16.810

Engineering Design and Rapid Prototyping

Lecture 1

Introduction to Design

Instructor(s)

Prof. Olivier de Weck

Teaching Assistants: Anas Alfaris, Nii Armar

January 9, 2007

Happy New Year 2007 !

We won't be designing White Knight or SpaceShipOne this IAP, but …

You will learn about "the design process" and fundamental building blocks of any complex (aerospace) system

16.810 Quote

- ***"The scientist seeks to understand what is; the engineer seeks to create what never was"***
  - **-Von Karman**

16.810 Outline

- Organization of 16.810
  - Motivation, Learning Objectives, Activities
- (Re-) Introduction to Design
  - Examples, Requirements, Design Processes (Waterfall vs. Spiral), Basic Steps
- “Design Challenge” - Team Assignments
  - Previous Years (2004, 2005)
  - This Year: MITSET (30 min), VDS (30 min)
  - Deliverables Checklist, Team Assignments
- Facilities Tour

Organization of 16.810

16.810 Expectations

- 6 unit course (3-3-0) – 7+1 sessions
  - TR1-5 in 33-218 , <u>must</u> attend all sessions or get permission of instructors to be absent
  - This is for-credit, no formal "problem sets", but expect a set of deliverables (see √-list)
  - Have fun, but also take it seriously
  - The course is a 3rd year "prototype" itself and we are hoping for your feedback & contributions
  - Officially register under 16.810 (Jan 2007) on WEBSIS

History of this Course

December 2002	Undergraduate Survey in Aero/Astro Department.
	Students expressed wish for CAD/CAE/CAM experience.
April 4, 2003	Submission of proposal to Teaching and Education
	Enhancement Program ("MIT Class Funds")
May 6, 2003	Award Letter received from Dean for Undergraduate Education ($17.5k)
June 5, 2003	Kickoff Meeting
Sept 18, 2003	Approved by the AA undergraduate committee (6 units)
Fall 2003	Preparation
Jan 5, 2004	First Class (Topic: Bicycle Frame Design)
Fall 2004	Preparation
Jan 4, 2005	Second Class (Topic: Race Car Wing Design)
Jan 2007	Third Class → Focus on helping student projects

see: http://ocw.mit.edu

Needs – from students

A 2001 survey of undergraduate students (Aero/Astro) – in conjunction with new Dept. head search

- There is a perceived lack of understanding and training in modern design methods using state-of-the-art CAD/CAE/CAM technology and design optimization.

- Individual students have suggested the addition of a short and intense course of rapid prototyping, combined with design optimization.

Boeing List of "Desired Attributes of an Engineer"

- A good understanding of engineering science fundamentals
  - Mathematics (including statistics)
  - Physical and life sciences
  - Information technology (far more than "computer literacy")
- A good understanding of design and manufacturing processes (i.e. understands engineering)
- A multi-disciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
  - Economics (including business practice)
  - History
  - The environment
  - Customer and societal needs
- Good communication skills
  - Written
  - Oral
  - Graphic
  - Listening
- High ethical standards
- An ability to think both critically and creatively - independently and cooperatively
- Flexibility. The ability and self-confidence to adapt to rapid or major change
- Curiosity and a desire to learn for life
- A profound understanding of the importance of teamwork.

• *This is a list, begun in 1994, of basic durable attributes into which can be mapped specific skills reflecting the diversity of the overall engineering environment in which we in professional practice operate.*
• *This current version of the list can be viewed on the Boeing web site as a basic message to those seeking advice from the company on the topic. Its contents are also included for the most part in ABET EC 2000.*

16.810 An engineer should be able to …

- Determine quickly how things work
- Determine what customers want
- Create a concept
- Use abstractions/math models to improve a concept
- Build or create a prototype version
- Quantitatively and robustly test a prototype to improve concept and to predict
- Determine whether customer value and enterprise value are aligned (business sense)
- Communicate all of the above to various audiences

  - Much of this requires “domain-specific knowledge” and experience
  - Several require systems thinking and statistical thinking
  - All require teamwork, leadership, and societal awareness

Slide from Prof. Chris Magee

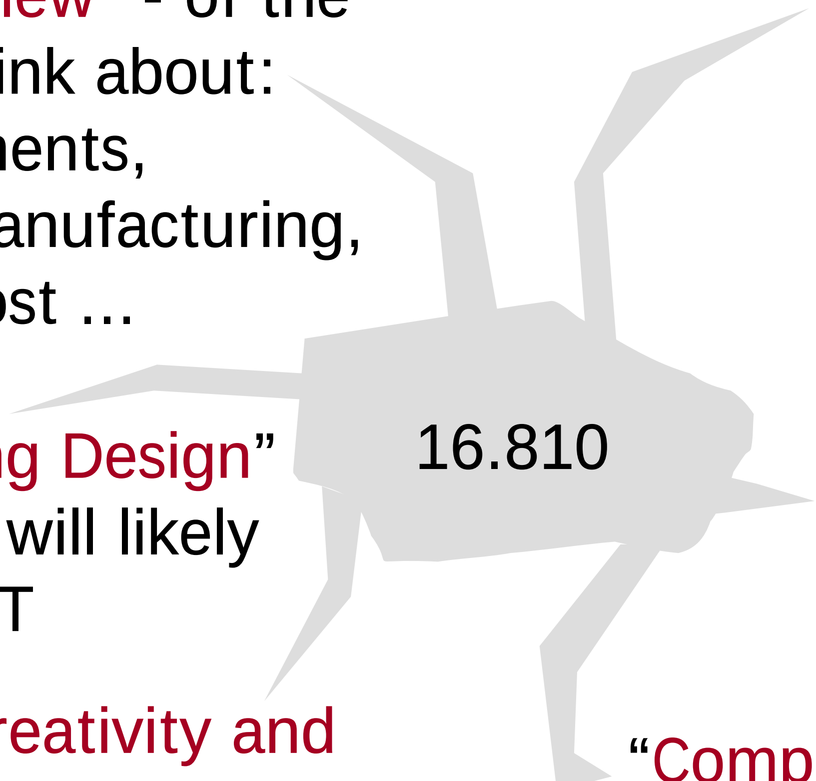
Leads to ➡ Course Objective

Develop a holistic view and initial competency in engineering design by applying a combination of human creativity and modern computational tools to the synthesis of a simple component or system.

Mind Map

"Holistic View" - of the whole. Think about:
- requirements, design, manufacturing, testing, cost …

"Competency" - can not only talk about it or do calculations, but actually carry out the process end-to-end



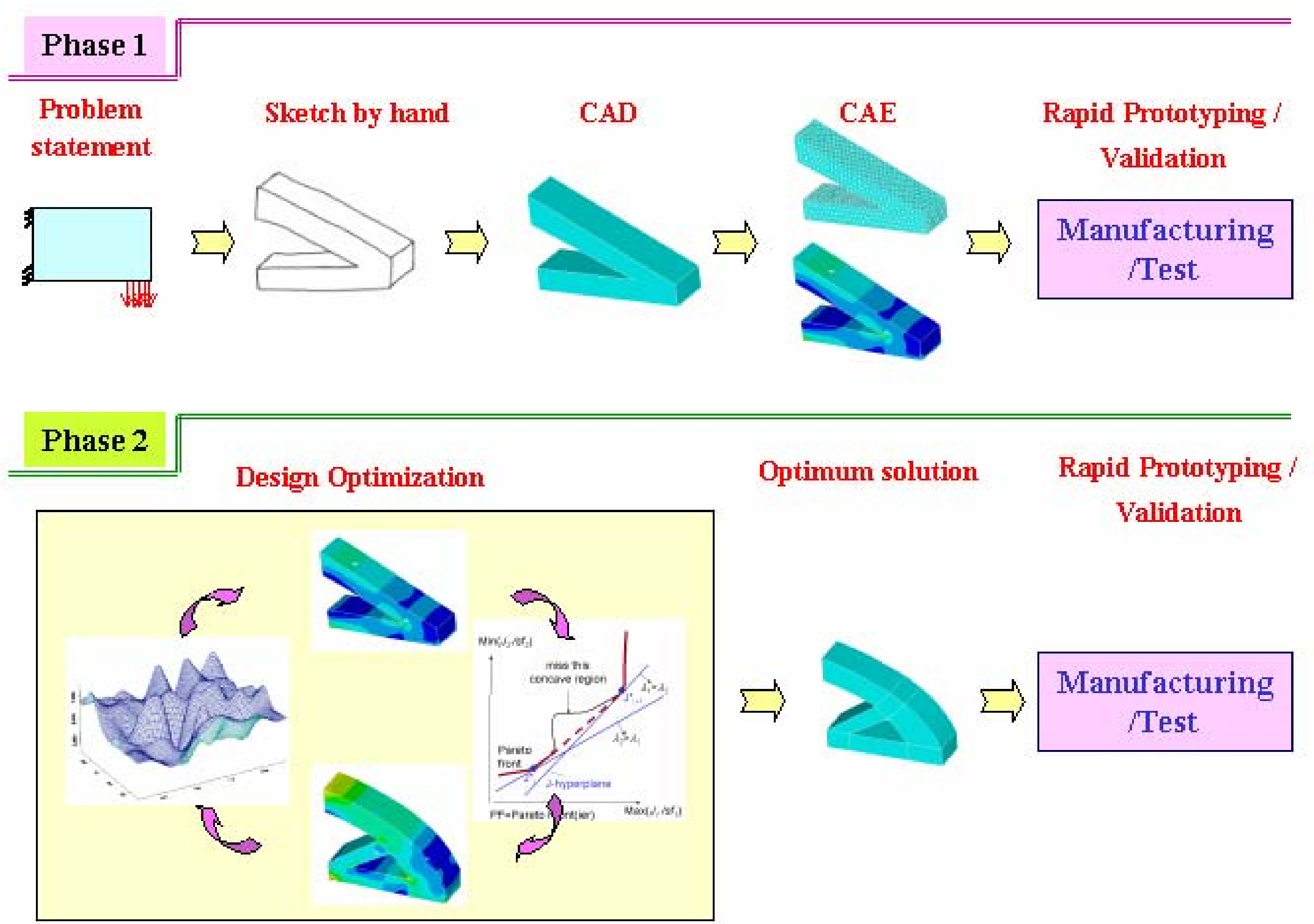
"Engineering Design" - what you will likely do after MIT

"Rapid Prototyping" - a hot concept in industry today.

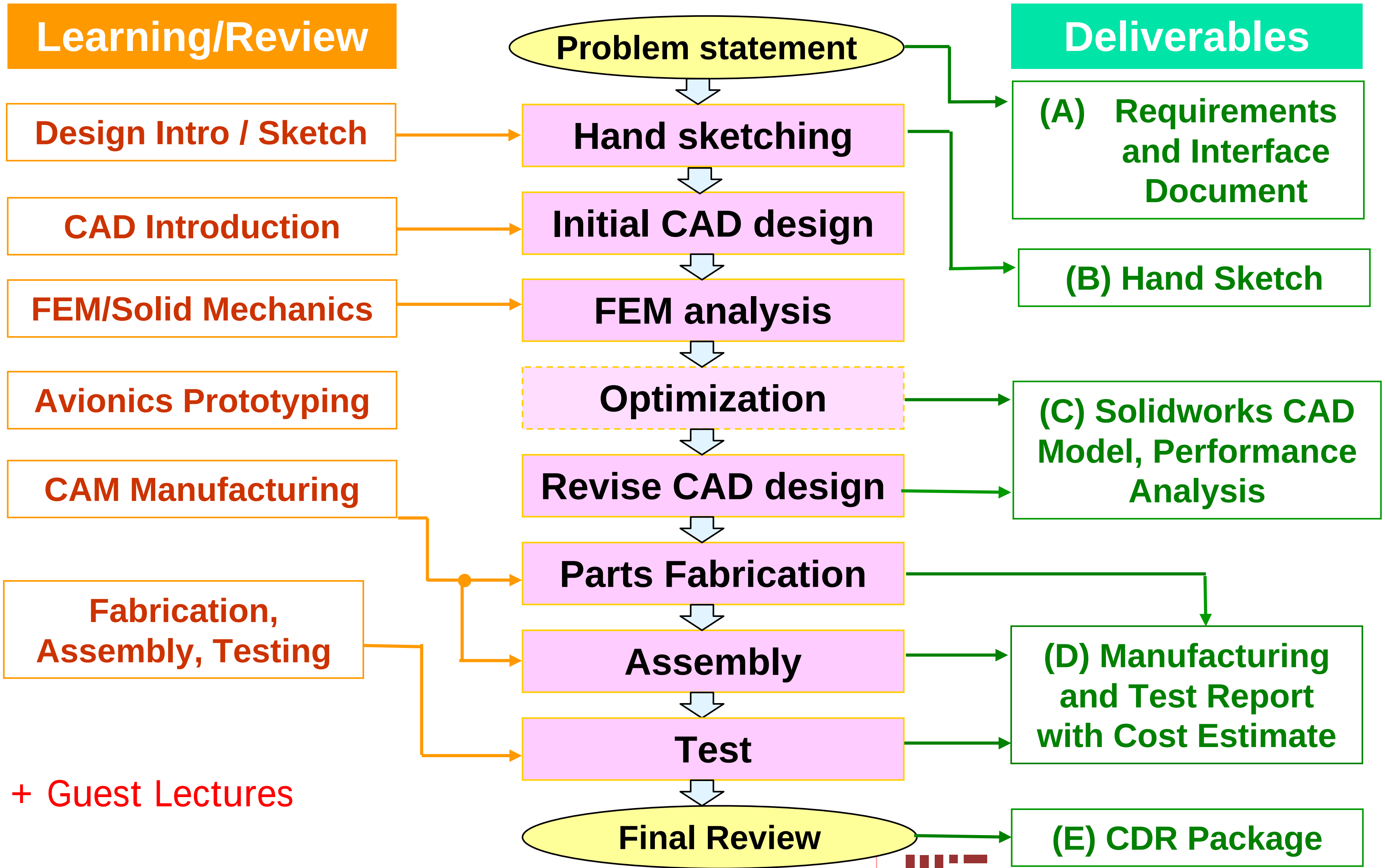
"Human Creativity and Computational Tools": design is a constant inter-play of synthesis and analysis

"Components / Systems": part of all aerospace systems, But must be "easy" to implement in a short time

Course Concept



Course Flow Diagram (2007)



+ Guest Lectures

Learning Objectives

At the end of this class you should be able to …

(1) Carry out a <u>systematic design process</u> from conception through design/implementation/verification of a simple component or system.

(2) Quantify the <u>predictive accuracy</u> of CAE versus actual test results.

(3) Explain the relative improvement that <u>computer optimization</u> can yield relative to an initial, manual solution.

(4) Discuss the complementary capabilities and limitations of the <u>human mind and the digital computer (</u>synthesis versus analysis<u>).</u>

16.810 Grading

- Letter Grading A-F *see checklist
- Composition
  - Design Deliverables* 70%
    - Requirements Document, Sketch, CAD Model & Analysis, Test & Mfg Report, Final Review Slides
  - Final Product 20%
    - Requirements Compliance
    - “Quality”
  - Active Class Participation 10%
    - Attendance, Ask Questions, Contribute Suggestions, Fill in Surveys

(Re-)Introduction to Design

Product Development - Design

Improved time-to-climb
Performance of F/A-18 in
Air-to-Air configuration by ~ 20%

Development
of Swiss F/A-18 Low Drag
Pylon (LDP) 1994-1996

"design" –
to create, fashion, execute,
or construct according to plan

Merriam-Webster

Design and Objective Space

Design Space

Design Variables

Wing Area

31.5 [in^2]

Aspect Ratio

6.2

Dihedral Angle

0 [deg]

Remember Unified ...?

Fixed Parameters

- air density
- properties of balsa wood

Objective Space

Performance

Time-of-Flight

5.35 sec

Distance

Ca. 90ft

Cost

Assembly Time

87 min

Material Cost

$ 4.50

Basic Design Steps

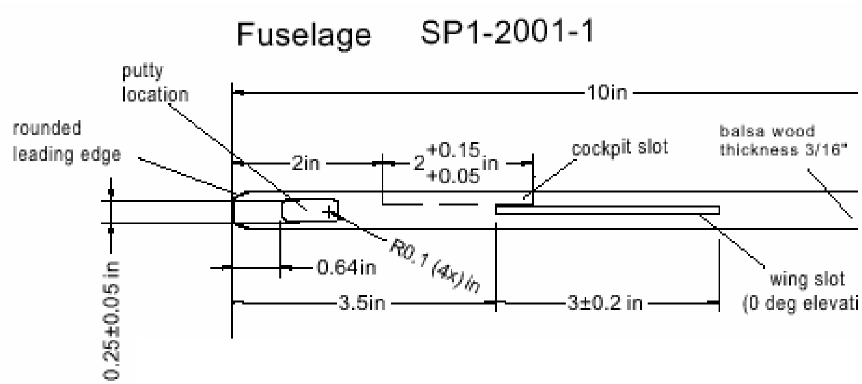
1. Define Requirements
2. Create/Choose Concept
3. Perform Design
4. Analyze System
5. Build Prototype
6. Test Prototype
7. Accept Final Design


"flying wing"

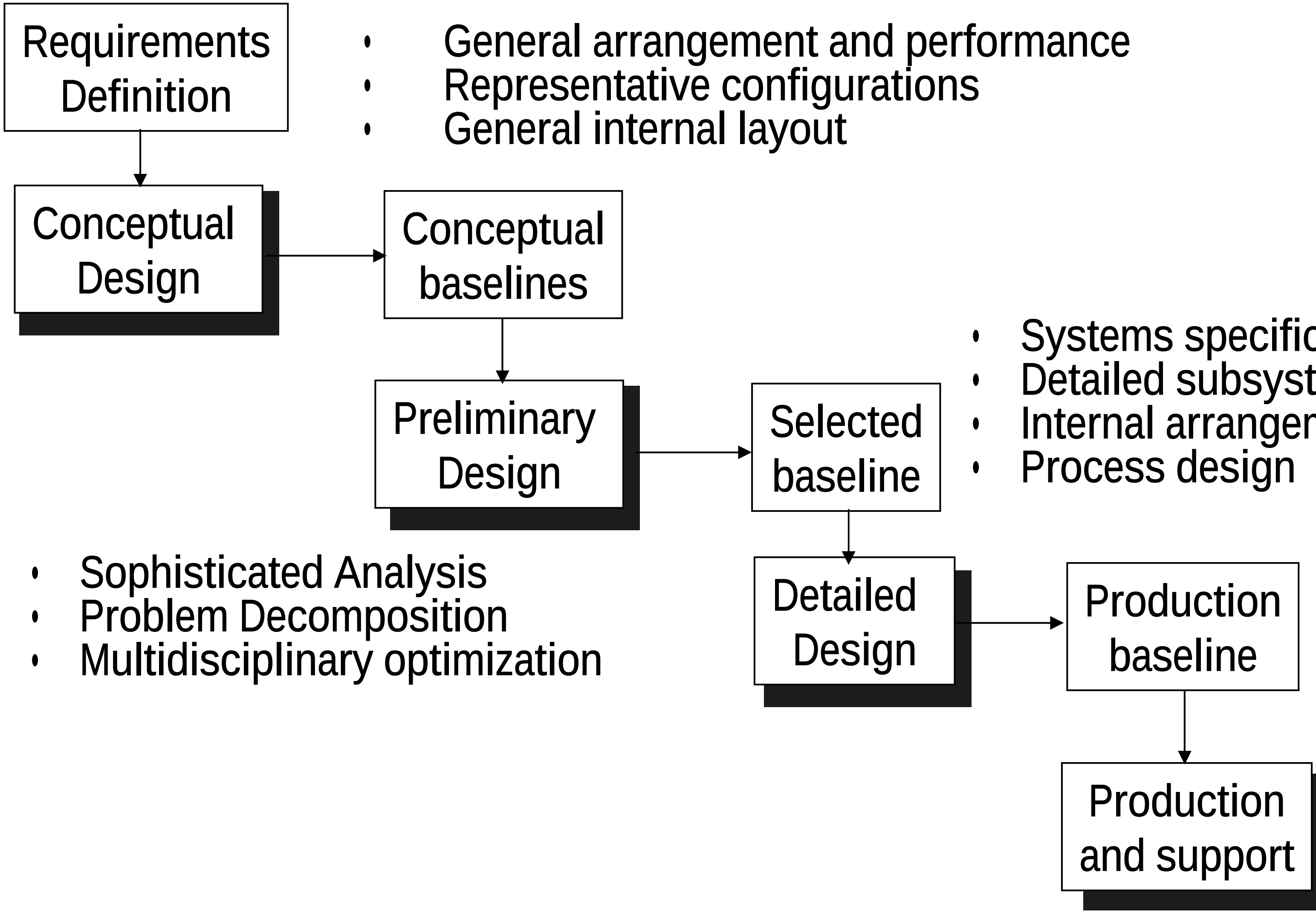

"monoplane"


"biplane"


"delta dart"



Typical Design Phases



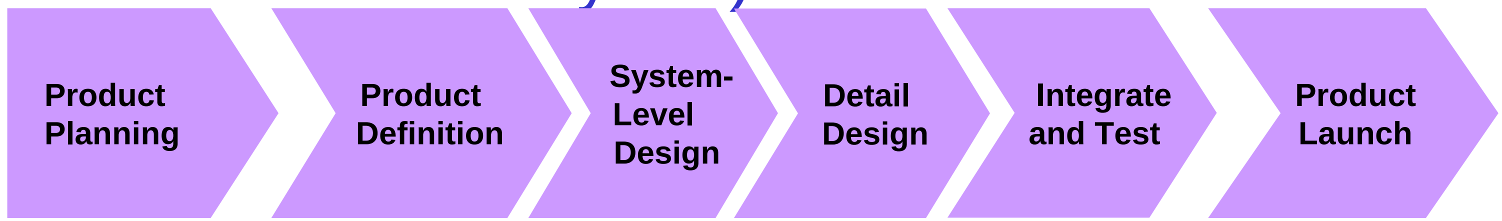
- General arrangement and performance
- Representative configurations
- General internal layout

- Systems specifications
- Detailed subsystems
- Internal arrangements
- Process design

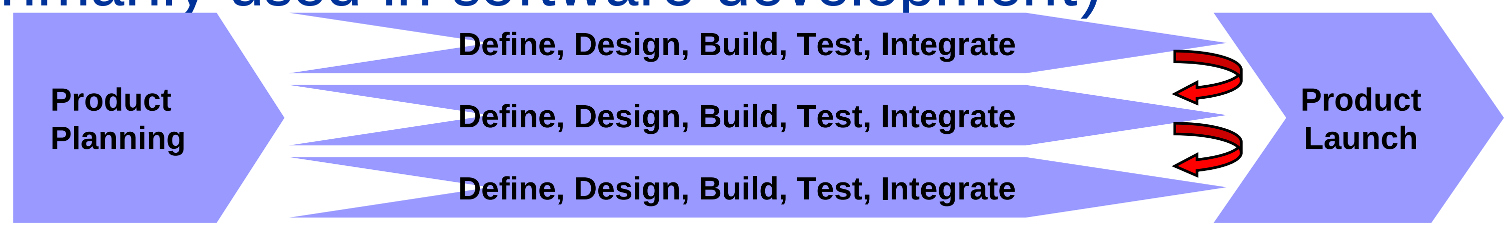
- Sophisticated Analysis
- Problem Decomposition
- Multidisciplinary optimization

Phased vs. Spiral PD Processes

Phased, Staged, or Waterfall PD Process
(dominant for over 30 years)



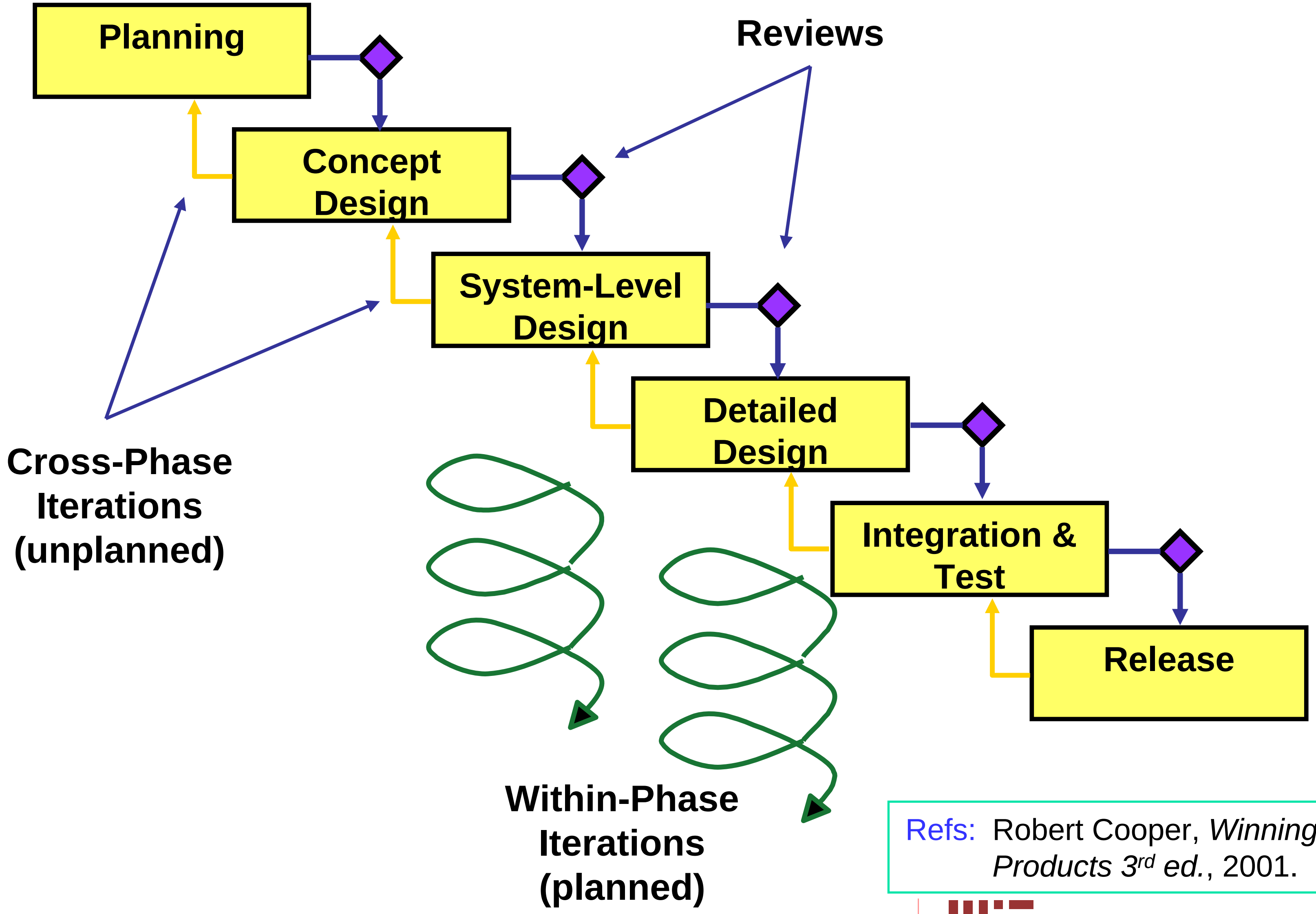
Spiral PD Process
(primarily used in software development)



Process Design Questions:

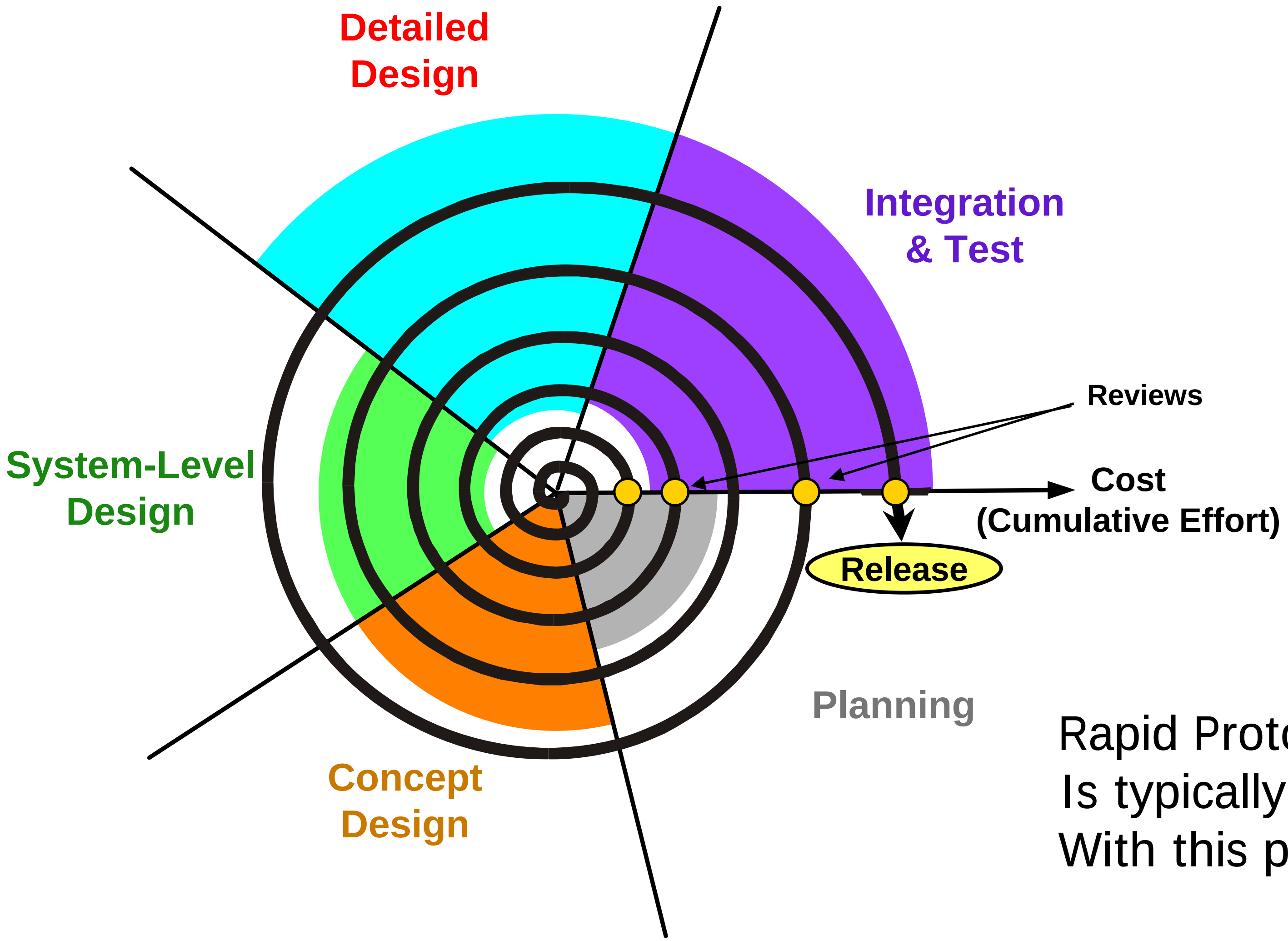
- How many spirals should be planned?
- Which phases should be in each spiral?
- When to conduct gate reviews?

Stage Gate PD Process



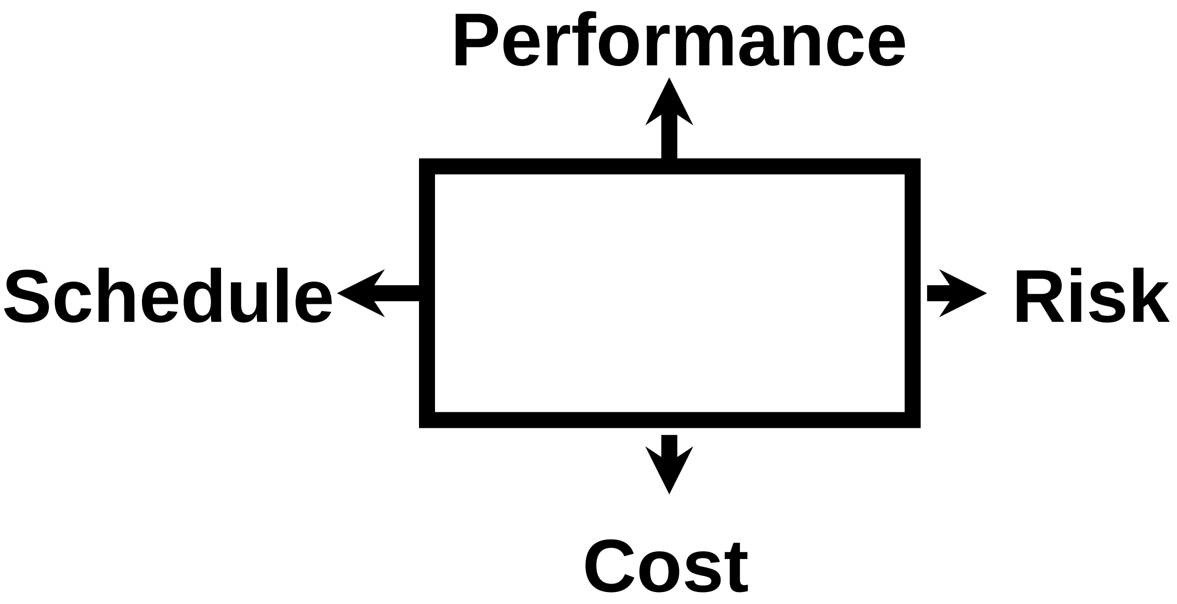
Refs: Robert Cooper, *Winning at New Products 3rd ed.*, 2001.

Spiral PD Process



Rapid Prototyping
Is typically associated
With this process

Basic Trade-offs in Product Development



- Performance - ability to do primary mission
- Cost - development, operation life cycle cost
- Schedule - time to first unit, production rate
- Risk - of technical and or financial failure

Ref: Maier, Rechtin, “The Art of Systems Architecting”

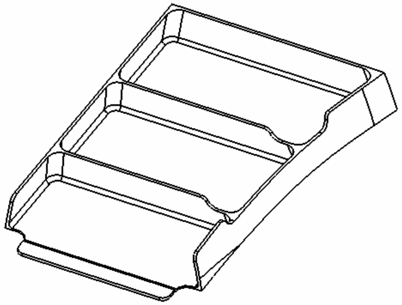
Key Differences in PDP's

- Number of phases (often a superficial difference)
- Phase exit criteria (and degree of formality)
- Requirement "enforcement"
- Reviews
- Prototyping
- Testing and Validation
- Timing for committing capital
- Degree of "customer" selling and interference
- Degree of explicit/implicit iteration (waterfall or not)
- Timing of supplier involvement

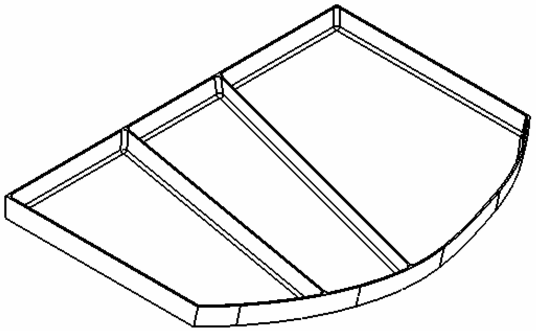
16.810

Hierarchy I: Parts Level

- deck components
  - Ribbed-bulkheads
  - Approximate dimensions
    - 250mm x 350mm x 30mm
    - Wall thickness = 2.54mm
- frame components
  - Ribbed-bulkheads
  - Approximate dimensions
    - 430mm x 150mm x 25.4mm
    - Wall thickness = 2mm
- keel
  - Ribbed-bulkhead
  - Approximate dimensions
    - 430mm x 660mm x 25.4mm
    - Wall thickness = 2.54mm

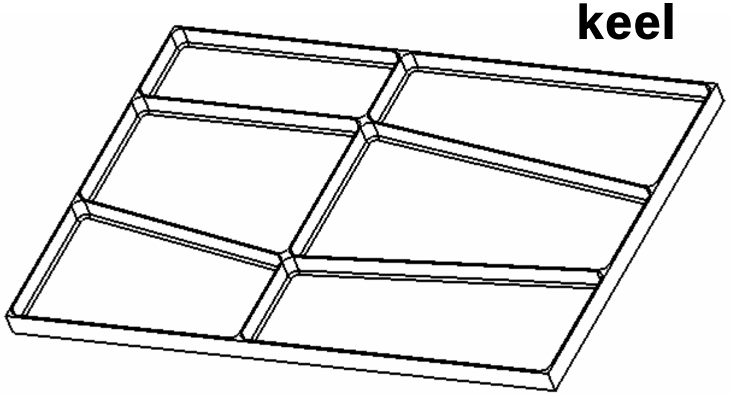


decks



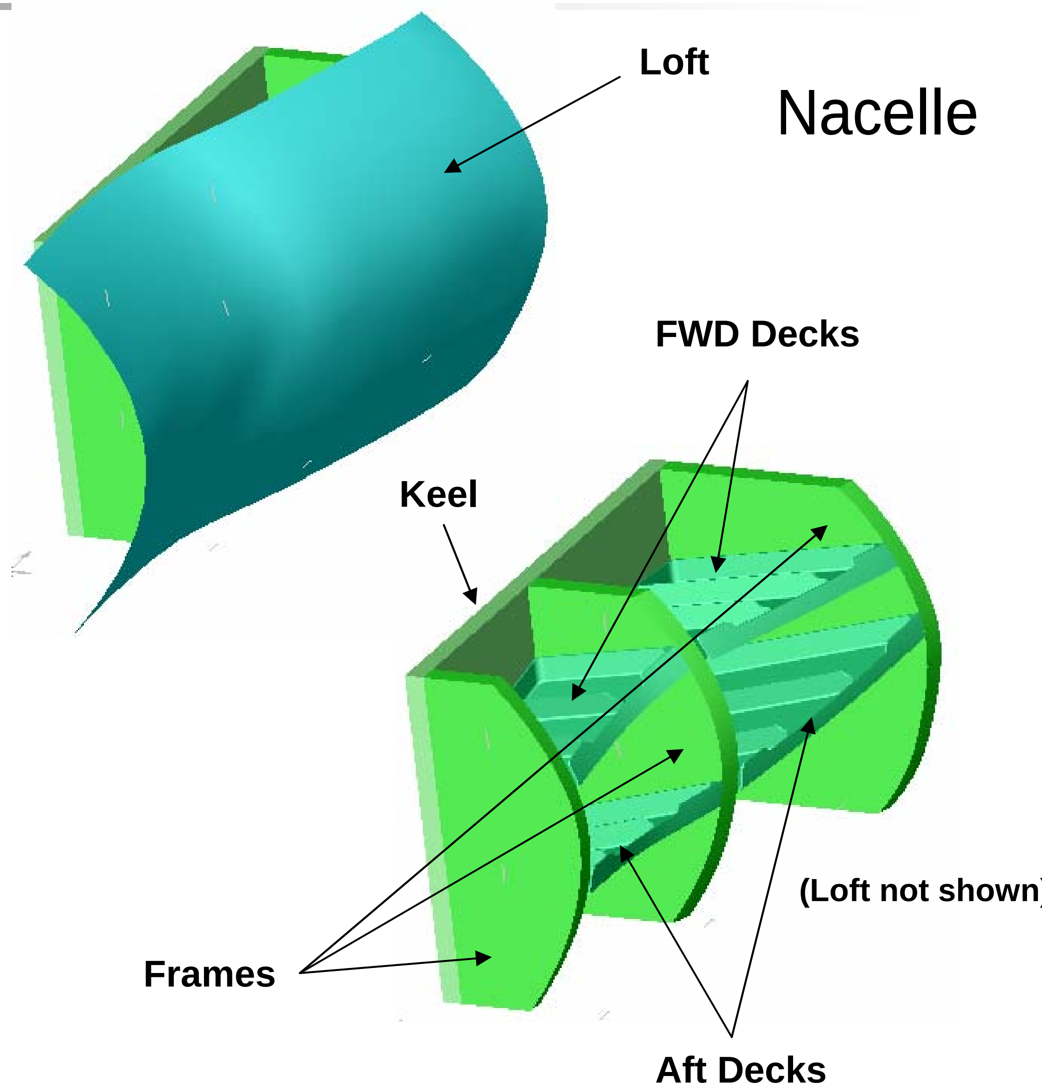
frames

keel



Hierarchy II: Assembly Level

- Boeing (sample) parts
  - A/C structural assembly
    - 2 decks
    - 3 frames
    - Keel
  - Loft included to show interface/stayout zone to A/C
  - All Boeing parts in Catia file format
    - Files imported into SolidWorks by converting to IGES format



Product Complexity

Assume 7-tree

$$\# levels = \left\lceil \frac{\log(\# \ parts)}{\log(7)} \right\rceil$$

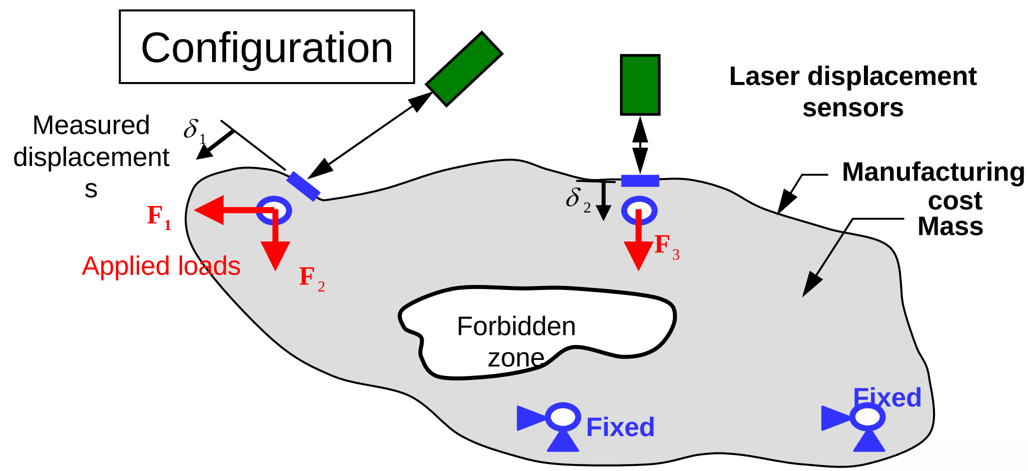
How many levels in drawing tree?

		~ #parts	#levels
Screwdriver	(B&D)	3	1
Roller Blades	(Bauer)	30	2
Inkjet Printer	(HP)	300	3
Copy Machine	(Xerox)	2,000	4
Automobile	(GM)	10,000	5
Airliner	(Boeing)	100,000	6

simple → complex

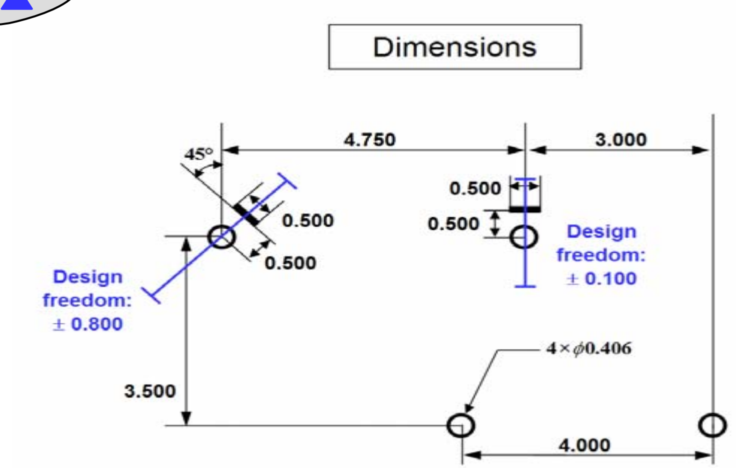
"Design Challenge" and Team Assignments

16.810 Project Description – IAP 2004

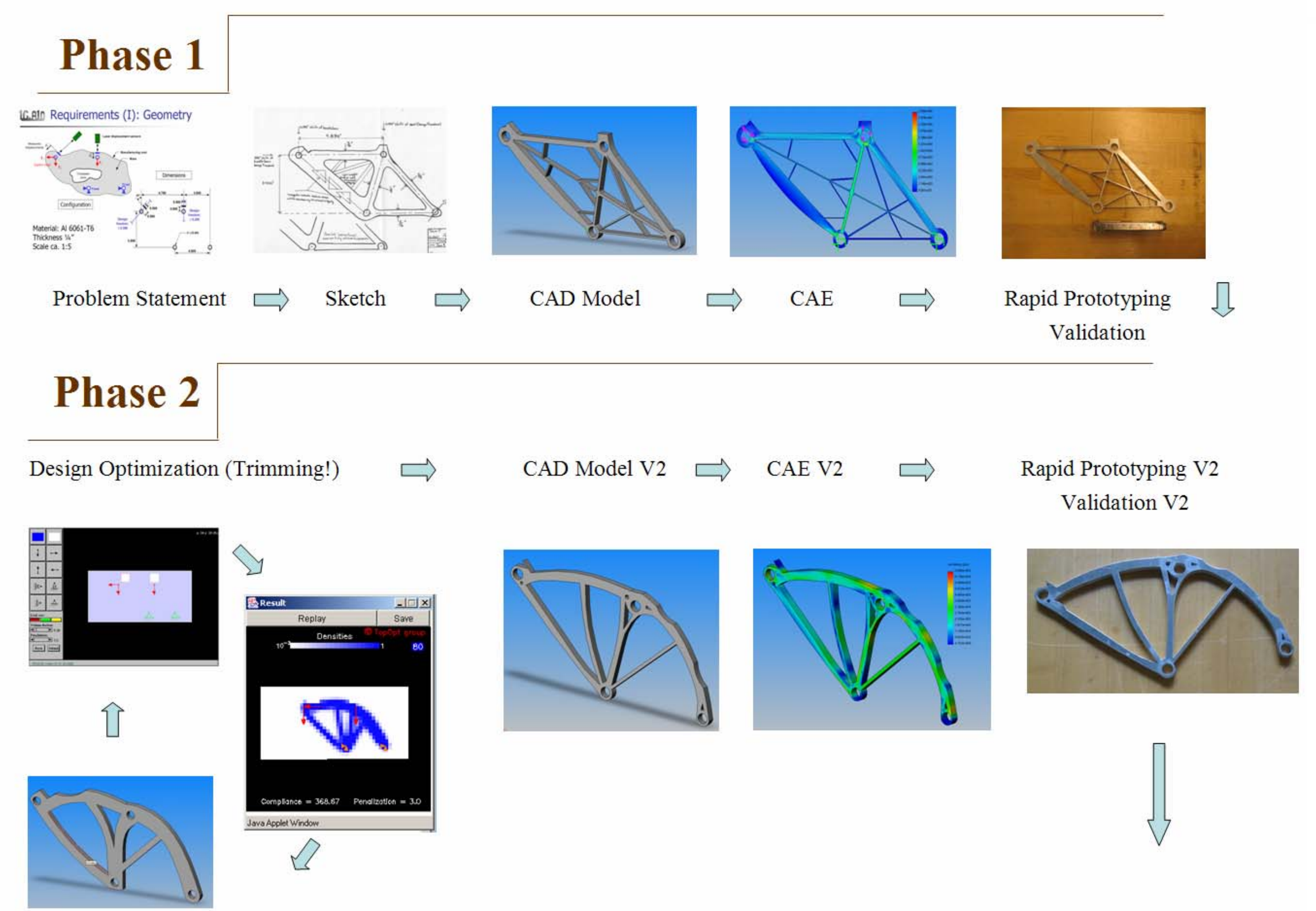


Model Bicycle Frame on 2-D plate

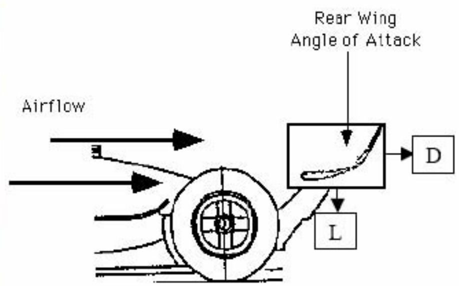
Material: Al 6061-T6
Thickness ¼”
Scale ca. 1:5

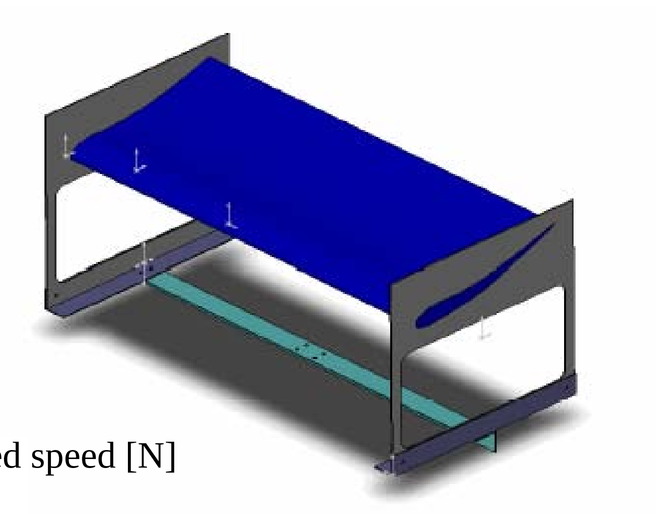


Project Deliverables – IAP 2004



Project Description – IAP 2005



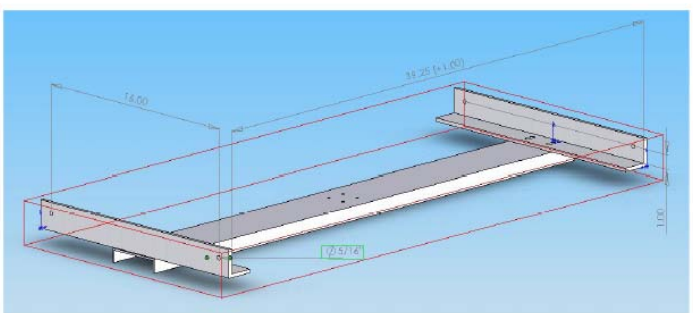


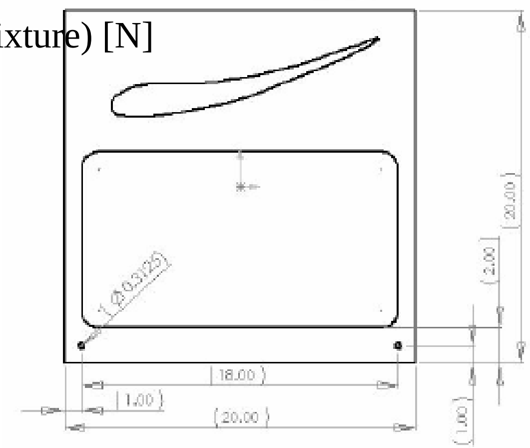
***maximize* [*F* = *L* – 3**D* – 5**W*]**

Where:

L = measured downforce (negative lift) at specified speed [N]
D = measured drag at specified speed [N]
W = total weight of the assembly (not including test fixture) [N]

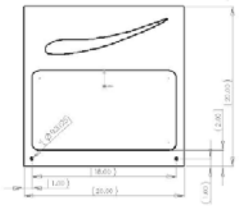
The nominal speed is 60 mph

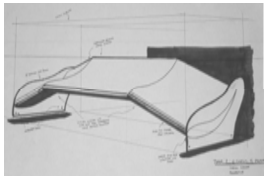


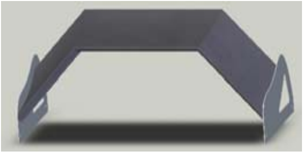


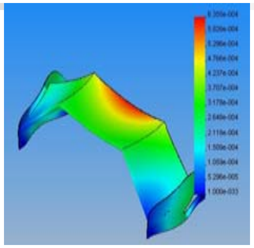
Project Deliverables – IAP 2005

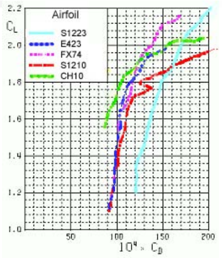
Phase 1





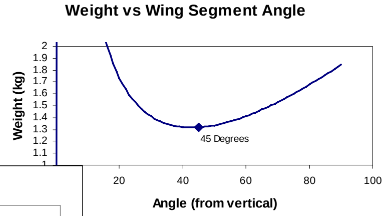


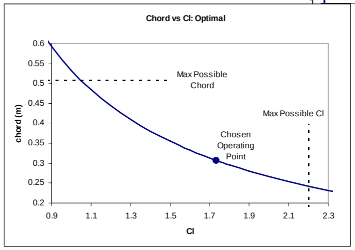




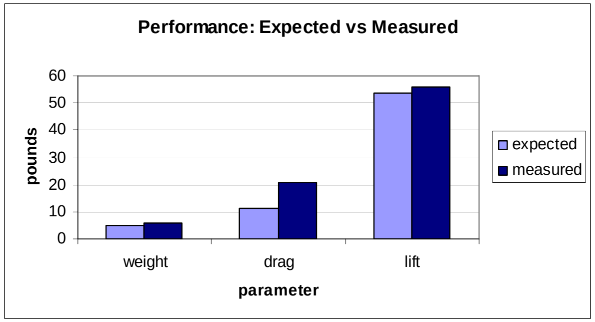
Problem Statement → Hand Sketch → Initial CAD → CAE (FEA) → CAE (CFD)

Phase 2





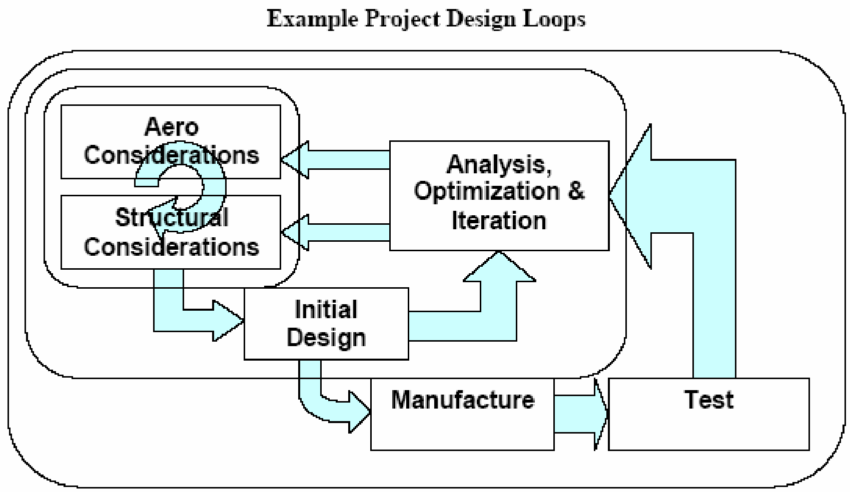
Design Optimization

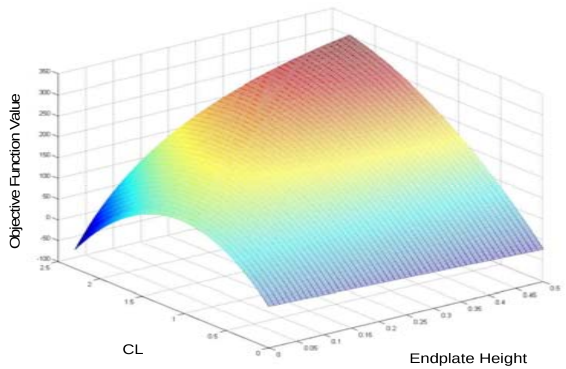


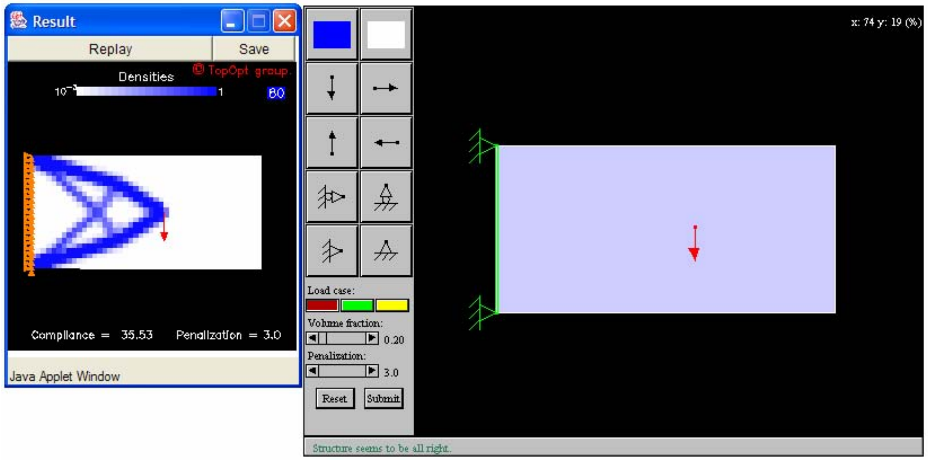
Prototype Testing and Validation

16.810 Optimization – 2004 & 2005

- Manual Iteration
  - Design loops (Spiral method)
- Software

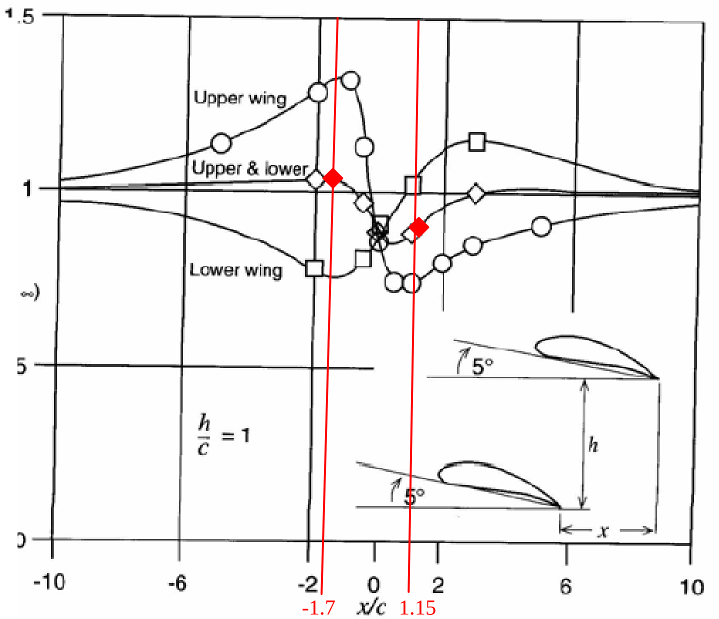




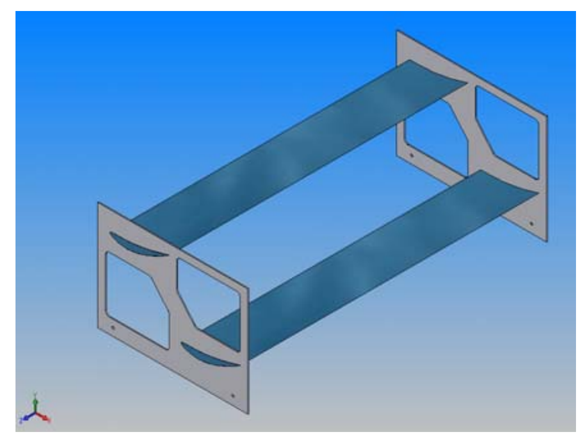


Learning from Mistakes

- Carrying out a full lifecycle creates memorable learning experiences
- Don't prevent students from making mistakes
- Example: bi-wing configuration
- Excerpt from Student Reflective Memo:



"I learned the value of constantly checking simulations against reality ..... My rear-wing design used a biplane setup, ...due to a huge oversight, the wings were actually arranged in an incorrect orientation which incurred a large drop in down force. ....This experience taught me a great lesson – always triple check your assumptions against your design. I spent hours and hours optimizing a design that was never constructed, simply because I was told to assume that the down force bonus would be experienced. I never bothered to verify this myself, and this disconnection had dire consequences."



16.810 IAP 2007 Challenge

- **Focused on Student-Driven Teams**
  - **VDS Vehicle Design Summit**
  - **MITSET Space Elevator Team**
- **Define/pick the current baseline configuration**
- **Create a performance model of the baseline configuration**
  - **VDS: miles-per-gallon [mpg]**
  - **MITSET: time-to-climb [sec]**
- **Pick 4-5 most critical components and subsystems based on performance sensitivity**
- **IAP 2007**
  - **assign 2-3 students per component/subsystem in the 1st session of IAP**
  - **design/redesign those components during weeks 2-3**
  - **manufacture and reintegrate during week 4**
  - **CDR at the end of IAP 2007 – look at performance improvement**

16.810 Team Presentations (30 min each)

- MIT Space Elevator Team (MITSET)

NASA Centennial Challenge
Power Beaming

- Vehicle Design Summit (VDS)

Assisted Human Power Vehicle (AHPV)

Image: VDS 1.0 – Summer 2006

Facilities Tour

Facilities Tour

* Design Studio (33-218)

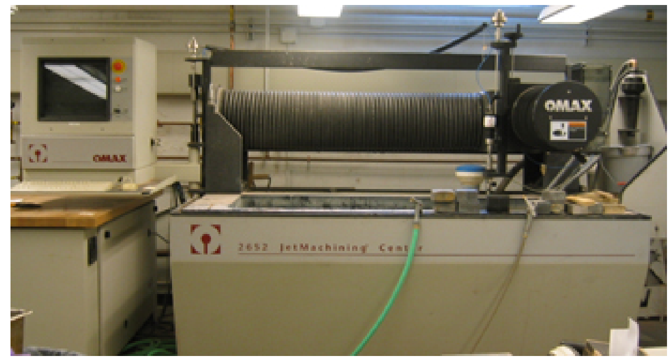
- 14 networked CAD/CAE workstations that are used for complex systems design and optimization.

*** Software to be used:**

- Xfoil
- Solidworks
- Cosmos
- Altium
- Omax
- Matlab

* Machine Shop

-Water Jet cutter, Wing cutter



* Wind Tunnel

-Subsonic aerodynamic testing

MIT Wright Brother's Wind Tunnel, see http://web.mit.edu/aeroastro/www/labs/WBWT/

16.810 Next Steps

- Form a Team
  - Pick MITSET or VDS
  - Pick a component/subsystem
  - Give your team a distinctive name
- Study the following
  - 16.810 documents: schedule, deliverables checklist, project description, Register on WEBSIS if not already done
- Get username and passwd on AA-Design LAN
- Complete Attendance Sheet
- Prepare for Thursday’s lecture:
  - Look at CAD/CAE/CAM manual (Sample Part)
  - Go through step-by-step
  - Signup for a machine shop slot for Waterjet Manufacturing (OMAX)