16.810

Engineering Design and Rapid Prototyping

Lecture 1

Introduction to Design

Instructor(s)

Prof. Olivier de Weck

January 4, 2005

16.810 Happy New Year 2005 !

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
  - Race Car Wing: Project Description, 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 , must 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 2nd year "prototype" itself and we are hoping for your feedback & contributions

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)
	see: http://ocw.mit.edu
Fall 2004	Preparation
Jan 4, 2005	Second Class (Topic: Race Car Wing Design)

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.**

16.810 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 <u>prototype</u> version
- Quantitatively and <u>robustly test</u> 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 <u>competency</u> in <u>engineering design</u> by applying a combination of <u>human creativity and modern computational tools</u> to the synthesis of a simple component or system.

Mind Map

16.810

"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

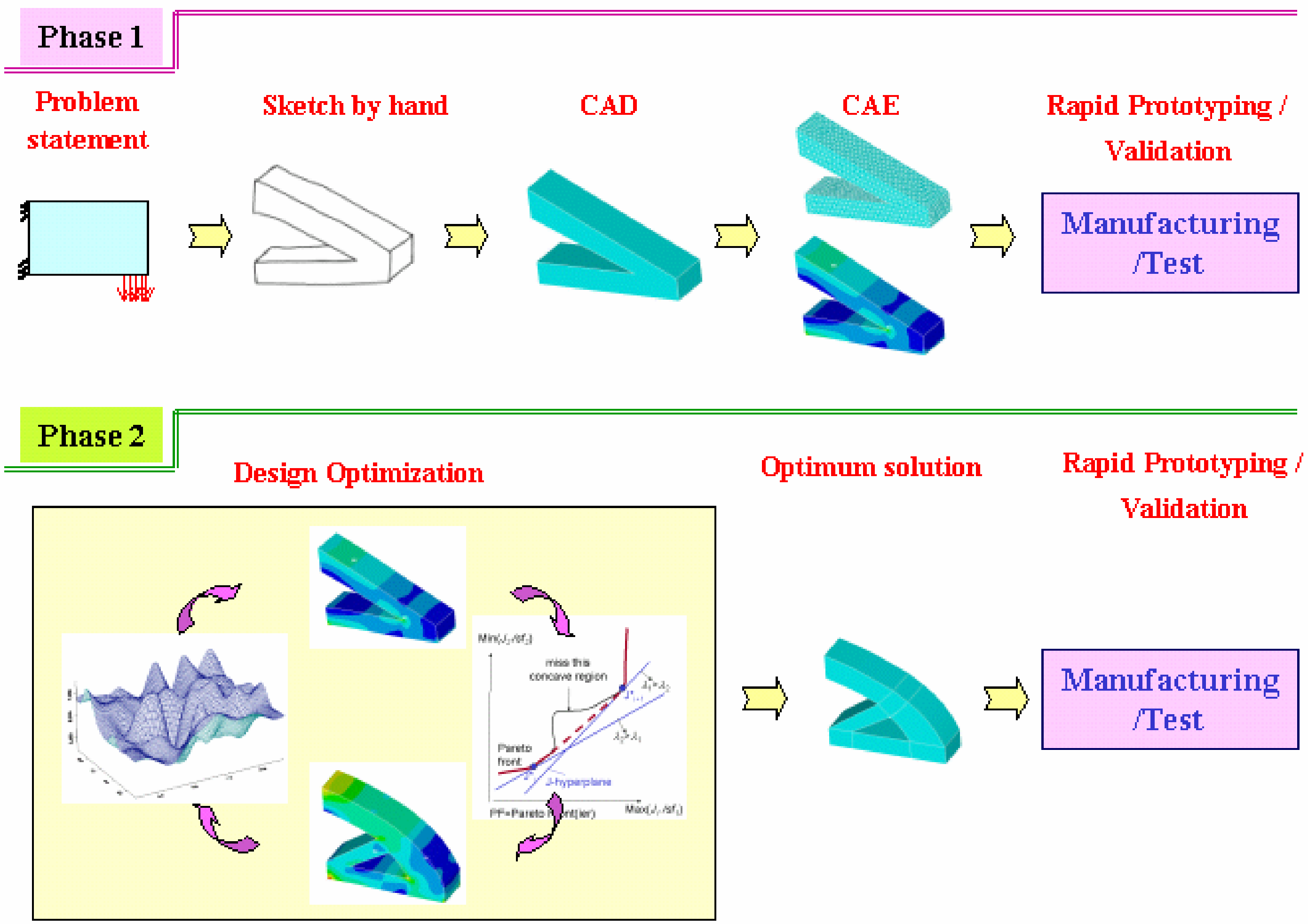
"Engineering Design" - what you will likely do after MIT

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

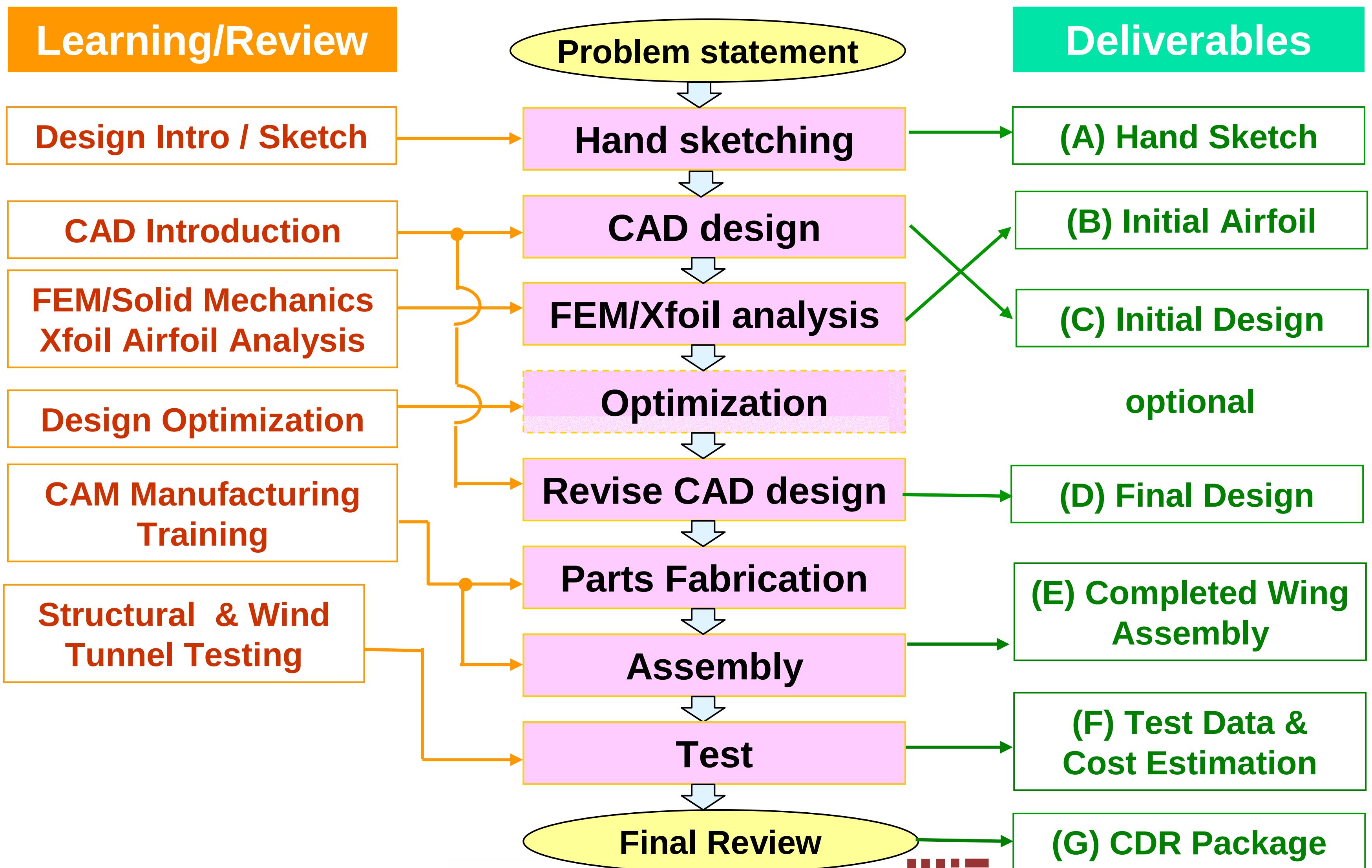
"Human Creativity and Computational Tools": design is a constant inter-play of synthesis and analysis

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

Course Concept



Course Flow Diagram (2005)



IAP 2005 Schedule

See separate handout

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).

16.810 Grading

- Letter Grading A-F *see req. checklist
- Composition
  - Design Deliverables* 60%
    - Sketch, 2D Airfoil report, Initial CAD model, Final CAD Model & Analysis, Test & Cost Report, Final Review Slides
  - Wing Assembly (Product) 20%
    - Requirements Compliance
  - Active Class Participation 20%
    - 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

16.810 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

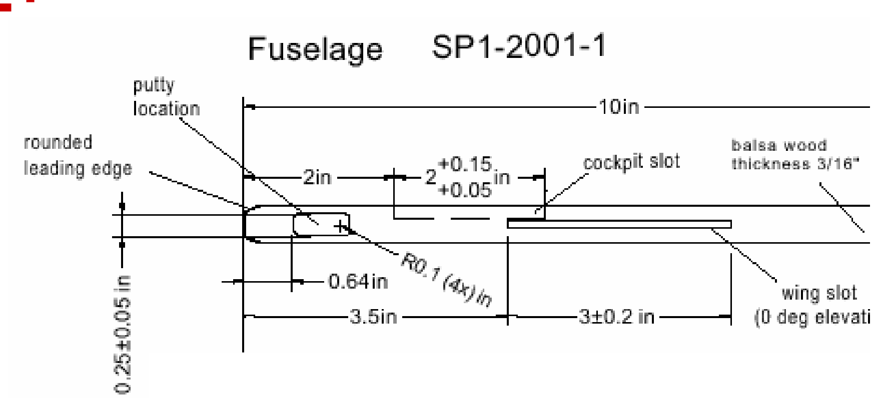
1. Define Requirements
2. Create/Choose Concept
3. Perform Design
4. Analyze System
5. Build Prototype
6. Test Prototype
7. Accept Final Design

"flying wing"

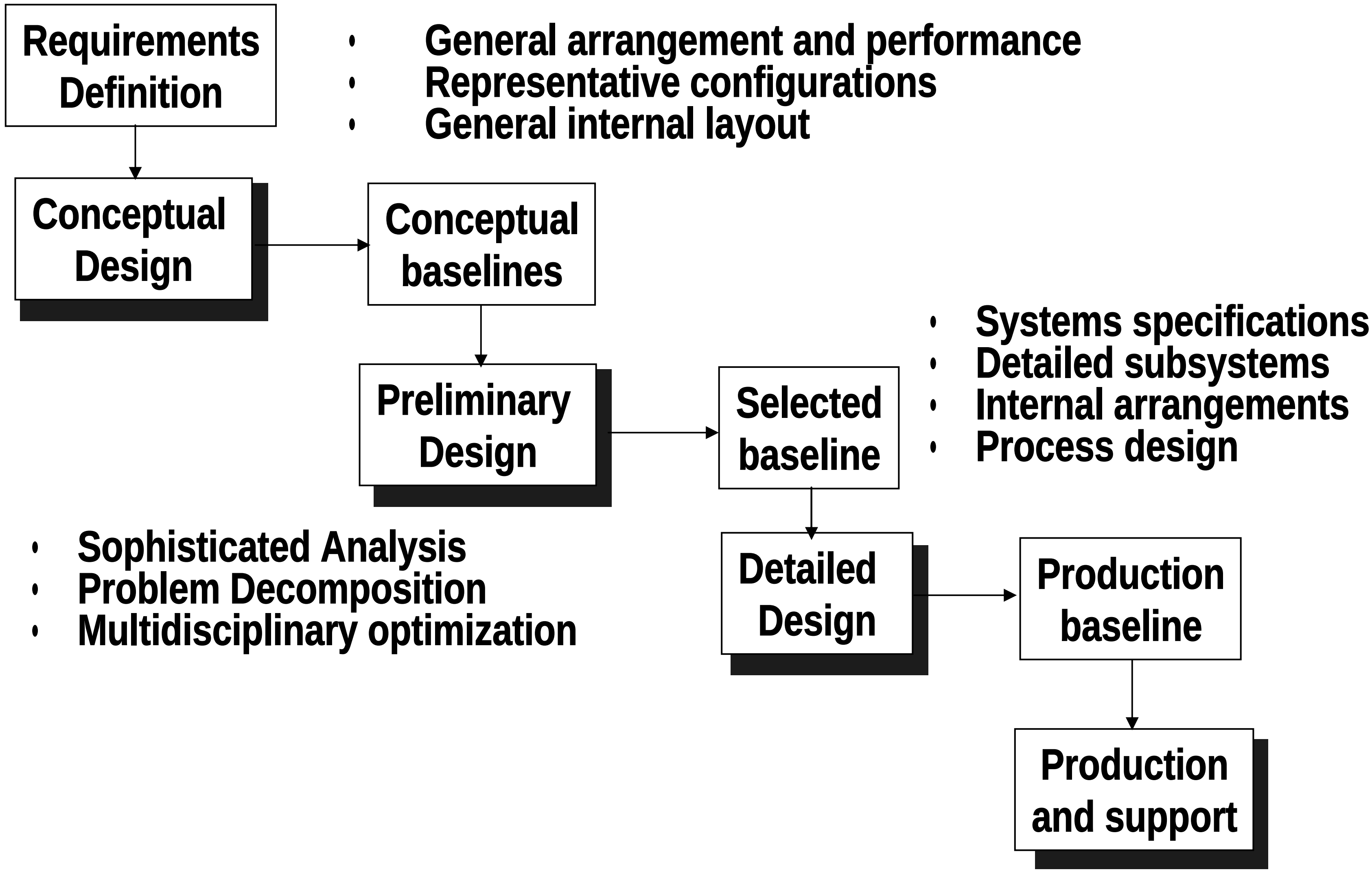
"monoplane"

"biplane"

"delta dart"

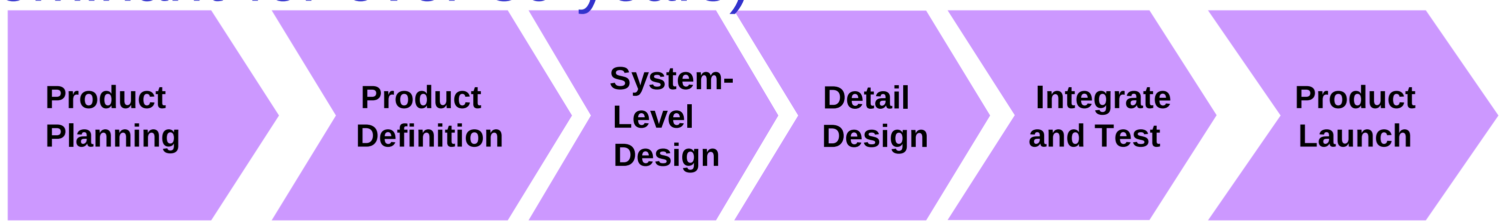


Typical Design Phases

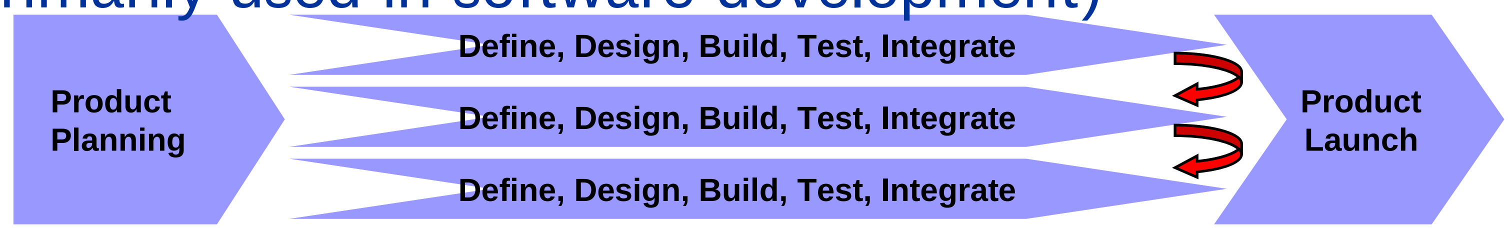


Phased vs. Spiral PD Processes

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



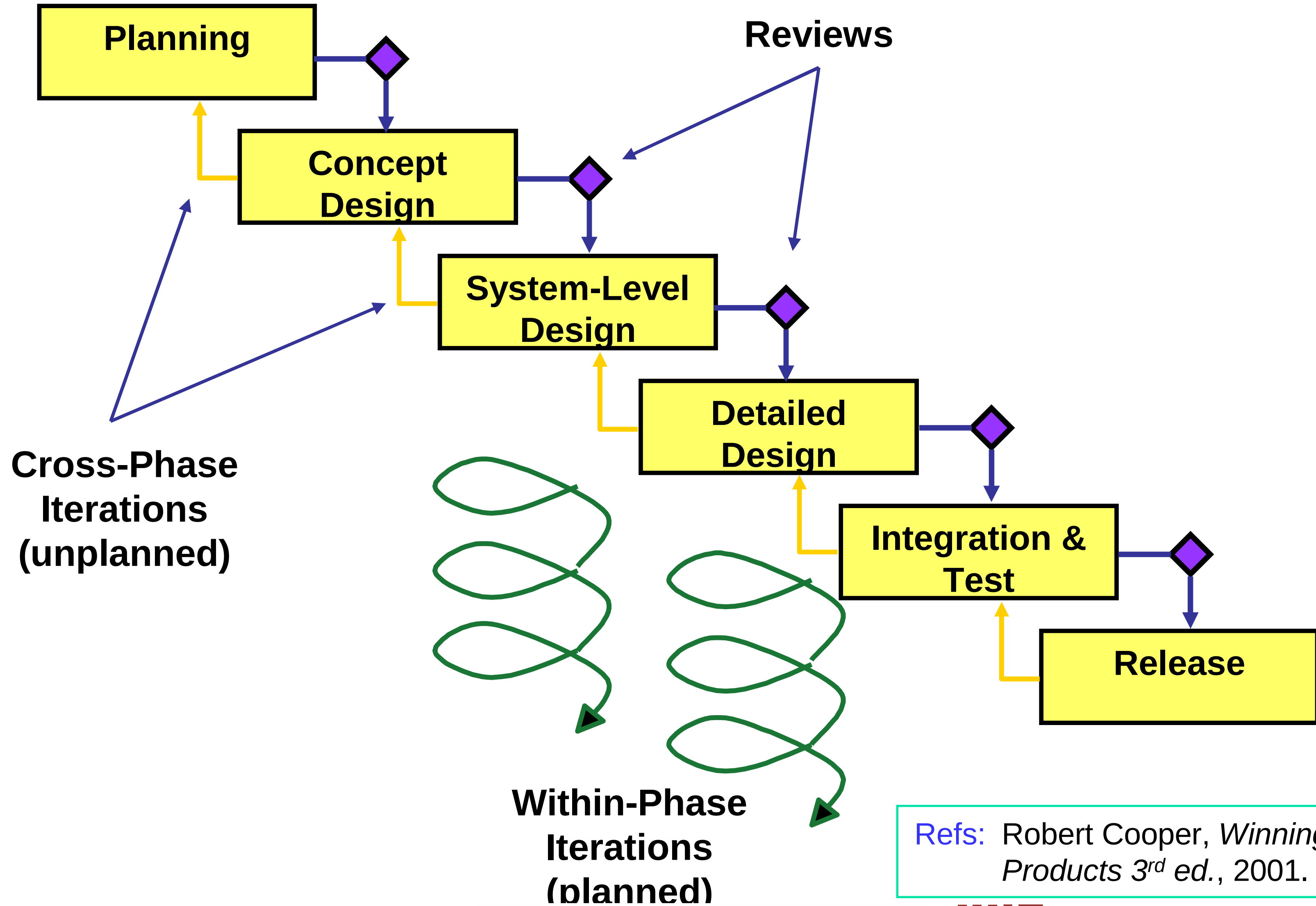
Spiral PD Process
(primarily used in software development)



Process Design Questions:

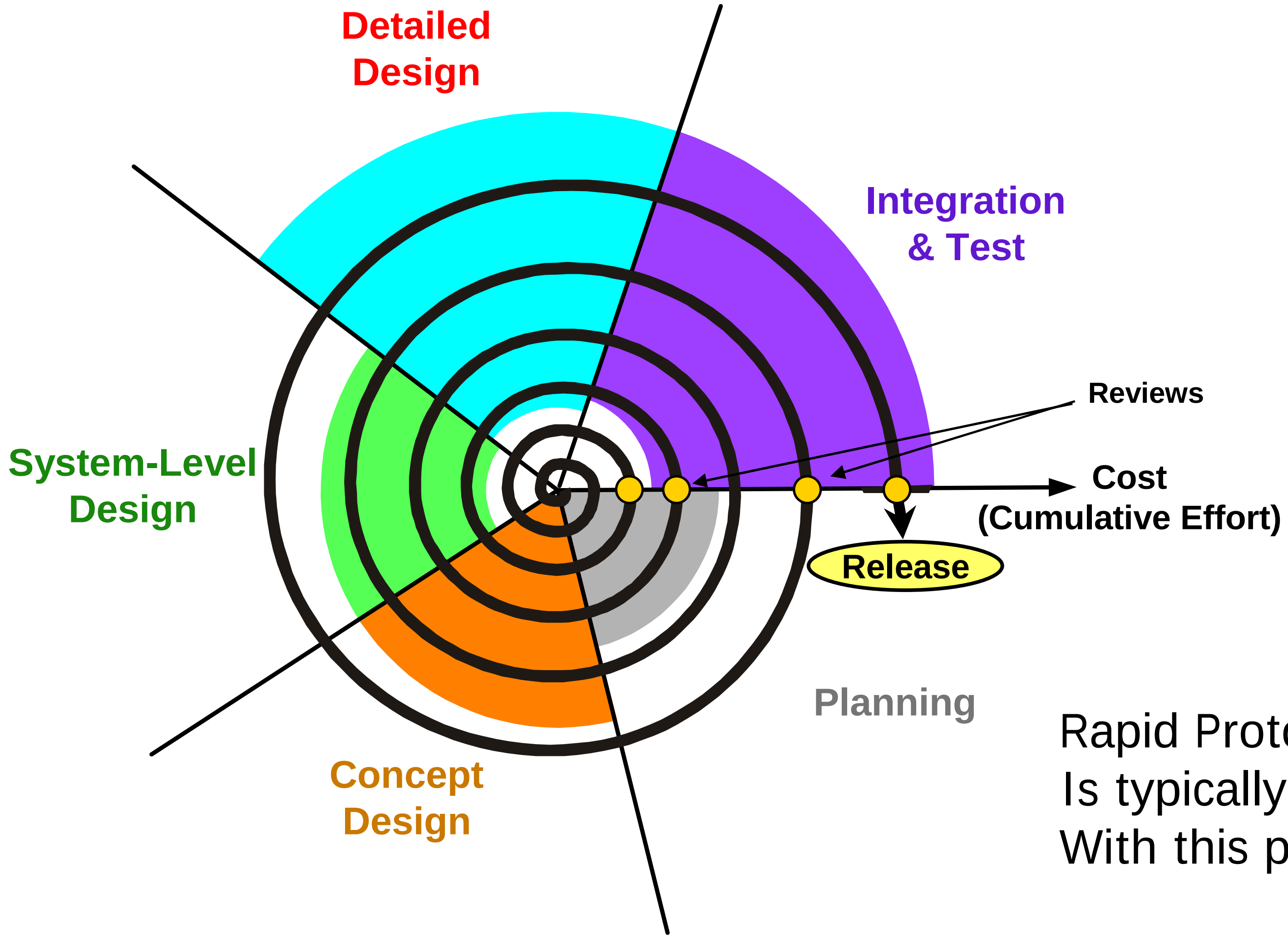
- How many spirals should be planned?
- Which phases should be in each spiral?
- When to conduct gate reviews?

Stage Gate PD Process



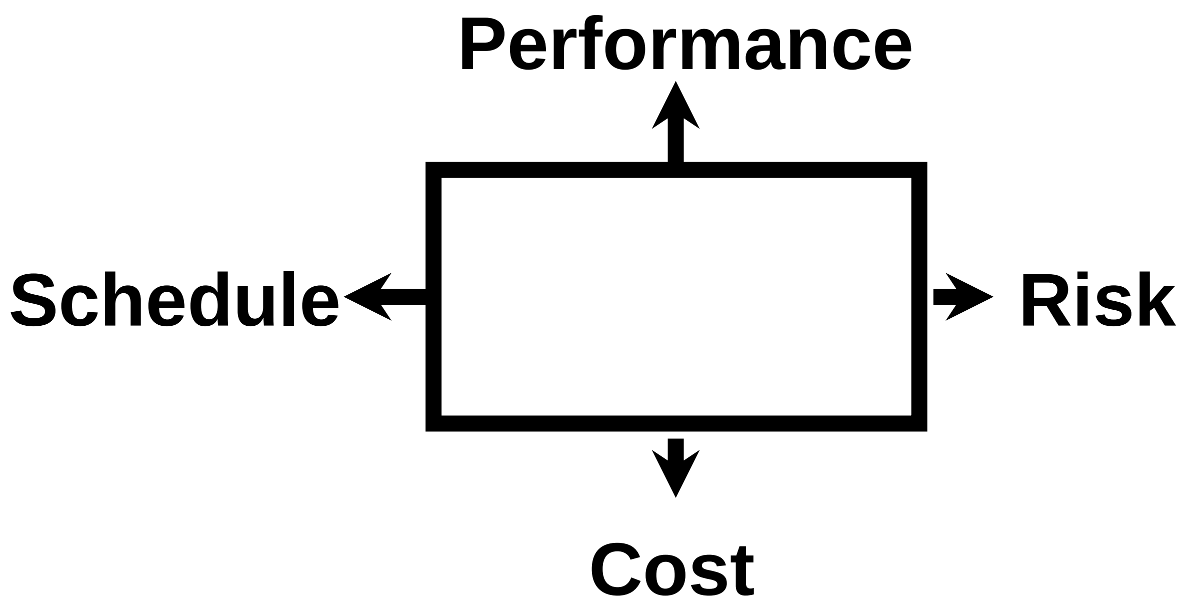
Refs: Robert Cooper, *Winning at New Products 3rd ed.*, 2001.

16.810 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

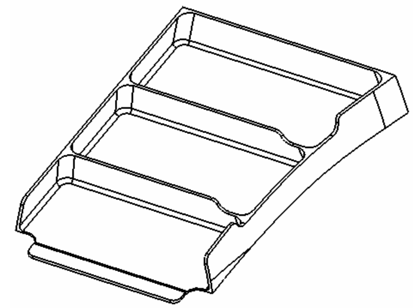
Ref: Maier, Rechtin, "The Art of Systems Architecting"

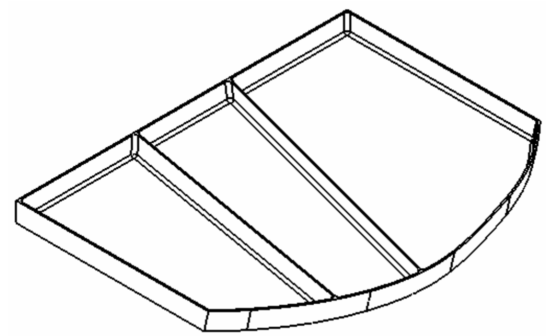
16.810 Key Differences in PDP's

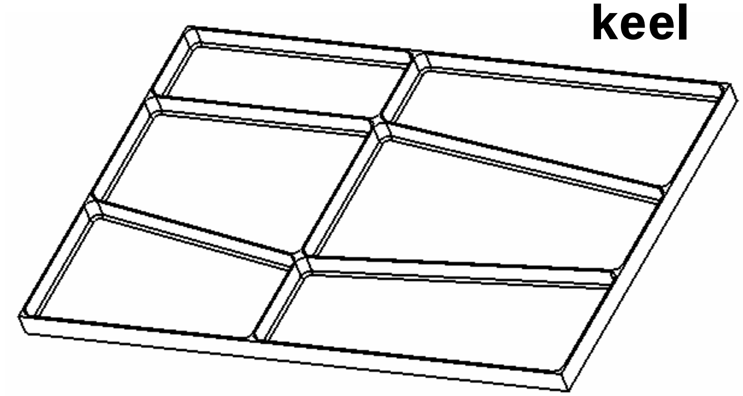
- Number of phases (often a superficial difference)
- Phase exit criteria (and degree of formality)
- Requirement "enforcement"
- Reviews
- Prototyping
- Testing and Validation
- Timing for committing capital
- Degree of "customer" selling and interference
- Degree of explicit/implicit iteration (waterfall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

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

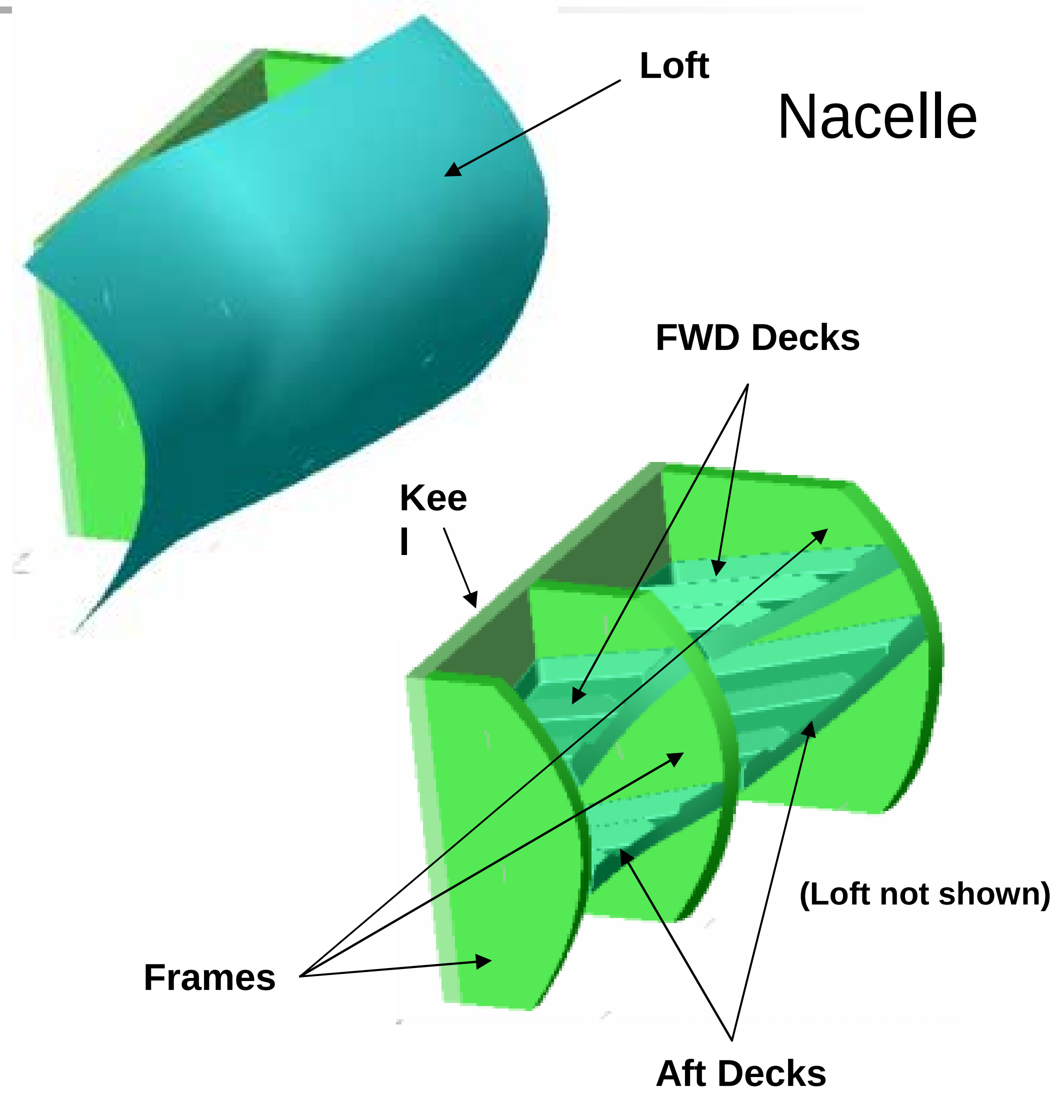






Hierarchy II: Assembly Level

- 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

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

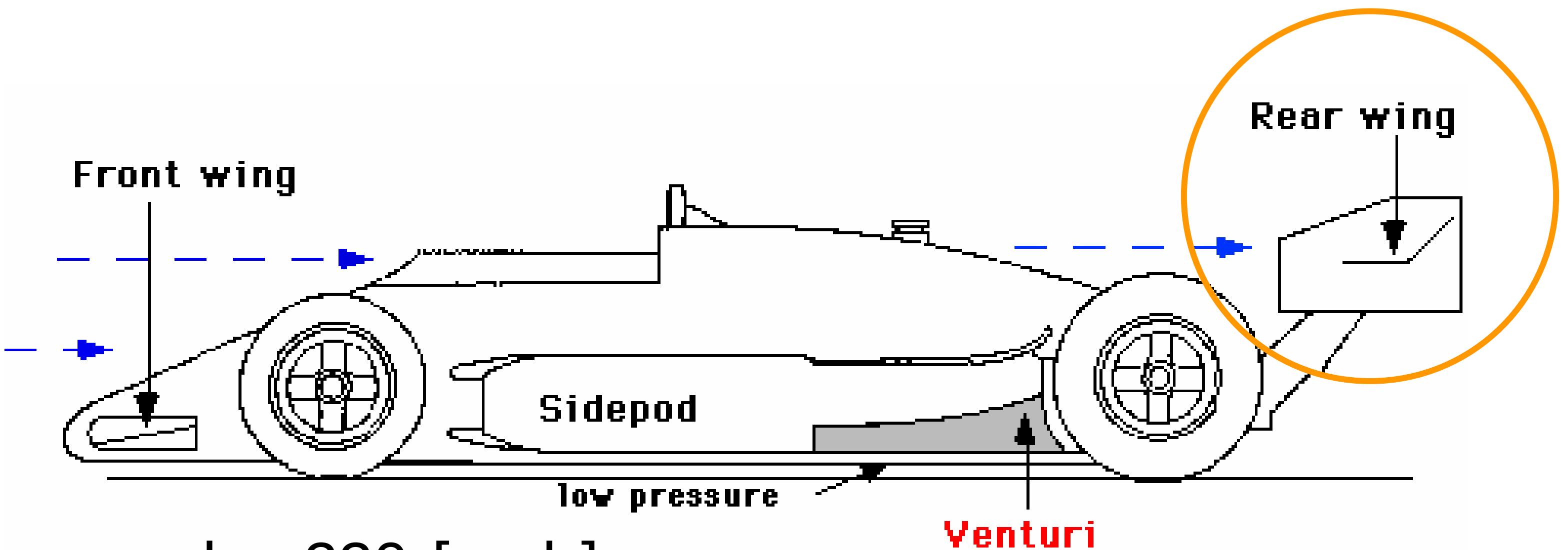
How many levels in drawing tree?

		~ #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

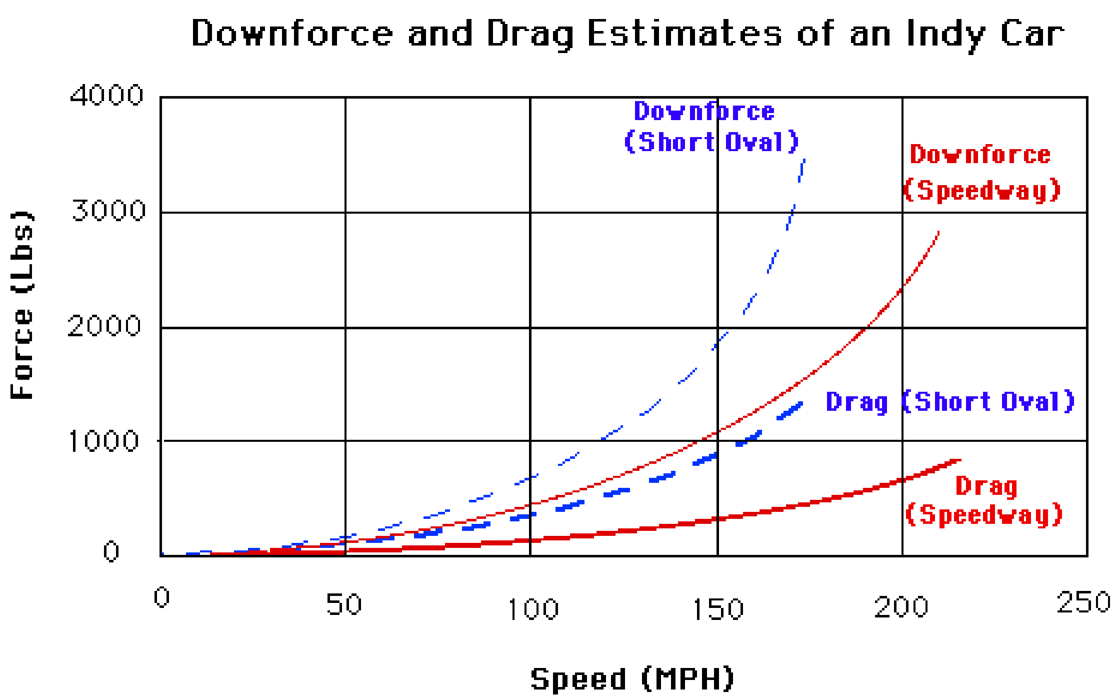
"Design Challenge" and Team Assignments

16.810 Design Challenge: Rear Wing



Max speed ~ 230 [mph]

16.810 Drag and Downforce go as ~ V^2

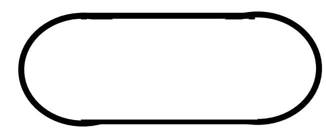


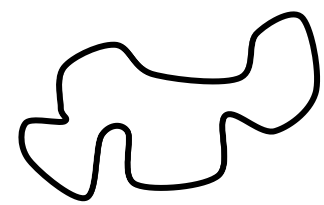
Drag force= $K_1 \cdot V^2$ (V = Velocity or Speed)

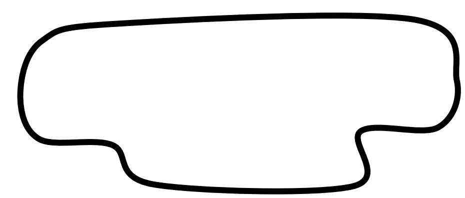
Downforce = $K_2 \cdot V^2$

Orders of Magnitude

	Down-force [lbs]	Drag [lbs]	L/D	Cd	Avg. Speed [mph]
Short Oval	3460	1310	2.64	1.397	165
Street Circuit	3040	1070	2.84	1.141	165
Speed-way	2835	972	2.92	0.669	220

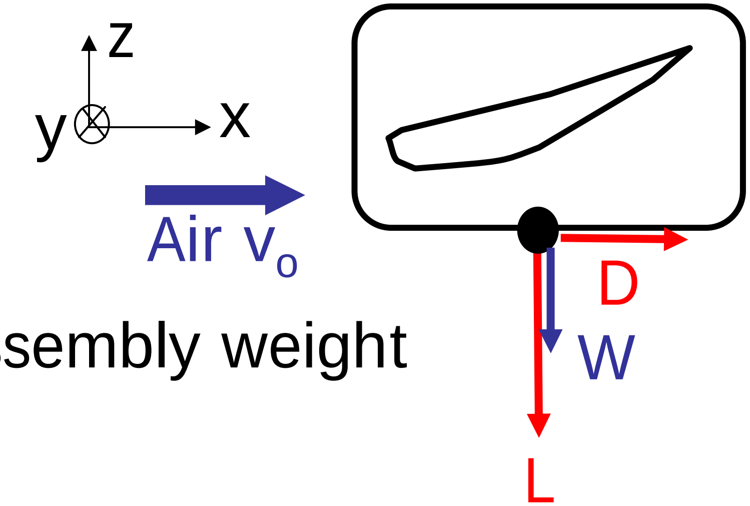






Ref: Galmer G-92 (Al Unser Jr.) – winner 1992 Indy 500 race

Objective & Constraints



- Objective
  - Max F=L-3*D-5*W
  - L=downforce, D=drag, W=assembly weight
  - Assume v_o=60 [mph]
- Constraints (must meet)
  - Design Envelope: 20” x 20” x 40”
  - Interface Standards (hole attachments)
  - No external energy source
    - See design project description for details
- Costs
  - Not scored, but keep track of (labor & materials)

Facilities Tour

Facilities Tour

* Design Studio

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

*** Software to be used:**

- Xfoil
- Solidworks
- Cosmos
- Omax
- web-based topology optimizer:

* Machine Shop

-Water Jet cutter, Wing cutter

* Wind Tunnel

-Subsonic aerodynamic testing

MIT Wright Brother's Wind Tunnel, see

16.810 Next Steps

- Study the following
  - 16.810 documents: schedule, deliverables checklist, project description, cost estimation sheet

- Get username and passwd on AA-Design LAN
- Complete Attendance Sheet
- Prepare for Thursdays lectures:
  - Download Xfoil program
  - Look at CAD/CAE/CAM manual