16.810 (16.682)

Engineering Design and Rapid Prototyping

Lecture 1

Course Introduction

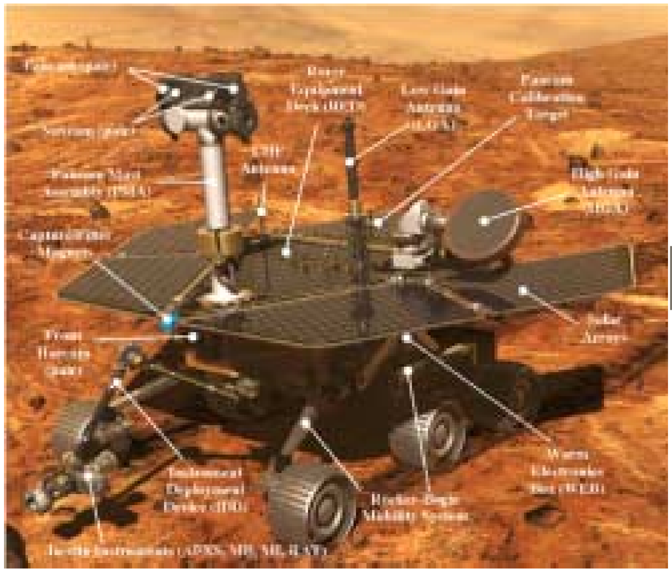
Instructor(s)

Prof. Olivier de Weck
deweck@mit.edu

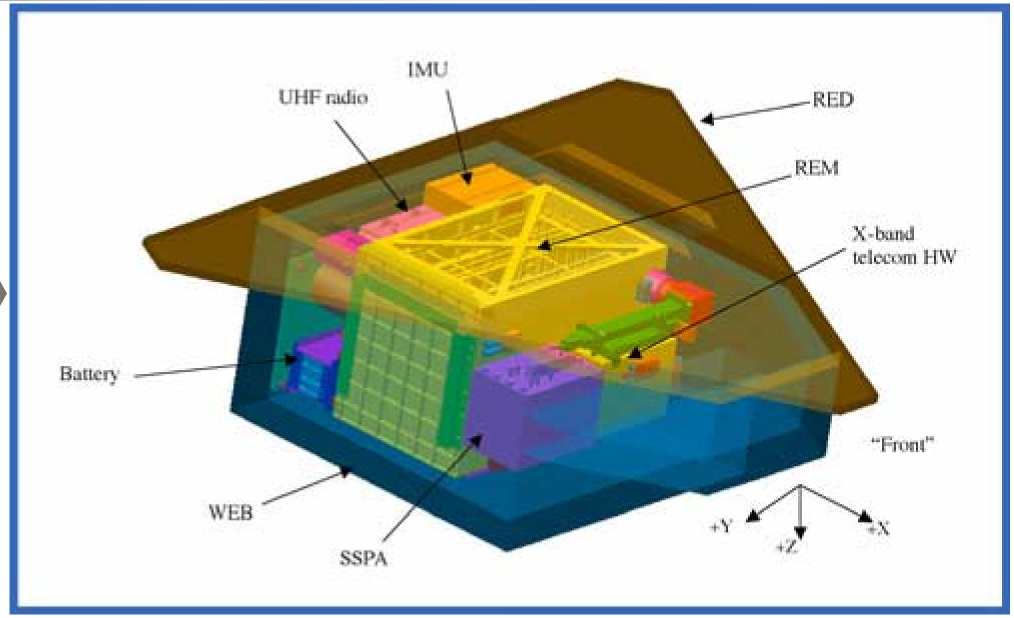
Dr. Il Yong Kim
kiy@mit.edu

January 5, 2004

Happy New Year 2004



Mars Rovers MER-A "Spirit"
landed Sat 1/3 11:35pm ET



Body Structure (Warm Electronics
Box WEB). Ref: http://marsrovers.jpl.nasa.gov

We won't be designing a Mars Rover this IAP, but ...

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

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 Assignment
  - Int’l Bicycle Corp., Requirement Sheets, Product Team Assignments
- Facilities Tour

Organization of 16.810 (16.682)

16.810 Expectations

- 6 unit course (3-3-0) – 11 sessions
  - MWF1-4 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
  - Have fun, but also take it seriously
  - The course is a "prototype" itself and we are hoping for your feedback & contributions
  - Officially register under 16.682 (Jan 2004) on WEBSIS

History of this Course

December 2002	Undergraduate Survey in Aero/Astro Department.
	Students expressed wish for CAD/CAE/CAM experience.
March 2003	Preliminary discussion among faculty and staff –
	O. de Weck, I.Y. Kim, D. Wallace, P. Young
April 4, 2003	Submission of proposal to Teaching and Education
	Enhancement Program ("MIT Class Funds")
April 22, 2003	Submission of the proposal to CMI (pending)
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

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.**

Needs – from industry

Industry wants/needs (dWo interpretation)

Engineers who

- **are trained in integrated design methods and tools**
- **have personally carried out the design process from conception to implementation at least once.**

Engineers who have an initial understanding of:

- **importance of requirements**
- **complementary roles of humans and computers in design**
- **difficulties at the CAD/CAE/CAM domain interfaces**
- **value of optimization**
- **importance of trading off competing objectives**
- **difference between predicted vs actual behavior of the artifacts they design**

the SCIENTIST / MATHEMATICIAN
vs
the *ENGINEER*

CONFOUNDING FACTS

- **Engineering requires thorough mathematical & scientific knowledge**
- **Engineers study science and math extensively**
- **Engineers may conduct scientific experiments while doing Engineering**
- **Scientists use engineering methods**
- **Some great engineers trained as scientists & mathematicians**
- **Some great scientists trained as engineers**
- **All require intensity, passion, creativity & intellectual effort**

BUT, THEY ARE DISTINCT

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

Slide from Prof. Chris Magee

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

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 Leads to ➡ Course Objective

Develop a <u>holistic view</u> 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 single <u>structural component</u>

16.810 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

16.810

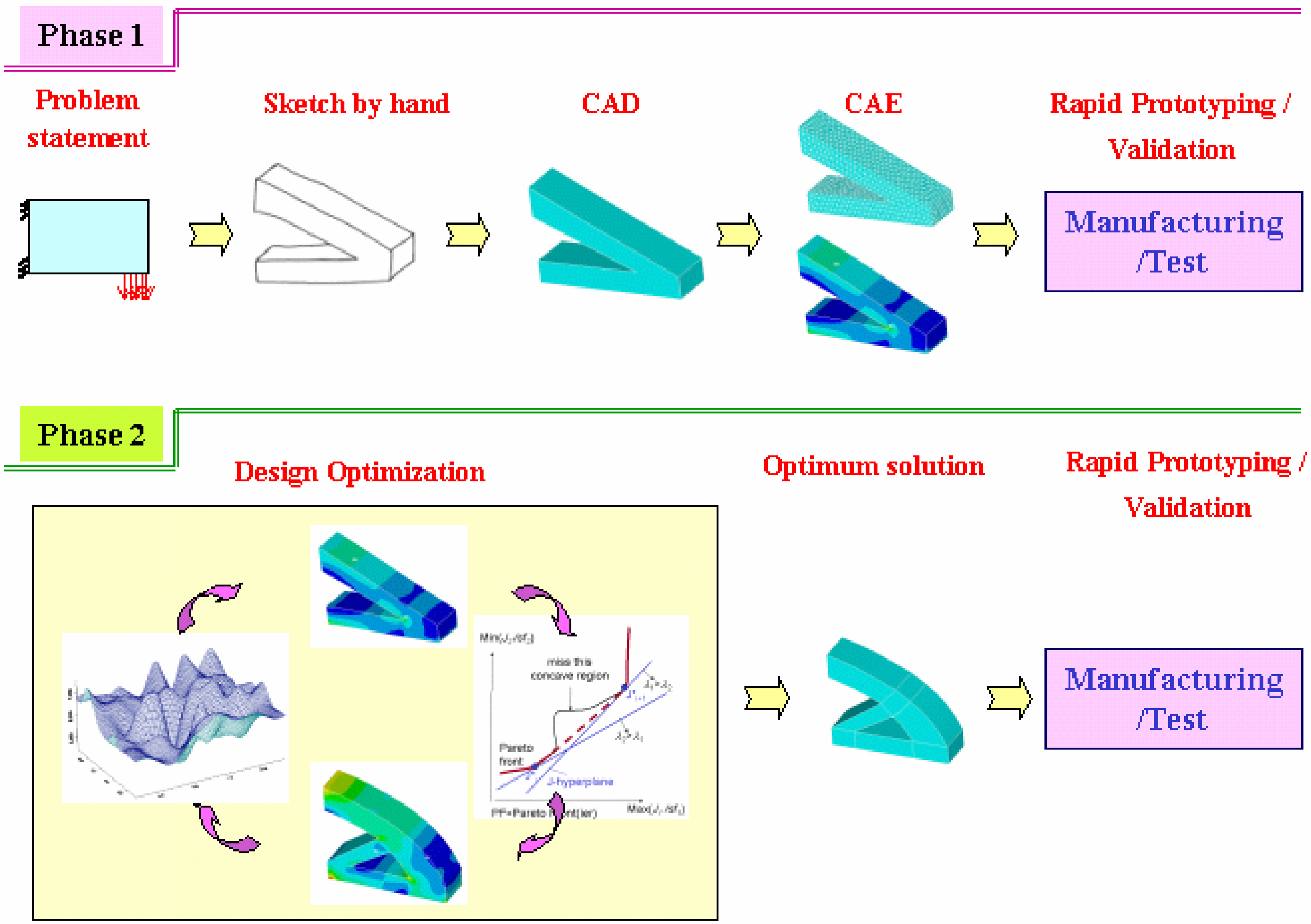
"Engineering Design" - what you will likely do after MIT

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

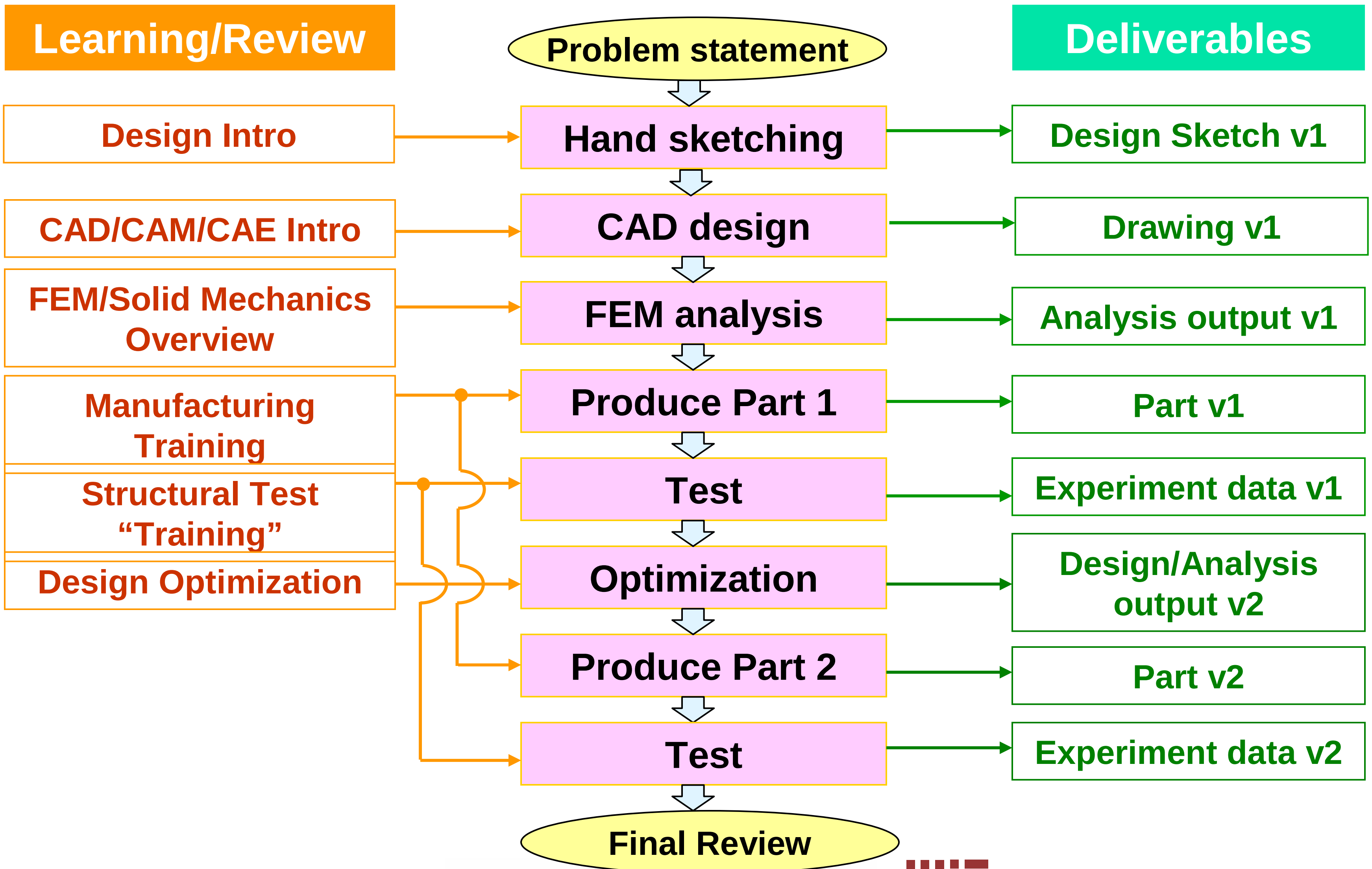
"Human Creativity and Computational Tools": design is a constant inter-play of synthesis and analysis

"Structural Components": part of all aerospace systems, "easy" to implement in a short time

Course Concept



Course Flow Diagram



IAP 2004 Schedule

Week		Monday	Wednesday	Friday
1	Lecture	L1 – Introduction (de Weck)	L2 – Hand Sketching (Wallace)	L3 – CAD modeling (Kim, de Weck)
	Hands-on activities	Tour - Design studio - Machine shop - Testing area	Sketch Initial design	Make a 2-D CAD model (Solidworks) Nadir
2	Lecture	L4 – Introduction to CAE (Kim)	L5 – Introduction to CAM (Kim)	L6 – Guest Lecture 1 (Bowkett) Rapid Prototyping
	Hands-on activities	FEM Analysis (Cosmos)	Water Jet Intro machine shop Omax (Weiner, Nadir)	Make part version 1
3	Lecture	Martin Luther King Jr. Holiday – no class	L7 – Structural Testing (Kim, de Weck)	L8 – Design optimization (Kim)
	Hands-on activities		Test part ver. 1 (Kane)	Introduction to Structural Optimization Programs
4	Lecture			L9 – Guest Lecture 2 (Sobieski) Multidisciplinary Optimization
	Hands-on activities	Carry out design optimization	Manufacture part ver. 2 Test part ver. 2	Final Review (de Weck, Kim)

MWF1-4pm in 33-218 (always meet at 1pm)
Last Lecture of IAP: January 30, 2004

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 single structural component.

(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
- Composition
  - Design Deliverables 50%
    - Sketch v1, Drawing v1, FEM Analysis v1/v2, Test Protocol v1/v2, Final Review Slides (3)
  - Parts (v1/v2) 30%
    - (Negotiated) Requirements Compliance
  - Active Class Participation 20%
    - Attendance, Ask Questions, Contribute Suggestions, Fill in Surveys

People

Instructors:

Prof. Olivier de Weck (deweck@mit.edu)

Assistant: Jackie Dilley (jdilley@mit.edu)

Dr. Il Yong Kim (kiy@mi.edu)

Postdoctoral Associate

Prof. David Wallace (drwallac@mit.edu) - ME

Staff:

- **Teaching Assistant – Bill Nadir (bnadir@mit.edu)**
- **Software/Design Studio – Fred Donovan (fjd@mit.edu)**
- **Manufacturing – Don Weiner (donw@mit.edu)**
- **Structural Testing – John Kane (kane@mit.edu)**

(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

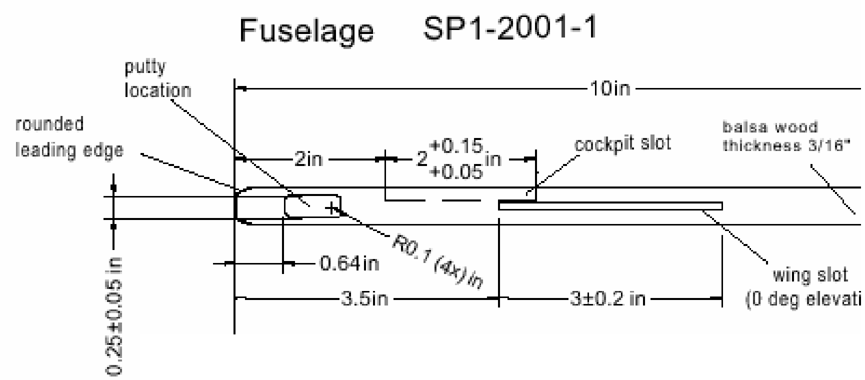
1. Define Requirements
2. Create/Choose Concept
3. Perform Design
4. Analyze System
5. Build Prototype
6. Test Prototype
7. Accept Final Design

"flying wing"

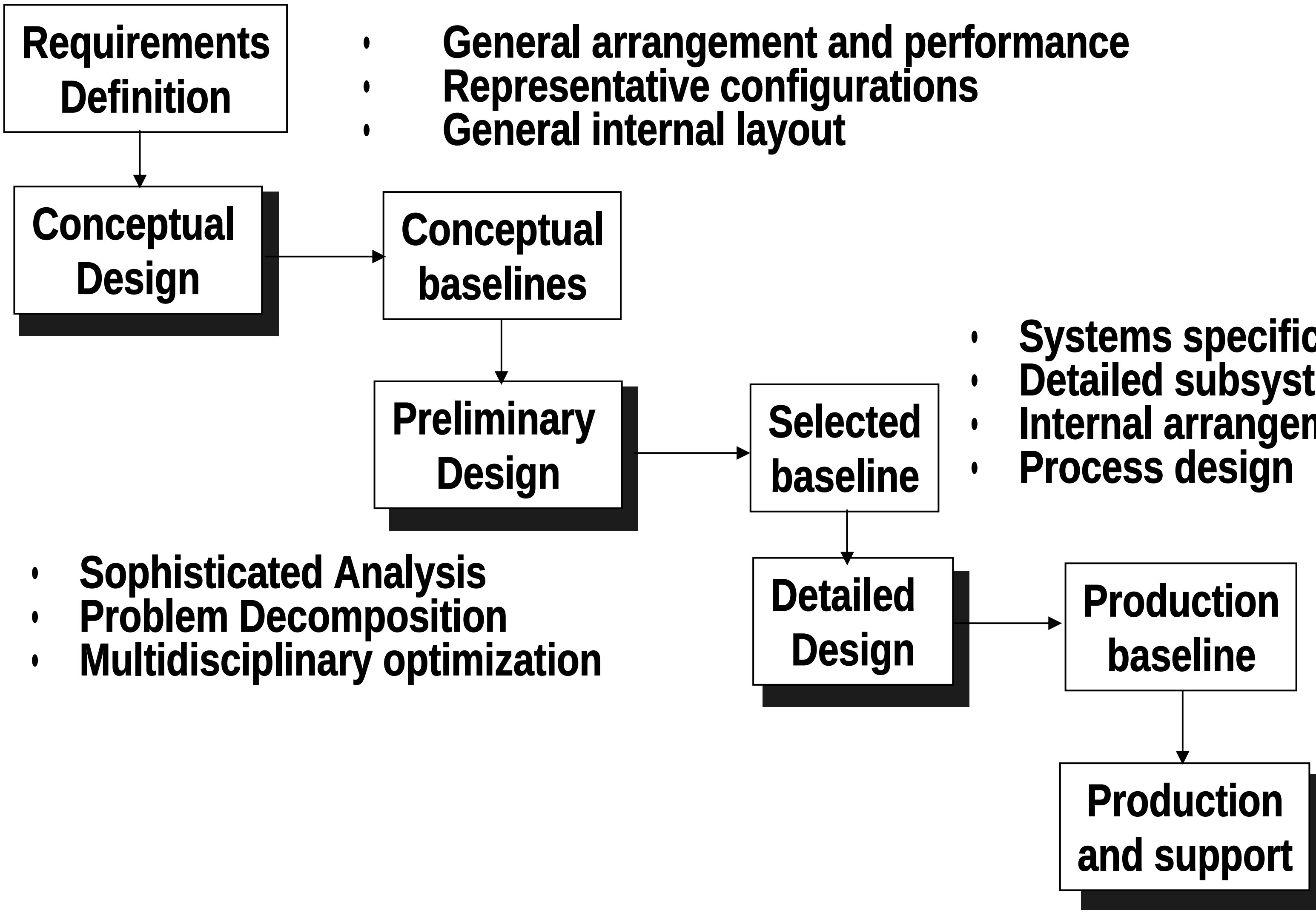
"monoplane"

"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

16.810 PDP

Product Development Process

"A PDP is the unique sequence of steps or activities, which an enterprise employs to conceive, design, and commercialize a product"

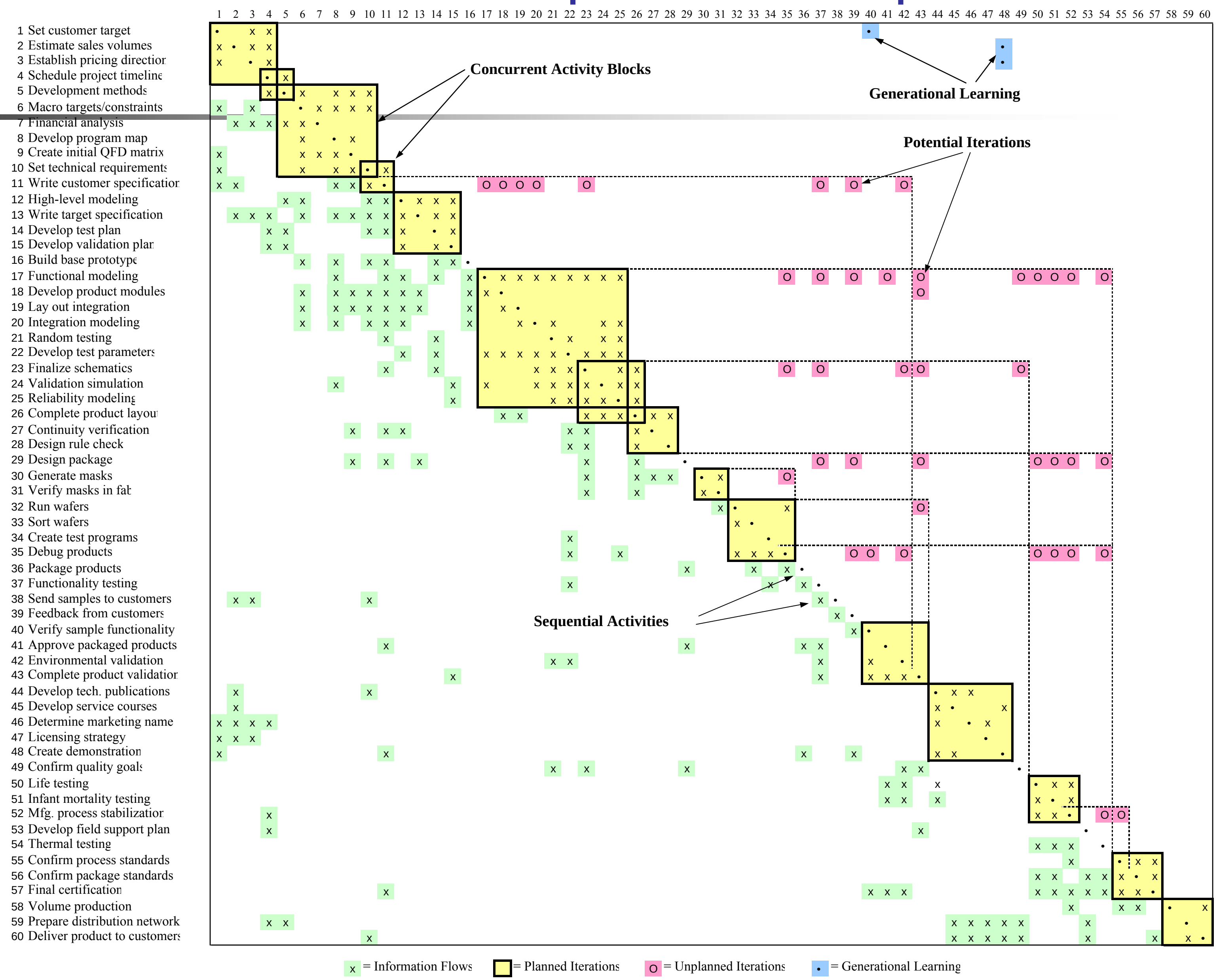
Ulrich and Eppinger

Always involves at least:

- Marketing
- Design
- Manufacturing

} core functions

Semiconductor Development Example

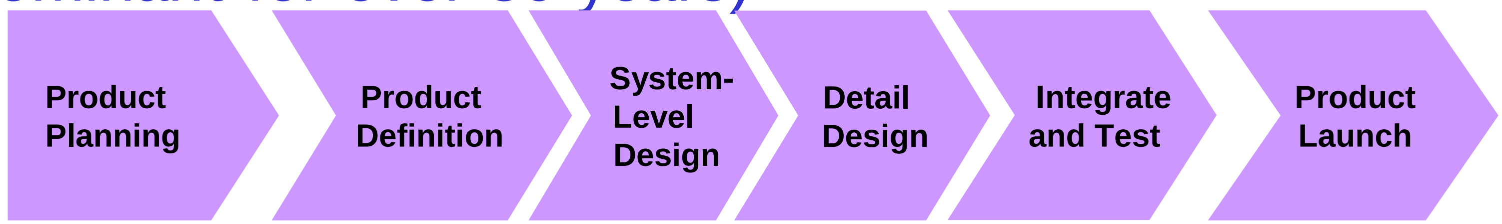


Massachusetts Institute of Technology

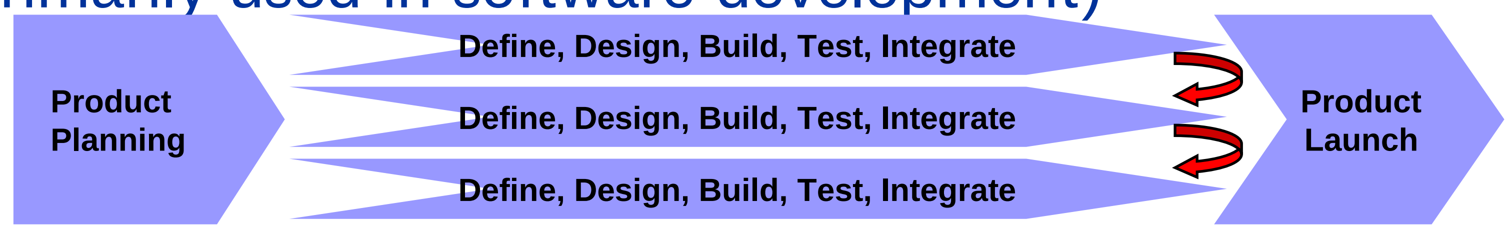
Ref: Prof. Eppinger

Phased vs. Spiral PD Processes

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



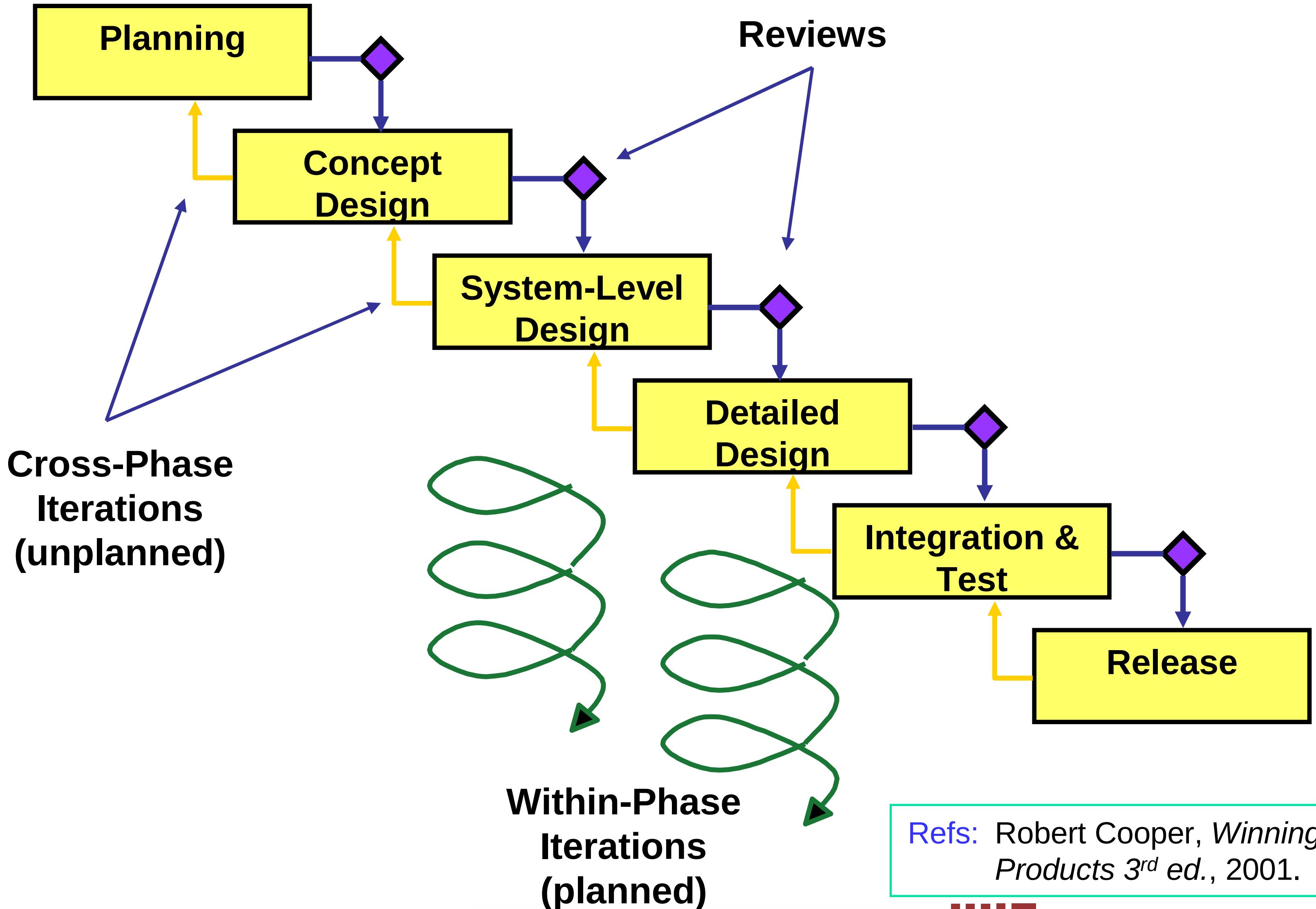
Spiral PD Process
(primarily used in software development)



<u>Process Design Questions:</u>

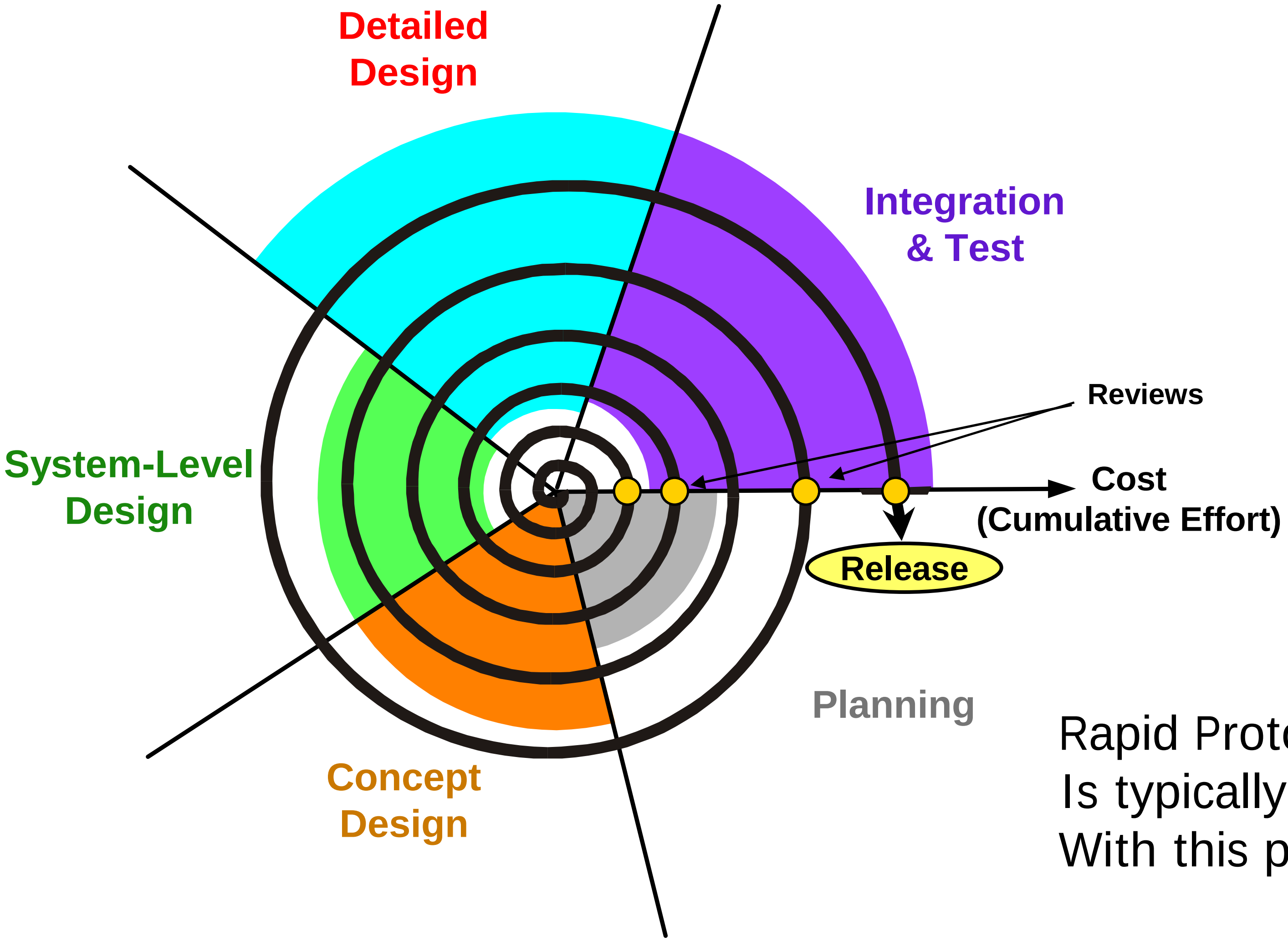
- How many spirals should be planned?
- Which phases should be in each spiral?
- When to conduct gate reviews?

Stage Gate PD Process



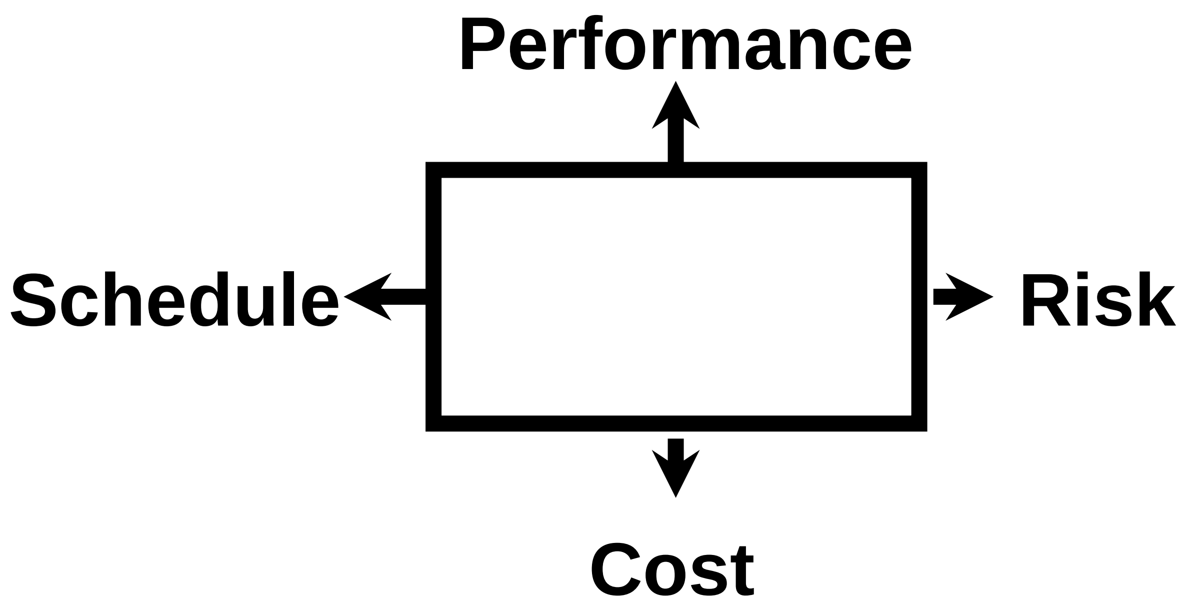
Refs: Robert Cooper, *Winning at New Products 3rd ed.*, 2001.

Spiral PD Process



Rapid Prototyping
Is typically associated
With this process

16.810 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

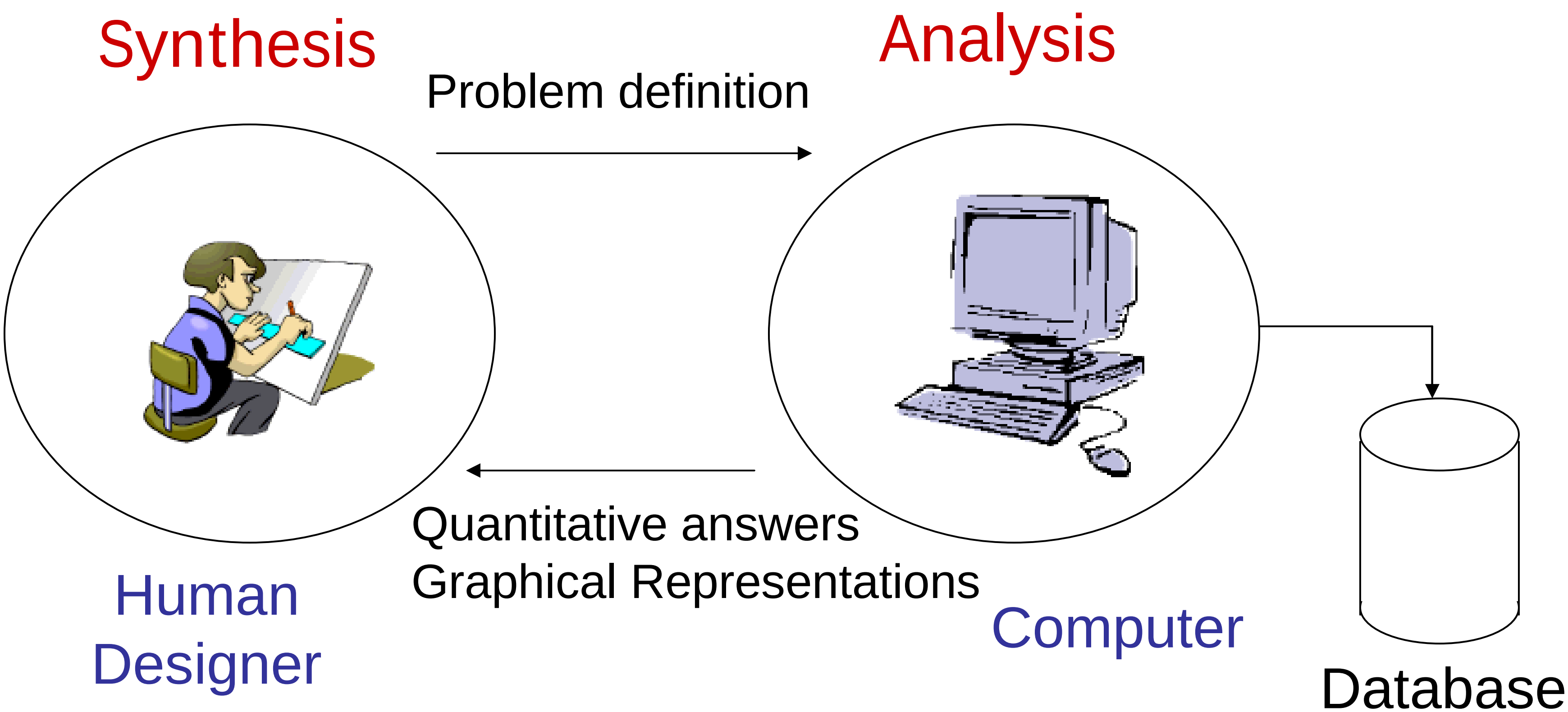
- Number of phases (often a superficial difference)
- Phase exit criteria (and degree of formality)
- Requirement "enforcement"
- Reviews
- Prototyping
- Testing and Validation
- Timing for committing capital
- Degree of "customer" selling and interference
- Degree of explicit/implicit iteration (waterfall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

Value of a structured PDP

A structured PDP ...

- increases value added, efficiency and competitiveness (e g. time to market) of the process
- provides something that can be learned and improved
- should be customized to product/market/culture
- should be based on underlying principles

Synthesis versus Analysis



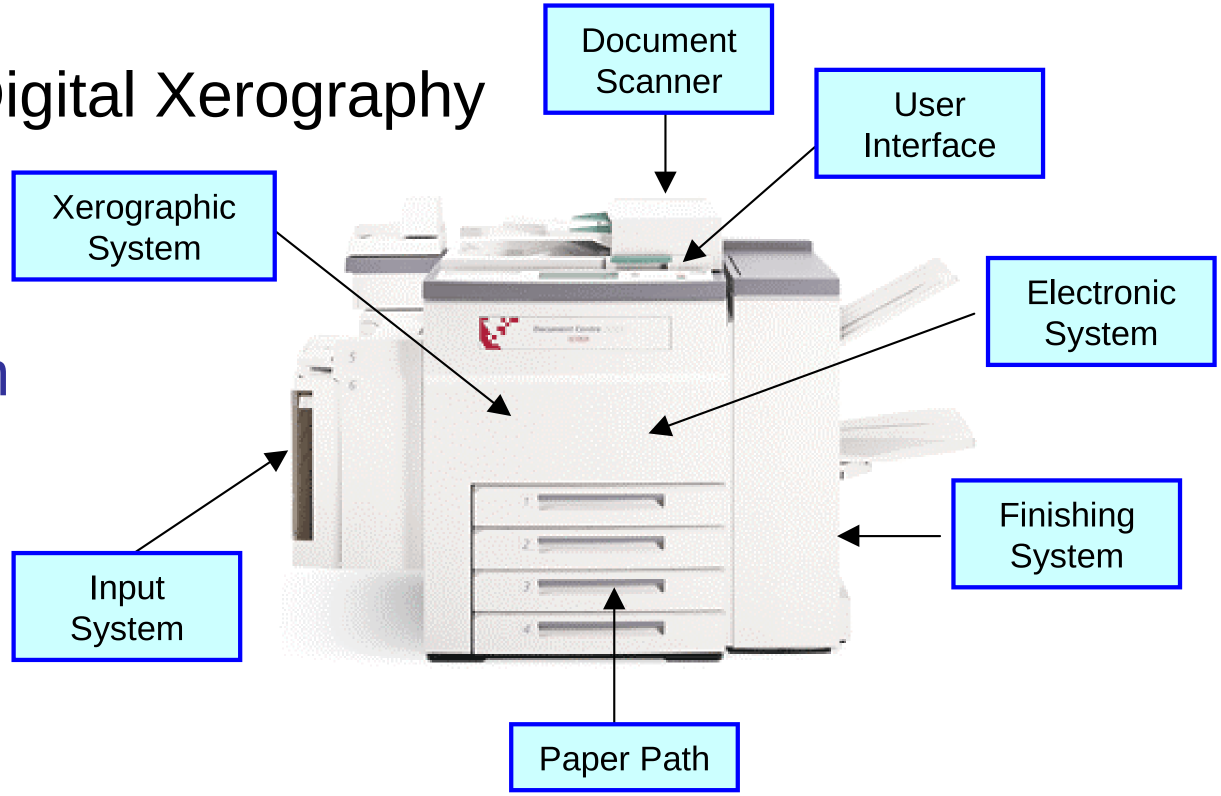
- *Creativity*
- *Intuition – Sanity Checks*
- *Controls the Process*

- *Number Crunching*
- *Interfacing*
- *Configuration Control*

Form versus Function

Concept: Network Digital Xerography

Form

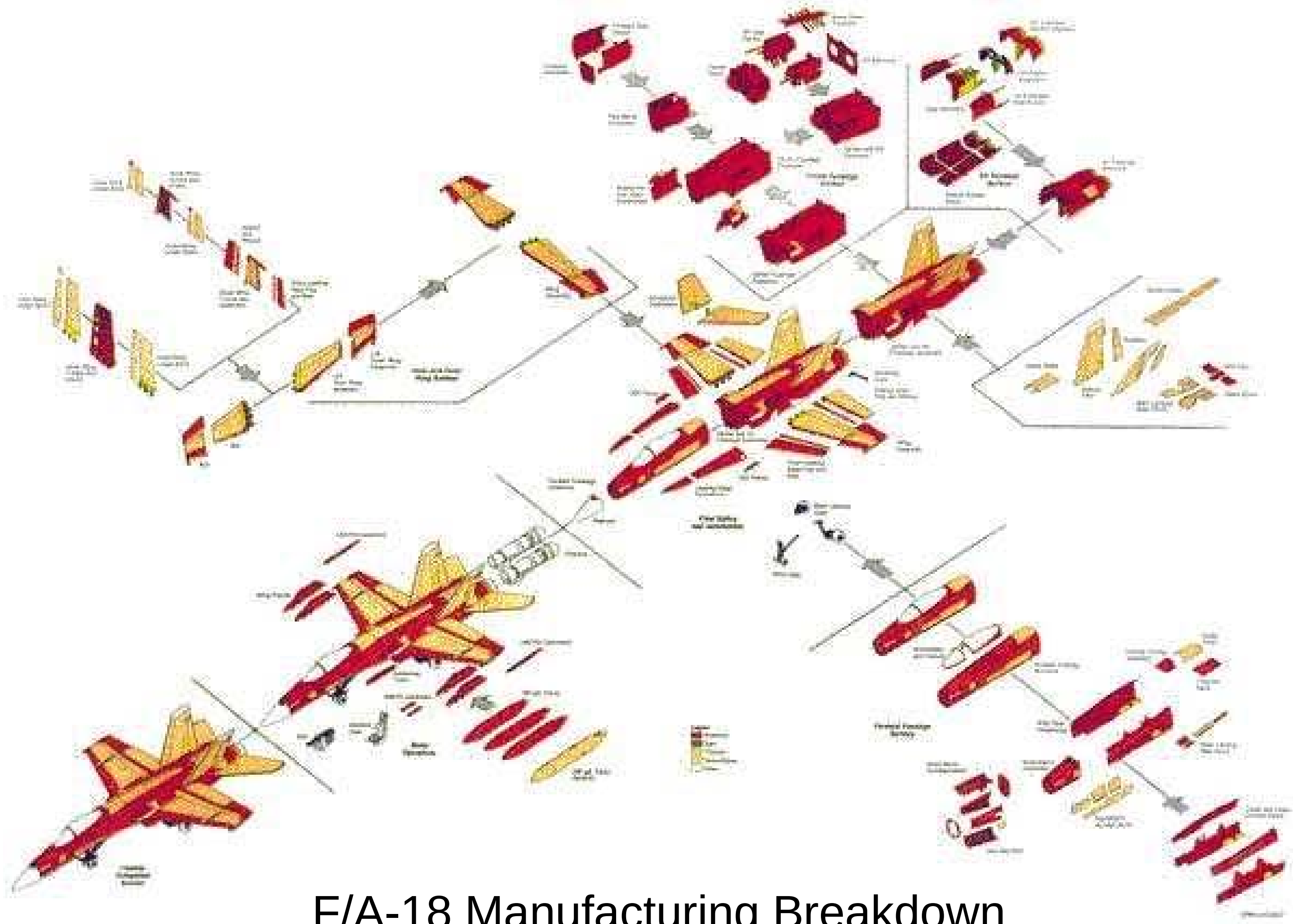


Functions

- Scanning, printing, and faxing from desktop
- Scan to file
- Network document distribution
- Remote document and device control

Xerox
Lakes Document
Processing System

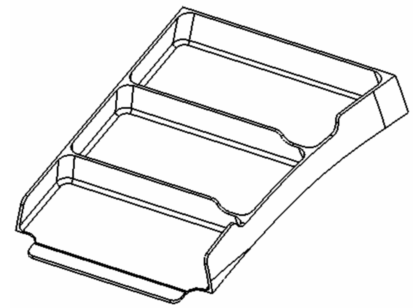
Design versus Manufacturing

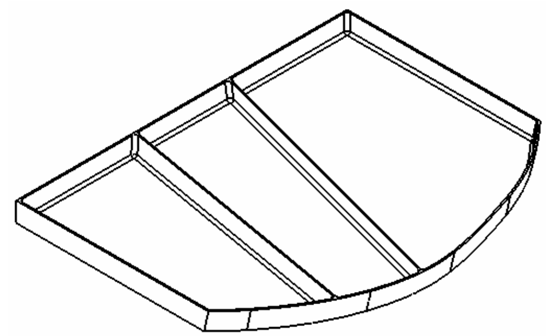


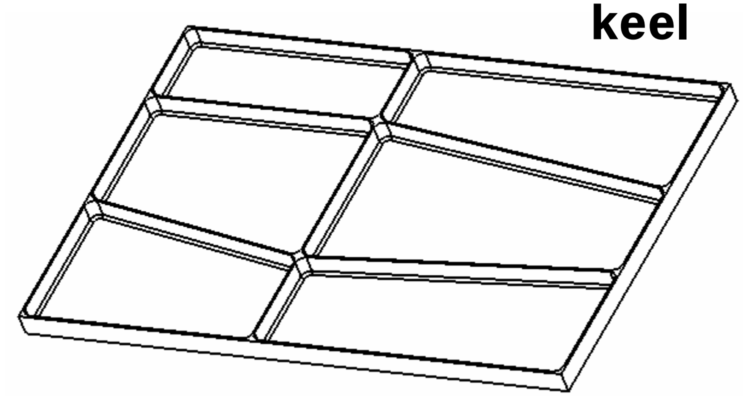
F/A-18 Manufacturing Breakdown

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

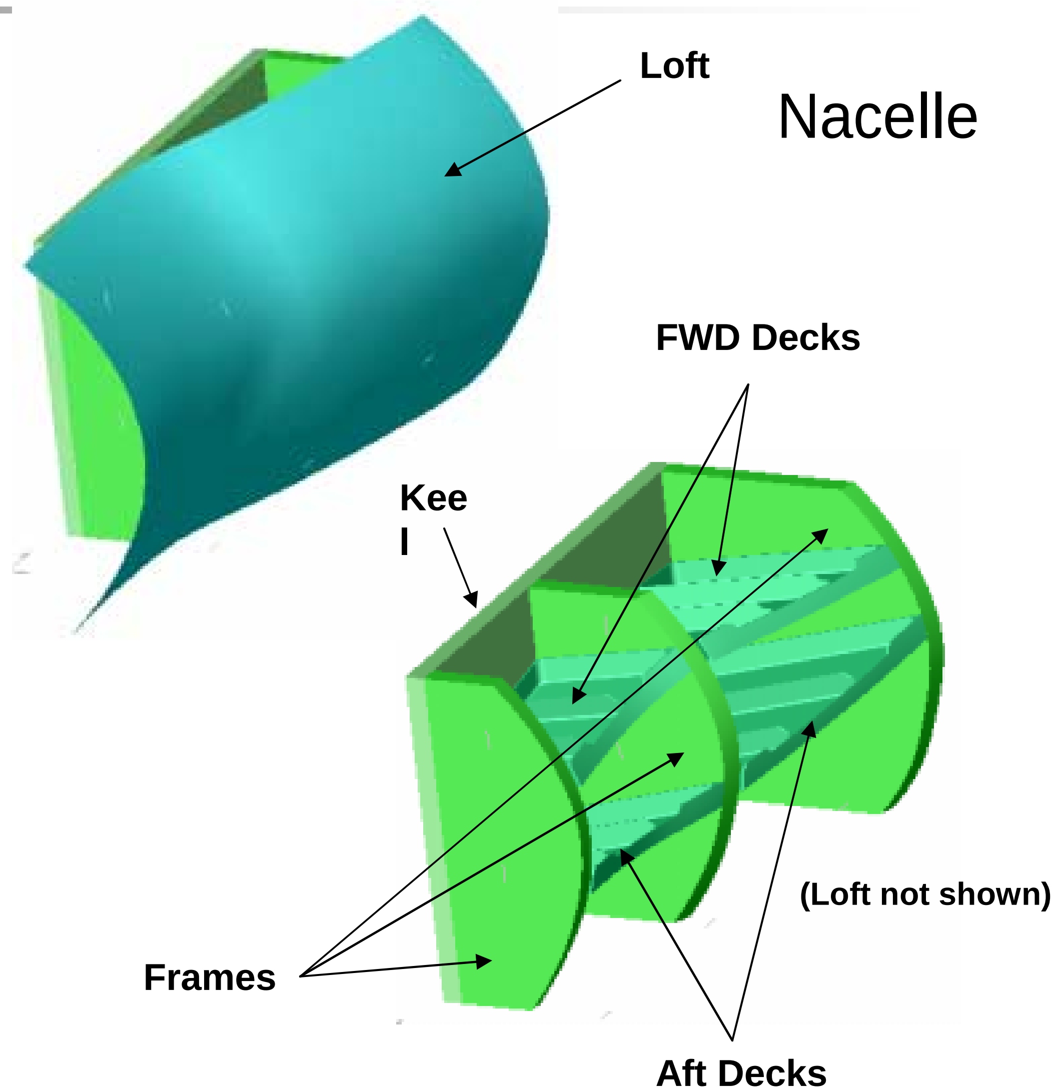




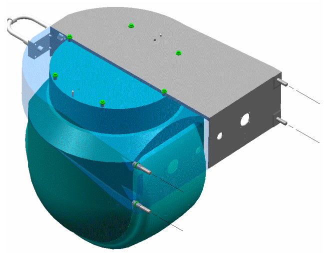


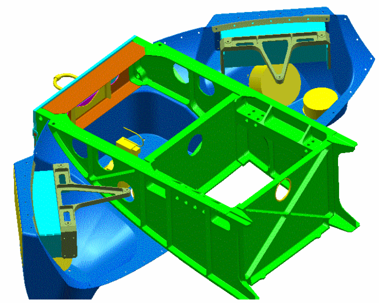
Hierarchy II: Assembly Level

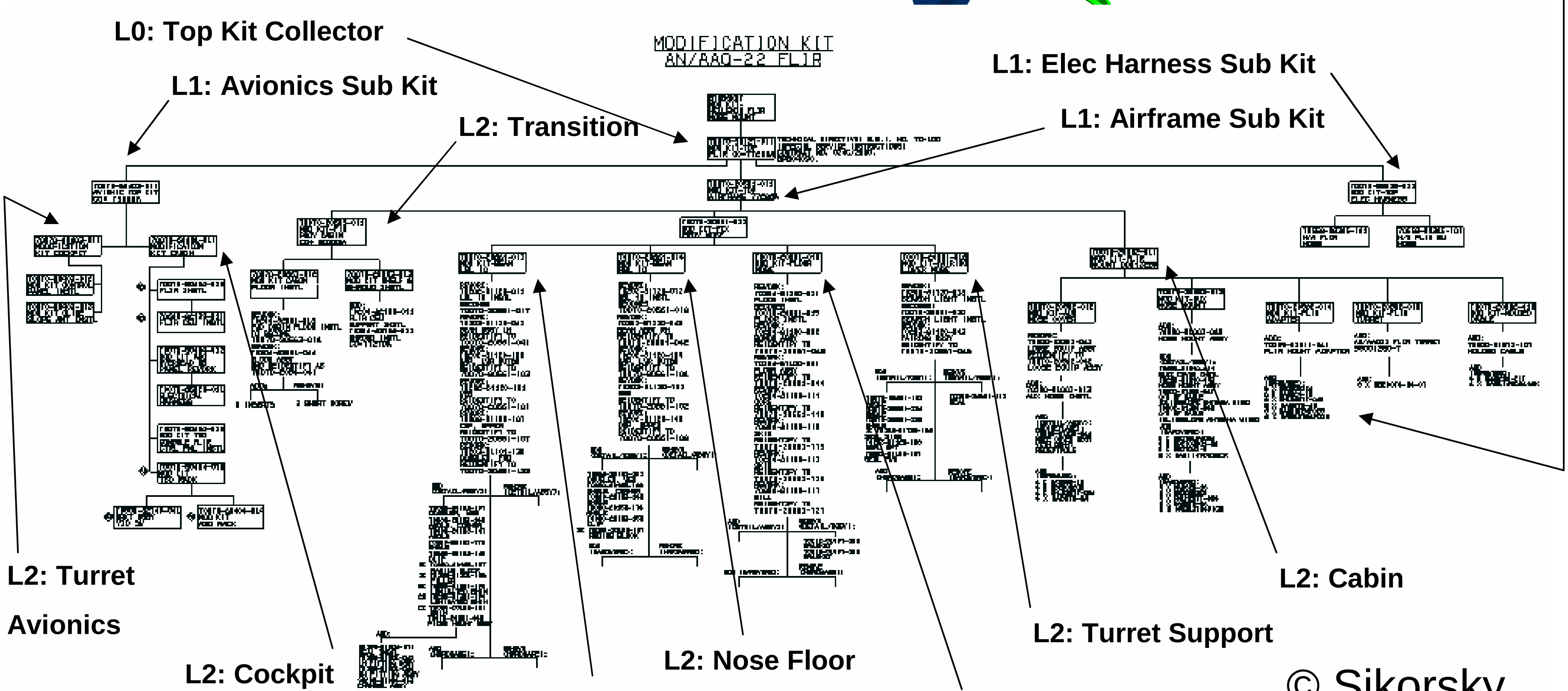
- Boeing (sample) parts
  - A/C structural assembly
    - 2 decks
    - 3 frames
    - Keel
  - Loft included to show interface/stayout zone to A/C
  - All Boeing parts in Catia file format
    - Files imported into SolidWorks by converting to IGES format



Hierarchy III: System Level







Product Complexity

Assume 7-tree

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

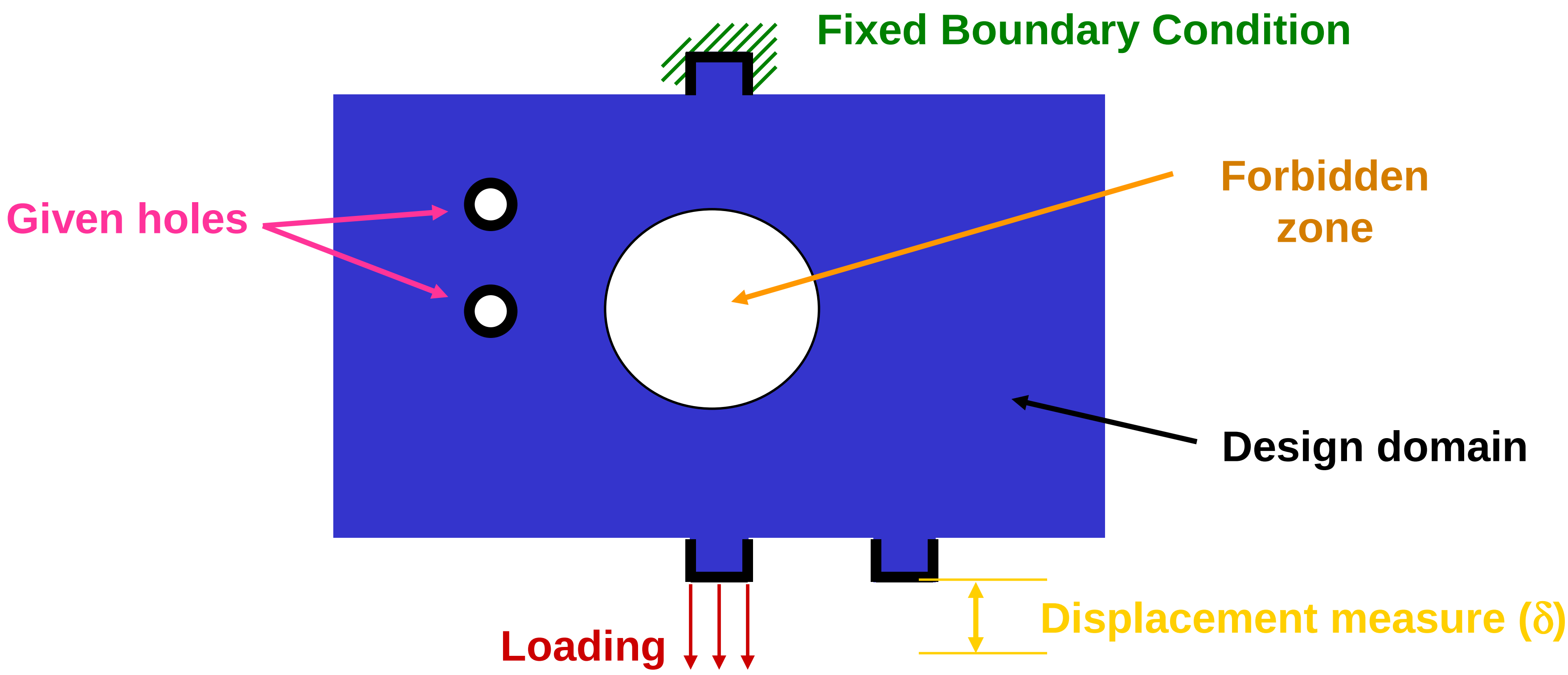
How many levels in drawing tree?

		~ #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

Design of a Structural Part



Problem statement:

$$\text{minimize mass}$$

$$\text{Subject to } \delta \le \delta_C$$

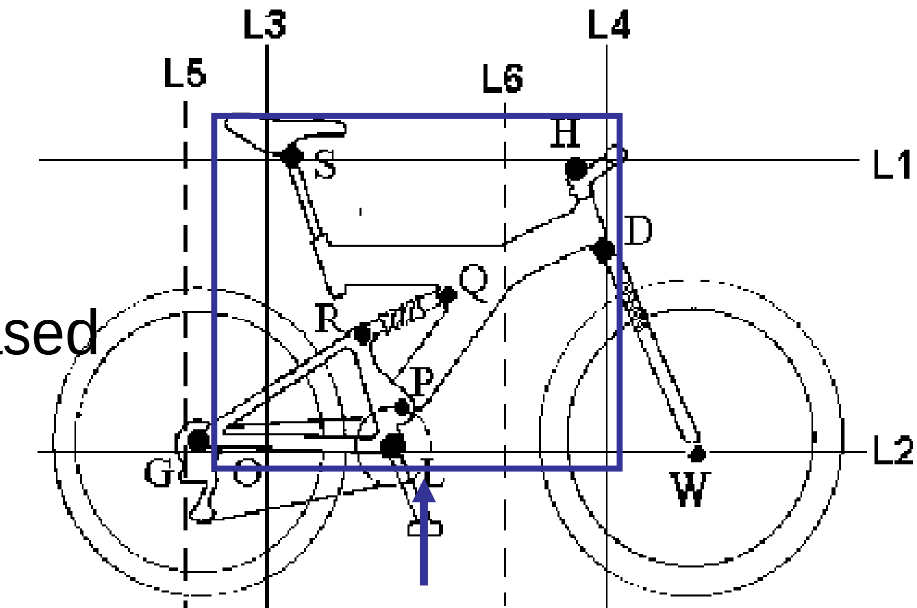
Setting: "Int'l Bicycle Corp."

We, the class, are collectively the staff of the "International Bicycle Corporation".

In the past we produced a "one-size fits all" product (Mass Production)

Recently there has been increased Market competition.

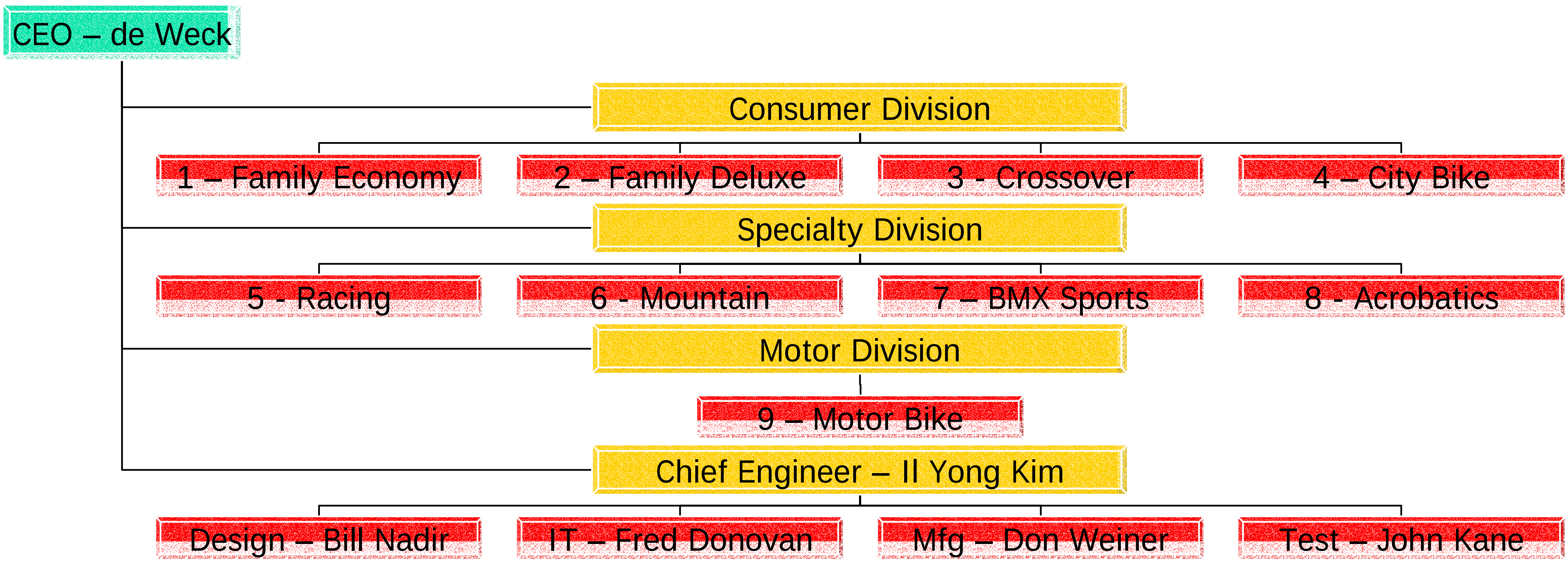
We need to start offering tailored products for different market segments (Mass Customization)



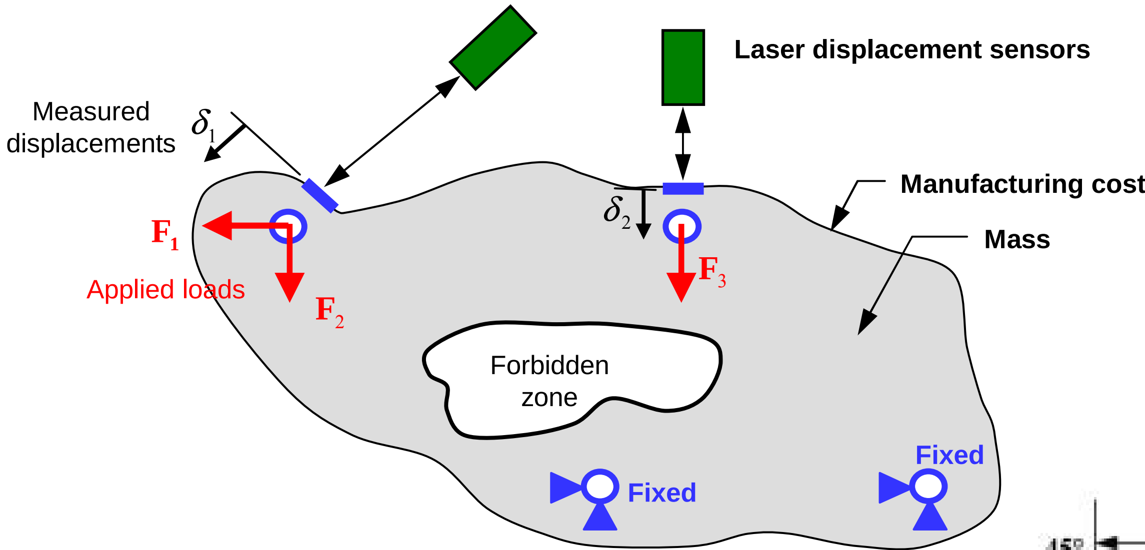
Design and Manufacture Frame

Y. M. Huang and J. C. Pan, "Topology Optimization and Dynamic Performance of a Bike Frame with Dampers," Proceedings of DETC'03, ASME 2003 Design Engineering Technical Conferences, Chicago, Illinois, USA, September 2-6, 2003.

Organization Chart

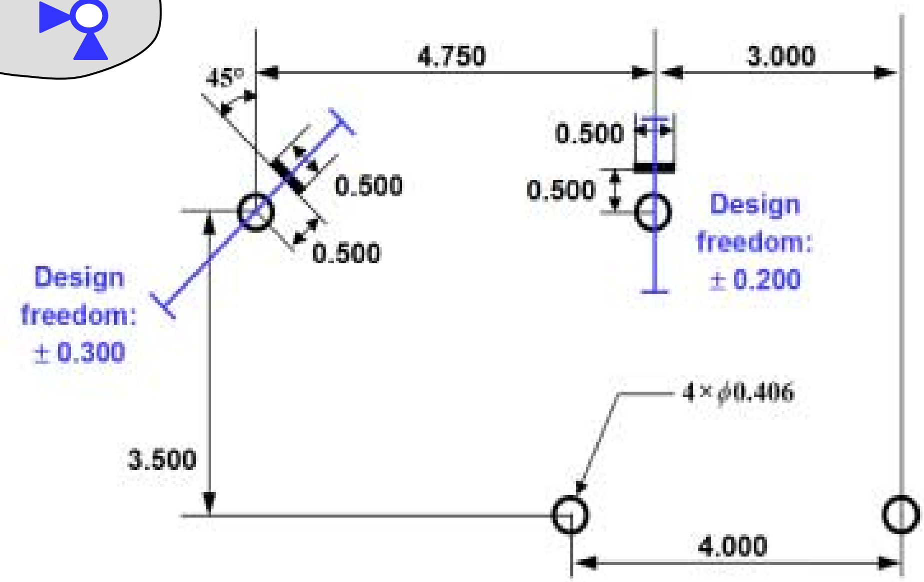


Requirements (I): Geometry



Configuration

Dimensions



Material: Al 6061-T6

Thickness ¼”

Scale ca. 1:5

16.810 Requirements (II): "Family Economy"

1. Market Description

This bicycle is to be designed for the mass consumer market. The expected sales volume is 100,000 per year. Affordability, excellent performance/cost ratio and light weight are most important to be successful in this market.

2. Requirements

Manufacturing Cost (C):	$C \leq \$3.50$/part
Performance ($\delta1$, $\delta2$, f1, m):	Displacement $\delta1 \leq 0.060$ mm
	Displacement $\delta2 \leq 0.009$ mm
	First natural frequency f1 ≥ 200 Hz
Mass:	≤ 0.110 lbs
Surface Quality:	2
Load Case:	F1 = 50 lbs / F2 = 50 lbs / F3 = 100 lbs

3. Priorities

"Ishii-Matrix"

Attribute	Constrain	Optimize	Accept
Cost	■		
Performance			■
Mass		■	

Modifications to these requirements have to be negotiated with Management.

16.810 Spiral Development (DSM)

1 – Requirements Analysis
2 – Concept/Sketching
3 – CAD Modeling (.prt)
4 – FEM Analysis
5 – Design Optimization
6 – Make Drawing (.dxf)
7 – CAM Layout (.ord)
8 – Manufacture (Omax)
9 – Structural Testing
10 – Accept Part

	1	2	3	4	5	6	7	8	9	10
1	1			X					X	
2	X	2		X					X	
3		X	3	X					X	
4			X	4	X				X	
5				X	5					
6		X				6				
7						X	7			
8							X	8		
9								X	9	
10	X			X				X	X	10

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:**

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

* Machine Shop

-Water Jet cutter

* Testing Lab

-Static and Dynamic Testing

Will carry out testing with a customized setup.

16.810 Next Steps

- Study 2 Page Requirements Sheets
  - Think about your team's concept
  - Product Name?
- Look at CAD/CAE/CAM manual
- Register on WEBSIS if not already done
- Complete Attendance Sheet
- Next Lecture
  - Wed 1/7/2004 at 1pm – "Hand Sketching"