System Problems and Labs (SPL) Curriculum

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Abstract

This document contains the syllabus for the system problems and laboratory (SPL) part of Unified Engineering. SPL is an important integrative set of learning activities. A simplified view is that if the individual engineering disciplines are the bricks, then SPL represents the mortar between these bricks. Four elements underlie SPL: The CDIO curriculum, the system problems and lectures, the laboratory exercises, and the design competition.

The new CDIO curriculum sets the learning objectives and was approved by the Course 16 faculty in May 2002. It encompasses the entire undergraduate program in Aeronautics and Astronautics. The key goal of the CDIO curriculum is to introduce, teach and utilize skills that are required during the four main lifecycle phases of an aerospace product: Conceive-Design-Implement-Operate. Additionally skills are taught that are decisive for personal and team success in an engineering environment such as technical communications, teamwork and project management. The CDIO learning objectives in Unified focus on skills that are needed early and support later activities in the professional area subjects (PAS) and the capstone courses. The main purpose of the system problems and the accompanying lectures is to create linkages between the individual disciplines in Unified Engineering. These disciplines are: Dynamics, Fluid Mechanics, Materials & Structures, Thermodynamics & Propulsion as well as Signals & Systems. The overall learning objective of the system problems is to develop a holistic view of aerospace engineering and a knowledge base and skill set that enable successful aerospace system development. The main purpose of the laboratory exercises is to apply and verify the knowledge gained from theory in a practical hands-on setting. The students will acquire the ability to verify the predictions made by theory with physical artifacts in a series of prepared and focused experiments. Key is the ability to develop physical models and to verify their validity by means of empirical data. Emphasis is put on proper and safe laboratory procedures, clear documentation and an understanding of real-world limitations. The aerial design competition will take place in spring 2003 and provides an opportunity to apply the disciplinary knowledge and individual professional skills to a remote-controlled aircraft competition in a team environment. The lifecycle of a real aerospace system is simulated with this “learning design-through-redesign” approach.

1. CDIO Curriculum

1.1 Unified Engineering Learning Objective

Students in Unified Engineering will learn how to apply discipline specific knowledge in Fluids, Materials & Structures, Dynamics, Signals & Systems and Thermodynamics & Propulsion to synthesize solutions to problems that typically surface in all lifecycle phases (C-D-I-O) of complex aerospace systems with the help of modeling and experimental techniques and to effectively communicate their results.

1.2 Measurable Outcomes

Students graduating from Unified Engineering will be able to:

1. Formulate appropriate coupled multi-disciplinary models of engineering systems based on physical laws and principles and identify the underlying assumptions and limitations of those models.
2. Conduct experimental investigations, analyze experimental results, quantify experimental uncertainty and generate simple empirical models.
3. Use physics-based and empirical-experimental models of engineering systems to evaluate proposed designs, conduct trade studies, and generate new design solutions.
4. Understand the role of aerospace engineering in a wider social context including economics, policy, safety, the environment, and ethics among others.
5. Communicate engineering results in written reports[1], using clear organization, proper grammar and diction, and effective use of graphs, engineering drawings, and sketches.

1.3 CDIO Curriculum Design

An overview of the CDIO Curriculum for Unified Engineering is shown in Appendix A. The parts of the curriculum that will be taught explicitly (beyond introduction) are:

T^1 = Primary Teaching

3.1.2. Team Operation
4.4.1 The Design Process
4.5.3 (Software Implementation)[2]

T^2 = Secondary Teach

2.2.4 Experimental Hypothesis, Test and Defense
2.4.5 Awareness of personal knowledge skills and attitudes
2.4.7 Time and Resource management
3.1.3 Team growth and evolution
3.2.2 Communication Structure
3.2.3 Written Communication
3.2.5 Graphical Communication
4.3.4 Development Project Management
4.4.3 Utilization of Knowledge in Design
4.4.4 Disciplinary Design
4.5.4 Hardware Software Integration
4.6.2 Training and Operations

[1] Oral communications is not an explicit learning objective for Unified Engineering.
[2] This will be restricted to a MATLAB introduction during AY 2002-2003. Integration of 16.070 occurs in future years.

2. SPL Lectures and System Problems

2.1 Lecture Overview

There are thirteen SPL lectures in each semester. The lectures are typically given on Thursdays and generally focus on topics of increasing difficulty. The system problems (SP) can only be solved successfully if the SPL lectures are attended regularly. The text in parentheses shows the laboratory exercise that is introduced during a given lecture. The detailed lecture content and learning objectives are shown in Section 2.3.

Fall 2002	(dates are confirmed, but subject to change – see announcements)
9-10-2002	SPL1: Introduction to Aerospace Systems
9-12-2002	SPL2: Technical Engineering Communication (Glider Lab#1)
9-19-2002	SPL3: Personal Resource Management
9-26-2002	SPL4: Modeling, Experiments and Stochastics (Balloon Lab#2)
10-3-2002	SPL5: System Performance Prediction (Water Rocket Lab#3)
10-10-2002	SPL6: Similitude and Dimensional Analysis (Electrical Circuit Lab#4)
10-17-2002	SPL7: Material Systems (Material Coupon Lab#5)
10-24-2002	SPL8: Design Process Introduction (Spring-Mass-Damper Lab#6)
10-31-2002	SPL9: Static and Dynamic System Behavior
11-7-2002	SPL10: Windtunnel Introduction (Pitot Tube Lab#7)
11-14-2002	SPL11: Low Speed Flight Systems (Subsonic Flow Lab#8)
11-21-2002	SPL12: System Simulation (Flight Simulation Lab#9)
12-5-2002	SPL13: Summary and Synthesis

Spring 2002	(dates are preliminary)
2-6-2003	SPL1: Introduction to Design Competition (High Speed Lab#10)
2-13-2003	SPL2: Requirements and Configuration Management
2-20-2003	SPL3: Teamwork and Project Management
2-27-2003	SPL4: Performance Estimation and Testing (Dragonfly Baseline Test)
3-6-2003	SPL5: Conceive and Design for Competition - Redesign Strategy
3-13-2003	SPL6: Composite Materials, CNC Foam Cutter (Composite Lab#11)
3-20-2003	SPL7: Implementation - Aerospace Manufacturing
4-3-2003	SPL8: Operations
4-10-2003	SPL9: Complex Structures and Systems (Truss Lab#12)
4-17-2003	SPL10: Validation, Verification and Acceptance (Modified Dragonfly)
4-24-2003	SPL11: Lifecycle Considerations (Electrical Instr./Avionics Lab#13)
5-1-2003	SPL12: Aerial Design Competition
5-8-2003	SPL13: Debriefing and Summary

The personal response system (PRS) will be used throughout the SPL lectures. Its purpose is twofold. For one it helps the faculty assess whether key concepts have been well understood, or whether significant ambiguities remain ("mud"). Secondly it is used to grade attendance and participation in the SPL lectures.

A set of lecture notes (annotated viewgraphs) will be available for each lecture. These will be posted electronically on the Unified website (see Section 5) before lecture and will not be distributed as hardcopies. It is the responsibility of each student to download, read and perhaps print these notes to ensure appropriate individual preparation.

2.2 Assignments for SPL (System Problems)

A key learning instrument is the weekly system problems ("SP"), which are given in addition to the disciplinary homeworks ("HW"). These SP problems apply the knowledge and skills gained in the SPL lectures and create linkages between the disciplines. The expected individual effort for an SP problem is roughly 4-6 hours/week. Some SP problems are to be solved individually, while others will be a team effort. The scope of the problems will be adjusted to reflect the expected effort level. The format of the SP problems will be somewhat different from previous years. Each SP problem now consists of two parts:

(I) Theoretical-Experimental Part

This part of the problem requires understanding and application of specific knowledge gained in the SPL lectures, disciplinary lectures or presentation and interpretation of experimental results. The problems are usually self-contained, well-defined and require a focused approach for a successful solution. (Example: Analyze stress-strain curve obtained from material coupon tests to estimate Young's modulus and yield stress).

(II) Applications-Systems Context Part

The second part of the SP problems places the topic of the first part in a wider aerospace systems context. The second part challenges the students to think and explore beyond the boundaries of the subject matter studied in class. These problems are usually more open-ended; less narrowly defined and require a holistic approach for a successful solution. (Example: Based on yield stress previously found, discuss material safety factors, material variations and FAA regulations for aerospace vehicle margins of safety). Sometimes a reading assignment will be included.

Schedule for SP ("system problems") – Fall 2002[3]:

Problem	Topic	Out	Due
SP1	Glider Design, Construction and Evaluation	9/11/02	9/27/02
SP2	Personal Resource Management	9/18/02	10/04/02
SP3	Balloon Flight Modeling	9/25/02	10/11/02
SP4	Water Rocket Modeling and Launch	10/02/02	10/18/02
SP5	Electrical Circuit and Similitude Analysis	10/9/02	10/25/02
SP6	Material Coupon Behavior	10/16/02	11/01/02
SP7	Design and Test of a Spring-Mass-Damper	10/23/02	11/08/02
SP8	Windtunnel Pitot Tubes and Air Data Systems	11/06/02	11/15/02
SP9	Low Speed Fluid Flow	11/13/02	11/22/02
SP10	Flight Envelopes and Simulators	11/20/02	12/06/02

Grading of the system problems will be on a scale of 0-100 and will be based both on completion (quantity) and accuracy of the answers (quality). Joe B score is 75.

2.3a Detailed Lecture Topics – Fall 2002

This section gives details about the topics covered in the individual SPL lectures. CDIO learning objectives that are covered by a lecture are also included along with their respective number (e.g. 3.2.5 Graphical Communication).

SPL1: Introduction to Aerospace Systems

Three principles of flight (buoyancy, airfoil lift, mass expulsion)
Introduction to systems theory, Aerospace systems example: F/A-18 aircraft
Product lifecycle introduction: C-D-I-O
The impact of (aerospace) engineering on society (4.1.2)
Overview for System Problems and Labs (SPL) in Unified Engineering

SPL2: Technical Engineering Communication (Glider Lab#1)

A brief history of technical communications
Fundamentals of communications (sender, receiver, intent, coding, decoding)
Written Communications: notes, memos, emails, letters, reports, papers, books
Graphical communications: sketches, engineering drawings, notebooks, plots
Oral Communications: discussions, meetings, phone calls, formal reviews, presentations
Special section on engineering drawings (examples, norms and standards)
Special section on laboratory reports
Introduction to balsa glider Lab#1, A/C design rules of thumb

[3] System Problems for Spring 2003 are to-be-determined (TBD).

Communication Strategy (3.2.1), Communication Structure (3.2.2)
Written Communication (3.2.3), Graphical Communication (3.2.5)
Active Learning: Build and fly a simple balsa glider that someone else designed based on short written documents, return feedback about manufacturability and flight performance.

SPL3: Personal Resource Management
Task prioritization (Eisenhower matrix), importance vs. urgency
Personal Resource Management: Time-Money-Health-Relationships
List of common time killers, Efficient execution of tasks, 20/80% rule
Professional Ethics, integrity, responsibility & accountability (2.5.1)
Engineering or … how to deal with mistakes (short video clip from "Apollo-Spider")
Roles and Responsibilities of Engineers (4.1.1)
Time and Resource Management (2.4.7)
Active Learning: Keep a precise log of your time spent for a week and compare to statistics for entire class – attempt to identify and eliminate "time killers".

SPL4: Modeling, Experiments and Stochastics (Balloon Lab#2)
Physical Reality – Modeling as an abstraction process, governing equations
Model assumptions, limitations and validity, Model Analysis
Simulation versus Experimentation
Models of deterministic systems: example: helium filled balloon
Models of stochastic systems: example: atmosphere
Problem Identification and Formulation (2.1.1)
Modeling (2.1.2), Analysis with Uncertainty (2.1.4)
Active Learning: Release helium-filled balloons outside (with return cards) and estimate (1) percentage of return, (2) longest flight and (3) landing ellipse parameters

SPL5: System Performance Prediction (Water Rocket Lab#3)
Definition of "performance metrics" for aerospace systems
Discuss mission phases of aerospace systems: aircraft, satellites, rockets
Reiterate/rederive rocket equation. Discuss variables that influence performance,
Sensitivity analysis, introduce Design of Experiments (DOE)
Process of performance prediction for a new/unknown system
Introduce Water Rocket Lab#4, governing equations, safety measures
Modeling (2.1.2)
Active Learning: Launch water rockets starting from a baseline with different modifications such as water levels and pressurization levels and compare their actual performance (h_{max}) with predictions.

SPL6: Similitude and Dimensional Analysis (Electrical Circuit Lab#4)
Similitude and Dimensional Analysis – "Honey I shrunk the kids"
Non-dimensionalization of problems, physical scale models
Buckingham's Pi Theorem – Scaling Analysis
Example: ship's model – aircraft model
Review electrical circuits – tie back to definition of a system
Introduce Electrical circuit lab#4
Estimation and Qualitative Analysis (2.1.3)
<u>Active Learning</u>: Test an existing active electrical circuit with a prescribed schematic (but unknown function) and compare its current/voltage behavior against predictions from network analysis – given the form of the circuit find its function.

SPL7: Material Systems (Coupon Lab#5)
Importance of material selection in aerospace engineering
Repeat Ashby diagrams – main effects:
Uniaxial Stress-Strain curves, failure modes, electrical and
thermal conductivity, Heat treatments, variations in properties
Yield Stress and fracture, Metal fatigue – Crack initiation and growth
Introduction to Material Coupon Lab#5
Society's Regulation of Engineering (4.1.3) – Safety Factors etc…
<u>Active Learning</u>: Subject coupons to static and dynamic loads and compare the observed behavior to theory – find out what material the coupons are made of

SPL8: Design Process Introduction (Spring-Mass-Damper Lab#6)
Reintroduce the system lifecycle C-D-I-O, Customer needs
Conceiving: System Architecture, Function, Form, Concepts, Value
Designing: Attributes of Form, design variables, introduction to optimization
Setting System Goals and Requirements (4.3.1)
Concept generation and selection
The Design Process (4.4.1), Creative Thinking (2.4.3)
Conceiving – Designing Phases
<u>Active Learning</u>: Design a simple spring-mass-damper system according to given user requirements (e.g. settling time) and test it in the laboratory

SPL9: Static and Dynamic System Behavior
Review notion of system states, transient response, and steady state response
Components and systems under static loads and dynamic loads
Mass and Geometric Constraints, Modeling and Physical Reality, Simulation
<u>Active Learning</u>: Demonstrate static and dynamic load cases in class

SPL10: Windtunnel Introduction (Pitot Tube Lab#7)
Review static and dynamic pressure,
Introduce history, characteristics and operations of Wright Brothers Wind Tunnel
Show system hierarchy: pressure ports- pitot tube – air data system – flight management system, show schematic of pitot ADS system on F/A-18 aircraft
Introduce Pitot and Static Tube Experiment (Lab#7)
Examples of aviation accidents – introduce Puerto Plata – Boeing 757 accident
Critical Thinking (2.4.4) – finding cause of accident
Active Learning: Run Windtunnel, record data from pitot tubes, critical data analysis

SPL11: Low Speed Flight Systems (Subsonic Fluids Lab#8)
Role of experimentation in the design process
Overview matrices of tests/experiments in aircraft/spacecraft development
Review mathematics for low speed flow over a cylinder and airfoil
Low Speed flow over Airfoil and Cylinder (Fluids), Introduce Lab#8
Active Learning: Record pressure distribution (perhaps polars) in experiment – understand lift versus drag

SPL12: System Simulation (Flight Simulation Lab#9)
Understand flight vehicle envelopes (Mach versus altitude)
Get a feel for low speed behavior (Flap settings versus stall speed)
Cockpit familiarization
Stall Behavior with Aircraft Simulator (Fluids)
Role of system simulators in development, testing and crew training
Active Learning: Fly aircraft on PC flight simulator to empirically determine flight envelope (Mach-versus-altitude) and stall speed as a function of flaps setting.

SPL13: Summary and Synthesis
Summarize key concepts from system problems and labs in the fall 2002
Multidisciplinary principles, methods and tools of an aerospace engineer (overview)
Preview spring 2002, Question and Answer session
Awards from Lab#2 (Helium Balloons)

2.3b Preview of SPL Lectures in Spring 2003

SPL1: Introduction to Design Competition
Reintroduce performance measures for aerospace vehicles, high-speed flight (example: Concorde, XR-71) versus low speed flight (example: F/A-18, Pilatus Porter), endurance, range, stall speed, ground roll distance, performance limiting factors. Introduction to

Dragonfly model airplane. Present ground rules for design competition. Introduce High Speed Lab#10.

SPL2: Requirements and Configuration Management

Introduce user needs, concept of value, stakeholders, requirements, contracts, requirements flowdown. Software and hardware configuration management. Parts numbering systems, requirements documents, requirements management. (4.3.1) Setting System Goals and requirements, Competition System Functional Requirements

SPL3: Teamwork and Project Management

Introduction to team work, division of labor, team communications – introduce MIT teamwork resources (Collaboration Toolbox). Essentials of project management: Gantt charts, PERT charts. Cost budgeting and comptrolling. Form teams for design competition, (3.1.2) Team operation, (3.1.3) Team Growth and Evolution, (4.3.4) Development project management

SPL4: Baseline Performance Estimation and Testing

Review modeling, analysis and simulation, performance predictions, error bars and uncertainty. Dragonfly baseline performance estimation. Verification of baseline flight performance (unmodified Dragonfly) in flight tests (Johnson).

SPL5: Conceive and Design for Competition

Review design process with emphasis on concept development, concept selection, preliminary design and detailed design. Sensitivity analysis relative to Dragonfly baseline performance. Strategy development for winning design competition, design by redesign.
(4.4.5) Multidisciplinary design, (4.4.6) Multiobjective design.

SPL6: Composite and Exotic Materials, Foam Cutter

Review material selection and composite materials in particular. Foam and exotic aerospace materials. Operation of foam cutter for wing and empennage manufacture. Composite materials lab#11, airfoil manufacture.

SPL7: Implementation and Aerospace Manufacturing

History of aerospace manufacturing, prototyping versus series production. WWII. Parts fabrication, subassembly and assembly processes, learning curve effects, economies of scale, quality and rework, manual production versus automation, hardware manufacturing process, AA machine shop introduction, carry out an assignment where learning curve effect becomes explicit. Hardware Manufacturing Process (4.5.2)

SPL8: Operations

Importance of operations for aerospace vehicles, operator crews and training, safety, accident investigations, system retirement, Dragonfly flight training, ground segments, Prepare and carry out visit to operations facility (Logan airport or Chandra mission control). Operations Guest Speaker, Pilot Training Program w/ DragonFly (Col. Young).

SPL9: Complex Structures and Systems (Truss Lab#12)

Aircraft systems hierarchy: details-parts-subassy-assy- system, behavior of complex (structural systems), linear vs non-linear systems, introduction to truss laboratory, emergence, example: International Space Station

SPL10: Validation, Verification and Acceptance (Dragonfly Tests)

Requirements validation, verification, typical aerospace vehicle tests for aircraft (ground vibration tests, full scale fatigue tests, flight test) and spacecraft (cryogenic, acoustic tests, vibration/launch load tests etc…), formal FAA and IATA certification procedures, customer acceptance and signoff, internal team testing of modified Dragonfly.

SPL11: Lifecycle Considerations (Electrical Inst./Avionics Lab#13)

Maintainability, reliability and upgradeability, logistics. Typical operations financial budgets. Clockcycle of different aerospace subsystems (structure versus avionics), Role of software in aerospace vehicles, Introduce Electrical Instrumentation/Avionics Lab (with Dragonfly R/C). Examples: F/A-18, B-52, B-58, Soyuz, Space Shuttle

SPL12: Design Competition

Prepare and carry out aerial design competition.

SPL 13: Debrief and Summary

Present results and lessons learned from design competition. Summarize CDIO with emphasis on: Team operation (3.1.2) and the design process (4.4.1), Reiterate Performance-Cost-Risk-Schedule tradeoffs in aerospace systems development.

3. Laboratory Exercises

This section contains a short description of the laboratory exercises during Unified Engineering. Appendix B shows how these labs fit into a greater context using the F/A-18 aircraft as an example. Appendix C shows how the labs map into the five aerospace disciplines of Unified Engineering. Labs that are marked with an asterisk (*****) have been conducted in previous years, but perhaps in a somewhat different form.

The overall learning objective for the laboratory exercises is given as the second measurable outcome on page 2. The laboratories are performed outside of the scheduled lecture times and time windows will be announced for each lab. Two undergraduate teaching assistants (UTAs) will be designated as the expert point-of-contact for each lab. The data analysis and interpretation for the labs is done as part (I) (theoretical-experimental part) of the system problems (SP). The fall semester 2002 carries nine laboratory exercises, the spring semester 2003 only four. The smaller number of labs in the spring allows dedicated work on modifying the Dragonfly airplanes for the design competition. Generally a lab should take <u>around two hours for data collection</u>, excluding data analysis.

3.1 Lab Descriptions Fall 2002

Lab#1 * **Glider** **integrated in SP1**

Design a balsa glider for minimum glide slope angle (maximum flight time) using only materials from a given parts list. Rules of thumb for aircraft/glider design will be presented to facilitate this task. Document the design in correct engineering drawings, parts list, assembly instructions and a cover letter. Pass design on to the next student in the alphabetical list. This student builds the glider according to the instructions and tests the glider by throwing it from a predetermined location. A reference glider will also be tested such that the results can be normalized for the entire class. The second student writes an evaluation report and has a personal, technical meeting with the first student to give feedback about manufacturability and flight performance.

Lab#2 (new) **Balloons** **integrated in SP3**

Model a helium balloon with a small payload mass consisting of a return card. Create a model of the atmosphere. Release helium balloons for the entire class outside (ca. 500-3000 total) and record atmospheric conditions at launch. Estimate (a) percentage of returned cards, (b) longest flight and (c) parameters of landing ellipse. Award for best estimates at the end of the term.

Lab#3* **Water Rocket** **integrated in SP4**

Analyze the multidisciplinary nature of a single-stage water rocket and model the mission phases: pressurization, release, ascent and ballistic flight. Create a mathematical model in Matlab or Excel taking into account the thermodynamics, aerodynamics and kinematics of the problem. Estimate the flight performance (h_{max}) of a standard baseline bottle. Estimate the main effect of pressurization level, water level, nose cones and fins and verify experimentally by launching water rockets outdoors.

Lab#4 (new) Electrical Circuit integrated in SP5

Test a simple electrical RLC-circuit where the schematic is given, but the function is not known. The students will then operate the circuit and compare voltage and/or current time histories to their predictions in order to find what the circuit actually does.

Lab#5* Material Coupons integrated in SP6

Quasi-uniaxial material coupons will be prepared and cut to size by the staff. The coupons will be numbered and made of materials that are common in aerospace engineering (aluminum, steel, titanium, composites, PVC) but the students will not be told what each material is. The students can then subject each coupon to a number of uniaxial loading conditions (static force, oscillatory force, electrical current, thermal heat) and observe and record the material response. With the help of their experimental results, Ashby diagrams and a large list of potential materials (the coupons are a subset of that list) the students have to guess which coupon is made out of which material.

Lab#6 (new) Spring-Mass-Damper integrated in SP7

This lab is the first to introduce the notion of design and requirements. The task in this lab is to design a simple spring-mass-damper system for a set of transient (impulse response) and steady-state response requirements. The students will be presented with a structural system that needs to be isolated with springs and a tunable damper. The task is to correctly choose the spring stiffness and amount of damping that will meet the requirements. The design can be quickly implemented using an existing set of springs and the variable damper and tested for the two excitation cases.

Lab#7* Pitot Tube and Windtunnel integrated in SP8

This lab introduces the 7ft x10ft Wright Brothers Wind Tunnel. This consists of learning the operating and safety procedures and taking readings from various pitot tubes in the tunnel and to compare the data against truth measurements (Pitot tubes X and Y) to estimate the airspeed. This data is then used to formulate an accident cause hypothesis for the related aircraft accident problem.

Lab#8* Subsonic Flow integrated in SP9

Measurement of low speed flow over a cylinder and airfoil. The Windtunnel is operated using knowledge and experience from the previous lab. First a cylinder is placed in a low speed flow of known velocity. Measure the static pressure on the cylinder as a function of air speed and compare to theory. (If time permits record polar for an airfoil).

Lab# (new) Flight Simulator integrated in SP10

The flight simulator is the last lab of the semester and attempts to give an integrative experience. Startup the simulator and fly a simple scenario whose staring point is preprogrammed. Answer a few questions about the cockpit configuration for familiarization purposes (e.g. what switch is located left of the XYZ pushbutton, what is its function?). Given an incomplete flight envelope of the aircraft (altitude-vs-Mach) complete the envelope by flying to the missing points on the simulator. Determine stall speed of the aircraft for various flap settings and compare to theory.

3.2 Preview of Labs in Spring 2003

Lab#10* **Supersonic Flow**

Take data for supersonic flow by placing various objects (e.g. prisms) in airflow and observe shock waves. Measure departure angle and compare to theory.

Lab#11 (new) **Composite Materials**

Test simple specimens of composite materials (CFC and sandwich/honeycomb) and experimentally determine their aggregate properties as a function of ply directions and matrix/fiber ratio. Compare to theoretical mixing laws.

Lab#12* **Structural Truss**

Subject a truss (built by and tested by staff beforehand) to various load cases and measure deflections at key points. Measure tension/compression in some critical truss members and compare to theory.

Lab#13* **Electrical Instrumentation/Avionics**

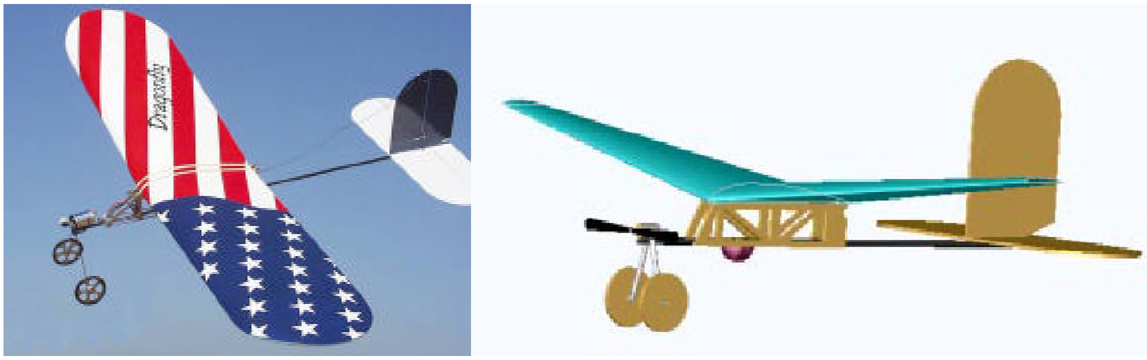
Test the remote control system for Dragonfly by hooking it up to an oscilloscope and observing periodic signals. Measure propeller speed using an opto-interrupter.

Additional experimental activities in the spring will consist of testing the modified versions of the Dragonfly aircraft. These tests, however, will be scheduled at the discretion of the various teams in the design competition (see below).

4. Design Competition

The main objective of SPL in the spring is to utilize the theoretical knowledge, experimental experience and individual skills to the benefit of an aerospace system development project. The fundamentals of teamwork and project management are taught early and applied here. The last few years have shown that a design competition is an effective means of stimulating the students and engaging them in a true CDIO experience.
Rather than designing a system from scratch – it has been shown that the design-by-redesign approach works well.

The starting point of the design competition is a **baseline** ("out of the box") version of the Dragonfly, see Figure 1(a). The dragonfly is a robust propeller-driven model aircraft which is battery powered. While the aircraft works well as is, the students will be tasked to modify Dragonfly from its baseline configuration to meet the objectives of the competition. In the spring of 2002 the objective was maximum endurance; see Figure 1(b).



(a) (b)

Fig. 1: (a) Baseline Dragonfly aircraft (http://flydma.com/planes/dragonfly.html), (b) Dragonfly "The Wing Bearer" (G. Barter, C. Johnson – Spring 2002) with modified wing for maximum endurance.

For spring 2003 the goals of the competition will also involve some single or a combination of multiple performance objectives – the design competition 2003 will be presented during the SPL1 lecture in February 2003. The aerial competition itself traditionally takes place in the MIT Johnson Athletic Center around a predefined track with dimensions of 195' by roughly 85'. Leading up to the aerial competition are a number of steps that simulate the product development process (PDP) of an aerospace enterprise:

- Introduction to design competition objectives, rules and constraints
- Form teams and get acquainted with teamwork and project management
- Analyze the functional requirements, create requirements document
- Pilot training course (voluntary flight training will probably be offered during IAP)
- Predict and verify baseline (unmodified) Dragonfly performance
- Establish strategy for winning competition, generate **C**oncepts and select one
- Preliminary **D**esign of system modifications, configuration management
- Detailed design, **I**mplementation of modified components and component tests
- System assembly, verification, validation and dry run
- Approval of design, configuration drawings as well as resource budgets
- Actual day of competition and system **O**peration
- Debriefing and lessons learned, awards

The design of the competition will be such that it focuses on the flying qualities, direct application of disciplinary knowledge and leads to a satisfying flight experience by avoiding unnecessary complexity.

5. Contact Information

SPL website: http://web.mit.edu/16.unified/www/

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[2] CDIO Curriculum Design, MIT Dept. of Aeronautics & Astronautics, May 2002

CDIO Design for Unified Engineering — Appendix A

Teach: (implies *Introduce*)

- Really try to get students to learn new material
- Learning objective is to advance at least one cognitive level (e.g. knowledge → comprehension, comprehension → application, etc)
- Typically 1 or more hours of dedicated lecture/discussion/laboratory time are spent on this topic
- Assignments/exercises/projects/homework are specifically linked to this topic
- This topic would probably be assessed on a test or other evaluation instrument

T^1 = Primary Teach = larger commitment of time & importance
T^2 = Secondary Teach = smaller commitment of time & importance

Introduce:

- Touch on or briefly expose the students to this topic
- No specific learning objective of knowledge retention is linked to this topic
- Typically less than one hour of dedicated lecture/discussion/laboratory time is spent on this topic
- No assignments/exercises/projects/homework are specifically linked to this topic
- This topic would probably <u>not</u> be assessed on a test or other evaluation instrument

Grayed out text with blank boxes indicates a ∅ in the Design

2.1 Engineering Reasoning and Problem Solving	**T^1**	**T^2**	**I**
2.1.1 (4.4) Problem Identification and Formulation			✹
2.1.2 (4.3) Modeling			✹
2.1.3 (4.0) Estimation and Qualitative Analysis			✹
2.1.4 (3.7) Analysis with Uncertainty			✹
2.1.5 (3.8) Solution and Recommendation			
2.2 Experimentation and Knowledge Discovery	**T^1**	**T^2**	**I**
2.2.1 (3.4) Hypothesis Formulation			
2.2.2 (3.0) Survey of Print and ElectronicLiterature			✹
2.2.3 (3.6) Experimental Inquiry			✹
2.2.4 (3.3) Hypothesis Test, and Defense		✹	
2.3 System Thinking	**T^1**	**T^2**	**I**
2.3.1 (2.9) Thinking Holistically			✹
2.3.2 (2.6) Emergence and Interactions in Systems			✹
2.3.3 (2.7) Prioritization and Focus			✹
2.3.4 (2.9) Tradeoffs, Judgement, Balance in Res.			✹
2.4 Personal Skills and Attitudes	**T^1**	**T^2**	**I**
2.4.1 (3.4) Initiative and willingness to take risks			✹
2.4.2 (3.4) Perseverance and flexibility			
2.4.3 (3.6) Creative Thinking			✹
2.4.4 (3.8) Critical Thinking			✹
2.4.5 (3.4) Awareness of one's personal knowledge, skills and attitudes		✹	
2.4.6 (3.1) Curiosity and lifelong learning			
2.4.7 (3.4) Time and resource management		✹	
2.5 Professional Skills and Attitudes	**T^1**	**T^2**	**I**
2.5.1 (3.7) Professional ethics, integrity, responsibility & accountability			✹
2.5.2 (2.7) Professional behavior			
2.5.3 (2.7) Proactively planning for one's career			
2.5.4 (2.9) Staying current on World of Engineer			
3.1 Teamwork	**T^1**	**T^2**	**I**
3.1.1 (3.4) Forming Effective Teams			✹
3.1.2 (4.0) Team Operation	✹		
3.1.3 (2.7) Team Growth and Evolution		✹	
3.1.4 (3.4) Leadership			✹
3.1.5 (3.0) Technical Teaming			✹
3.2 Communication	**T^1**	**T^2**	**I**
3.2.1 (3.5) Communication Strategy			✹
3.2.2 (3.8) Communication Structure		✹	
3.2.3 (3.9) Written Communication		✹	
3.2.4 (3.1) Electronic/Multimedia Communication			✹
3.2.5 (3.4) Graphical Communication		✹	
3.2.6 (4.1) Oral Presentation and Interpersonal Communication			✹

4.1 External And Societal Context	**T^1**	**T^2**	**I**
4.1.1 (2.2) Roles and Responsibility of Engineers			✹
4.1.2 (2.5) The Impact of Engineering on Society			✹
4.1.3 (1.7) Society's Regulation of Engineering			✹
4.1.4 (1.4) The Historical and Cultural Context			
4.1.5 (2.2) Contemporary Issues and Values			
4.1.6 (2.1) Developing a Global Perspective			
4.2 Enterprise And Business Context	**T^1**	**T^2**	**I**
4.2.1 (1.6) Appreciating Different Enterprise Cultures			
4.2.2 (2.2) Enterprise Strategy, Goals and Planning			
4.2.3 (1.8) Technical Entrepreneurship			
4.2.4 (1.8) Working Successfully in Organizations			
4.3 Conceiving and Engineering Systems	**T^1**	**T^2**	**I**
4.3.1 (3.2) Setting System Goals and Requirements			✹
4.3.2 (3.2) Defining Function, Concept and Architecture			✹
4.3.3 (3.1) Modeling of System and Ensuring Goals Can Be Met			
4.3.4 (3.0) Development Project Management		✹	
4.4 Designing	**T^1**	**T^2**	**I**
4.4.1 (3.9) The Design Process	✹		
4.4.2 (2.9) The Design Process Phasing and Approaches			✹
4.4.3 (3.4) Utilization of Knowledge in Design		✹	
4.4.4 (3.4) Disciplinary Design		✹	
4.4.5 (3.4) Multidisciplinary Design			✹
4.4.6 (3.5) Multi-objective Design			✹
4.5 Implementing	**T^1**	**T^2**	**I**
4.5.1 (2.3) Designing the Implementation Process			
4.5.2 (2.1) Hardware Manufacturing Process			✹
4.5.3 (2.4) Software Implementing Process	✹		
4.5.4 (2.4) Hardware Software Integration		✹	
4.5.5 (2.7) Test, Verification, Validation and Certification			✹
4.5.6 (2.0) Implementation Management			
4.6 Operating	**T^1**	**T^2**	**I**
4.6.1 (2.6) Designing and Optimizing Operations			✹
4.6.2 (2.2) Training and Operations		✹	
4.6.3 (2.4) Supporting the System Lifecycle			
4.6.4 (2.4) System Improvement and Evolution			✹
4.6.5 (1.5) Disposal and Life-End Issues			
4.6.6 (2.3) Operations Management			

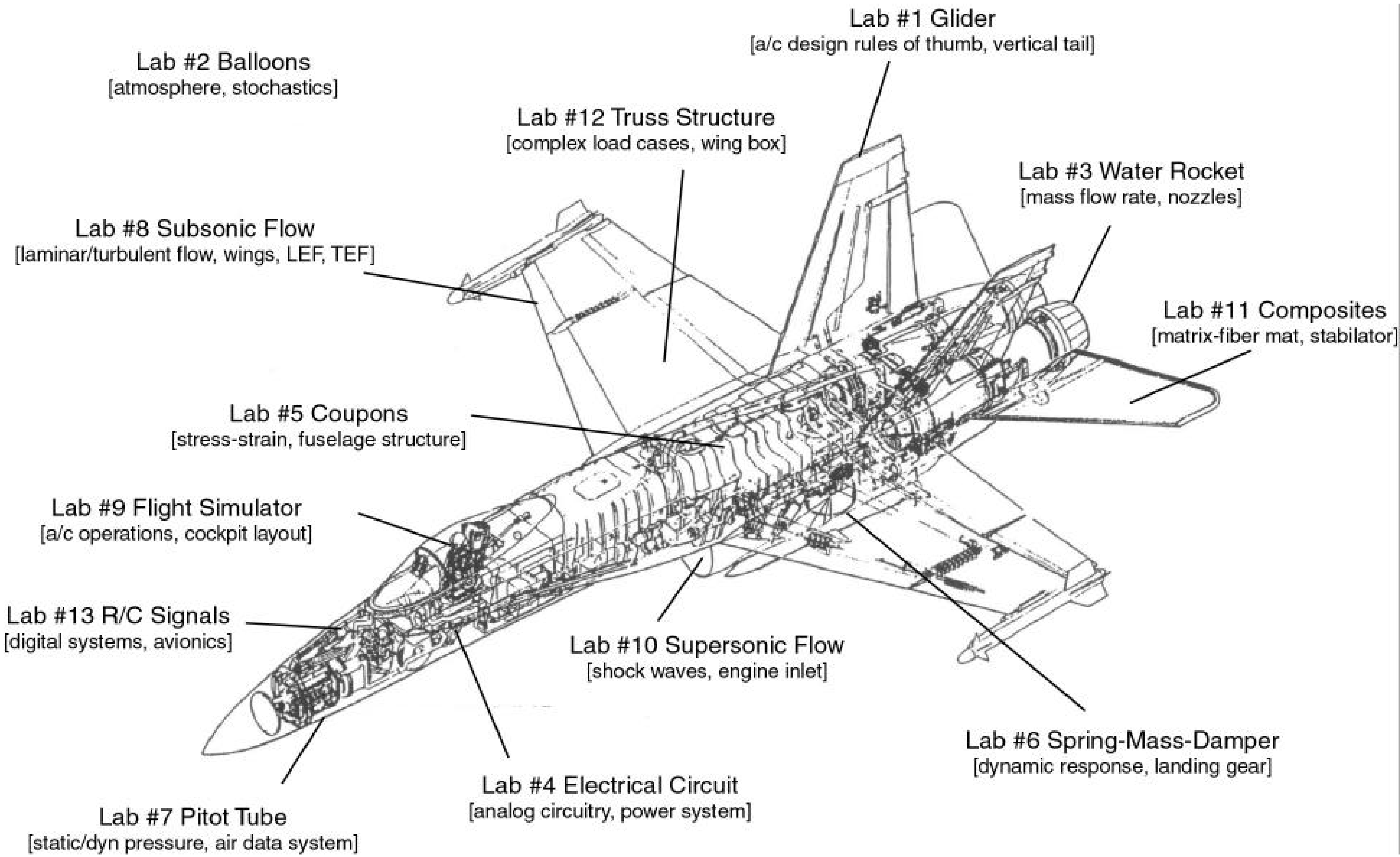

Fig. 2 Overview of Unified Engineering Labs and their potential context using the F/A-18 aircraft system

Table 1: Laboratory Exercise to Discipline Mapping Matrix **Appendix C**

Labs (Fall 2002)	Materials & Structures	Fluids	Thermodynamics & Propulsion	Systems & Signals	Dynamics
1. Glider	-	Drag and lift – glide angle – A/C design rules of thumb	-	-	Pitch and roll stability
2. Balloons	-	Atmospheric properties - winds	State transformation of a gas control volume – 1st /2nd law	-	Buoyancy
3. Water Rockets	-	Drag, nozzle flow	Rocket equation	-	Accelerated body – ballistic flight
4. Electrical Circuit	-	-	-	RLC-circuit design and operation	First order and second order dynamics - ODEs
5. Material Coupons	Elasticity; material fatigue;	-	Thermal conductivity	Resistivity	-
6. Spring-Mass-Damper	Vibrations, damping	-	-	-	Single DOF oscillator response
7. Pitot Tube	-	Dynamic versus static pressure, windtunnel ops	-	System block diagrams	-
8. Subsonic Flow	-	Lift-drag polars, pressure distribution	-	-	-
9. Flight Simulator	-	Stall behavior of wings with flaps	Aircraft flight envelopes	Cockpit layout	-

Labs (Spring 2003)	Materials & Structures	Fluids	Thermodynamics & Propulsion	Systems & Signals	Dynamics
10. Supersonic Flow	-	Shock waves	Stagnation points, Aerothermodynamic heating	-	-
11. Composites	Matrix-Fiber material properties	-	Material heating – vacuum – autoclave curing process	-	-
12. Truss Structures	Force/Torque Equilibrium FEM Intro	-	-	-	Local modes versus global modes
14. Electrical Instrument and Avionics R/C	-	-	-	Pulse width modulation (PWM), servoes	System response to various excitations