MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF
AERONAUTICS AND ASTRONAUTICS

16.82 / 16.821

Flight Vehicle Design
New CDIO Capstone Course

Subject Syllabus

Fall 2003/Spring 2004

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Massachusetts Institute of Technology

You are responsible for reading and understanding this document.

1 16.82x - General Description

CDIO: Conceive, Design, Implement, and Operate will take you through all the activities required to create a final aerospace product. In this context the goals of CDIO are:

- To educate students to master a deeper working knowledge of the technical fundamentals

- To educate future engineers to lead in the creation and operation of new products/systems

- To educate future researchers to understand the importance and strategic value of their work

Our vision is to provide students with an education that stresses the fundamentals and is focused on real world systems and products. This course will provide an integrated education that provides experiential learning through a rich offering of team based *design, build, and operate* projects; both in the classroom and a state of the art Learning Laboratory.

For every product there is a concept, a vision of something new. The design of the project creates a user's manual for the implementation. Each part of this manual must be self consistent; each section must allow physical implementation. At the same time, the result must be visionary, either in the way in which it meets the customer needs, advances scientific knowledge, exploits new technology and processes, or reaps return for investors. Good analysis, careful design, and precise implementation will translate into success.

In this class, each of you will be part of one team, the CDIO team. We will analyze the objectives, design a product to meet all the specified requirements, implement our design in a final working product, and operate it to evaluate its performance in a controlled environment. As part of the Systems Engineering and Architecture (SE&A) curriculum, the class will emphasize the design process. While there are many definitions of SE&A, one definition, closest to the philosophy behind CDIO, is "the, ensemble of coordinated analyses, simulations, and processes which lead to the design of a technical product which best meets the needs of an identified customer." It is essential that any systems design tell the "whole" story. The whole story consists of why, which, what, how, when, and where:

- Why: the requirements define the customer's needs and why the mission is worth conducting.

- Which: The trade analysis compares different mission architectures and determines which architecture best meets the requirements and therefore the customer needs.

- What: The design describes what will actually be built and operated to conduct the mission.

- How: The program plan describes the organizational structure, resource allocation, funding profile, and schedule. In essence, it describes how the mission will be deployed.

- When: As part of the program plan, the schedule describes when different mission development and deployment stages will occur and how they depend upon each other.

- Where: Also as part of the program plan, the hardware flow details where the following are located: component procurement sources, sub system integration facilities, test and validation sequence, and operations facilities.

16.82x is a complicated course - it is part of the capstone sequence in the Department of Aeronautics and Astronautic, it is also used to fill the Institute Laboratory requirements, and it is a communication intensive course within the department. Furthermore, note that CDIO, as 16.82x, is part of an ongoing educational experiment. The course aims to provide each of you a lifecycle experience with a hardware related, complex aerospace system. You will be part of a large team environment, which emphasizes communication, teamwork, planning, and responsibility. In addition, you will also be individually responsible for designing, building, operating, and analyzing a specialized subsystem in a laboratory setting. In this way you will be exposed to the interfaces between the needs of the team and the responsibilities of the individual team members. We will have a fixed delivery schedule, strict requirements and restrictions, and several reviews. We believe that these experiences will be of great educational value, and hope each of you will both learn and enjoy it.

2   The Project

UAVs will play a key role in many future air missions that are of long duration (crop and pipeline inspection) or have high risk (surveillance and reconnaissance). Both the DoD and Dept. of Homeland Security are particularly interested in developing approaches that use teams of heterogeneous vehicles (i.e., air, on/underwater, ground) to perform missions such as persistent surveillance and harbor protection. These teams will have to coordinate in uncertain, dynamic, and potentially hostile environments with possibly very low data rate communication.

The objective of the new CDIO Capstone course will be to design and demonstrate the coordination and control of a small team of unmanned heterogeneous vehicles (1 air and 2 ground) that could be used to perform these types of missions. These teams will compete in a variation of the game called capture the flag (similar to the "Roboflag" game being played at Cornell University, http://roboflag.mae.cornell.edu/). Capture the flag has a very simple set of rules, but it contains many of the key characteristics present in the real-world problems. We will modify the rules slightly to add a small, autonomous flying vehicle to the team. The addition of the flying vehicles adds an additional strategic dimension to the game because they can be used to perform surveillance and/or jump over the opponent and capture the flag. These strategies will be explored in more detail by the students taking the course.

Mission Statement:

> Demonstrate an autonomous control system for an indoor flying vehicle.

- Demonstrate - the vehicle and its control system must be designed to accomplish the following tasks:

  1. Achieve the objective of take-off, hover in place for 5 minutes 2m above the ground, continuously pointing an onboard camera at a fixed target (20cm x 20cm) with sufficient stability (min 100 x 100 pixels) that an operator (e.g. Prof. How) can easily identify (85% of the time) the color, shape, and orientation of the target, and then land within 1m of the target
  2. Take-off, fly (3m off the ground) to a specified point (covering a 10m distance in less than 1min), then hover in place for 2min (same specifics as part 1), return to original point and land.
  3. Take-off, fly to a known point (10m in less than 1min), search for a nearby ground target (20cm x 20cm) that is moving very slowing (speed < 5cm/s)in a specified region (2m x 2m) in less than 1min. When found, have the UAV track the target (height > 2m) and display the target's progress to the operator for a period of 2mins.
  4. To extend the flying range of the UAV, this vehicle must be designed to autonomously take-off and land on one of the rovers.

  Note that only task 1 must be demonstrated in flight on 12/5. However, the team must demonstrate in the final report that their design would be able to accomplish tasks 2–4.

- Autonomous - no human input within the low-level control loops. A human operator could be used to provide high-level guidance, such as identifying a target and its location.

- Indoor flying vehicle - In general we would give you the freedom to choose between the various alternative vehicles, but since time is short, we have chosen to use a quad-rotor vehicle shown in Fig. 1.

Fig. 1: Quad-rotor UAV. See http://www.draganfly.com/draganflyerxpro.php

Note that there are 2 main phases to the project. The goal of Phase 1 is to conceive and design a complete autonomous control system for the UAV. The second phase of 16.82x occurs in the spring semester and it involves completing tasks 2–4 and explores using this autonomous UAV combined with 2 ground rovers to form a coordinated team, which can then be used to play capture the flag (implement and operate).

Note that this project will focus on the performance, stability, and control requirements (mechanical structure, sensors, and low-level control). The emphasis here will be on individual initiative, application of fundamental principles, and the compromises inherent in the engineering design process. As such, this course will draw heavily on basic elements of the *information technologies* contributing to the Department's efforts to integrate topics such as control, autonomy, software, communications, and networking into the curriculum. Material not covered by other courses will be covered in the course lectures, as necessary.

There is a very tight budget for the design project, so all purchases must be signed-off by the team and approved by Prof. How or Col. Young. The team will have a limit of $15K, but you must set aside a fair percentage (e.g. $3K) as MR (Management Reserve). So you can spend an amount up to $12K but anything beyond has to be very much rationalized and justified.

3   Administrative Details

	Room	Extension	E-mail
Course Faculty			
Jonathan How	33-328	3-3267	jhow@mit.edu
Office Hours: By appointment			
on TTh afternoon			
Col. Pete Young	33-240	3-5340	pwyoung@mit.edu
office hours by appointment			
Mark Drela			
Writing Program Faculty			
Jennifer Craig	37-441	2-3841	jcraig@mit.edu
Office Hours: By appointment			
Graduate Teaching Assistant			
Arthur Richards	33-409	3-3132	arthurr@mit.edu
Office Hours: By appointment			
Course Admin. Assistant			
Margaret Yoon	33-336	2-1536	myoon@mit.edu

Course webpage: http://web.mit.edu/course/16/16.82/www/

Communications Instruction Page: http://cdio-prime/aaarchive/aeroastro/index.htm

Class Email List: 16.82-students@mit.edu and 16.82-instructors@mit.edu

4   Schedule

Good scheduling is key to getting the work done in the allotted time. Formal status and design reviews provide not only the opportunity to present the program progress to the Faculty and the other students, but also provide intermediate milestones to ensure that each group is making consistent assumptions about the resources allocated to them. The following tables outline the course schedule and deliverables. These may change during the semester, but you will be given ample warning.

As discussed above, the overall schedule is to have a prototype that was designed to accomplish all of the required tasks and has demonstrated hovering flight by 12/5. The remaining objectives and the interaction with the ground rovers will then be demonstrated in the second semester.

Since much of the work in this course is experimental, we will be organizing 3 hour lab sessions for the groups to meet, talk with the faculty, and perform experiments. The times for these will be scheduled early in the semester - attendance will be mandatory.

4.1 Communications Activities and Technical Deliverables

Wk		
#1		9/4 • Course introduction • Team selection (ask for lead volunteers)
#2	9/9 • Requirements flow-down • Control I • Short discussion on collaboration and its place in this course. • Each student writes a 1 page report on collaboration due 9/11.	9/11 • Control II • Sensing • Short lecture on how to give a briefing.
#3	9/16 • How do you write good software • Communication - issues and terminology • Short lecture on progress reports.	9/18 • Oral presentations from each team on their trade studies (2 people from each team for 10mins each)
#4	9/23 • Progress report #1 due from each individual. (3-5 pages including graphics)	9/25 • Describe a requirements document and its purpose
#5	9/30	10/2 • **Vehicle subsystem requirements document due.** (Sub-system team report.)
#6	10/7	10/9 • Report on how well each subsystem is meeting the requirements (oral presentation from 1 member of each team.) • Team-level iteration/redistribution of resources
#7	10/14 • Description of a hardware plan	10/16 • **Hardware plan document due**
#8	10/21	10/23
#9	10/28	10/30 • Status report due on the subsystem experiments and current status. (Short individual written reports - 1 page.)
#10	11/4	11/6
#11	11/11 Holiday	11/13 • Status report due on the integration of the subsystems and current status. (Short subteam written reports - 2 pages.)
#12	11/18	11/20
#13	11/25	11/27 Holiday
#14	12/2	12/4
#15	12/9 • Group oral presentation (Team)	12/11 • Final written report (Team)

4.2   Grading Criteria

Date	Item	Value (Technical)	Value (Comm)
9/11	Report on collaboration	0	5
9/18	Oral presentation on the current status of the trade studies	3	10
9/23	Progress report #1 (individual)	3	10
10/2	Vehicle subsystem requirements document (sub-team)	10	10
10/16	Hardware plan document (team)	20	15
10/30	Status report (individual)	5	10
11/13	Status report (sub-team)	7	10
12/5	Final flight tests	7	0
12/9	Group oral presentation (team - given by those that have not spoken)	20	10
12/11	Final written report (team)	20	15
12/11	Notebook submission (individual)	5	5
	Total	100	100

Note: The final grade is weighted 75% on your technical score and 25% on your communication score.

4.3   Communication curriculum

The new CDIO capstone course, 16.82/821, has a strong communication component because we believe that efficient and effective written and oral communication skills are essential for engineers. We have organized the communication instruction and practice around both oral and written communication in both short and longer formats. We also pay explicit attention to collaborative process in the teams because communication and collaboration are parts of most complex processes.

What are the assignments? The assignments are part of the course design process. Individual written documents will range from 2-5 pages while more formal,team-written reports will be longer. Also, students will practice oral communication skills in short briefings as well as in longer, more formal team presentations. Each assignment will be evaluated for technical content as well as communication skill. At the end of the semester, the communication grade will compose 25% of the final course grade.

Individual writing and oral presentation	Group writing and oral presentation
Short report on collaboration (9/11)	Vehicle subsystem requirements document (10/2)
Short briefing on current trade studies status (9/18)	Hardware plan (10/16)
Progress report (9/23)	Status report (11/13)
Status report (10/30)	Final oral presentation (12/9)
	Final written report (12/11)
	Individual technical notebooks (12/11)

How will communication be taught? Jennifer Craig, a lecturer in communication, will teach short modules on communication skills in the days before the assignment is due. Also, notes will be posted to the course Web site for additional support. She will assess the communication skills in all assignments and conference with teams and/or individuals to answer questions. Lastly, she will hold office hours in a breakout room in the study lounge of Bldg. 37: Monday p.m. 2:45 - 5:00, Tuesday a.m. 9:30 - 10:30. Other times are available by appointment. (jcraig@mit.edu or 452-3841) Students, individually or in teams, should feel comfortable in contacting her.

5   Description

5.1   Sub-Teams

We anticipate that there will be four sub-teams within the class, the leaders of which will be chosen in the first week.

- Team leaders will be responsible for managing the activities of their team members as they conduct trade studies, analyses, and other engineering activities. They are not responsible for doing all the work of the team, but they are responsible for making sure that all the tasks are clearly and appropriately assigned and completed; staying in touch with the team process and helping resolve conflicts where possible; scheduling meetings and work sessions. Individual team leads will work with other team leads as well as the faculty and staff to make sure that sufficient progress is being made in the individual disciplinary areas. Team leaders keep written records of work assignments and progress; these records should be accessible to other members of the team in case of illness or emergency.

- Individual team members will be responsible for communicating status, progress, problems encountered, etc. to their team leaders for review at periodic status reviews.

There will be an opportunity to switch both groups and the leaders after submitting the team has submitted the hardware plan document (10/16). The sub-teams are expected to take the lead in the following areas:

- **Vehicle** – responsible for:

  - Flying and modeling the vehicle
    - ◇ Developing a simulink simulation for analysis and testing
    - ◇ Modeling/Characterizing& verifying Actuators
    - ◇ Parameter ID and model updating
  - Developing the video payload & vehicle tracking display for the operator
  - Systems analysis for the project
    - ◇ Interface control documents to distribute the mass, power, size
    - ◇ Form spreadsheets that track the current data (with confidence) to track performance and margins versus time (weekly)
    - ◇ Spreadsheet should form database for simulink model
    - ◇ Track assumptions and interfaces

- **Communication** – responsible for:

  - Determine the Data Rate & Device
  - Identify which parts of the computation can/must be done onboard and off-board
  - Determine latency and throughput
  - Add model to the simulink

- **Sensor** – responsible for:

  - Responsible for converting the Objectives into Sensor requirements and Sensor Options
  - Decisions - Purchase and verification that device meets specifications
  - Integrate into the Simulation
  - Demonstrate component features
  - Integrate and test.

  – Estimation and sensor blending

- **Control** – responsible for:

  – Control requirements to meet the payload pointing goals?

  – How write code to close the loops?

  – Design controllers for all phases of flight

  – Integrate into the simulink

5.2   Semester Plan

The first semester will be split into four main periods:

- Trade studies - detailed comparison of the alternative hardware and software solutions that meet the system (or subsystem) requirements. Objective is to establish the pros/cons of each approach so that they can be evaluated.

  – The plan is to start with this comparison in a relatively general form and then make a specific trade study for this project. The products of these trades will be the Oral presentation (9/18) and progress report #1 (9/23)

- Overall and subsystem design - building on your new understanding of the pros/cons of the various hardware and software solutions, the objective of the next period will be to develop a detailed design for both the overall system and each sub-system.

  – The products of this period are two key documents - the vehicle subsystem requirements document produced by each sub-team (10/2) and the Hardware plan document (10/16).

  – The vehicle subsystem requirements document should precisely identify the requirements for each subsystem to achieve the overall objectives. The vehicle sub-team should focus on how the resources have been allocated amongst the sub-teams.

  – The hardware plan document must describe in detail the specific hardware that you plan to use for each sub-system, why that choice was made, and that it will meet the subsystem requirements. The document should also clearly show that the integrated sub-systems will meet both the requirements and the physical constraints. Full team report giving a fully integrated hardware design wherein each subsystem is shown to meet its requirements with some margin and the overall system is shown to meet the functional goals.

- Subsystem testing - given an approved design, the next step is to purchase and test the various parts of the subsystems. The results from these experiments will be reported in two reports (11/16) and (11/30). The first report (11/16) should discuss the experiments done to verify the hardware that has been purchased/built and the second report (11/30) must show that the subsystem requirements have been achieved.

- Integration and flight - the next step is to integrate the pieces and perform a flight test (12/5).

6   Learning Objectives for 16.82x

The goal of 16.82x is to enable you to master the relevant methods, processes, and techniques necessary for conceiving, designing, implementing, operating, and documenting an experimental project aimed at the investigation of a hypothesis.

Implicit in this goal is the development of your communication skills so you can convey technical contributions to other professionals in the field through oral and written reports.

6.1   Demonstration of Communication Skills

Although the communication aspects of 16.82x are included in the learning objectives and measurable outcomes, they are important enough that we list below the communication skills you will demonstrate during the course. This includes

- Ability to select a communications strategy (choice of what to communicate)

- Ability to implement a communications strategy (implementation of the above choice) including selection of graphical techniques

- Ability to orally communicate technical and project management material

- Ability to effectively communicate with a team partner and with an extended team of stakeholders.

Assessment of your learning follows from the measurable objectives and takes several different forms:

- Professional level laboratory notebooks assessed on technical content and

- Written and oral assignments that exhibit your technical and your communication skills.

7 Details

7.1 Late Submission of Work

All written material, including notebooks, is required to be submitted at the time and location listed on the course calendar. Any written material submitted after this time will be graded as late with a penalty of 25% per day of the maximum possible grade. Permission to submit written material late without penalty may only be obtained from the course faculty if there is a valid reason. Except in extreme cases, this permission must be obtained at least two days prior to the due date. You will be using computers and software for preparation of professional-level work. Remember, however, that computer-related disasters are not considered excuses for missing deadlines. Back-up your files!

7.2 Plagiarism

Plagiarism is defined as the act of presenting someone else's words, ideas, illustrations, or other intellectual property as your own. All use of another person's, company's, or institution's words, ideas, illustrations, or intellectual property must be properly referenced and acknowledged according to AIAA standards. If in doubt about whether to reference or not, double-check with a course faculty member. Also, be aware that a student who knowingly allows his or her work to be copied is also guilty of plagiarism. Plagiarism is a serious transgression and will result in penalties.

7.3 Division of Work in Project Teams

Working together: teams are expected to work together in defining their problem, exploring design options, constructing the apparatus, taking data, and discussing other aspects of their project. Because of the team nature of the course, a few clarifications relating to academic honesty are provided below.

Oral progress reports and oral presentations are regarded as a combined effort and normally are graded as such. Partners should participate equally in both the presentation and the question-and-answer session. Figures, tables of data, graphs, and typeset equations used in oral and written deliverables can and likely should be prepared jointly between team members.

Working separately: Notebooks must be kept separately. In the execution of an experiment, one partner may take data while the other operates the experiment. In that case, data should be transferred from one notebook to another by hand or photocopy. In general, however, each notebook should be an individual effort, documenting the project's progress. Written material reflects the degree of understanding, which you

have gained from the work, and your capacity to convey the results to others. Everyone is highly encouraged to discuss organization, results, conclusions, etc. with your partner, faculty advisor, and staff members. However, any solely authored written reports must be individual efforts. Duplication or direct paraphrasing of text is not allowed and is considered to constitute plagiarism.

7.4   Written Report Style Guidelines

Technical and professional writing follows certain stylistic conventions. Professional Societies (AIAA, ASME, IEEE, etc.) and organizations (NASA, FAA, etc,) have style guidelines for their publications. A style guide will be made available online and in hardcopy. It is representative of aerospace professional and organization style guides. Please consult the Writing Program Faculty if you have questions.

7.5   Writing References

On-line writing references are available at:
http://web.mit.edu/uaa/www/writing/links/
Of particular interest for 16.82x is the Mayfield Electronic Handbook of Technical and Scientific Writing, which can be accessed from the above web address.

7.6   Submission of Written Assignments

Four hard copies are due of all written assignments. These should be single-sided and stapled to ease the reading and correction process. In addition, each assignment should be submitted electronically in PDF and, Word format (if using Word) to Prof. How (jhow@mit.edu) by 5pm of the due date.

In addition, an electronic submission of the Oral Presentation is expected. Further instructions about the electronic submissions will be given as the date approaches. At the end of the semester, we will ask if you be willing to grant the course faculty permission to use material from your written or oral presentations for future classes. Such permission is purely voluntary and in no way affects the evaluation of your performance in the class.

7.7   Oral Progress Report

The Oral Progress Report is a briefing on the status of the project. Because the Progress Reports must stand alone, a brief review of motivation, background, objectives, success criteria and approach is required. The reports should present the problems encountered in the execution of the plans, outline the steps necessary to address the problems, and cite anticipated changes in design or program.

Each speaker will only have 10 minutes to present their progress report. This will be followed by a 5-minute question and answer session. Time limits are strictly followed; speakers will not be permitted to continue beyond the limits. For this reason, it is important that members of a team rehearse well in advance for each presentation and carefully divide the time among the speakers.

8   Experimental Design References

Resources that we have found particularly useful are held in The Seaman's Aerospace Library:

- Beckwith, T. G., Mechanical Measurements, 5th Edition, New York: Addison-Wesley, 1993.

- Jensen, C. H., Engineering Drawing and Design, New York: Gregg Division, McGraw-Hill, 1990.

- Brown, Sally A., 500 Tips for Research Students, Philadelphia: Kogan, 1995.

- Hansman, R. John, Measurement, MIT Video Series. An excellent series of 8 videos on various aspects of measurements.

The following texts on experiment design are available at Barker Library.

- Cox, D. R., Planning of Experiments, New York: Wiley, 1958.

- Bragg, G. M., Principles of Experimentation and Measurement, Englewood Cliffs, N.J.: Prentice-Hall,1974.

- Diamond, W. J., Practical Experiment Designs for Engineers and Scientists, Belmont, Calif.: Lifetime Learning Publications, 1981.

- Hicks, C. R., Fundamental Concepts in the Design of Experiments, New York: Holt, Rinehart, and Winston, 1982.

- Doebelin, E. O., Engineering Experimentation: Planning, Execution, Reporting, New York: McGraw-Hill, 1995.