesis. Parameter adjustment for optimization of specific dynamic performance indices. Illustrative application of these principles to aircraft and missile systems. *Li*

16.32 *Principles of Instrumentation and Control* (A)
Prereq.: 16.31
Year: G (2) 3–0–9
System design with random inputs and disturbances. Analysis of system characteristics with time varying parameters. Nonlinear system performance analysis. Switching technique applied to control and instrumentation. Optimalizing control systems. Adaptive control system design principles for aircraft and spacecraft. Sampled data control system analysis. *Li*

16.33 *Instrumentation and Control Laboratory* (A)
Prereq.: 16.31
Year: G (1) 2–2–6
To be taken simultaneously with 16.31. Laboratory exercises on instruments and control systems designed to provide experimental familiarity with principles set forth in 16.31. Various test methods to evaluate static and dynamic characteristics of instruments and control systems. Various schemes for improvement of static and dynamic performance. *Li*

16.35 *Special Problems in Instrumentation and Control* (A)
Prereq.: 16.32
Year: G (1 or 2) *Arr.*
Problems of interest to qualified individual students in consultation with the instructor. *McKay*

16.36 *Dynamic Measurements* (A)
Prereq.: 16.31
Year: G (2) 2–2–6
Measurement and data processing of various physical quantities encountered in engineering practice, with emphasis on methods to improve dynamic response and to reduce disturbing effects. Detailed study of data-handling methods and transducer designs for pressure, vibration, flow, and temperature measurement for both industrial and space flight applications. *Li*

16.37 *Statistical Problems in Automatic Control* (A)
Prereq.: 16.30, 18.05
Year: G (1) 3–0–9
Statistical problems of importance to control engineers. Review of probability theory with application to such problems as evaluation of probability of kill. Introduction to sample theory with application to determination of the CPE for missile systems. Extensive treatment of random processes in linear feedback systems including optimum design of such systems; brief treatment of nonlinear systems in presence of random noise. *Vander Velde*

16.38 *Physical Components of Control Systems* (A)
Prereq.: 6.18
Year: G (2) 3–0–6
Effect of component performance characteristics on the control system problem. Consideration of mechanical, electrical and electromechanical components with emphasis on non-ideal effects. Specification of components to meet particular system requirements. Numerous lecture references to applications in aircraft, missile, and spacecraft guidance. *R. K. Mueller*

16.39T *Space Dynamics and Gyroscopic Instruments* (A)
Prereq.: 16.01
Year: G (1) 3–1–6
Consideration of origins of inertial space concepts and application to interpretation of measured data. Generalized theory of accelerations and velocities of bodies in spaces which are moving with respect to inertial space. Application of general theory and of Newtonian mechanics to theory of gyroscopic instruments. Space integrators and stabilization. Development of treatment from standpoint of engineer, using methods of vectors and of conventional analysis. Application to gyroscopic devices in airborne and marine navigation. *Wrigley*

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16.392 *Inertial Guidance* (A)
Prereq.: 16.39T
Year: G (2) 3–0–6

Fundamentals of self-contained automatic marine, aircraft, and missile guidance. Character of terrestrial and extraterrestrial gravitational fields; space navigation. Force measurement for navigation purposes with accelerometers for position computation referred to gyroscopically maintained coordinate systems. Combinations of accelerometers, gyroscopes, and computers to form inertial guidance systems. Terrestrial navigation and Schuler tuning; computation of the geographic vertical from moving bases; damping and other system design problems. Effect of component uncertainties on system performance. Inertial control of vehicles to programmed paths. Utilization of possible environmental contact and measurement. *Hovorka*

16.40T *Control Systems Principles*
Prereq.: 16.39T
Year: G (1) 4–0–8

Analysis of automatic control systems, including analytic, graphical and analog computer methods. Response of systems described by linear and incrementally linear equations. Stability of feedback control systems. Nondimensional treatment of linear constant-coefficient differential equations. System modification to control dynamic and interference errors. Examples chosen for flight vehicle systems. *Stockard*

16.41 *Introduction to Weapons Systems* (RA)
Prereq.: 16.39T, 16.40T
Year: G (1, 2) 4–0–8

Static and dynamic behavior of weapons system components and subsystems from standpoint of functional performance, in terms of harmonic analysis and elementary classical physics. Development of a coherent pattern for associating solutions in terms of nondimensional variables with typical weapons system engineering problems. Numerical and graphical methods for determining transient stability of feedback systems. Limitations imposed by uncertainties and interferences on performance of physical equipment. Introduction to theoretical statement of fire control problem and to inertial navigation. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *Markey*

16.42 *Weapons Systems* (RA)
Prereq.: 16.41
Year: G (1, 2) 3–0–9

Generalized treatment of weapons systems problem and methods available for its solution by physical concepts and vectors. Application of gyroscopic and other equipment for interference isolation, tracking, and computing in weapons systems. Fire control principles for airborne and marine weapons systems. Fundamentals of inertial guidance and its application to ships, aircraft, missiles, and spacecraft. Examples taken from service systems. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *Wrigley, Markey*

16.43 *Weapons Systems Laboratory* (RA)
Prereq.: 16.42
Year: G (1, 2) 1–3–5

Demonstration of principles treated in 16.42. Various experiments on characteristics of fire control instrument components, including gyroscopic elements, data transmission systems, and integrating units. Experiments on service fire control equipment and special demonstration units to study static and dynamic performance characteristics of typical airborne and anti-aircraft equipment. Problems of solution time, smoothing, and tracking. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *R. K. Mueller*

16.44T *Automatic Control of Flight Vehicles* (A)
Prereq.: 16.11, 16.302, 16.39T
Year: G (2) 3–0–6

Application of design techniques and principles to advanced automatic control systems for air and space vehicles. Synthesis of control systems from standpoint of meeting mission specifications. Analysis of adaptive control systems; their use in meeting performance requirements over widely changing environments encountered by high-speed aircraft and manned spacecraft. Typical engineering problems associated with design of control equipment, considering limitations and uncertainties of components, random input effects, mass cross-coupling effects, etc. *Whitaker*

16.45T *Vehicle Guidance Systems* (A)
Prereq.: 16.39T, 16.40T
Year: G (1) 3–0–6

Generalized treatment of vehicle guidance systems by physical concepts and vectors. Fundamentals of inertial guidance and of guidance systems based on radiation. Application to ships, aircraft, and spacecraft. *Markey*

16.46T *Astronautical Guidance* (A)
Prereq.: 16.392
Year: G (2) 3–0–6

Critique of vehicle guidance system theory and design methods, both for inertial and radiation types; mathematical models for dynamics of rotationally controlled bodies; astronomy review and space guidance trajectories; kinematic measurements and relativity. *Wrigley*

16.48 *Structural Problems in Weapons* (RA)
Prereq.: 2.01, 16.42
Year: G (2) 3–0–9

Static and dynamic stress analysis of flight vehicle structures. Theory of shock loading. Effect of structural response on fire control system. Fundamentals of gun and gun mounting structural analysis. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *Mar*

16.49 *Special Problems in Weapons Systems* (RA)
Prereq.: 16.42
Year: G (1 or 2) *Arr.*

Problems of interest to qualified students in consultation with the instructor. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *Wrigley*

16.50 *Vertical Take-Off Aircraft* (A)
Prereq.: 16.11
Year: G (1) 3–0–6

Analysis of performance and inherent stability and control characteristics of vertical take-off and landing aircraft, VTOL, including helicopters, convertiplanes, tilt wing, vectored lift and jet vertical risers. *Miller*

16.51 *Advanced Vertical Take-Off Aircraft* (A)
Prereq.: 16.50
Year: G (2) 3–0–6

Application of fundamental principles of aeroelasticity, airplane dynamics, thermodynamics, and automatic control to problems encountered in the design of aircraft capable of vertical take-off and landing, VTOL. Problems of control and stability during conversion to horizontal flight, design of aircraft stabilization systems, dynamics of wing-rotor combinations and of rigid or articulated rotors, and analysis of specialized power plant requirements for direct jet lift. *Miller*

16.53 *Aircraft Propulsion*
Prereq.: 2.25 or *16.02;* 2.40
Year: 3 (2); 4 (S) 3–0–6
Review of mechanics of compressible fluids. Applications to analysis and design of gas turbines, rockets, and ram jets. Limits on performance imposed by thermodynamics, fluid mechanics, and strength. *E. S. Taylor*

16.56 *Rocket Engines* (A)
Prereq.: 2.213; or 2.252 and 16.53; or 2.48
Year: G (2) 3–0–9
Application of fundamental principles of fluid mechanics and thermodynamics to the analysis and design of rocket engines. Discussion of propellants, thrust chambers, regenerative cooling, and turbopump systems. Theory developed by application to a preliminary design study of a rocket engine for a missile or satellite. *E. S. Taylor*

16.60 *Advanced Aeronautical Problems* (A)
Prereq.: 16.11 or 16.20
Year: G (1 or 2) *Arr.*
Individual advanced work by properly qualified graduate students. Problems selected in consultation with the instructor. *Staff*

16.605 *Aeronautical Problems*
Prereq.: ——
Year: 4 (1 or 2) *Arr.*
Individual or group work by properly qualified students. Problems chosen in consultation with instructor. *Staff*

16.65 *Aeronautical Engineering Laboratory*
Prereq.: 16.11, 16.20, 16.30
Year: 4 (1) 3–3–6
Lectures and experiments selected to illustrate the principles and practices of experimental aeronautics in the fields of aerodynamics, structures, and automatic control systems. *Bicknell*

16.66 *Fluid Dynamics Laboratory* (A)
Prereq.: 16.65
Year: G (1 or 2) *Arr.*
Graduate laboratory subject in fluid mechanics and related fields, conducted as individual projects arranged between student and instructor. *Mollö-Christensen*

16.70 *Aircraft Detail Design*
Prereq.: ——
Year: 2 (1) 3–5–0
Aircraft drafting room practice and the preparation of airplane assembly, subassembly, and detail part drawings. Lectures and drafting room exercises covering air frame detail design, landing gear and landing gear control system mechanisms, fuel systems, airplane graphics, and the preparation of a weight estimate and balance diagram for a complete airplane. *Bentley*

16.71T *Aeronautical Engineering*
Prereq.: 16.11, 16.20, 16.70
Year: 4 (1) 2–10–0

16.72 *Aeronautical Engineering*
Prereq.: 16.30, 16.71T
Year: 4 (2) 0–9–3
Design of an airplane or rocket vehicle including layout, weight, balance, and performance estimates, structural design and preliminary stress analysis, stability and control analysis including design of a simple automatic control system. Emphasis on individual initiative and independent application of fundamental design principles and on presentation of a final report. *Koppen*

16.74 *Advanced Design* (A)
Prereq.: 16.105, 16.72
Year: G (1) 2–6–4
Application of current design and operations analysis methods to the determination of the optimum vehicle capable of satisfying a given mission. Weight estimation from preliminary structural design and aeroelastic considerations, performance substantiation, evaluation of functional suitability, control system analysis and determination of optimum propulsive device. Considerable latitude in the choice of mission; use of the vehicle primarily as a means of illustrating methods used during the preliminary design stages in the development of aircraft and rocket vehicles. *Miller*

16.761 *Orbital and Ballistic Flight* (A)
Prereq.: 16.02, 16.11
Year: G (1) 3–0–6

16.762 *Orbital and Ballistic Flight* (A)
Prereq.: 16.761
Year: G (2) 3–0–6
Performance of ballistic and orbital missiles and space craft. Atmosphere and space environment of vehicles; orbital mechanics; ballistic trajectories; performance parameters of rocket motors; powered flight and re-entry trajectories; guidance navigation and control as affecting flight mechanics and vehicle design; kinematics of interception trajectories, aerodynamics and structures of vehicle design; vehicles system design considerations. First term strongly oriented toward fundamental celestial mechanics and trajectory kinematics and dynamics; second term strongly oriented toward effects on vehicle design of component technologies. *Stever, Sandorff*

16.81 *General Aeronautics*
Prereq.: 18.03
Year: 4 (1) 3–0–6
Characteristics of aircraft, engines, and propellers for non-aeronautical students. *Markham*

16.82 *Introductory Aeronautical Engineering*
Prereq.: 18.03
Year: 2 (1) 3–0–3
Introduction to aircraft, their components and general principles of flight. *Markham*

16.851 *Industrial Practice*
Prereq.: ——
Year: 3 (S) 40 h.p.w.

16.852 *Industrial Practice*
Prereq.: ——
Year: 3 (1) 40 h.p.w.
Six months of practical work carried out by the cooperative students in manufacturing, engineering, research, and developments at the plants of organizations participating in the cooperative program. *Markham*

16.91 *Aeroelasticity* (A)
Prereq.: 16.02
Year: G (1) 3–0–6
Dynamics of elastic structures. Self-excited dynamic instability, such as occurs in flying vehicles. Stress on formulation of self-excited vibration problems and approximate methods for their solution. *Mollö-Christensen*

(A) indicates a subject given primarily for graduate students. (R) indicates a subject restricted to special groups because of content. Other notations are described on the first page of this Section.

16.92 ***Advanced Aeroelasticity* (A)**
Prereq.: 16.91
Year: G (2) 3–0–9
Presentation of field of aeroelasticity from unified viewpoint applicable to all types of flight vehicles throughout range of airspeeds. Derivation of aeroelastic operators and unsteady airloads from governing variational principles. Forced response, static and dynamic eigenvalues of simplified systems, one-dimensional structures and two-dimensional structures. Special topics of interest to the aeroelastician, with emphasis on aerodynamic operators. *Ashley*

16.93 ***Aeroelasticity Laboratory* (A)**
Prereq.: 16.91
Year: G (1) 2–2–2
Experimental study of problems in structural dynamics and aeroelasticity. *Halfman*

16.94 ***Dynamics of Structures* (A)**
Prereq.: 16.21, 16.91
Year: G (2) 3–0–9
Fundamental variational principles in dynamics; Lagrange's equation and Hamilton's principle. Vibration characteristics of unrestrained elastic systems. Dynamic stresses produced during transient response of aircraft and missile structures to rapidly applied forces. Response of structures to continuous random disturbances. Current structural dynamics problems. *Dugundji*

17.

Building Engineering and Construction

17.401 ***Advanced Job Management* (A)**
Prereq.: 1.922
Year: G (1) 3–0–6
Development of the organization of large projects with reference to the initial economic survey, time schedules, job organization, and integration of construction procedures. The character of contract instruments, legal requirements for job insurance and the expedition of materials to accomplish speed and quality. *McCreery*

17.402 ***Construction Management Seminar* (A)**
Prereq.: 1.921, 1.922
Year: G (2) 3–0–6
Continuation of 17.401 in seminar form. Diagnosis of failures and their causes; integration of the electrical, mechanical and sanitary services into building construction; analysis of architectural concepts in the light of existing construction procedures; study of professional relations in the conduct of contracting as a profession. Extensive contributions by the students. Field trips to illustrate difficult situations. Participation of contractors, architects and engineers from a variety of projects. Field surveys, library research papers, term paper. *McCreery*

17.42 ***Construction Analysis Seminar* (A)**
Prereq.: 1.921
Year: G (2) 2–0–4
Exploration of analytical approaches to solution of many variables entering into construction, including flow of components, structural problems, influence of site conditions, materials technology, economic feasibility and cost analyses affecting optimum solution. Case system largely employed. *Heger*

17.73 ***Materials — Wood, Plastics, Fabrics***
Prereq.: 8.02
Year: 4 (2) 3–0–3
Mechanical and physical properties of wood in relation to growth, structure and other characteristics which influence its use in construction and engineering. Strength, moisture content, preservative treatment, wood products, identification, and selection of species for various uses. Fundamental properties and uses of plastics; basic characteristics of coatings and fabrics used in construction. *Wood Handbook;* Dietz, *Construction Materials.* *Dietz*

17.74 ***Materials — Masonry and Metals***
Prereq.: 8.03
Year: 4 (1) 3–2–4
Primarily for architectural students with emphasis on masonry materials, concrete, and metals. Factors affecting the durability of masonry structures. Principles underlying metals, alloys, corrosion and welding of metals. About two-thirds of subject on masonry materials, and the balance on metals. Laboratory work testing brick and mortar; concrete and concrete beams; ferrous and non-ferrous metals; wood, plastics, and laminates; thermal conductivity of walls. Murray, *Masonry Materials; Laboratory Manual;* Williams & Homerberg, *Principles of Metallography.* *J. A. Murray, McGarry*

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...mes Rice, John Chase, J. P. Robinson, F. W. Lincoln Jun., Thomas Aspinw

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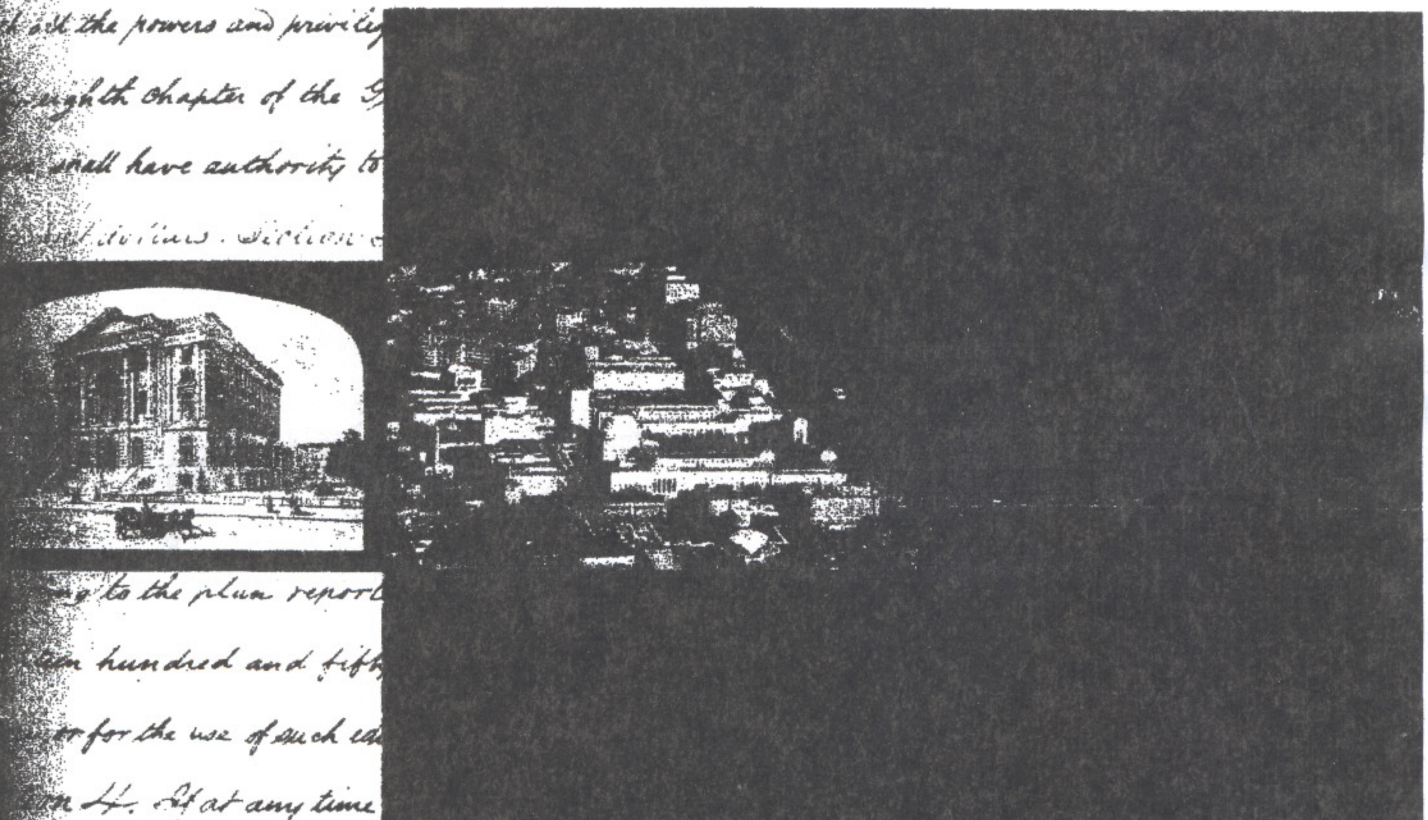

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Department of Aeronautics and Astronautics

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Professor of Aeronautics and Astronautics; Head of the Department; Director of the Instrumentation Laboratory

RAYMOND LEWIS BISPLINGHOFF, SC.D.
Professor of Aeronautics and Astronautics; Deputy Head of the Department

ROBERT LOUIS HALFMAN, S.M.
Associate Professor of Aeronautics and Astronautics; Executive Officer

JEROME CLARKE HUNSAKER, SC.D., ENG.D.
Professor of Aeronautical Engineering, Emeritus

OTTO CARL KOPPEN, S.B.
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EDWARD STORY TAYLOR, S.B.
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RENE HARCOURT MILLER, M.A.
Professor of Flight Vehicle Engineering

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Associate Professor of Aeronautics and Astronautics

WALTER HENRY GALE, S.M.
Associate Professor of Aeronautics and Astronautics; Special Assistant

JOSEPH BICKNELL, S.M.
Associate Professor of Aeronautics and Astronautics

PAUL EDWIN SANDORFF, S.B.
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Associate Professor of Aeronautics and Astronautics

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Associate Professor of Aeronautics and Astronautics

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Associate Professor of Aeronautics and Astronautics

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Associate Professor of Aeronautics and Astronautics

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Assistant Professor of Aeronautics and Astronautics

MYRON ARNOLD HOFFMAN, SC.D.
Assistant Professor of Aeronautics and Astronautics

JUDSON RICHARD BARON, SC.D.
Assistant Professor of Aeronautics and Astronautics

JOHN DUGUNDJI, SC.D.
Assistant Professor of Aeronautics and Astronautics

WINSTON ROSCOE MARKEY, SC.D.
Assistant Professor of Aeronautics and Astronautics

WALLACE EARL VANDER VELDE, SC.D.
Assistant Professor of Aeronautics and Astronautics

JAMES LEE STOCKARD, S.B.
Assistant Professor of Aeronautics and Astronautics

GORDON CEDRIC OATES, PH.D.
Assistant Professor of Aeronautics and Astronautics

Research Associates

MYRON JACQUES BLOCK, B.S.
LEON HOMER SCHINDEL, SC.D.

Professors Emeriti

JEROME CLARKE HUNSAKER, SC.D., ENG.D.
Professor of Aeronautical Engineering, Emeritus

SHATSWELL OBER, S.B.
Professor of Aeronautical Engineering, Emeritus; Lecturer

AERONAUTICS AND ASTRONAUTICS

Aeronautics and astronautics deal with the problems of manned or unmanned vehicles that operate above the earth's surface. These include fixed-wing aircraft, helicopters, ballistic missiles, guided missiles, and space vehicles. Successful realization of systems based on such devices requires that solutions be found for the static and dynamic problems of sustentation, fluid resistance to motion, propulsion, strength and elasticity of minimum-weight structures, manual and automatic control, and measurements under difficult environmental conditions. It is the primary objective of the Department of Aeronautics and Astronautics to give a clear understanding of all these important problems and to provide students with a broad background of education in the art and science of applying sound judgment in achieving acceptable solutions for practical situations.

More than any other, the factor which influences the educational climate of the Department is the extensive, vigorous participation by faculty members in the activities of one or more of the several departmental research laboratories. Because all faculty members are actively interested in teaching, the aeronautical research problems of one day can and often do become the classroom examples or assignments of the next. Many undergraduate and graduate students find that part-time employment in one of the laboratories provides experience that is an invaluable supplement to formal courses. Such experience commonly suggests thesis projects. The Department is proud that all of its extensive research facilities are available to its student body for thesis work or instruction, and that the utilization is high for both of these purposes. Many of the basic contributions to aeronautical science in such areas as automatic control, inertial navigation, turbojet engines, aeroelasticity, and aerodynamic heating originated from student-faculty collaboration on thesis projects.

The *Aeroelastic and Structures Laboratory* conducts a wide variety of investigations on the interrelation between aerodynamic and elastic forces. Wind tunnels and a shock tube are available for low-speed or high-speed dynamic testing. The structural test facility contains equipment for static or dynamic loading of aircraft components and material samples. Electrothermal furnaces permit study of high-temperature gradients and transient effects.

The *Aircraft Instruments Laboratory* operates extensive equipment for studying the performance of measuring and control systems, with particular emphasis on instructing students in the fundamentals of such systems and providing thesis facilities. Items available include an electronic simulator, harmonic synthesizer, environmental facility, and apparatus for measuring vibratory characteristics of instruments.

The *Gas Turbine Laboratory* facilities are devoted to the study of fluid-dynamic phenomena in turbines, compressors, and combustion chambers; boundary-layer flow; and mixing of jets. The Laboratory includes an 8 by 8 inch supersonic wind tunnel, along with other experimental apparatus of all types related to aircraft propulsion research.

The *Instrumentation Laboratory* is a defense research organization devoted to research and development on fire control and inertial guidance and space navigation systems. Its equipment includes several digital and analog computers as well as an extensive facility at Hanscom Air Force Base near Boston. Research projects are organized in such a way that students may obtain advanced professional experience, similar to an internship, in instrumentation and weapons systems. Valuable sources of thesis material are provided in these fields. Results of current research are being applied directly to graduate academic subjects and ultimately to undergraduate teaching in the Department.

The *Naval Supersonic Laboratory* conducts basic research and development on high-speed flight. Typical projects inquire into hypersonic gasdynamics, heat and mass transfer, magnetogasdynamics, loads on airframes, physics of gases, and communication through high temperature flow fields. The facility contains a 10,000 horsepower 18″ x 24″ wind tunnel which operates at both subsonic and supersonic Mach numbers up to 7.5, pressures to 7 atmospheres, and temperatures to 1500°R. Additional tunnels include a 5″ x 5″ Mach number 5 circuit and a magnetogasdynamic facility operating in the low supersonic Mach number range at temperatures up to 50,000°K.

The *Wright Brothers Wind Tunnel Facility* includes a low-speed wind tunnel, with elliptic throat 7½ by 10 feet and operating pressures ¼ to 4 atmospheres. This tunnel also serves as the reservoir for an intermittent transonic wind tunnel with a 22-inch slotted-wall test section, and for an intermittent supersonic tunnel with continuously variable Mach number between 1.2 and 2.0, particularly adapted for the measurement of oscillatory air loads and aeroelastic stability.

The *Fluid Dynamics Research Group* is not directly associated with any one facility but takes advantage of the staff and equipment of any and all departmental laboratories that are able to make contributions to its research.

THE UNDERGRADUATE CURRICULA

Aeronautics and Astronautics (Course XVI)

Undergraduate education in aeronautics and astronautics is regarded as a period of grounding in fundamentals, of acquiring habits of learning and patterns of thought. During the first two years, the undergraduate curriculum is devoted almost entirely to providing a strong preparation in the basic sciences, the engineering sciences, and mathematics. A working mastery of mathematics, chemistry, physics, thermodynamics, mechanics, material science, and electrical science is a necessary prerequisite to the subsequent study of professional subjects in aeronautics and astronautics. The professional subjects are contained largely in the third and fourth years of the undergraduate curriculum.

Each student has a wide choice in the selection of these professional subjects; he may make this choice to correspond with his own aptitude and interests, constrained only by the necessity of pursuing a well-balanced program of adequate depth. The exact program which he follows is arrived at jointly with his Faculty Counselor. Although a variety of combinations of the professional subjects may be designed, the Department suggests two general types of programs which in its judgment prepare students especially well for aeronautics and astronautics. These are termed the Engineering Program and the Engineering Science Program. The Course leads to the degree of Bachelor of Science in Aeronautics and Astronautics.

ENGINEERING PROGRAM

Unlike most engineering curricula, aeronautical and astronautical engineering has the distinguishing feature of being polarized around a flight vehicle. This polarization provides for students a continuous object and goal which is of great motivating value in the learning process. The flight vehicle, to be sure, may cover a wide spectrum of devices from helicopters to space craft; but all such devices have five elements in common:

(a) A propulsion system.
(b) A control and guidance system.
(c) An external shape of maximum aerodynamic efficiency.
(d) A structure of minimum weight and maximum strength.
(e) A suitable compromise among the elements (a) through (d), so as to produce a flight vehicle which best fulfills a given mission requirement.

Professional subjects embracing the five common elements form the heart of the engineering program. The professional subjects corresponding to elements (a) through (d) are offered in a generalized way so that they provide a substantial foundation for all forms of flight vehicles. Subjects corresponding to element (e) have as their objective bringing together the previous professional disciplines in the synthesis of a flight vehicle. Here students work under the close supervision of the staff to employ their creative skills to devise a vehicle which satisfies given mission requirements. More important, each student's critical technical judgment is exercised in making the necessary compromises among many conflicting technical requirements. His desire for individual specialization is satisfied by elective subjects.

The curriculum requirements for the Engineering Program are given below:

1. ENGINEERING PROGRAM CURRICULUM

			Total units
GENERAL INSTITUTE REQUIREMENTS (*see page 83*)			176
	PHYSICS 8.03 and 8.04 *or* 8.031 and 8.041 must be taken. ECONOMIC PRINCIPLES I (14.01) is required as one of the humanities and social science electives.		
DEPARTMENTAL PROGRAM			
	Required subjects		
16.81T	FLIGHT VEHICLES	3 0 6	
3.14	ENGINEERING MATERIALS	4 2 4	
16.201	SOLID MECHANICS I	4 0 6	
16.20T	FLIGHT VEHICLE STRUCTURES I	4 0 6	
2.40T	HEAT ENGINEERING	3 0 6	
16.02	AERODYNAMICS	4 2 6	
16.11T	FLIGHT VEHICLE AERODYNAMICS AND DYNAMICS	4 0 5	
16.53	PROPULSION	3 0 6	
16.01T	DYNAMICS	4 2 6	
6.43	INTRODUCTION TO ELECTRICAL SCIENCE	4 2 4	
6.44	INTRODUCTION TO ELECTRICAL SCIENCE	4 0 6	

(*continued*)

Required subjects (continued)

16.30	PRINCIPLES OF AUTOMATIC CONTROL	3 0 9	
16.62	EXPERIMENTAL PROJECTS I	2 4 4	
16.71T	FLIGHT VEHICLE ENGINEERING	2 3 7	
	THESIS	9	
			153
	Elective subjects		
	Unspecified		41
Total units required for the S.B. degree			370

ENGINEERING SCIENCE PROGRAM

The period since World War II has been one of intense change in flight vehicle technology. The earliest airplane designers, although not ignorant of scientific methods, developed their machines largely by intuitive invention and empiricism. As the commercial and military usefulness of their product was demonstrated, there arose an intense desire to increase its performance and efficiency. This motivated intense research activity in the professional fields of propulsion, control and guidance, aerodynamics, and structures. The result is a new era in flight vehicle development in which scientific methods logically applied by teams have accomplished processes which were judged impossible a few years ago. Thus, research and the resulting development have become integral and highly important parts of flight vehicle technology. It is the purpose of the curriculum in the Engineering Science Program to prepare students to work at the frontiers of research for improvement of flight vehicles. The principal distinguishing feature of the engineering science curriculum is its emphasis on increased depth in the areas of physics, mathematics, gasdynamics and solid mechanics. Since a proper balance between theory and experiment is the keystone to progress in research and development, there is also emphasis on laboratory experience. Substantial elective time permits the student to reach more deeply into areas of his choice.

Like the engineering curriculum, the engineering science curriculum is designed as a terminal program. It is expected, however, that a rearrangment of Course content to permit a smooth transition into graduate work will be a common feature.

The curriculum requirements for the Engineering Science Program are given in the next column:

2. ENGINEERING SCIENCE PROGRAM CURRICULUM

			Total units
GENERAL INSTITUTE REQUIREMENTS (*see page 83*)			176
	PHYSICS 8.031 and 8.041 are prescribed. ECONOMIC PRINCIPLES I (14.01) is required as one of the humanities and social science electives.		
DEPARTMENTAL PROGRAM			
	Required subjects		
16.81T	FLIGHT VEHICLES	3 0 6	
3.14	ENGINEERING MATERIALS	4 2 4	
16.201	SOLID MECHANICS I	4 0 6	
16.202	SOLID MECHANICS II	4 0 6	
2.40T	HEAT ENGINEERING	3 0 6	
16.03	GASDYNAMICS	4 2 6	
16.01T	DYNAMICS	4 2 6	
16.62	EXPERIMENTAL PROJECTS I	2 4 4	
16.63	EXPERIMENTAL PROJECTS II	2 6 4	
6.43	INTRODUCTION TO ELECTRICAL SCIENCE	4 2 4	
6.44	INTRODUCTION TO ELECTRICAL SCIENCE	4 0 6	
8.051	ATOMIC AND NUCLEAR PHYSICS	4 0 5	
18.05	ADVANCED CALCULUS FOR ENGINEERS	3 0 6	
18.06	ADVANCED CALCULUS FOR ENGINEERS	3 0 6	
	THESIS	9	
			150
	Elective subjects		
	Unspecified		44
Total units required for the S.B. degree			370

The Honors Course

Students who wish to pursue a coordinated schedule of studies through their senior and graduate years may apply for the Honors Course group; a limited number of students of superior ability are selected each year for the group by the Department. A member of the Department aids each member in planning the senior and graduate schedules which are best suited to his individual interests. The program requires completion of all unit and humanities requirements for the Bachelor's degree and for either the Master's degree or the degree of Engineer in Aeronautics and Astronautics, but only a single thesis of not less than 30 units in the graduate program.

The Honors Course leads to the degree of Bachelor of Science in Aeronautics and Astronautics and either the degree of Master of Science in Aeronautics and Astronautics or the degree of Engineer in Aeronautics and Astronautics, awarded simultaneously at the end of the graduate program.

Aeronautics and Astronautics (Cooperative Course) (Course XVI-B)

The cooperative program for Aeronautics and Astronautics undergraduates provides the opportunity for about six months of experience in an industrial organization before the professional work of the senior year. Continuous contact with industrial problems enables students to discover and develop their aptitudes and interests to better advantage than would be possible with shorter periods of employment. The program does not interfere with the student's academic progress nor with his extracurricular activities in association with his classmates.

The cooperating companies of the aircraft industry pay the students at prevailing rates during their period of employment. The students pay their own transportation and living expenses while away from the Institute.

Students who are interested in the program should apply to Department Headquarters for a set of Personnel Record Forms prior to December 1 of their sophomore year. These forms should be completed and returned by December 15, with an added statement specifying the location where the student prefers to work.

Representatives of the cooperating companies come to the Institute to interview interested students and to determine, together with the Department representative, the distribution of those selected for employment. Students who are thus selected become regular employees during their period of employment in an aircraft plant and are subject to the regulations of the company. They are expected to carry the Course through to completion unless exceptional circumstances intervene.

A list of the companies cooperating in this program is available at the Headquarters of the Department of Aeronautics and Astronautics.

Juniors in the Cooperative Course are also eligible for the Honors Course described above.

CURRICULUM IN THE COOPERATIVE COURSE (COURSE XVI-B)

The Cooperative Course leads to the degree of Bachelor of Science in Aeronautics and Astronautics. The curriculum requirements for this degree are the same as for the Engineering Program in Course XVI, except for the addition of required plant work:

16.851	INDUSTRIAL PRACTICE	40 h.p.w.
16.852	INDUSTRIAL PRACTICE	40 h.p.w.

GRADUATE STUDY IN AERONAUTICS AND ASTRONAUTICS

Graduate students in the Department of Aeronautics and Astronautics study and conduct research in the engineering and scientific aspects of many problems of flight transportation. Fields of endeavor may be fairly general; programs may be oriented to aeronautical or astronautical engineering or to aeronautics or astronautics, in which case there will be less emphasis on engineering applications. Major fields of specialization include vehicle design and operation, aerodynamics or gas dynamics, space mechanics, structures, aeroelasticity, propulsion, instrumentation, and automatic control. For successful graduate work in any of these fields, strong preparation and aptitude in applied mathematics and physics are necessary foundations. Students may elect subjects in other departments which bear a useful relation to their program.

Advanced study in the Department leads to the degrees of Master of Science in Aeronautics and Astronautics, Engineer in Aeronautics and Astronautics, Materials Engineer, Doctor of Science or Doctor of Philosophy in Aeronautics and Astronautics, and Doctor of Science in Materials Engineering.

Entrance Requirements for Graduate Study

In addition to the general requirements for admission to the Graduate School, all applicants must have completed strong fundamental undergraduate subjects in thermodynamics, mechanics, electrical engineering, and automatic control. Additional undergraduate preparation is a prerequisite for specialization in particular fields. Some prerequisites may be completed early in a graduate program.

The Graduate Degrees

MASTER OF SCIENCE IN AERONAUTICS AND ASTRONAUTICS

For this degree, at least one year of an approved graduate program is required, including thesis. Two terms of advanced mathematics beyond DIFFERENTIAL EQUATIONS (18.04) or its equivalent must be included. This degree is also awarded simultaneously with the Bachelor of Science in Aeronautics and Astronautics upon successful completion of the five-year Honors Course program.

Although excessive specialization is undesirable, it is expected that most candidates for this degree will concentrate in a single professional field, not seeking the same breadth of educational background implied by the Engineer degree.

ENGINEER IN AERONAUTICS AND ASTRONAUTICS

For this degree the student must satisfactorily complete at least two years of an approved graduate program, including thesis. Subjects in a variety of professional specialties are required, so as to provide a broad foundation in both aeronautical and astronautical science and their engineering applications.

Requirements for admission to candidacy for the degree of Engineer in Aeronautics and Astronautics are more rigorous than for the degree of Master of Science in Aeronautics and Astronautics.

DOCTOR OF SCIENCE (OR PHILOSOPHY) IN AERONAUTICS AND ASTRONAUTICS

To be recommended for this degree by the Department of Aeronautics and Astronautics, the student must complete an approved program, including thesis. Such a program probes more deeply into a special field than the program for the Engineer degree and does not necessarily include the same breadth of engineering applications. Competence must be demonstrated by a General Examination consisting of written and oral parts. The thesis must demonstrate the student's ability to carry out independent original research of high quality on a problem of aeronautical or astronautical science or engineering.

DOCTOR OF SCIENCE WITH SPECIALIZATION IN THE FIELD OF INSTRUMENTATION

For the Doctor's degree in this field, the student is required to complete an approved program, including thesis, in the interrelated professional fields of instrumentation. This work involves the cooperative effort of the Departments of Aeronautics and Astronautics (Instrumentation and Weapons Systems Divisions), Electrical Engineering, Mechanical Engineering, Mathematics, and Physics. The program is administered, for registration purposes, by the Department of Aeronautics and Astronautics. The General Examination includes both written and oral parts. The thesis must demonstrate the ability of the student to do original research of high grade on a problem of instrumentation or weapons systems engineering.

MATERIALS ENGINEER AND DOCTOR OF SCIENCE IN MATERIALS ENGINEERING

There has arisen in recent years a very strong interaction between the field of materials and flight vehicle development. It may be said that material properties impose limitations on either the performance or efficiency of most flight vehicles and their propulsion systems. Graduates who have preparation in the combined fields of aeronautics and astronautics and material science are required in increasing numbers to deal with these important interdisciplinary problems.

Graduate students with undergraduate backgrounds in aeronautics and astronautics may pursue programs leading to the degrees of Materials Engineer or Doctor of Science in Materials Engineering. The same general requirements for the completion of these degrees are applicable as for the corresponding degrees in Aeronautics and Astronautics.

Programs of study leading to the degrees of Materials Engineer and Doctor of Science in Materials Engineering are arranged on an individual basis, depending upon the preparation of the student. In general, such programs will involve a substantial number of subjects in the fields of metallurgy, physics, and chemistry in addition to subjects within the Department.

Language Requirement

No language requirement is made for candidates for the Master of Science or Engineer degrees. A candidate for the Doctor of Science degree must demonstrate competence in reading two foreign languages in his major field. Each student's choice of languages must be approved by his Graduate Registration Officer.

Financial Assistance for Graduate Study

The Department offers several fellowships for full-time study in aeronautics and astronautics; these are described in Appendix A of this Catalogue. In addition, graduate students may earn part or all of their expenses as part- or full-time assistants. These duties, concerned with either teaching or research, provide valuable educational experience.

DESCRIPTIONS OF SUBJECTS

The subjects and descriptions given in this Section are subject to change. The final list of subjects to be given in 1960–61 will be published with the class schedules prior to the beginning of each term.

(A) following the name of a subject indicates that it is an approved subject for a graduate degree.

(R) following the name of a subject indicates that it is restricted to special groups because of content; all subjects open only to special groups are so noted at the end of the description of the subject.

The information given below the number and name of the subject is as follows:

1. The number(s) of prerequisite subjects, if any. Numbers in italics indicate subjects which may be taken simultaneously with the subject described.
2. The year classification (and term) for which the subject is normally scheduled. This is indicated as follows: "1" is a first-year subject only, and not accepted for upperclass credit; "U" is an undergraduate subject above the first year; "G" is a graduate subject.
3. The time distribution of the subject, showing in sequence the units allotted to: recitation and lecture; laboratory, drawing, or field work; and preparation. Each unit represents 15 hours of work. The total unit credit for a subject is obtained by adding together all the units shown. One unit of recitation or lecture credit, and two units of laboratory or drawing credit, are each equivalent to one semester hour.

Arr. indicates that time units are specially arranged.

4. The name of the instructor(s) in charge, when known at press time.

15.942 *Seminar in Business Practices* (A)
Prereq.: 15.18
Year: G (1) 3–0–6
Investigation of the principles of top management policy making. Derivation of authority, the corporate objective, influences on the decider, activation and appraisals of policy decisions. Case studies of selected companies illustrating the principles discussed. (*Restricted to Sloan Fellows.*) *Hudgins*

15.951 *Special Studies in Management* (A)
Prereq.: ——
Year: G (1) *Arr.*

15.952 *Special Studies in Management* (A)
Prereq.: ——
Year: G (2) *Arr.*
For graduate students who desire to do advanced work or to carry out some special investigation of a management problem not specifically covered elsewhere and not qualifying as a thesis. Readings, conferences, laboratory and field work, and reports. *Staff*

15.96 *Administrative Theory and Practice* (A)
Prereq.: 15.312, 15.412, 15.712, 15.812
Year: G (1) 3–0–6
Especially designed for graduate students who look forward to ultimate responsibilities in the top management of industry. Initial problems confronting the new business administrator. Formulation of methods of approach to administrative problems. Techniques of negotiation, mediation and group deliberation. Relationships of top management to subordinates, investors, vendors, customers, associates, community, government, and the public. Underlying principles leading to long-term continuity and tenure. Evening conferences with business administrators and industrialists.

15.971T *Seminar in Research Management* (A)
Prereq.: 15.371
Year: G (2) 2–0–7
Organizational and human relations aspects of managing laboratories and groups engaged in research and development, with consideration of the psychological and social factors in creative work. Readings, discussions, field studies, and reports. *Marquis*

15.975 *Seminar in Management of Improvement* (A)
Prereq.: 15.371
Year: G (1) 3–3–3
Examination of the improvement function in management. Review of literature on creativity as it affects innovation in industrial operation. Human relations problems in industrial change. The role of the manager in fostering improvement. The use of the conference as an improvement tool. Field work in comparative analysis of representative improvement programs.
L. B. Moore, Lodahl

15.98 *Seminar in Administration* (A)
Prereq.: 15.18
Year: G (1) 3–0–6

15.99 *Seminar in Administration* (A)
Prereq.: 15.18
Year: G (2) 3–0–6
Study of fundamental economic, financial, organizational and administrative relationships analyzed and discussed by experienced leaders in business, labor and public administration. Examination of managerial philosophies and practices in the field and in seminar discussions. (*Restricted to Sloan Fellows.*) *Wynne*

16.

Aeronautics and Astronautics

16.01 *Flight Dynamics*
Prereq.: 16.00, *18.04*
Year: U (1) 4–1–5
Dimensional analysis. Kinematics of a rigid body in general motion. Mass properties of rigid bodies, ellipsoid of inertia, geometric and mass symmetries. Dynamics in general motion of a group of particles, a rigid body, a body of variable mass. Euler's dynamical equations, gyroscope equations, rocket equations with application to aircraft, spacecraft and their components. Linear systems, free and forced oscillations, multiple degrees of freedom, classical and operational methods of analysis. System performance and stability. Examples of nonlinear systems. *Halfman*

16.01T *Dynamics*
Prereq.: 8.02, 18.03
Year: U (1, S) 4–2–6
Dynamics, with applications to aeronautical and astronautical problems. Kinematics and dynamics of particles and of groups of particles. Relative motion as seen by accelerating and rotating observers. Particles of variable mass. Mass properties of rigid bodies, the inertia tensor, geometric and mass symmetries. Kinematics and dynamics of a rigid body in general motion. Euler's dynamical equations, gyroscope equations. (*Not offered 1960–61.*)
Halfman

16.02 *Aerodynamics*
Prereq.: 2.40T, *16.01T*
Year: U (1, 2) 4–2–6
Description of gaseous environment of vehicles in flight, considered as a continuous medium and from viewpoint of kinetic theory. Application of the conservation laws of mass, momentum and thermodynamic energy to real and perfect fluids in motion. One-dimensional flow of a perfect gas, with simple aeronautical and astronautical illustrations. Fundamentals of three-dimensional fluid motion; applications, with special reference to nonviscous incompressible flow; airfoil and wing theory. Elementary examples of viscous flow; boundary layer. *Ashley*

16.03 *Gasdynamics*
Prereq.: 2.40T, *16.01T*, *18.05*
Year: U (1) 4–2–6
Fundamentals of fluid dynamics presented so as to meet the needs of students interested in research. Physics and thermodynamics of gases from the phenomenological and atomistic viewpoints. Conservation laws for a continuous fluid medium and their specialization to nonviscous perfect gas. One-dimensional flow. Constant-density flow, with emphasis on the two-dimensional case. Introduction to small-perturbation concepts and to methods for analyzing compressible fluid motion. *Ashley*

(A) indicates a subject given primarily for graduate students. (R) indicates a subject restricted to special groups because of content. Other notations are described on the first page of this Section.

16.041 ***Aerodynamics — Viscous Fluids*** **(A)**
Prereq.: 16.02, *18.05*
Year: G (1) 3–0–9
Introduction to viscous flows. Basic flow equations; exact solutions; low Reynolds number cases; boundary layer flows; brief discussion of stability; transition; turbulent boundary layers. Lectures to be supplemented by occasional demonstrations. *Bicknell, Finston*

16.042 ***Aerodynamic Heating*** **(A)**
Prereq.: 16.041, *18.06*
Year: G (2) 3–0–9
Extension of discussion in 16.041 to include thermodynamic aspects. Kinetic heating at high speeds; heat transfer through boundary layers; discussion of methods of reducing surface temperatures. Application to hypersonic aircraft and re-entry bodies, including real gas effects at high temperatures. *Finston*

16.051 ***Topics in Gas Dynamics*** **(A)**
Prereq.: 16.02 or 16.03; *18.05*
Year: G (1) 3–0–9

16.052 ***Topics in Gas Dynamics*** **(A)**
Prereq.: 16.051
Year: G (2) 3–0–9
Concepts for compressible medium flow. Fundamental conservation relations and nature of the medium. Methods appropriate for subsonic, transonic, supersonic, and hypersonic inviscid flows in two and three dimensions. Similarity concepts. Rarefied and real gas effects. Introduction to nonequilibrium flows. Application to bodies and wings. *Baron*

16.065 ***Physics of High Speed Gas Flows*** **(A)**
Prereq.: 16.02
Year: G (1) 3–0–9
Review of statistical mechanics as basis for the equations of motion of a gas. Physical nature of transport phenomena. Mechanism of vibrational excitation, dissociation, ionization, radiation and relaxation effects. Free molecule and slip flows. Introduction to magnetohydrodynamics and plasma flows. *Trilling*

16.07 ***Aerodynamics and Dynamics of Missiles*** **(A)**
Prereq.: 16.02, 16.11T
Year: G (1) 3–0–6
Introduction to aerodynamic techniques useful for predicting performance and stability of slender vehicles in high-speed flight at all altitudes in planetary atmospheres. Flow of compressible fluid past bodies, wings, and more general configurations. Slender-body methods, Newtonian theory, other approximate techniques and their limitations. Estimation of forces and moments at subsonic, transonic, supersonic, and hypersonic speeds. Similarity laws and area rules. Some quasi-linear and nonlinear dynamic problems peculiar to slender vehicles. *Ashley*

16.081 ***Advanced Gas Dynamics*** **(A)**
Prereq.: 16.052, 18.06
Year: G (1) 3–0–9

16.082 ***Advanced Gas Dynamics*** **(A)**
Prereq.: 16.081
Year: G (2) 3–0–9
Two-semester subject for advanced graduate students. Fundamentals of gas dynamics of continua with examples from widely diverse fields such as boundary layer theory, acoustics, rotary flows, potential flows, and jet and wake flows. Discussion of unsolved as well as solvable problems. Free use of mathematical tools. *Mollö-Christensen*

16.10 ***Space Flight Dynamics*** **(A)**
Prereq.: 16.01
Year: G (2) 3–0–6
Satellite librations and some effects of nonspherical gravitational fields. Elementary inertial navigation and the Schuler pendulum. Calculus of variations in flight engineering with applications to dynamic aircraft performance and interplanetary rocket flight; classical minimum principles. General motion of "rigid" bodies of variable mass. Relativity and space flight. *Halfman*

16.105 ***Applied Aerodynamics*** **(A)**
Prereq.: 16.02, 16.11T
Year: G (1) 3–0–6
Studies of flight vehicle performance including aerodynamics and characteristics of various types of power plant for a wide range of Mach numbers. *Ober*

16.11T ***Flight Vehicle Aerodynamics and Dynamics***
Prereq.: 16.01T; 16.02 or 16.03
Year: U (2, S) 4–0–5
Motions of flight vehicles under the action of aerodynamic and gravitational loads. Discussion of methods of predicting aerodynamic loads with special consideration of their validity. Small disturbance methods leading to classical dynamic stability of flight vehicles. *Bicknell*

16.15 ***Advanced Stability and Control of Aircraft*** **(A)**
Prereq.: 16.11T
Year: G (1) 3–0–6
Various features of stability and control of aircraft, including airplane motion with free controls; rotary derivatives; airplane frequency response to control motion; controls and control forces. *Larrabee*

16.20 ***Structures***
Prereq.: 2.37 or 2.38
Year: U (2) 4–0–6
Fundamental theory and methods for static strength analysis and design of airplane components. Elasticity relations and practical two-dimensional plasticity. Properties and failure modes of ductile materials, including combined stresses, fatigue, and elevated temperature effects. Solid sections, simple shells, and stiffened-skin structures under shear, bending, torsion, and compression; both elastic and plastic effects. *Mar, Bisplinghoff*

16.20T ***Flight Vehicle Structures I***
Prereq.: 16.201
Year: U (1, 2) 4–0–6
Theories of elasticity and plasticity in three-dimensional orthogonal curvilinear coordinates. Thermoelasticity. Specialization to solid sections, simple shells and stiffened skin structures under shear, bending torsion and compression; both elastic and plastic effects. Elementary concepts of stability. Principles of minimum weight design. Laboratory demonstrations. (*Not offered 1960–61.*) *Mar, Bisplinghoff*

16.201 ***Solid Mechanics I***
Prereq.: 3.14
Year: U (2) 4–0–6
Fundamentals of solid mechanics presented to build upon the atomistic view as presented in an introductory subject in material science. Establishment of a connection between this viewpoint and the physics of solids on a phenomenological basis. Concepts of stress and strain. Equilibrium and compatibility of solids in three dimensions. Behavior and modes of failure of materials under extreme environmental conditions. Laboratory demonstrations. *Bisplinghoff*

16.202 *Solid Mechanics II*
Prereq.: 16.201
Year: U (2) 4–0–6
Theories of elasticity and plasticity in three dimensional orthogonal curvilinear coordinates. Tensor properties of stress and strain. Energy methods. Thermoelasticity. Elastic and plastic bending and twisting of beams. Concepts of stability. Elementary theory of plates including elastic and plastic buckling. Laboratory demonstrations. (*Not offered 1960–61.*) *Bisplinghoff*

16.21 *Theory of Structures*
Prereq.: 16.20
Year: U (1) 4–0–6
Introduction to the energy theorems in structural analysis. Influence coefficients and statically indeterminate structures. Flight vehicle shell structures; load distribution in multi-cell and tapered stiffened shells, analysis of fuselage rings, general stability problems. Introduction to plate theory, small and large deflections. *Dugundji*

16.21T *Flight Vehicle Structures II*
Prereq.: 16.20T
Year: U (2) 3–1–6
Energy methods in solid and structural mechanics. Influence coefficients. Vibrations of structural components. Introduction to shell theory with applications to the analysis of flight vehicle shell structures with and without internal pressure. Analysis of rings and bulkheads. Theories of elastic and plastic stability with applications to flight vehicle shell structures. Laboratory experiments. (*Not offered 1960–61.*) *Dugundji*

16.22 *Shell Structures* (A)
Prereq.: 16.20
Year: G (2) 3–0–6
General formulation of problems in shell structures of arbitrary shape using methods of tensor calculus. Effects of aerodynamic heating on stresses and distortion. Consideration of nonlinear phenomena including large displacements, "snap-through," and buckling. *Pian*

16.25 *Advanced Theory of Structures* (A)
Prereq.: 16.20
Year: G (1) 3–0–6
Varying content from year to year as new methods for analysis of all-metal aircraft become available for examination. Probable effects on structural analysis methods to be expected from new trends in design. *Dugundji*

16.30 *Principles of Automatic Control*
Prereq.: 6.18T, 16.01T
Year: U (2) 3–0–9
Analysis of automatic control systems, including analytical, graphical, and analog methods. Formulation of control system performance equations leading to solutions for transient and steady state inputs. Non-dimensionalized treatment of simple linear systems and extension to more involved automatic control loops. Selected aeronautical and astronautical control problems. *McKay*

16.302 *Aeronautical Systems*
Prereq.: 16.30
Year: U (1) 3–0–6
Lectures and individual projects dealing with aeronautical and astronautical control systems. Lectures include case studies of representative systems. Individual projects involving selection and execution of two tasks, for each of which oral and written presentations are made. *McKay*

16.31 *Principles of Instrumentation and Control* (A)
Prereq.: 16.30
Year: G (1) 3–0–9
Generalized concepts of system performance analysis based on frequency, transient and error coefficient methods. Combined use of feedback and programmed control systems for improving adaptive capability of systems under adverse environmental changes. Principles of system synthesis. Parameter adjustment for optimization of specific dynamic performance indices. Illustrative application of these principles to aircraft and missile systems. *Li*

16.32 *Principles of Instrumentation and Control* (A)
Prereq.: 16.31
Year: G (2) 3–0–9
System design with random inputs and disturbances. Analysis of system characteristics with time varying parameters. Nonlinear system performance analysis. Switching technique applied to control and instrumentation. Optimalizing control systems. Adaptive control system design principles for aircraft and spacecraft. Sampled data control system analysis. *Li*

16.33 *Instrumentation and Control Laboratory* (A)
Prereq.: 16.31
Year: G (1) 2–2–6
To be taken simultaneously with 16.31. Laboratory exercises on instruments and control systems designed to provide experimental familiarity with principles set forth in 16.31. Various test methods to evaluate static and dynamic characteristics of instruments and control systems. Various schemes for improvement of static and dynamic performance. *Li*

16.35 *Special Problems in Instrumentation and Control* (A)
Prereq.: 16.32
Year: G (1 or 2) *Arr.*
Problems of interest to qualified individual students in consultation with the instructor. *McKay*

16.36 *Measurement, Telemetry and Data Processing* (A)
Prereq.: 16.30
Year: G (2) 2–2–6
Measurement of physical quantities under various operating conditions and at remote locations. Methods of converting physical phenomena, such as pressure, vibration, flow rate, geometric position, to analog or digital signals suitable for transmission and data handling. Data processing techniques and specialized computations to reduce measured signals to a form better suited for specified application. Emphasis on accuracy, speed, and methods for overcoming disturbing effects at various stages of the system. *Li*

16.37 *Statistical Problems in Automatic Control* (A)
Prereq.: 16.30, 18.05
Year: G (1) 3–0–9
Statistical problems of importance to control engineers. Review of probability theory with application to such problems as evaluation of probability of kill. Introduction to sample theory with application to determination of the CPE for missile systems. Extensive treatment of random processes in linear feedback systems including optimum design of such systems; brief treatment of nonlinear systems in presence of random noise. *Vander Velde*

(A) indicates a subject given primarily for graduate students. (R) indicates a subject restricted to special groups because of content. Other notations are described on the first page of this Section.

16.38 *Physical Components of Control Systems* (A)
Prereq.: 6.18T
Year: G (2) 3–0–6

Effect of component performance characteristics on the control system problem. Consideration of mechanical, electrical and electromechanical components with emphasis on non-ideal effects. Specification of components to meet particular system requirements. Numerous lecture references to applications in aircraft, missile, and spacecraft guidance. *R. K. Mueller*

16.39 *Space Dynamics and Gyroscopic Instruments* (A)
Prereq.: 16.01T
Year: G (1) 3–1–6

Consideration of origins of inertial space concepts and application to interpretation of measured data. Generalized theory of accelerations and velocities of bodies in spaces which are moving with respect to inertial space. Application of general theory and of Newtonian mechanics to theory of gyroscopic instruments. Space integrators and stabilization. Development of treatment from standpoint of engineer, using methods of vectors and of conventional analysis. Application to gyroscopic devices in airborne and marine navigation. *Wrigley*

16.392 *Inertial Guidance* (A)
Prereq.: 16.39
Year: G (2) 3–0–6

Fundamentals of self-contained automatic marine, aircraft, and missile guidance. Character of terrestrial and extraterrestrial gravitational fields; space navigation. Force measurement for navigation purposes with accelerometers for position computation referred to gyroscopically maintained coordinate systems. Combinations of accelerometers, gyroscopes, and computers to form inertial guidance systems. Terrestrial navigation and Schuler tuning; computation of the geographic vertical from moving bases; damping and other system design problems. Effect of component uncertainties on system performance. Inertial control of vehicles to programmed paths. Utilization of possible environmental contact and measurement. *Wrigley*

16.40 *Control Systems Principles*
Prereq.: 16.39
Year: G (1) 4–0–8

Analysis of automatic control systems, including analytic, graphical and analog computer methods. Response of systems described by linear and incrementally linear equations. Stability of feedback control systems. Nondimensional treatment of linear constant-coefficient differential equations. System modification to control dynamic and interference errors. Examples chosen for flight vehicle systems. *Stockard*

16.41 *Introduction to Weapons Systems* (RA)
Prereq.: 16.39, 16.40
Year: G (1, 2) 4–0–8

Static and dynamic behavior of weapons system components and subsystems from standpoint of functional performance, in terms of harmonic analysis and elementary classical physics. Development of a coherent pattern for associating solutions in terms of nondimensional variables with typical weapons system engineering problems. Numerical and graphical methods for determining transient stability of feedback systems. Limitations imposed by uncertainties and interferences on performance of physical equipment. Introduction to theoretical statement of fire control problem and to inertial navigation. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *Markey*

16.42 *Weapons Systems* (RA)
Prereq.: 16.41
Year: G (1, 2) 3–0–9

Generalized treatment of weapons systems problem and methods available for its solution by physical concepts and vectors. Application of gyroscopic and other equipment for interference isolation, tracking, and computing in weapons systems. Fire control principles for airborne and marine weapons systems. Fundamentals of inertial guidance and its application to ships, aircraft, missiles, and spacecraft. Examples taken from service systems. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *Wrigley, Markey*

16.43 *Weapons Systems Laboratory* (RA)
Prereq.: 16.42
Year: G (1, 2) 1–3–5

Demonstration of principles treated in 16.42. Various experiments on characteristics of fire control instrument components, including gyroscopic elements, data transmission systems, and integrating units. Experiments on service fire control equipment and special demonstration units to study static and dynamic performance characteristics of typical airborne and anti-aircraft equipment. Problems of solution time, smoothing, and tracking. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *R. K. Mueller*

16.44 *Automatic Control of Flight Vehicles* (A)
Prereq.: 16.11T, 16.302, 16.39
Year: G (2) 3–0–6

Application of design techniques and principles to advanced automatic control systems for air and space vehicles. Synthesis of control systems from standpoint of meeting mission specifications. Analysis of adaptive control systems; their use in meeting performance requirements over widely changing environments encountered by high-speed aircraft and manned spacecraft. Typical engineering problems associated with design of control equipment, considering limitations and uncertainties of components, random input effects, mass cross-coupling effects, etc. *Whitaker*

16.45 *Vehicle Guidance Systems* (A)
Prereq.: 16.39, 16.40
Year: G (1) 3–0–6

Generalized treatment of vehicle guidance systems by physical concepts and vectors. Fundamentals of inertial guidance and of guidance systems based on radiation. Application to ships, aircraft, and spacecraft. *Markey*

16.46 *Astronautical Guidance* (A)
Prereq.: 16.392
Year: G (2) 3–0–6

Critique of vehicle guidance system theory and design methods, both for inertial and radiation types; mathematical models for dynamics of rotationally controlled bodies; astronomy review and space guidance trajectories; kinematic measurements and relativity. *Wrigley*

16.49 *Special Problems in Weapons Systems* (RA)
Prereq.: 16.42
Year: G (1 or 2) *Arr.*

Problems of interest to qualified students in consultation with the instructor. (*Restricted to selected officers of the U. S. Air Force, Army, and Navy.*) *Wrigley*

16.50 *Vertical Take-Off Aircraft* (A)
Prereq.: 16.11T
Year: G (1) 3–0–6

Analysis of performance and inherent stability and control characteristics of vertical take-off and landing aircraft, VTOL, including helicopters, convertiplanes, tilt wing, vectored lift and jet vertical risers. *R. H. Miller*

16.51 *Advanced Vertical Take-Off Aircraft* (A)
Prereq.: 16.50
Year: G (2) 3–0–6
Application of fundamental principles of aeroelasticity, airplane dynamics, thermodynamics, and automatic control to problems encountered in the design of aircraft capable of vertical take-off and landing, VTOL. Problems of control and stability during conversion to horizontal flight, design of aircraft stabilization systems, dynamics of wing-rotor combinations and of rigid or articulated rotors, and analysis of specialized power plant requirements for direct jet lift. *R. H. Miller*

16.53 *Propulsion*
Prereq.: 2.25 or 16.02 or 16.03; 2.40T
Year: U (2, S) 3–0–6
Review of mechanics of compressible fluids. Applications to analysis and design of gas turbines, rockets, and ram jets. Limits on performance imposed by thermodynamics, fluid mechanics, and strength. *E. S. Taylor*

16.56 *Astronautical Propulsion* (A)
Prereq.: 16.051, 16.53, 18.06
Year: G (1) 3–0–9
Application of fundamental principles of fluid mechanics and thermodynamics to the analysis of selected special problems found in the research and development of liquid propellant engines and nuclear, ion, arc, and magnetohydrodynamic engines. Discussion of possible and most suitable application of the various engines. *E. S. Taylor, Oates*

16.60 *Advanced Aeronautical Problems* (A)
Prereq.: 16.11T or 16.20
Year: G (1 or 2) *Arr.*
Individual advanced work by properly qualified graduate students. Problems selected in consultation with the instructor. *Staff*

16.605 *Aeronautical Problems*
Prereq.: ——
Year: U (1 or 2) *Arr.*
Individual or group work by properly qualified students. Problems chosen in consultation with instructor. *Staff*

16.62 *Experimental Projects I*
Prereq.: 16.81T or 16.82
Year: U (1, 2) 2–4–4
Experimental projects in the field of aeronautics and astronautics. Emphasis on the role of the experimental method in relation to analysis, and on the student's responsibility in project leadership. *Staff*

16.63 *Experimental Projects II*
Prereq.: 16.62
Year: U (1) 2–6–4
Philosophy of 16.62 applied to more complex problems. *Staff*

16.66 *Fluid Dynamics Laboratory* (A)
Prereq.: 16.63 or 16.65
Year: G (1 or 2) *Arr.*
Graduate laboratory subject in fluid mechanics and related fields, conducted as individual projects arranged between student and instructor. *Mollö-Christensen*

16.70 *Aircraft Detail Design*
Prereq.: ——
Year: U (1) 3–5–0
Aircraft drafting room practice and the preparation of airplane assembly, subassembly, and detail part drawings. Lectures and drafting room exercises covering air frame detail design, landing gear and landing gear control system mechanisms, fuel systems, airplane graphics, and the preparation of a weight estimate and balance diagram for a complete airplane. *Bentley*

16.71T *Flight Vehicle Engineering*
Prereq.: 16.11T, 16.20T
Year: U (1) 2–3–7

16.72T *Flight Vehicle Engineering*
Prereq.: 16.71T
Year: U (2) 2–3–7
Design of an airplane or rocket vehicle including layout, weight, balance, and performance estimates, structural design and preliminary stress analysis, stability and control analysis. Emphasis on individual initiative and independent application of fundamental design principles and on presentation of a final report. *Koppen*

16.74 *Advanced Design* (A)
Prereq.: 16.105, 16.72T
Year: G (1) 2–6–4
Application of current design and operations analysis methods to the determination of the optimum vehicle capable of satisfying a given mission. Weight estimation from preliminary structural design and aeroelastic considerations, performance substantiation, evaluation of functional suitability, control system analysis and determination of optimum propulsive device. Considerable latitude in the choice of mission; use of the vehicle primarily as a means of illustrating methods used during the preliminary design stages in the development of aircraft and rocket vehicles. *R. H. Miller*

16.761 *Orbital and Ballistic Flight* (A)
Prereq.: 16.01; 16.02 or 16.03
Year: G (1) 3–0–6

16.762 *Orbital and Ballistic Flight* (A)
Prereq.: 16.761
Year: G (2) 3–0–6
Performance of ballistic and orbital missiles and space craft. Atmosphere and space environment of vehicles; orbital mechanics; ballistic trajectories; performance parameters of rocket motors; powered flight and re-entry trajectories; guidance navigation and control as affecting flight mechanics and vehicle design; kinematics of interception trajectories, aerodynamics and structures of vehicle design; vehicles system design considerations. First term strongly oriented toward fundamental celestial mechanics and trajectory kinematics and dynamics; second term strongly oriented toward effects on vehicle design of component technologies. *Stever, Sandorff*

16.78 *Control and Guidance in Flight Transportation* (A)
Prereq.: 16.11T, 16.30
Year: G (1) 3–0–6
Study of the functional and technical aspects of the overall air transportation problems associated with enroute navigation, landing and take-off, and traffic control. Consideration of the interrelationships between the characteristics of the airplane as a whole and the facilities, equipment, and environment, with the view of evolving a comprehensive solution to the air navigation and control problem that meets the desired system performance. Study of existing navigation, traffic control, and automatic control systems. *Whitaker*

16.81T *Flight Vehicles*
Prereq.: 8.01
Year: U (1) 3–0–6
The role of science and engineering in the development of aircraft and space craft. Examination of the fundamental problems and solutions of these problems in the light of current technology. *Draper*

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16.82 ***Introductory Aeronautical Engineering***
Prereq.: 18.03
Year: U (1) 3–0–3
Introduction to aircraft, their components and general principles of flight. *Markham*

16.851 ***Industrial Practice***
Prereq.: —
Year: U (S) 40 h.p.w.

16.852 ***Industrial Practice***
Prereq.: —
Year: U (1) 40 h.p.w.
Six months of practical work carried out by the cooperative students in manufacturing, engineering, research, and developments at the plants of organizations participating in the cooperative program. *R. H. Miller*

16.91 ***Aeroelasticity*** **(A)**
Prereq.: 16.02
Year: G (1) 3–0–6
Dynamics of elastic structures. Self-excited dynamic instability, such as occurs in flying vehicles. Stress on formulation of self-excited vibration problems and approximate methods for their solution. *Mollö-Christensen*

16.92 ***Advanced Aeroelasticity*** **(A)**
Prereq.: 16.91
Year: G (2) 3–0–9
Presentation of field of aeroelasticity from unified viewpoint applicable to all types of flight vehicles throughout range of airspeeds. Derivation of aeroelastic operators and unsteady airloads from governing variational principles. Forced response, static and dynamic eigenvalues of simplified systems, one-dimensional structures and two-dimensional structures. Special topics of interest to the aeroelastician, with emphasis on aerodynamic operators. *Ashley*

16.94 ***Dynamics of Structures*** **(A)**
Prereq.: 16.21, 16.91
Year: G (2) 3–0–9
Fundamental variational principles in dynamics; Lagrange's equation and Hamilton's principle. Vibration characteristics of unrestrained elastic systems. Dynamic stresses produced during transient response of aircraft and missile structures to rapidly applied forces. Response of structures to continuous random disturbances. Propagation of elastic and plastic stress waves. *Mar*

17.

Building Engineering and Construction

17.401 ***Advanced Job Management*** **(A)**
Prereq.: 1.921
Year: G (1) 3–0–6
Development of the organization of large projects with reference to the initial economic survey, time schedules, job organization, and integration of construction procedures. The character of contract instruments, legal requirements for job insurance and the expedition of materials to accomplish speed and quality. *Dietz*

17.402 ***Construction Management Seminar*** **(A)**
Prereq.: 1.921
Year: G (2) 3–0–6
Continuation of 17.401 in seminar form. Diagnosis of failures and their causes; integration of the electrical, mechanical and sanitary services into building construction; analysis of architectural concepts in the light of existing construction procedures; study of professional relations in the conduct of contracting as a profession. Extensive contributions by the students. Field trips to illustrate difficult situations. Participation of contractors, architects and engineers from a variety of projects. Field surveys, library research papers, term paper. *Dietz*

17.42 ***Construction Analysis Seminar*** **(A)**
Prereq.: 1.921
Year: G (2) 2–0–4
Exploration of analytical approaches to solution of many variables entering into construction, including flow of components, structural problems, influence of site conditions, materials technology, economic feasibility and cost analyses affecting optimum solution. Case system largely employed. *Heger*

17.73 ***Materials — Wood, Plastics, Fabrics***
Prereq.: 8.02
Year: U (2) 3–0–3
Mechanical and physical properties of wood in relation to growth, structure and other characteristics which influence its use in construction and engineering. Strength, moisture content, preservative treatment, wood products, identification, and selection of species for various uses. Fundamental properties and uses of plastics; basic characteristics of coatings and fabrics used in construction. *Wood Handbook;* Dietz, *Construction Materials.* *Dietz*

17.74 ***Materials — Masonry and Metals***
Prereq.: 8.03
Year: U (1) 3–2–4
Primarily for architectural students with emphasis on masonry materials, concrete, and metals. Factors affecting the durability of masonry structures. Principles underlying metals, alloys, corrosion and welding of metals. About two-thirds of subject on masonry materials, and the balance on metals. Laboratory work testing brick and mortar; concrete and concrete beams; ferrous and non-ferrous metals; wood, plastics, and laminates; thermal conductivity of walls. Murray, *Masonry Materials; Laboratory Manual;* Williams & Homerberg, *Principles of Metallography.* *McGarry*

17.741T ***Mechanical Behavior of Plastics*** **(A)**
Prereq.: 3.14
Year: G (1) 3–2–4
Relation between chemical composition, physical structure, and mechanical behavior of plastics or synthetic high polymers. Study of types of polymers; fundamentals of viscoelastic phenomena such as creep, stress relaxation, stress-rupture, mechanical damping, impact; effects of chemical composition and structure on viscoelastic and strength properties; methods of mechanical property evaluation. Influences of plastics fabrication methods. Emphasis on recent research techniques and results. Laboratory on individual project basis investigating problems related to current Plastics Research Laboratory programs. *McGarry, R. D. Andrews*

17.742T ***Composite Materials*** **(A)**
Prereq.: 3.14
Year: G (2) 3–2–4
Concepts underlying formation, characteristics and behavior of plastics-based composites such as fiberglass