
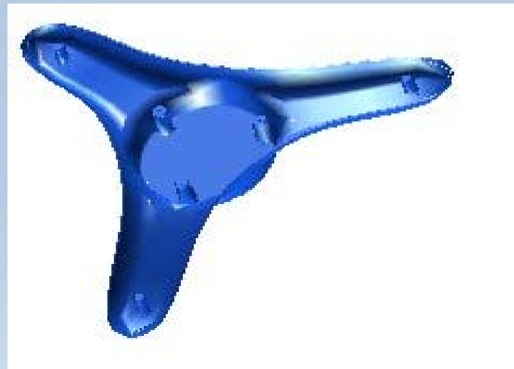
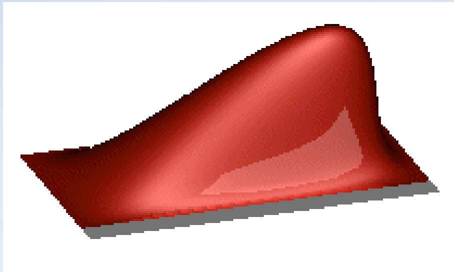
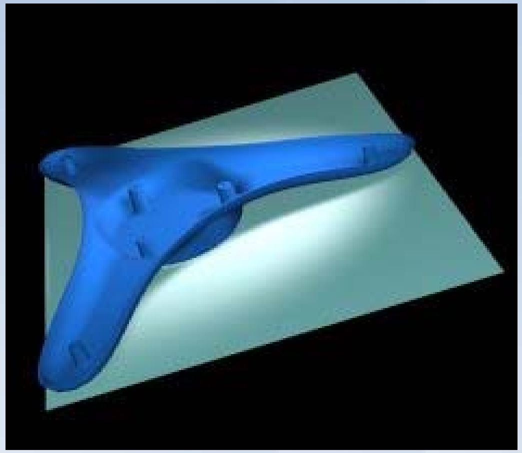

Lectures 8,9,10,11,12,13,14
Engineering Design

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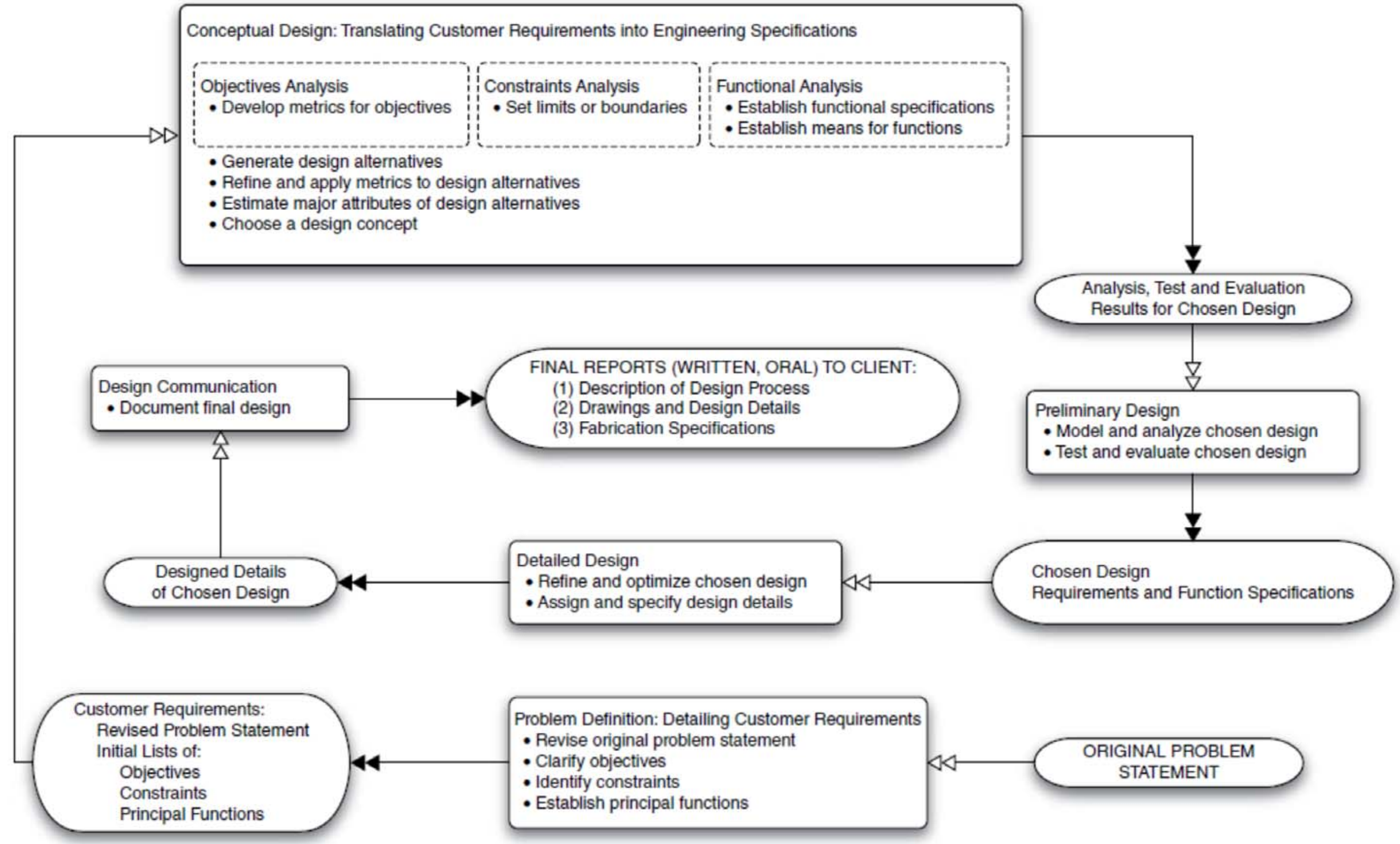
Istanbul Technical University

Course Description

The product development process is covered from problem identification through detail design and evaluation.

- The Scope of Design,
- The Necessity for Systematic Design,
- Fundamentals of Systematic Approach;
- Fundamentals of Technical Systems;
- Process of Planning and Designing;
- General methods for Finding and Evaluating Solutions;
- Steps of Conceptual Design and Embodiment Design;
- Principles of Embodiment Design;
- Developing Size Ranges and Modular Products;
- Design for Quality and Minimum Cost.

A five-stage model of the design process



A five-stage model of the design process

- **Problem Definition**: Detailing Customer Requirements
- **Conceptual Design**: Translating Customer Requirements into Engineering Specifications
- **Preliminary Design**: Model and analyze chosen design, Test and evaluate chosen design
- **Detailed Design**: Refine and optimize chosen design, Assign and specify design details
- **Design Communication**: Document final design

Engineering Design

1. **Introduction**
2. **Fundamentals**
3. **Process of Planning and Designing**
4. **General methods for Solutions (Heuristics)**
5. **Product Planning and Clarifying the Task**
6. **Conceptual Design**
7. **Embodiment Design**
8. **Design for X**

Engineering Design

1. **Introduction:** The Scope of Design, The Necessity for Systematic Design Project Proposal Preperation and Project Management.
2. **Fundamentals:** Fundamentals of Technical Systems,. Fundamentals of Systematic Approach. **Process of Planning and Designing:** General Problem-Solving Process, Flow of work During the Process of Planning and Designing.
3. **General methods for Finding and Evaluating Solutions:** Solution Finding Methods, Selection and Evaluation Methods.

Engineering Design

3. **Product Planning and Clarifying the Task:** Product Planning, Clarifying the Task.
4. **Conceptual Design:** Steps of Conceptual Design, Abstracting to Identify the Essential Problems, Establishing Function Structures, Developing Working Structures, Developing Concepts, Examples of Conceptual Design
5. **Embodiment Design:** Steps of Embodiment Design, Checklist for Embodiment Design, Basic Rules of Embodiment Design. **Design for X:** Design for Manufacturing, Design for Quality, Design for Recovery

Design Project

- Concept Development Process
- Problem Formulation – Customer Need Identification

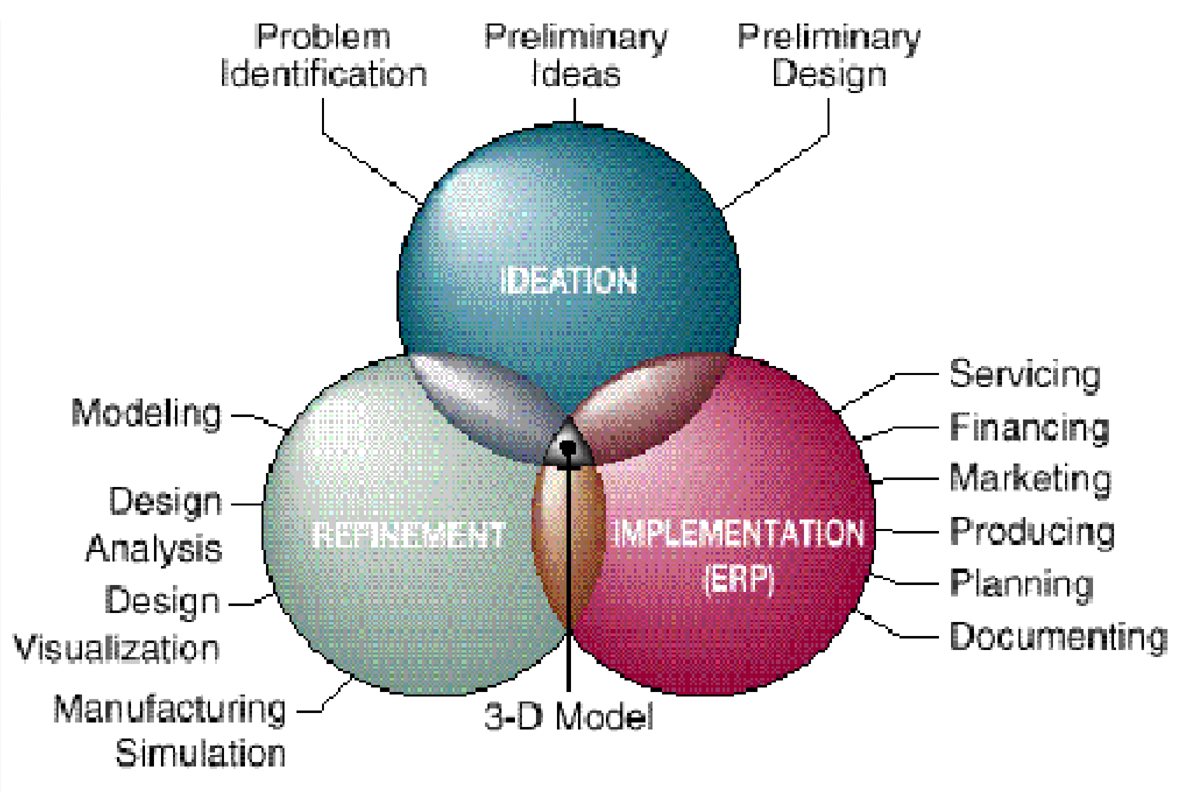
References

- Engineering Design A Systematic Approach, G. Pahl, W. Beitz, Springer-Verlag, 2007
- Engineering Design a Project-based Introduction, G. L. Dym, Wiley, 4ed, 2014
- Engineering Design Principles, Ken Hurst, Elsevier Science & Technology Books, 1999
- Case Studies in Engineering Design, Clifford Matthews, John Wiley & Sons, Inc., 1998
- Engineering Design Methods, N. Cross, John Wiley & Sons, 1989

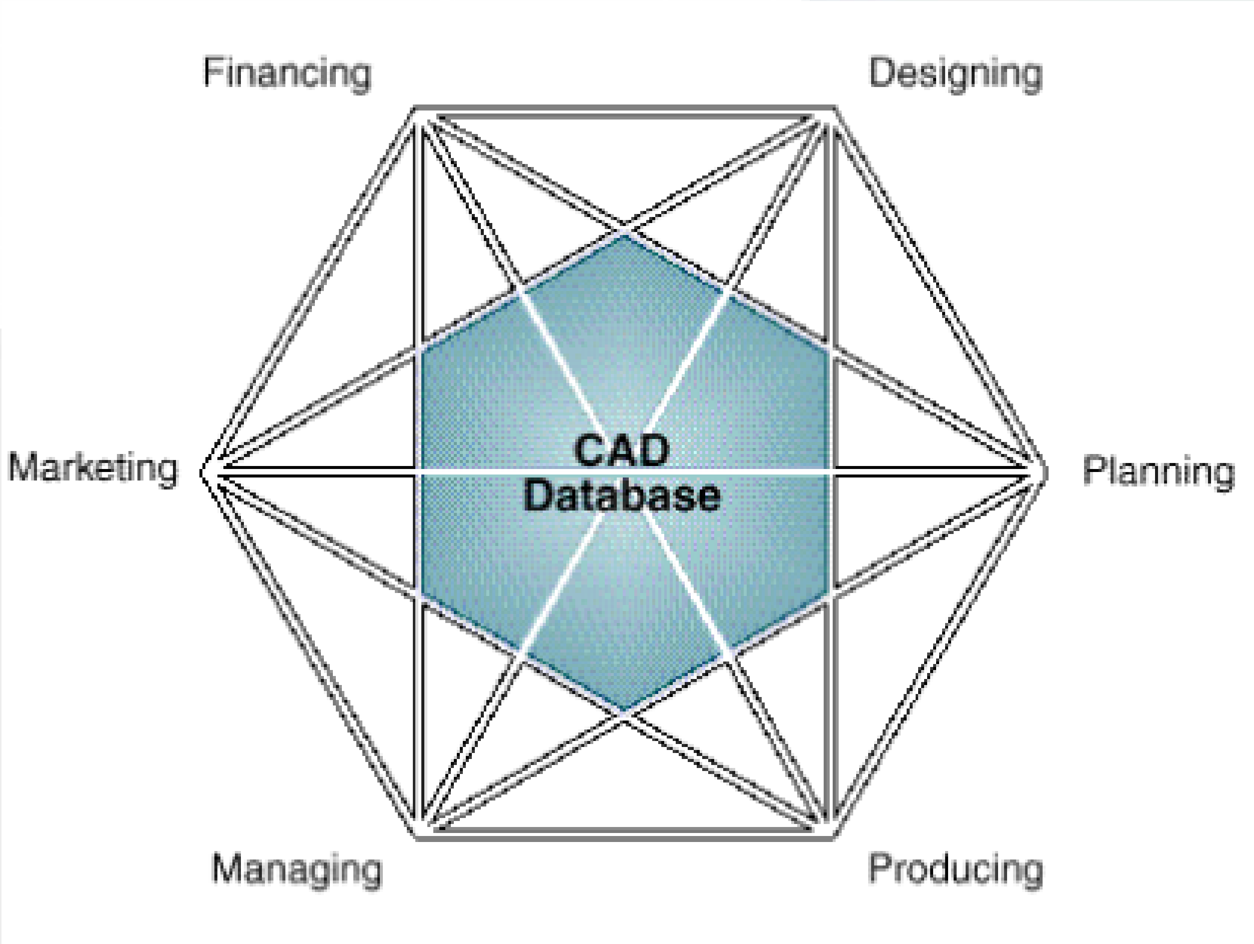
Concurrent engineering design

Engineering design process consists of three overlapping areas:
- Ideation
- Refinement
- Implementation

which all share the same 3D CAD database.



Sharing the CAD database



Basic Design

Before we begin,

1. Design is the satisfaction of need.
2. Design is never an exact process, and each design will differ.
3. Try to do it right the first time.
4. Most design methods try to cut the problems into smaller problems.

Basic Design

One of the common problems encountered by designers is the overwhelming number of details. Most design methods focus on dealing with detail overload. The challenges a designer faces are,

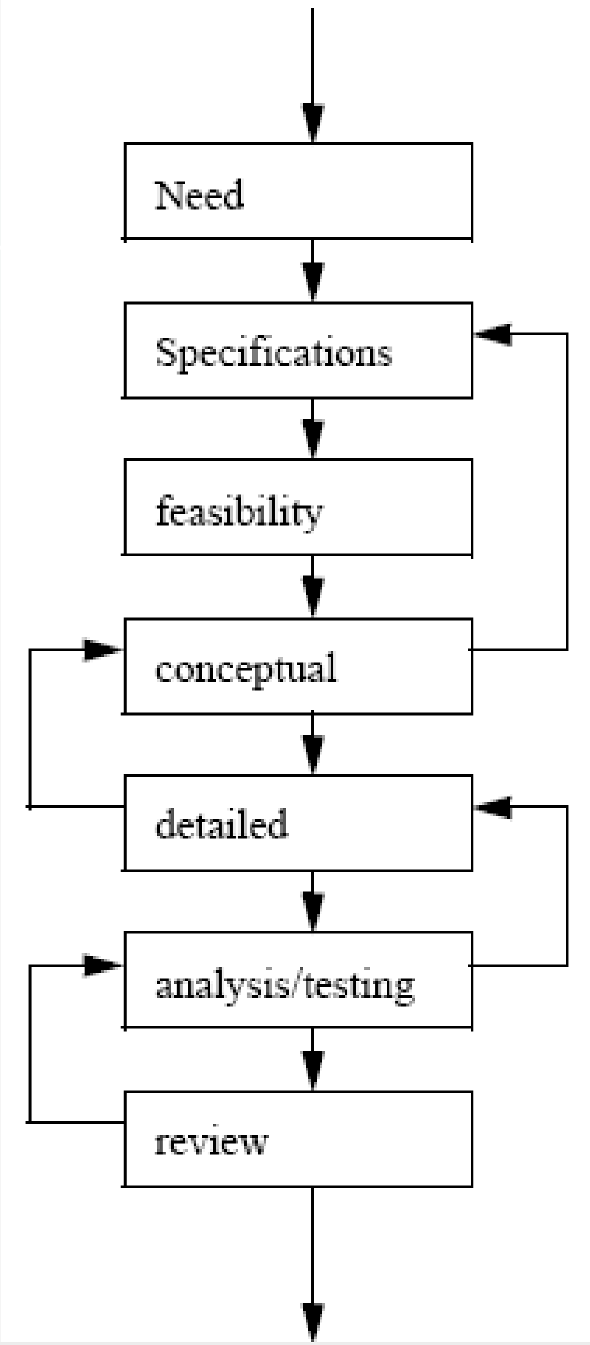
- Multiple technologies require arbitrary decisions
- A design will have many components that interact, and the effects of changes can be widespread
- Economics
- Other competitive designs

Design stages

Design is typically referred to as having certain stages,

- Conceptual
- Synthesis
- Detailed
- Analysis

The typical stages of design include,

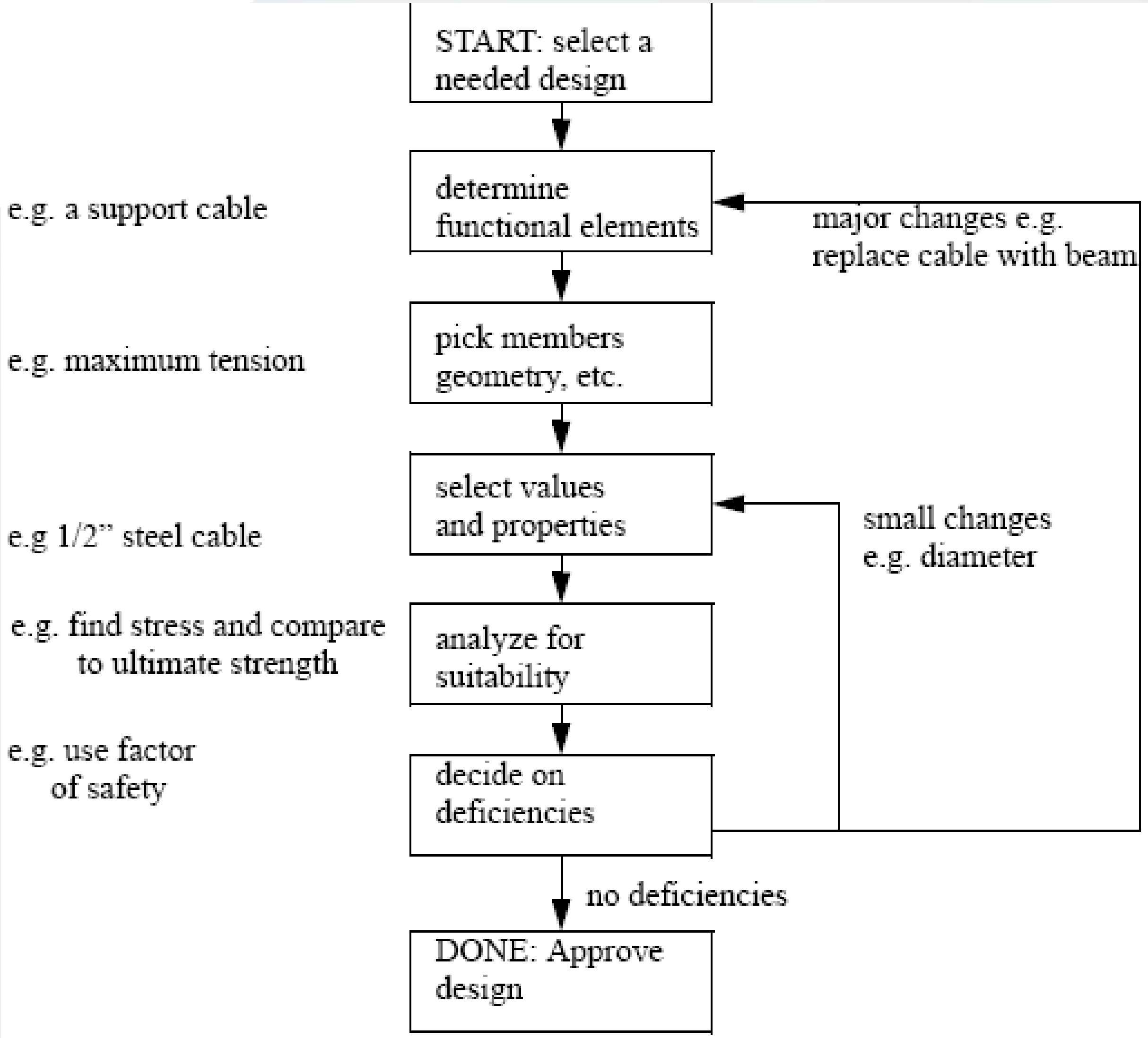


Design factors commonly considered are,

- Functional requirements
- Physical constraints
- Specifications
- Aesthetics
- Usability / user interface
- Cost
- Manufacturing
- Evaluation/testing/analysis
- Maintenance
- Retirement

Detailed design sequence

A more detailed design sequence is shown below



Detailed design sequence

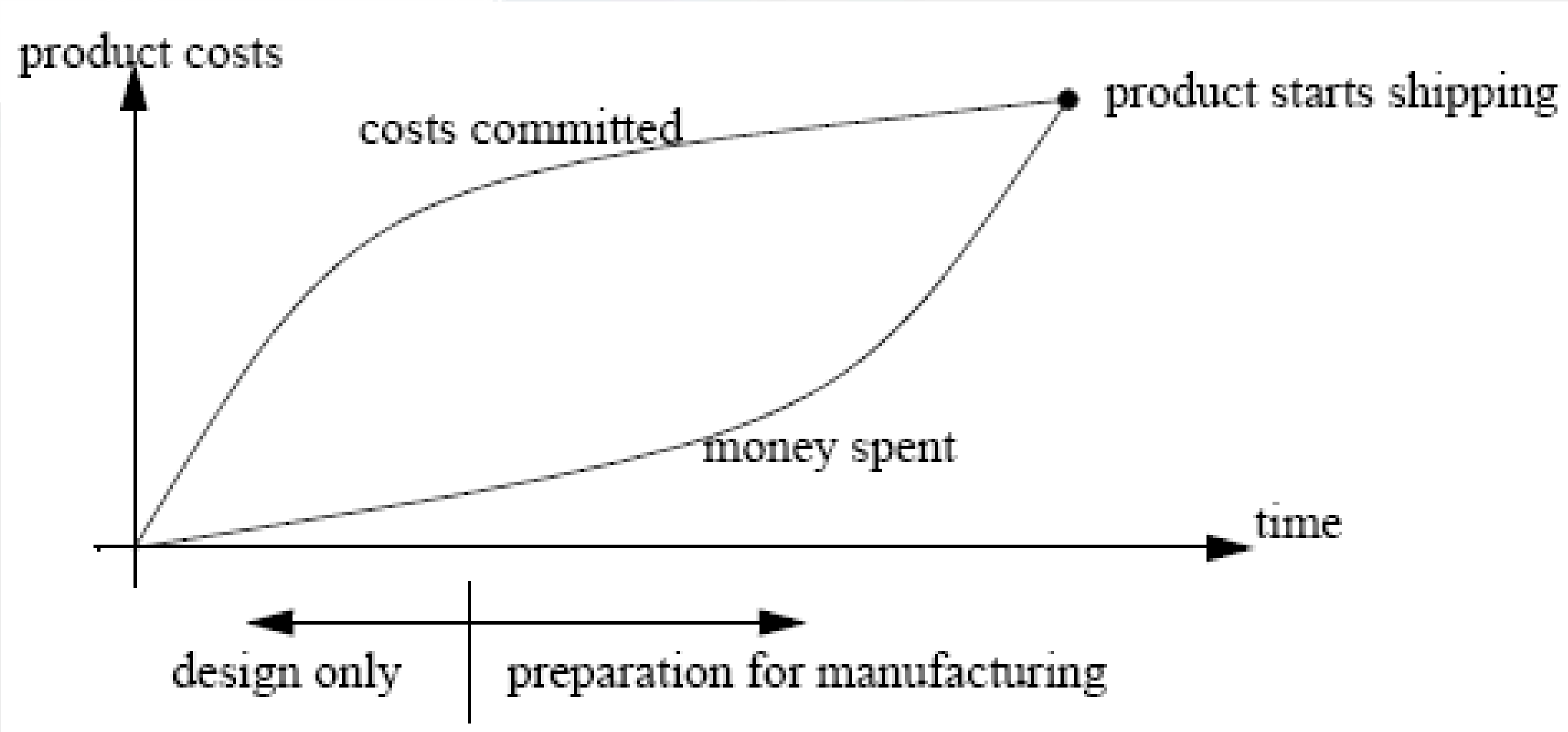
- **Conceptual** - The selection of general components to go into a system. At this point the exact form of final point is inexact. At this point we might be deciding to put wheels on a car.
- **Synthesis** - The selection of components or devices for the system. At this point the general geometry, and components for the system are selected.
- **Detailed** - Exact dimensions are finally assigned to parts in the system.
- **Analysis** - The review of design details to determine suitability. This is done after the exact design is complete. It may lead to redesign.

Detailed design sequence

- **The activity of design** creates a dilemma for management in that it **adds to** the overall cost of a product, but it can also **reduce the final cost** of a product.
- We can **draw graphs** that illustrate the total amount committed in **the final cost** from the first concept, to the final product. Most of the final cost is determined by decisions early in the design phase.

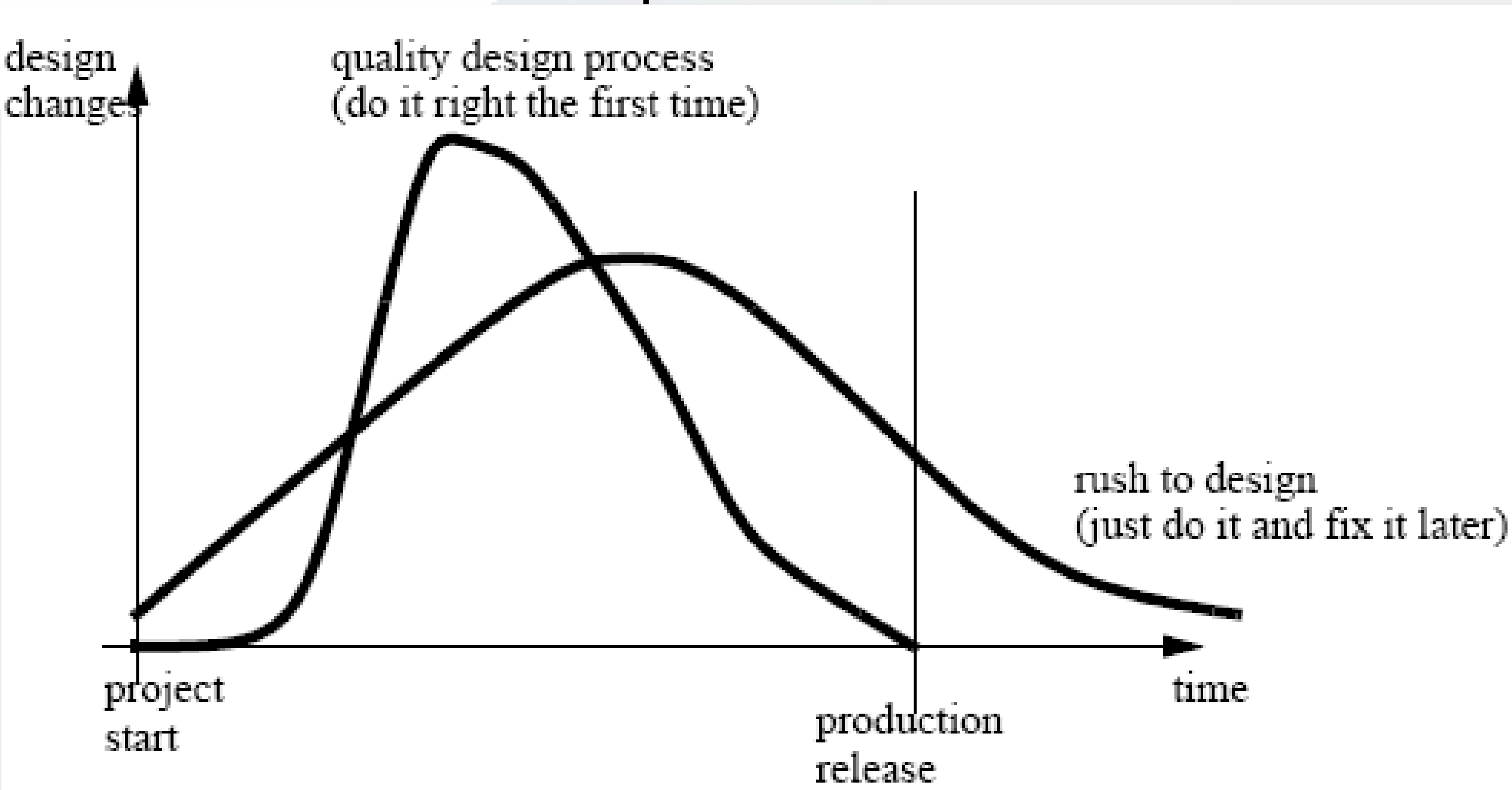
Cost

The total amount committed in the final cost from the first concept, to the final product.



Design

By planning for design, and then committing fully, we can obtain a better product.



Design

- Over-the-wall is an engineering approach that has developed because of management pressures.
- It helps split designs into clean stages and responsibilities. This approach does simplify management up front, but requires fire fighting as problems arise.

A product life cycle has four phases,

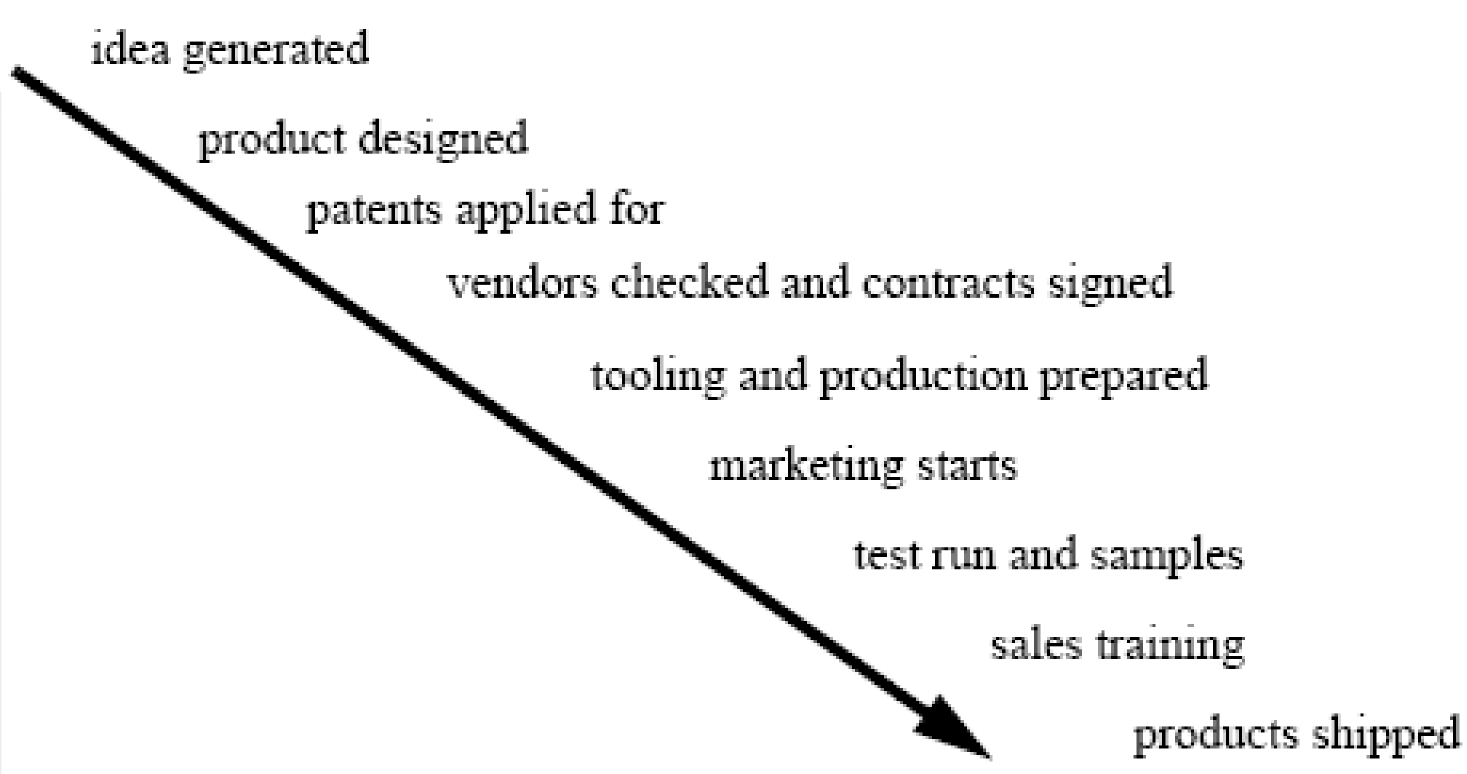
1. Identify needs, plan and design
2. Manufacture and deliver
3. Use, maintain, repair
4. Retire

References

- Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.
- “design.pdf” at http://claymore.engineer.gvsu.edu

Commercial

The commercial view of product development typically looks like,



Other significant functions

Other significant functions that will be considered are,

- Documentation user/service manuals
- Maintenance / service / installation training
- Packaging
- Governement forms in regulated industries
- Business plans for financing - banks or venture capital
- Market survey and testing

Product design

When designing a product there are certain terms that designers use,

Configuration	Form	Refine
Connection	Function	Reversing
Components	İnterface	Substituting
Copying	Magnifying	Transition
Decomposing	Rearranging	

Legal Design Axioms

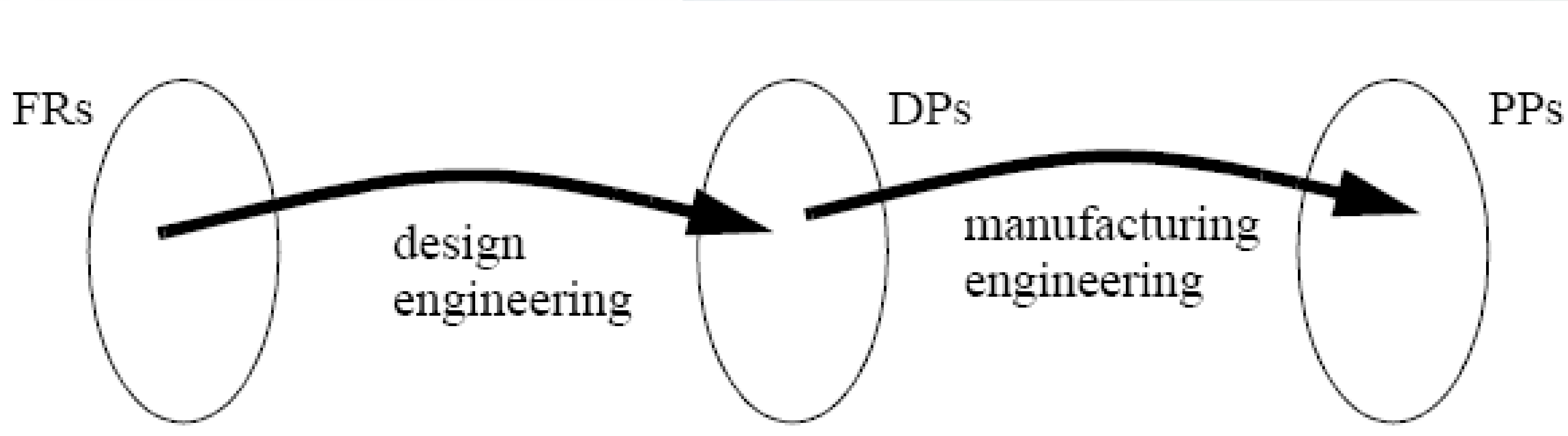
Some rules to follow to reduce the chance/success of a law suit

- The design process should examine hazards and probabilities (e.g., FMEA)
- Make sure that all employees conform to the current standards and legal requirements (e.g. toxicity)
- Inspection and quality control in manufacturing
- Clearly written warning labels and manuals that outline proper use and hazards
- Keep good records of all tests, inspections, etc.

Specifications

- Specifications are a brief list of functional objectives.
- These are often called Functional Requirements (FRs).
- We can look at the design process as mapping Functional Requirements (FRs) to Design Parameters (DPs).
- We can also look at mapping from the design parameters to the Process Parameters (PPs) as the task of process engineering.

Specifications



- Examples of DPs could be # of engine cylinders, or a final dimension.

Specifications

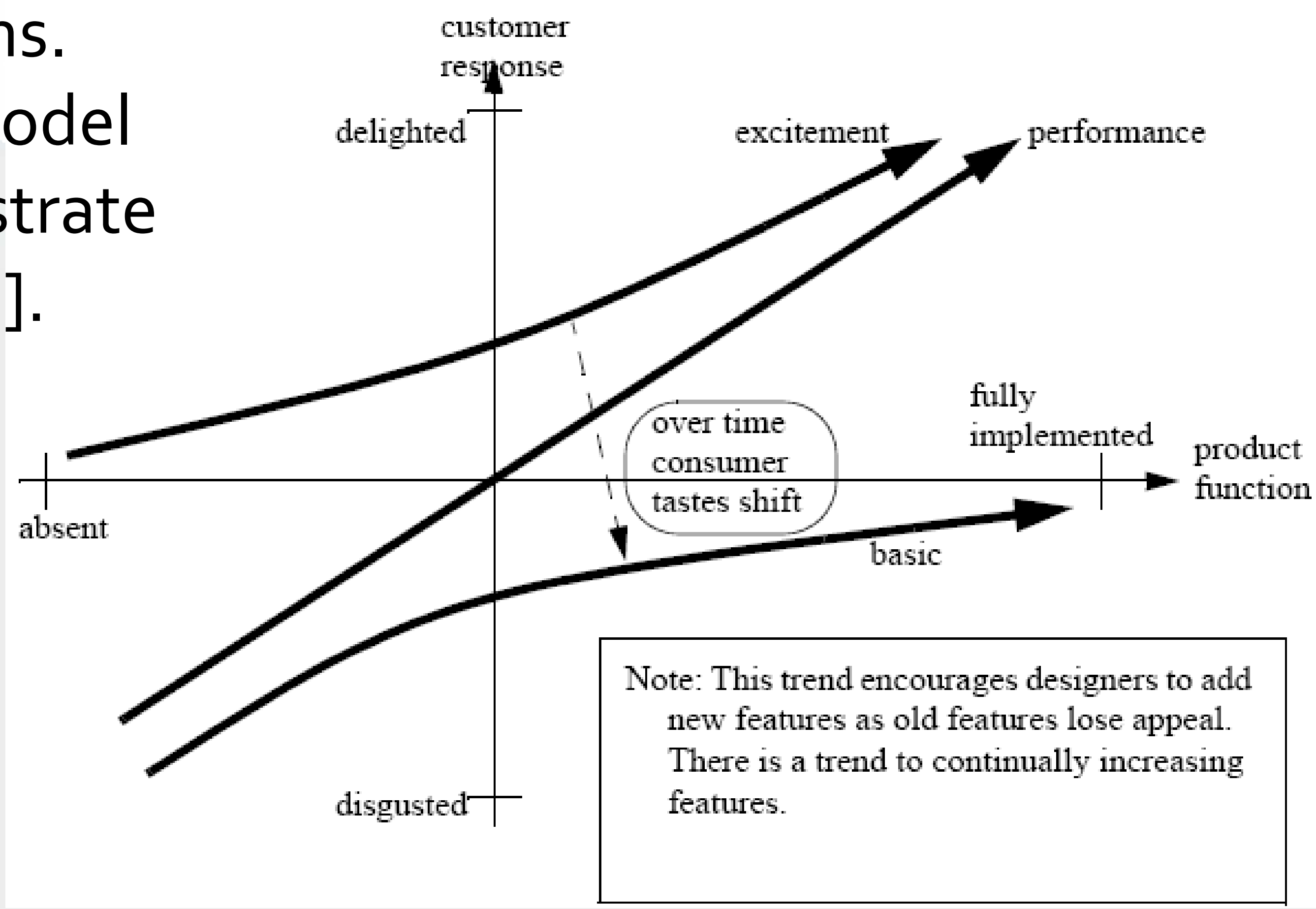
Good rules of thumb for specifications are,

- Try to talk in general terms that focus on the function instead of solution (e.g., "the automobile should be able to move on ground with a 12 inch variation in height" instead of "the axle clearance should be 12 inches").
- Break requirements into separate parts.
- Keep the requirements as simple as possible.
- Avoid vague language, use numbers and technical goals.
- Don't specify more FRs than needed.

Specifications

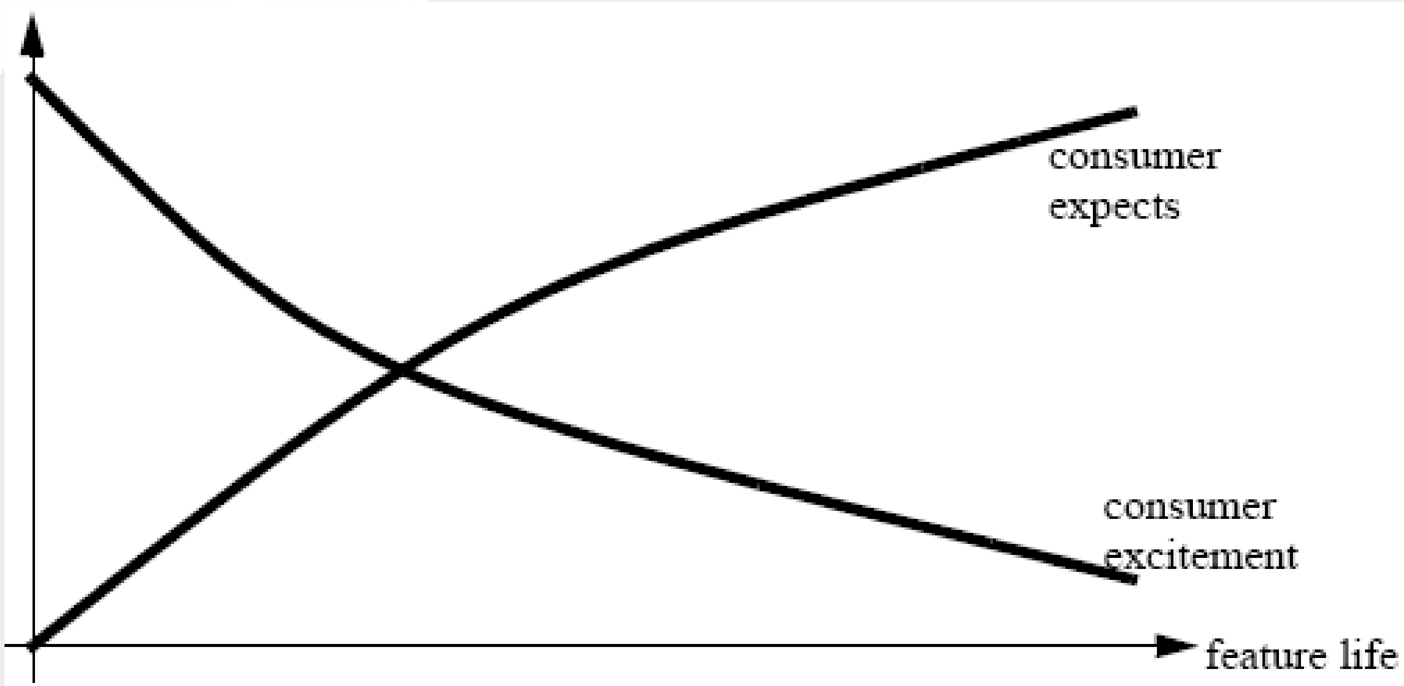
In design we should try to meet, not exceed specifications.

The Kano model helps to illustrate this [Ullman].



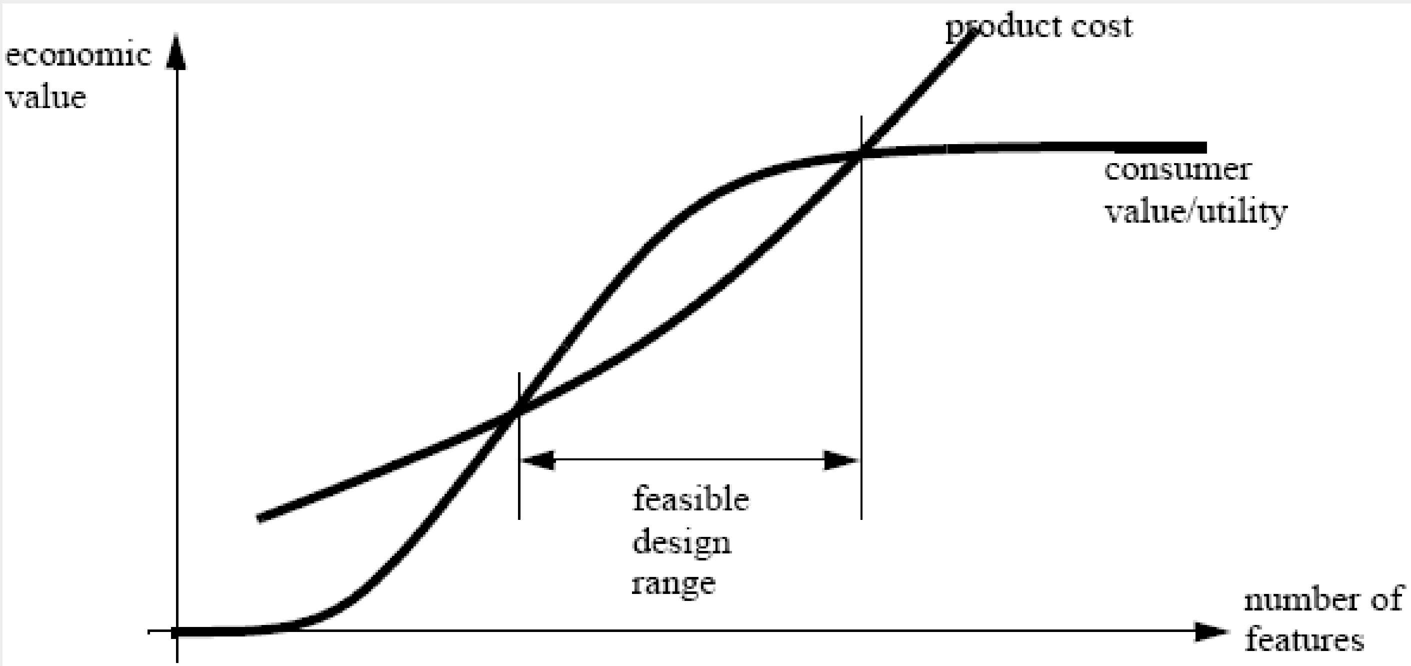
Specifications

If we construct a graph we can show how the consumer response shifts as a function of time



Specifications

We can combine a number of new and old features in products as FRs. These will affect both customer expectations and product cost. A graph shows what marketing departments research in terms of customer needs.



Specifications

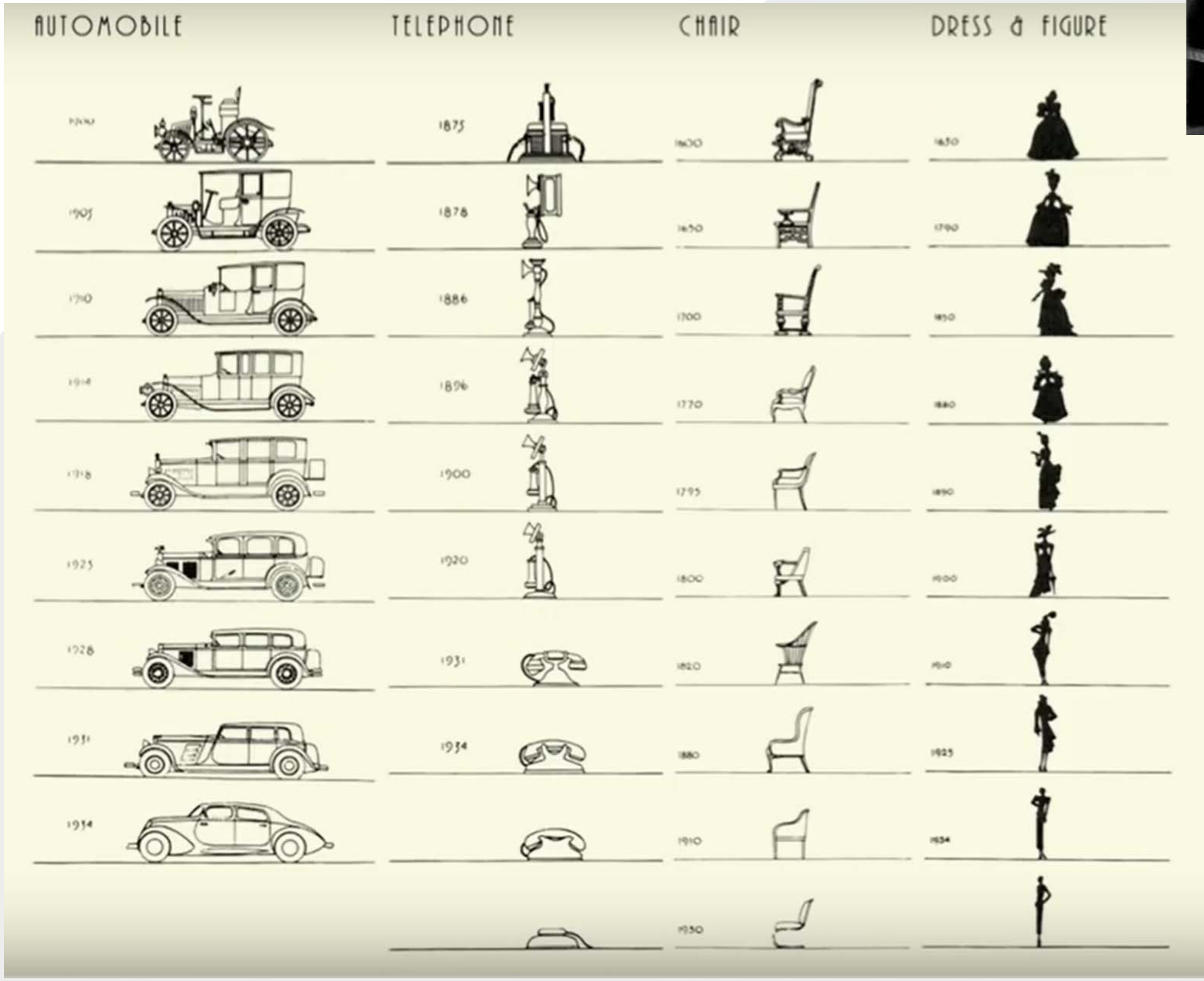
For new products we can try to determine their value with market surveys and by examining competitors products.

10 Heuristics: How Designers Think

(sezgisel çözüm arama yöntemleri)

- Empiricism (Trial & Error) (knowledge comes only or primarily from sensory experience, tecrübe deneysel çalışma) (Deneycilik akılcılığın rasyonalizmin karşıtıdır)
- Empiricism (Bullseye) (ilk başta insan zihni boştur)
- Study History
- Ignore History
- Reframe Constraints
- Embrace (hug) Failure over Fearing Failure
- Emphasis on Proportions
- Aim for Wow! First principles over fashion trends
- Reverse Engineer from Perfection
- Eat your own dog food over observe dogs eating food

Study History   Ignore History



Study History

Study History , Reframe Constraints






Reframing Problems over Accepting

Analogical Insights Reframing Problems

Reframing Problems over Accepting

Customer doesn't know what's Right

over Customer is Always Right

Aim for Wow!

Aim for Wow!

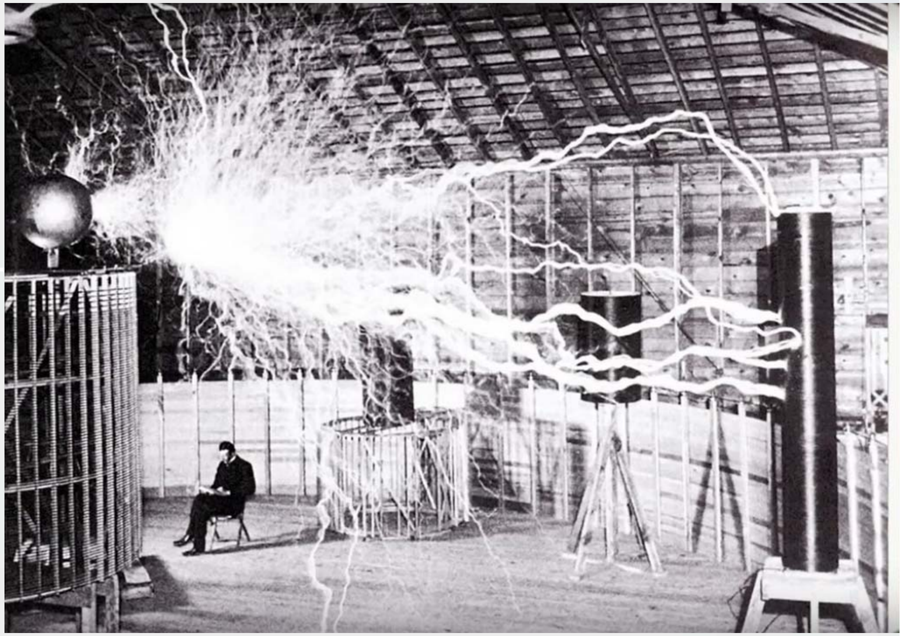
- shock absorber shoes

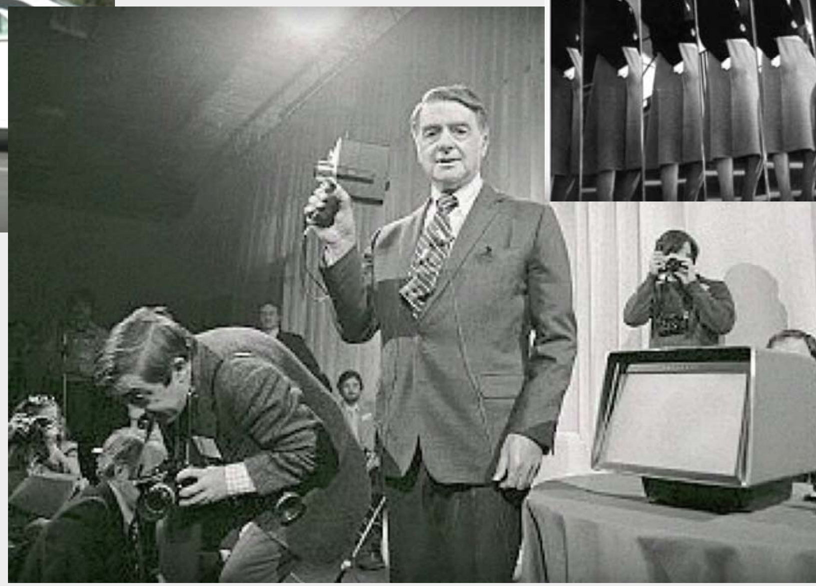
vacume cleaner

- compliance

Embrace (hug) Failure

over Fearing Failure





Emphasis on Proportions

Eat your own dog food

over observe dogs eating food

First principles over fashion trends

10 Heuristics (sezgisel arama yöntemleri)

- Elegant Simplicity
- Inside-Out Craftsmanship
- Embracing (hug) Failure
- Never Leave Well Enough Alone
- Reframing (constraints) Problems
- Customer doesn't know what's right
- Analogical Insights
- Eat your own dog food
- First principles over fashion trends
- Zealous (gayretli) Missionaries

Design Methods

Black Box Design

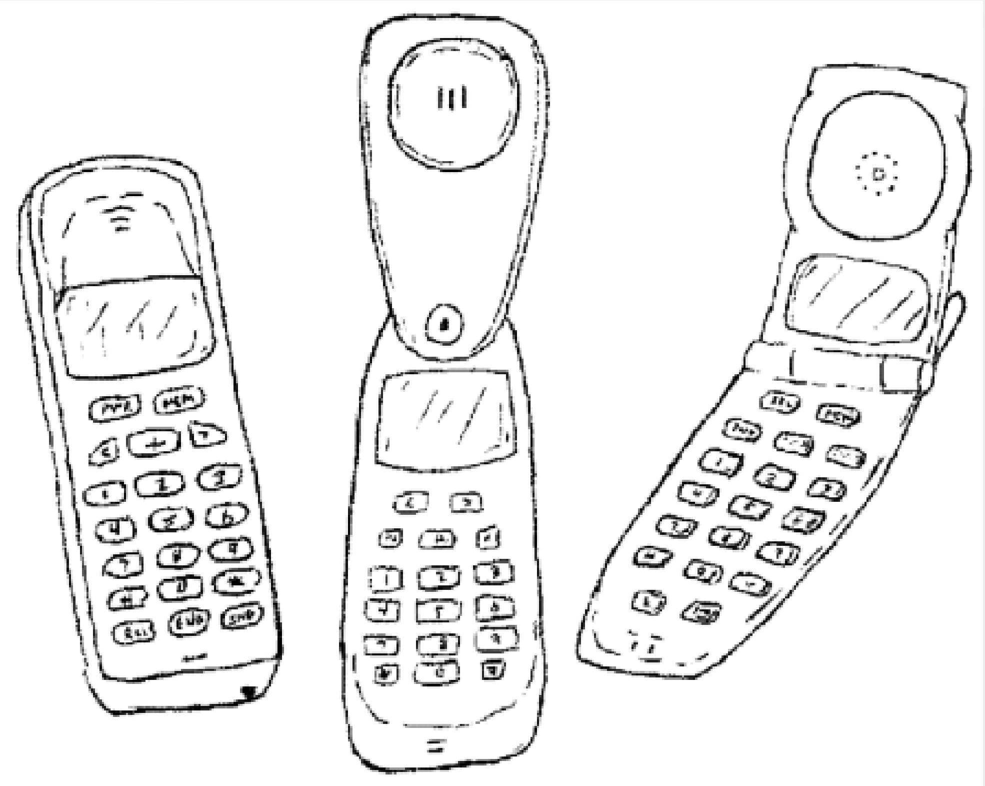
- Characterized by considering inputs and outputs only, while disregarding what is in the box.
- This approach can be used for off-the-shelf components.
- There is a heavy dependance on the manufacturers specifications.

Conceptual Design

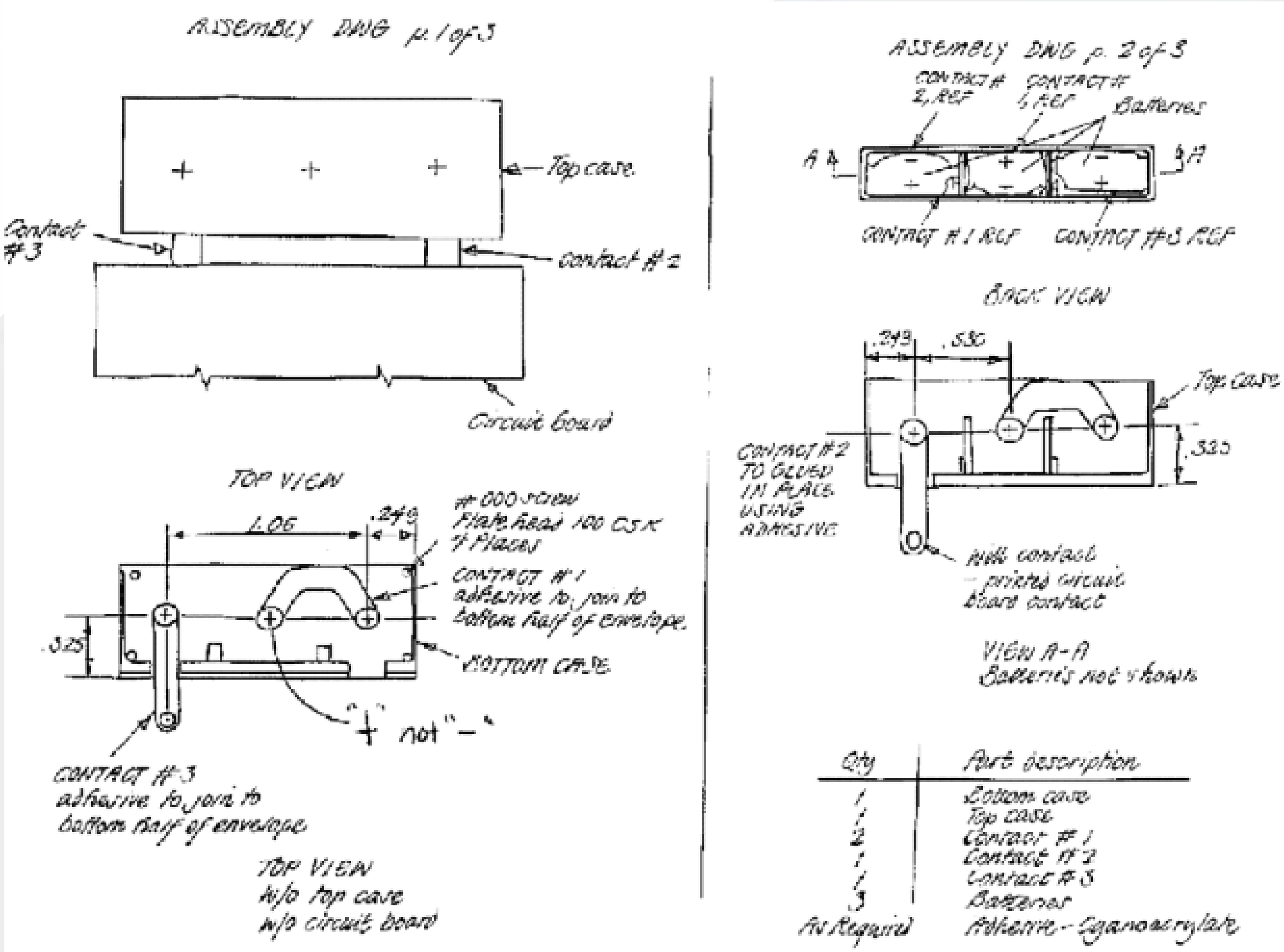
- The first creative stage of any design is to generate concepts such as the choice between gasoline or electric powered vehicles.
- The most important rule in conceptual design is generate a few concepts and then select the best.

Preliminary design sketches for cell phone

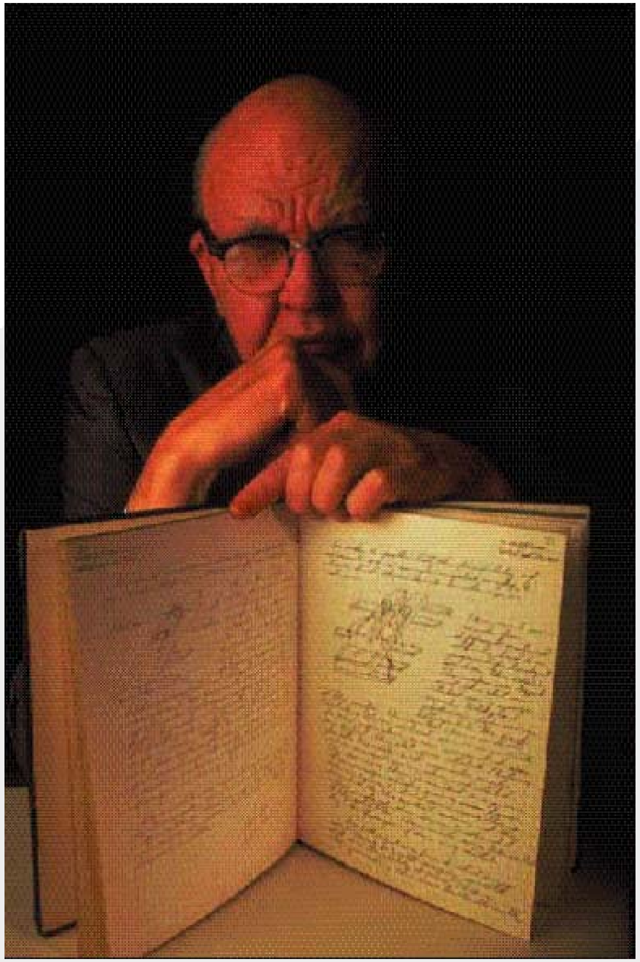
- Ideation drawing phase
- Rough sketches
- Conceptual computer model

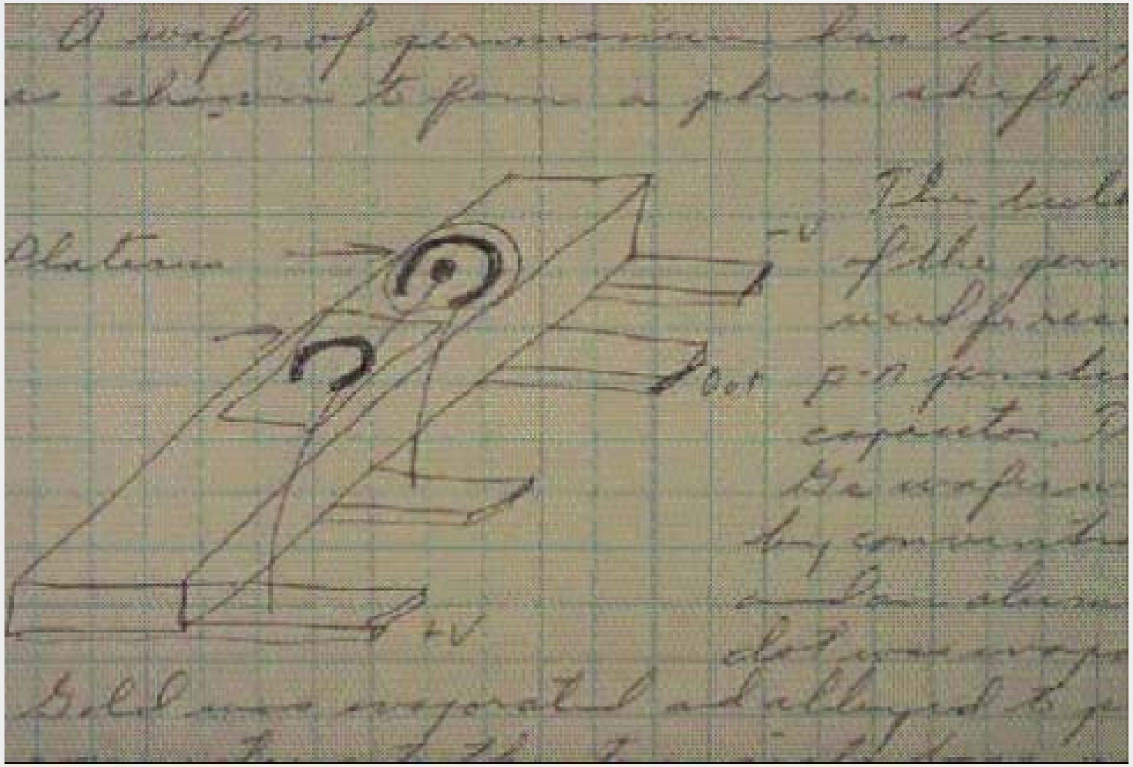


Pages from a designer's sketch notebook



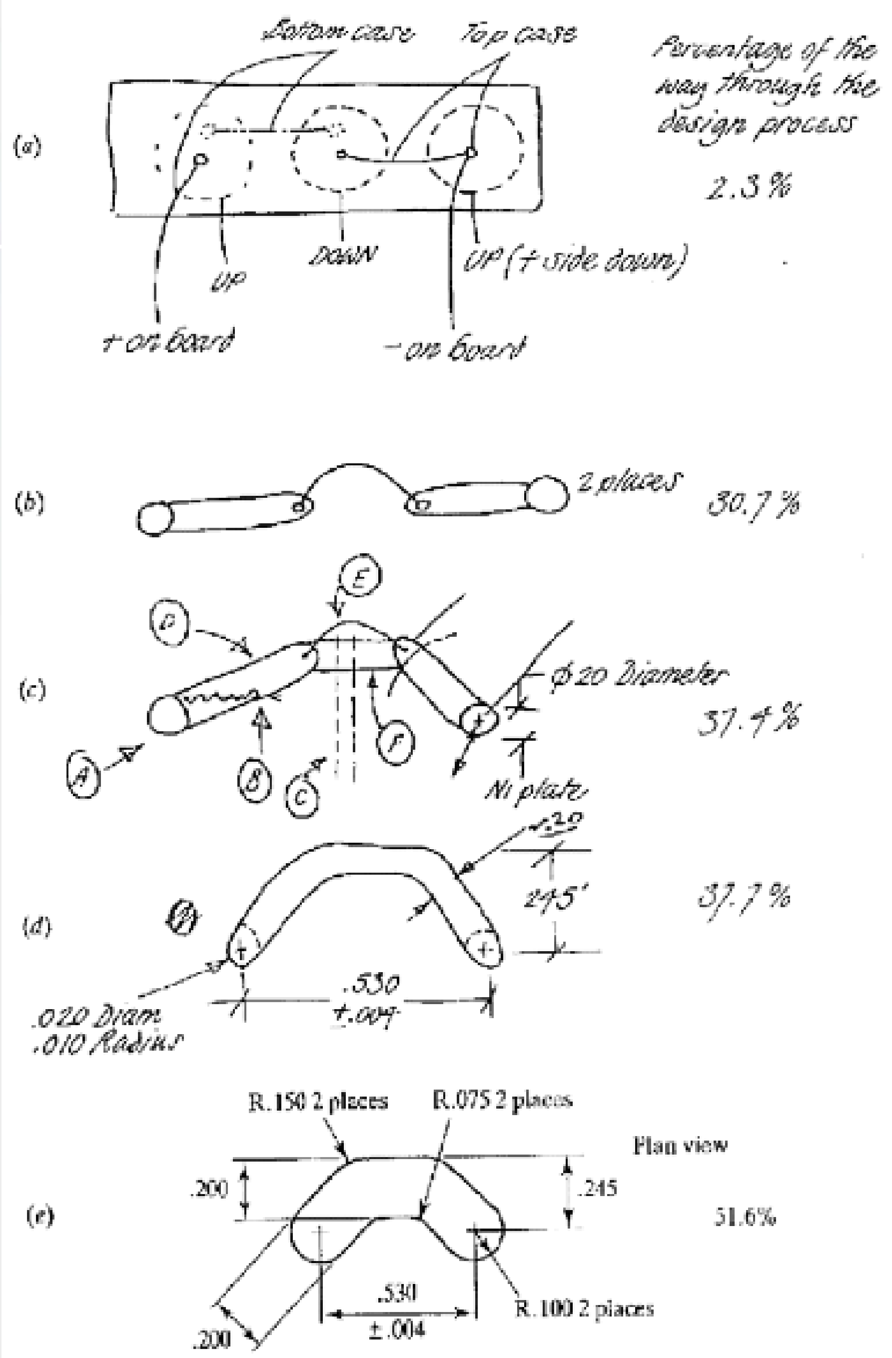
Designer’s notebook as a historical record





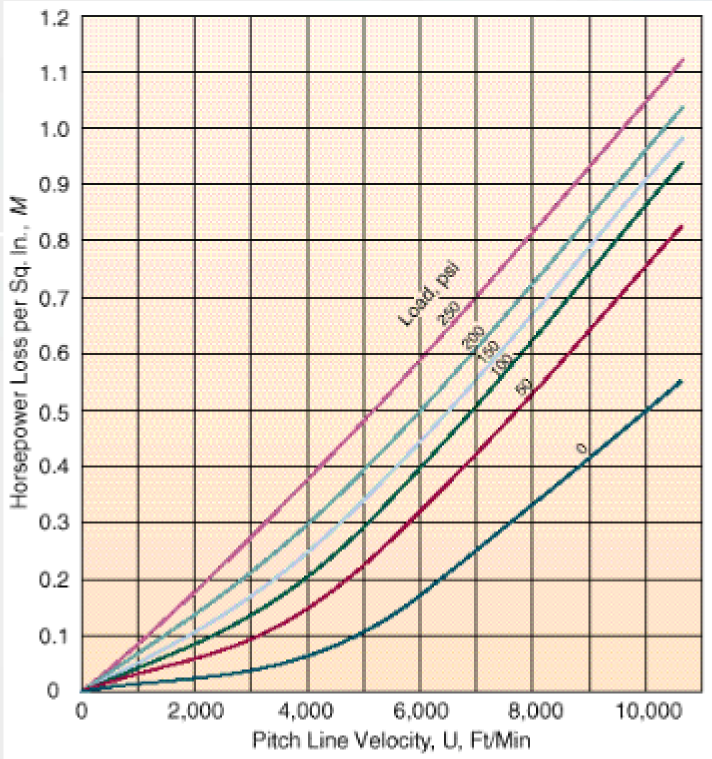
Refinement

of a battery contact design



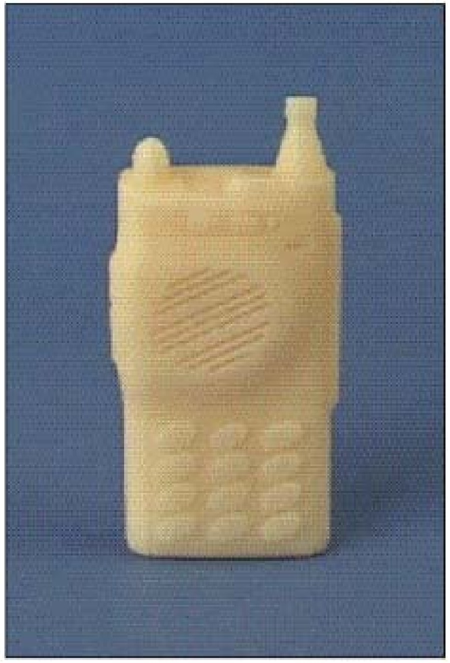
Modeling

- Mathematical predictive model (power loss of a thrust bearing at various speeds)



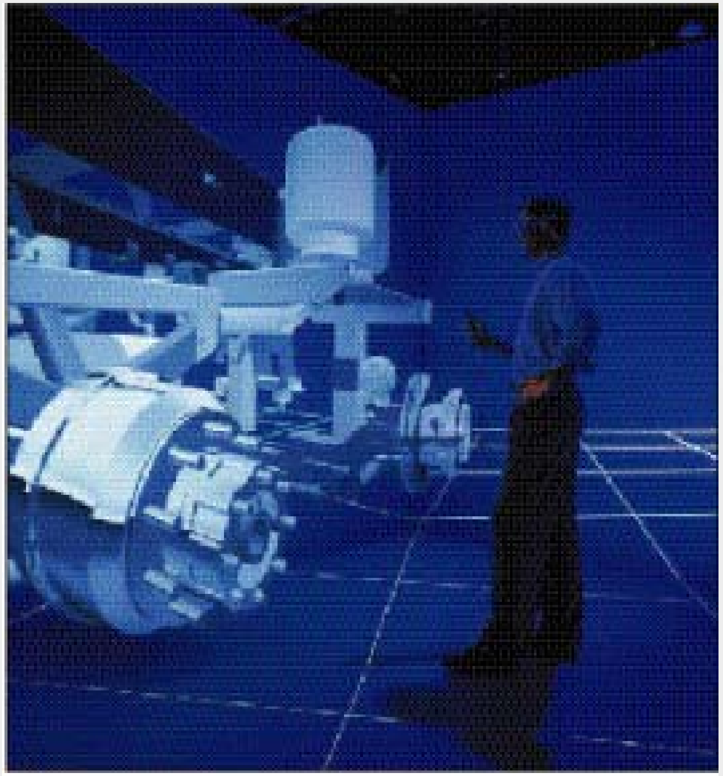
- Real model created from clay

Modeling



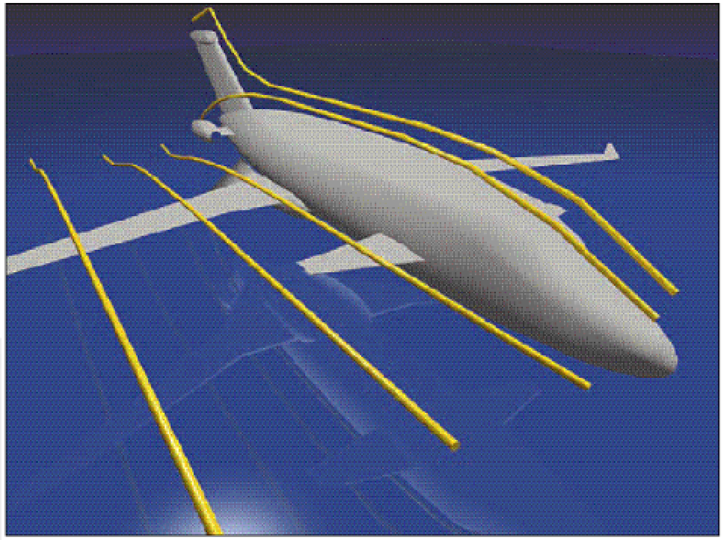
Real model of a portable hand-held radio created with a rapid prototyping system
(Courtesy of 3D Systems, Inc.)

Stereolithography system used to create rapid prototypes of parts.
(Courtesy of 3D Systems, Inc.)

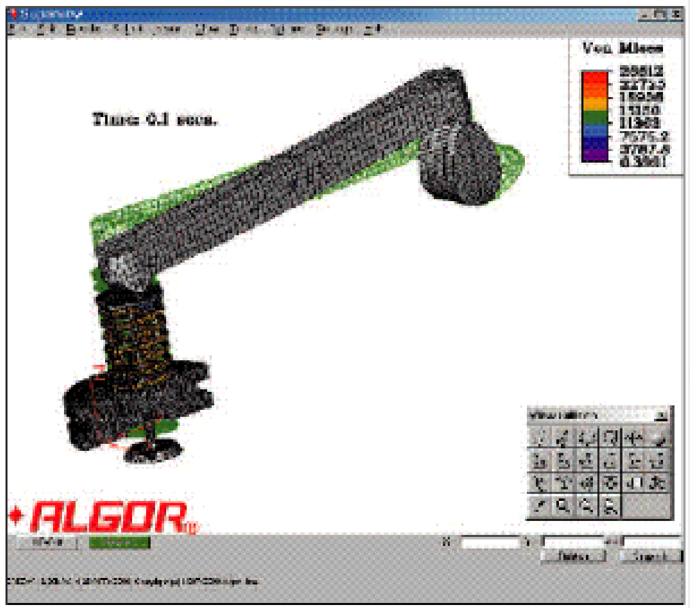


Virtual reality technology

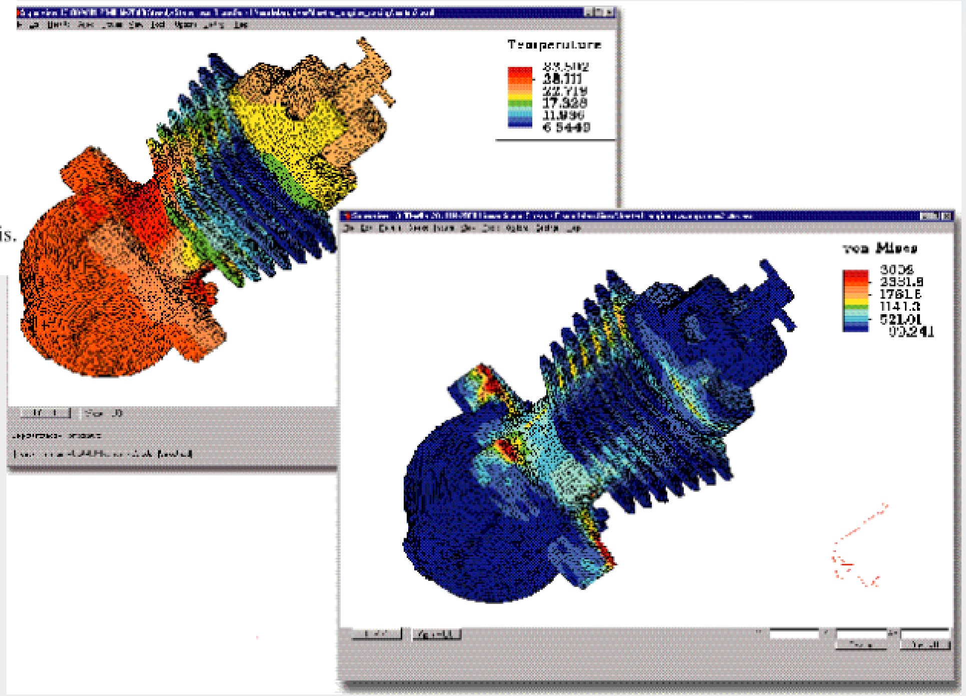
Modeling and simulation

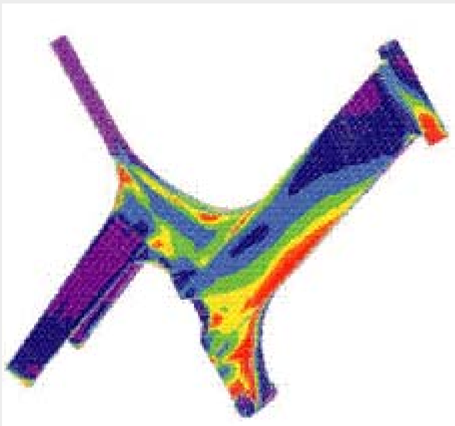


Computer model simulating an aircraft in a wind tunnel
The computer model supplements or replaces the need for physical models in engineering analysis.
(Courtesy of Gary Bertoline.)



Motion analysis





Generation of Concepts

- This is the typically the hardest part of design.
- When talking about invention - this is the 'inspiration'

- Brain Storming
- Basically this method generates a large number of diverse concepts using a group.

Brain Storming

One approach might be,

1. Have a meeting individuals (6-12 is good) related to the design tasks.
2. Make it clear that criticism is not allowed and every idea is good.
3. Ask everyone to write ideas on separate pieces of paper.

Brain Storming

4. Start going round the room one at a time, and ask for the ideas. (Don't allow criticism or judgement!) After the idea is given, the paper is placed in the center of the table.
5. This continues until all ideas are exhausted. (Participants should generate new ideas based on what they have heard from others). Encourage participants to suggest ridiculous ideas.
6. Go through the ideas in the middle of the table, and vote for the best one(s).

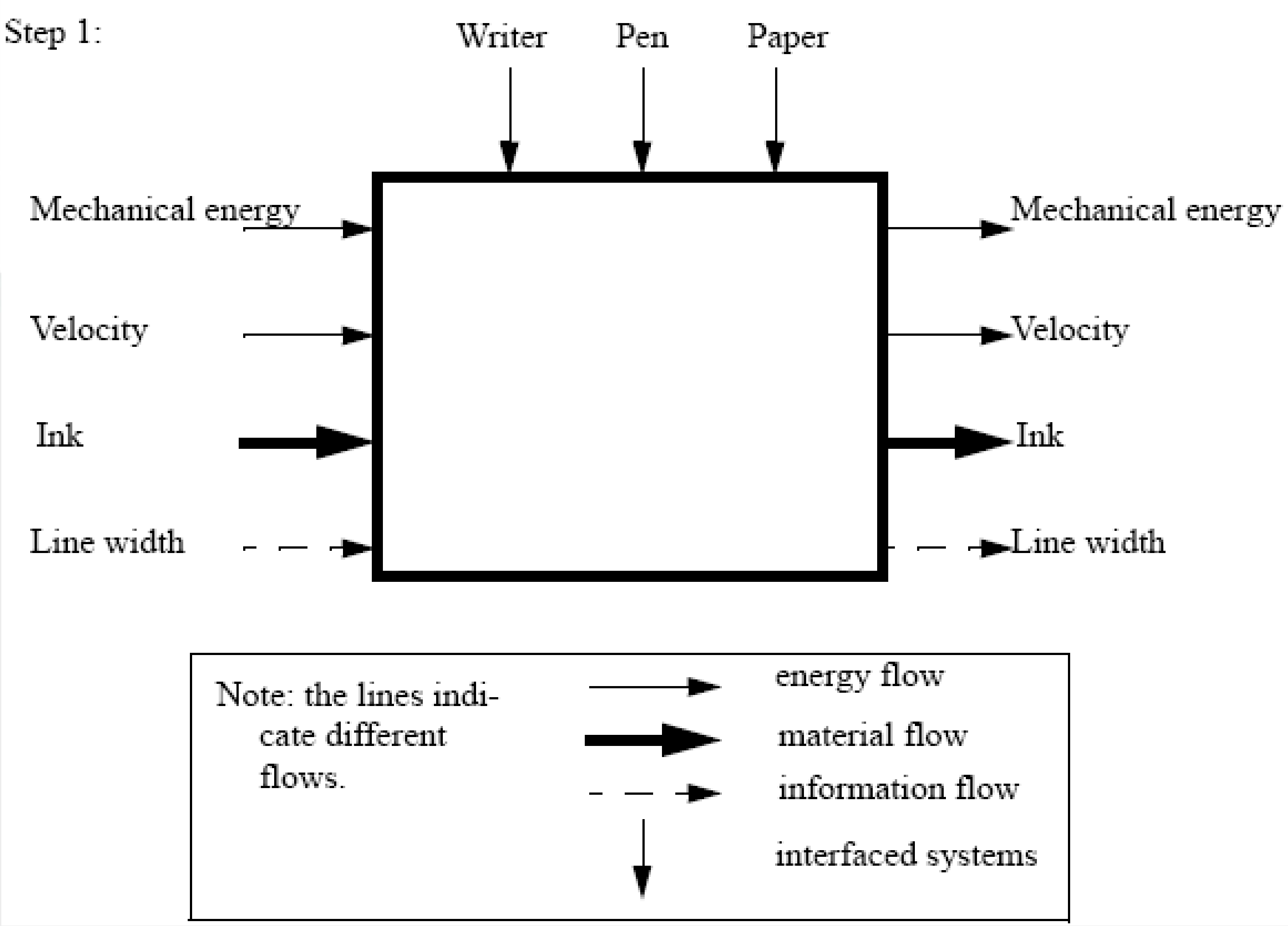
Practice Problems

- Use brain storming to develop concepts for putting on shoes

Diagramming

- We can break functions down to subfunctions shown as black boxes
- Basically we draw functional blocks that show interfaced systems and indicating inputs and outputs of information, energy and materials.
- We can start by drawing one main box for a function (e.g., ‘a pen must draw a consistent line width)

Diagramming



Diagramming

The rules of thumb when creating the main diagrams are,

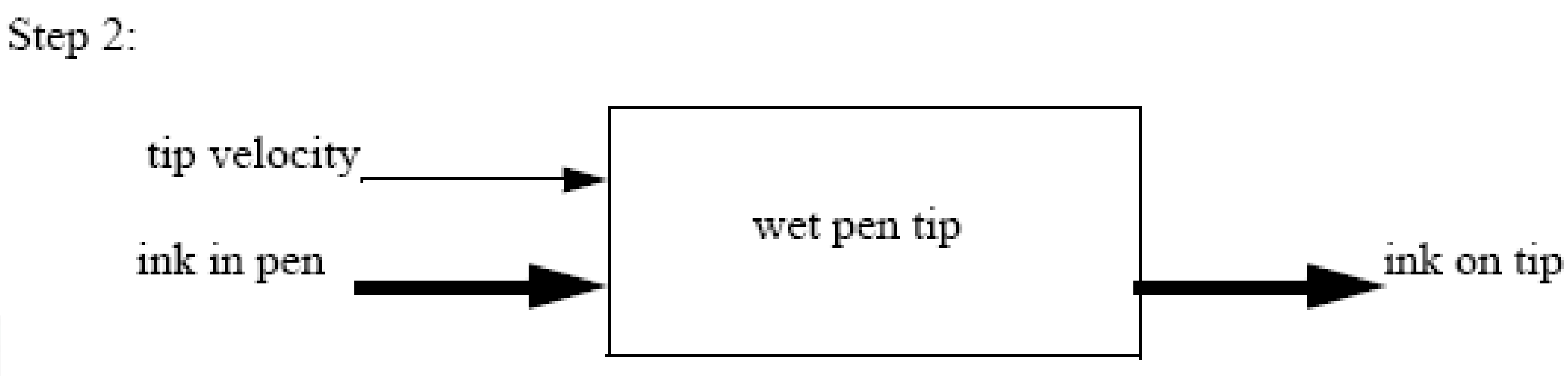
- Pick reasonable function boundaries (not too much or too little)
- Conserve energy and material
- Indicate interfacing/involved parts of the system
- Add information flows to determine how well the system is performing

Diagramming

(as with IDEF) we can break the main function into sub functions. To do this we,

- Make sub function boxes that show how
- Create as many boxes as possible
- List alternates
- Make sure all applicable flows are included
- Consider sequences
- Use standard notations
- Use available documents, parts, etc to develop ideas
- Don’t be afraid to add new items not on the first diagram

Diagramming



- We can then combine the function blocks into a single diagram. (Step 3)
- Finally, we convert the diagram to a conceptual design. The functional diagram(s) are used to provide clues, and in many cases they will lead directly to a design. (Step 4)

Practice Problems

Considering the example started in the notes,

a) develop more subfunction blocks for the pen

b) using the previous blocks, draw a detailed functional diagram

c) Develop a final pen design using the final diagram.

Patents

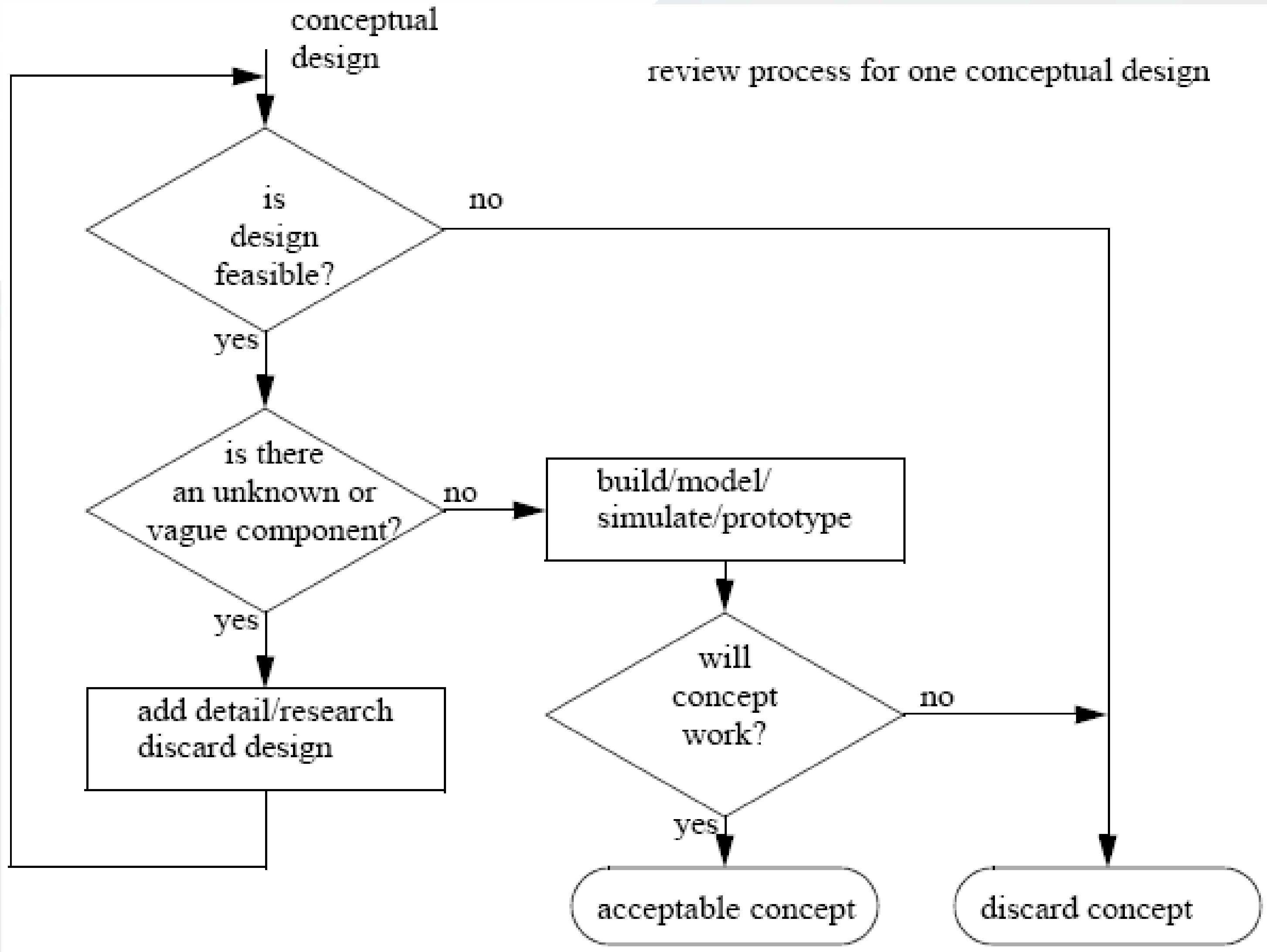
- Use patents as a source for ideas
- Using keywords patents can be searched on-line

- A patent is typically made of common parts. The most useful are,
- an abstract
- references
- a long description
- a set of specific claims

Concept Evaluation and refinement

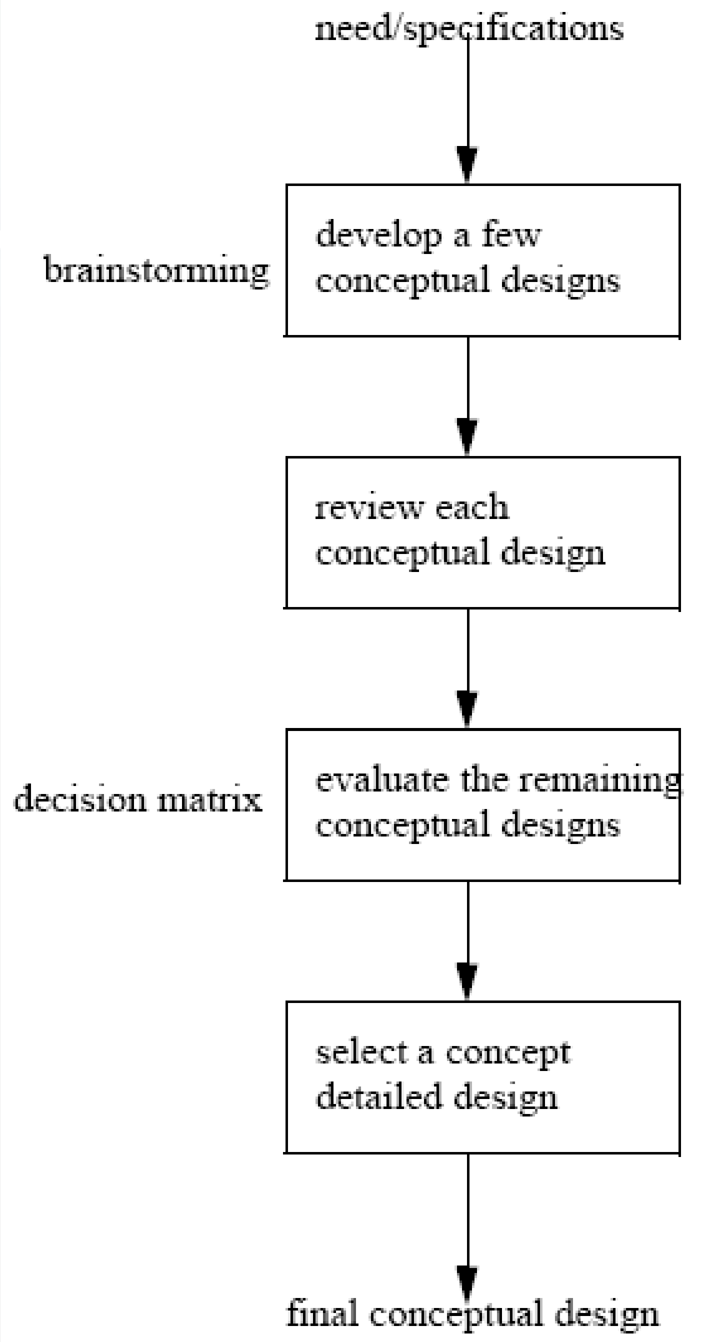
- After design concepts have been developed they must be reviewed.
- When evaluating concepts, we are best to start with many concepts and then refine,

Concept Evaluation



Conceptual design

Process to generate a conceptual design



Decision Matrix

- Basically we set some criteria, give them a value, and then compare conceptual designs to it.
  The final results are numerical.

- For this method we,

1. List the conceptual designs as columns.
2. List the criteria as rows (these criteria are like those used in QFD).
3. A weight is given to each criteria.

Decision Matrix

4. A score is given to the concept for each criteria. The ranking is done relative to one of the design concepts, with the middle of the scale being the first concept. A scale of -3 to +3 is reasonable.
5. Using the criteria weights, the column values are multiplied and added to get a score for the design.
6. The design with the highest score is often judged the best candidate for detailed design (although other designs may be chosen).

A decision matrix for a syringe

A decision matrix for a self-administered syringe

		CONCEPTS					
		A (reference) Master Cylinder		DF Lever Stop		E Dial Screw	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of Handling	5	3	0.15	3	0.15	4	0.2
Ease of use	15	3	0.45	4	0.6	4	0.6
Readable settings	10	3	0.3	3	0.3	5	0.5
Dosage accuracy	25	3	0.75	3	0.75	2	0.5
Durability	15	3	0.45	5	0.75	4	0.6
Manufacturability	20	3	0.6	3	0.6	2	0.4
Portability	10	3	0.3	3	0.3	3	0.3
	Total Score		3.00		3.45		3.10
	Rank		3		1		3
	Continue?		No		Yes		No

Human Factors/Ergonomics

- Ergonomics is the study of the interactions/interface between humans and machines/processes.

- There are a variety of areas for ergonomic analysis
- manufacturing - reducing worker stress (physiological) can reduce health problems (lost days), decrease product cost and increase product quality.
- consumer - increasing ease of use can increase utility of the product.

Ergonomics

- Ergonomics is the basis for many design methods such as DFA

- Ergonomics takes into account,
- body proportions
- strength
- desired function

- Non-ergonomic designs typically lead to personal injuries (and hence lawsuits, etc.)

Ergonomics

- Typical ergonomic problems in manufacturing are listed along with possible solutions,
- discomfort - uneeded strain on worker (e.g. hunching over)
  1. training for proper lifting methods
  2. rearrange operation locations and sequence to reduce unnatural motions.
- efficiency - unnatural motions slow production
  1. training for proper lifting methods
  2. rearrange operation locations and sequence to reduce unnatural motions.

Ergonomics

- cummulative trauma disorders - muscle strain injuries (lifting 30lb packages all day)
  1. training for proper lifting methods
  2. use special lifting equipment
- repetitive stress injuries - repeated motions. For example carpel tunnel syndrome in the wrists.
  1. rearrange operation locations and sequence to reduce unnatural motions.
  2. use ergonomically redesigned equipment (e.g. computer keyboards)

Ergonomics

- information overload/confusion - excessive, inappropriate or a lack of detail. (e.g. Fighter pilots, airtraffic controllers)
  1. redesign displays to be clear with a minimum amount of good information
  2. use of color coding and pictures
  3. simplify controls to minimum needed

Ergonomics

- eye strain - fine focus or bad lighting
  1. adjust lighting
  2. use magnifying lenses
- noise - direct hearing or annoyance. (e.g., piercing tones, just too noisy)
  1. special hearing protection equipment
  2. redesign workspace to reduce noise reverberation
  3. redesign equipment to reduce sound emmisions

Safety

- It is natural for a machine to have hazardous parts/functions/flows.
- If the risk (probability) of comming in contact is high we call this danger

Safety

Typical hazards include,

- Pinch points
- Crushing
- Collision with moving objects
- Falling from heights
- Slippery surfaces
- Explossion
- Electric shock
- Temperature/fire
- Toxicity
- Physical strain

Environment

- Environmental considerations are a natural consideration of the design process and can be considered an extension of safety.
- Design factors that will impact the environment include,
  - discharges/waste (gas, liquids, solids) from production processes
  - energy/fuel utilization in production
  - aging of the product - decay, inert, toxic, etc.
  - energy/fuel efficiency in use

Environment

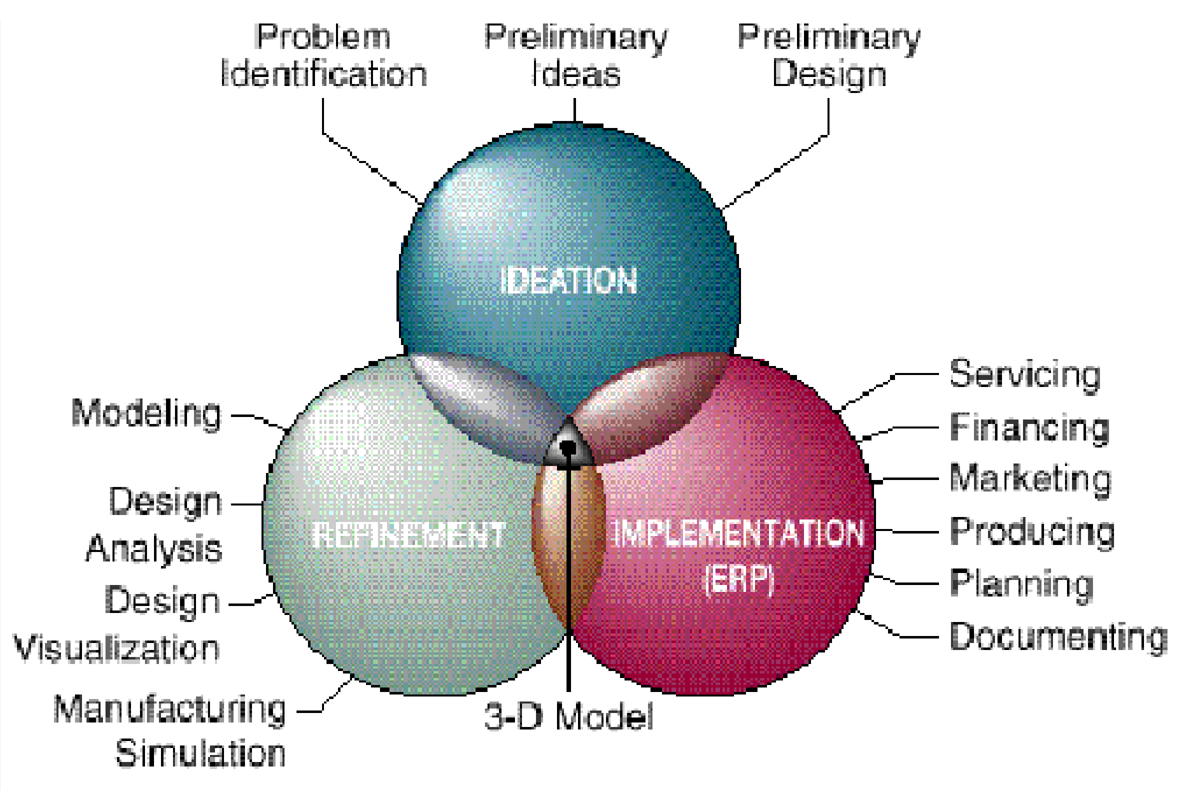
- There are a wide variety of laws, agencies and organizations that influence manufacturing and consumer products,
  - OSHA (Occupational Safety and Health Administration)
  - EPA (Environment Protection Agency)
  - NIOSH (National Institute for Occupational Safety & Health)
  - UL (Underwriters Laboratory)
  - CSA (Canadian Safety Association)

Concurrent engineering design

Engineering design process consists of three overlapping areas:

- Ideation
- Refinement
- Implementation

which all share the same 3D CAD database.



Concurrent Engineering

Some methods have already been identified for supporting concurrent engineering,

- Axiomatic Design
- Design For Manufacturing (DFM) guidelines
- Design For Assembly (DFA)
- Taguchi Methods
- Group Technology
- Failure-Mode and Effects Analysis (FMEA)
- Value Engineering
- Simulation

Concurrent Engineering

The advantages of the various tools can be any of the following,

- Optimize design satisfaction of customer requirements
- Simplify designs
- Ensure manufacturability
- Optimize production ease and cost.

Design For X

- During design, we often focus on the final product, and not its manufacture.
- The Design For X (DFX) philosophy suggests that a design be continually reviewed from the start to the end to find ways to improve production and other non-functional aspects.
- These rules are nothing new, they are just common sense items written down, but they can be a good guide through the design process.

Design For X

Advantages of these techniques are,

- Shorter production times
- Fewer production steps
- Smaller parts inventory
- More standardized parts
- Simpler designs that are more likely to be robust
- They can help when expertise is not available, or as a way to reexamine traditional designs
- Proven to be very successful over decades of application

Design For X

- These techniques can be used as a very substantial part of concurrent engineering.
- Some of the DFX acronyms are, (modified from [Dodd, 1992])

Design For X

• DFA	Design For Assembly
• DFD	Design For Disassembly
• DFEMC	Design For ElectroMagnetic Compatibility
• DFESD	Design For Electrostatic Discharge
• DFI	Design For Installability
• DFM	Design For Maintainability
• DFM	Design For Manufacturability
• DFML	Design For Material Logistics
• DFP	Design For Portability (Software)
• DFQ	Design For Quality
• DFR	Design For Redesign
• DFR	Design For Reliability
• DFR	Design For Reuse
• DFS	Design For Safety
• DFS	Design For Simplicity
• DFS	Design For Speed
• DFT	Design For Test

Design For Assembly (DFA)

- These techniques attempt to simplify products to ease the assembly process, without compromising functionality of the product.
- First, consider the basic steps involved in assembly,

1. a) parts are purchased, and put into inventory, or storage bins. b) parts are manufactured, and put into inventory, or storage bins.
2. batches of parts are often inspected for quality.
3. the batches are moved to the work station.
4. the partially completed assembly may be already at the work station, or the operator may accept it from another source (e.g., a belt on an assembly line)

Design For Assembly (DFA)

5. the part base will be set in position.
6. The operator will pick a part from the parts bin.
7. the operators will (if not already) position the part correctly in their hand, and prepare to insert it into the work.
8. The operator will guide the part into the final position.
9. The operator will move the two parts so that they fit together
10. The operator will perform any fastening operations required.
11. Additional alignment or quality inspection steps may sometimes be included.

Design For Assembly (DFA)

- Each one of these steps has potential for problems, or improvement. For example, if one part can be modified to match another, we cut the need to perform steps 1 to 5 in half. For each part that can be eliminated we reduce steps 1-11.

Design For Assembly (DFA)

One report of these techniques applied to circuit boards [Boothroyd and Knight, 1993] reports,

- manufacturing costs down almost 20-30%
- component costs down 10-20%
- component counts down almost 25-40%
- board densities down almost 5-20%
- problem parts down over 20-90%
- yield up over 30-50%

Design rule summary

Part Design

1. Eliminate/minimize tangling between parts in feeders.
2. Use symmetry to reduce the orientation time during handling
3. If symmetry is not possible, use obvious features to speed orientation

Product Design

1. Reduce the number of parts when possible
2. Build the part in layers from the top on the bottom, using gravity to locate parts
3. Have the already assembled product stable on the work surface
4. Have the work lie in a horizontal plane
5. Use chamfers and fillets to ease mating of parts.
6. Use snap-fits, and other quick fasteners, avoid screws, glue, etc.

Rules for Manual/Automatic Assembly

The basic strategies of DFA for automated assembly are,

1. Reduce the number of parts
2. Allow assembly from the top of a fixtured part
3. Develop symmetry for easy part orientation
4. Use guides to simplify part mating, such as chamfers
5. Aim for snap-fit connectors, avoid screws
6. Reduce handling problems

Rules for Manual/Automatic Assembly

The basic rules of DFA for manual assembly are,

1. the number of parts should be reduced
2. parts should be standardized where possible
3. alignment operations should be reduced
4. locating and aligning features should be used
5. allow clear paths for parts being added to the assembly

Rules for Manual/Automatic Assembly

The basic rules of DFA for manual assembly are,

6. add orientation features so that parts can only be assembled in the correct orientations
7. consider part feeding/picking from batches
8. introduce symmetries to reduce the need for reorientation
9. add orientation features to simplify orientation identification

Reducing the Number of Parts

Designs often include more parts than are necessary

- A set of questions must be satisfied for any two parts in an assembly to justify their being separated

1. Do the parts move relative to one another?
2. Must the parts be made of different materials?
3. Must the parts be separable for maintenance or manufacture

Reducing the Number of Parts

- Some simple ideas possible are,

1. Instead of attaching labels on plastic parts, add the lettering into the mold so that the letters are added at the time of molding. The completely eliminates a part, and the associated operations.

Reducing the Number of Parts

2. In sheet metal parts create features using sheet metal, instead of attaching them with other means. Some examples are,

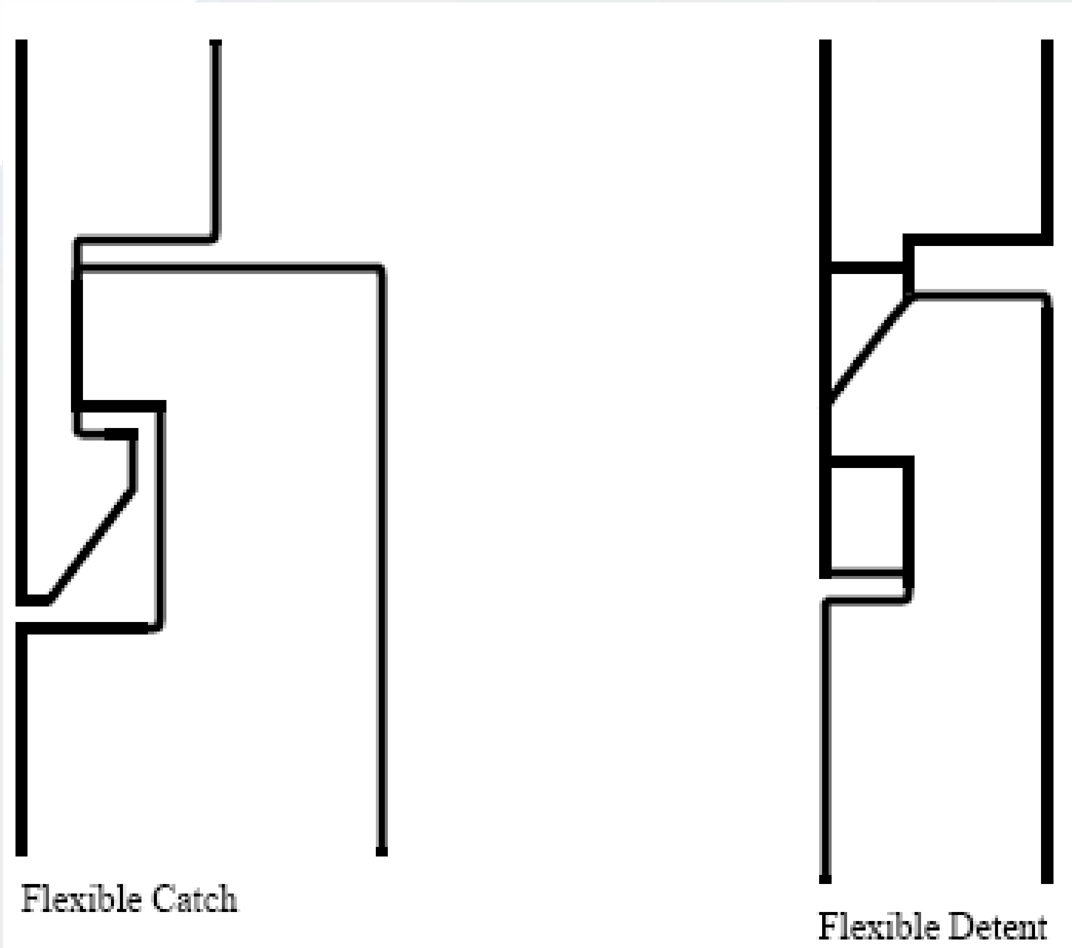
- instead of adding hook to a sheet metal part, cut and bend hooks out of the sheet metal
- don't add screw standoffs to metal, but punch the metal to create a standoff, and tap the hole.

Reducing the Number of Parts

3. When possible use snap fits instead of screws. Most screwed connectors require 1 nut, 1 bolt, typically 2 or more washers, and possibly a lockwasher, as well as a great deal of time and dexterity to assembly. Snap fittings can be made very simple and fast. NOTE: press fits can also be considered for these operations, although their need for higher forces can be a negative.

Reducing the Number of Parts

Snap fittings
When possible use snap fits instead of screws.



Reducing the Number of Parts

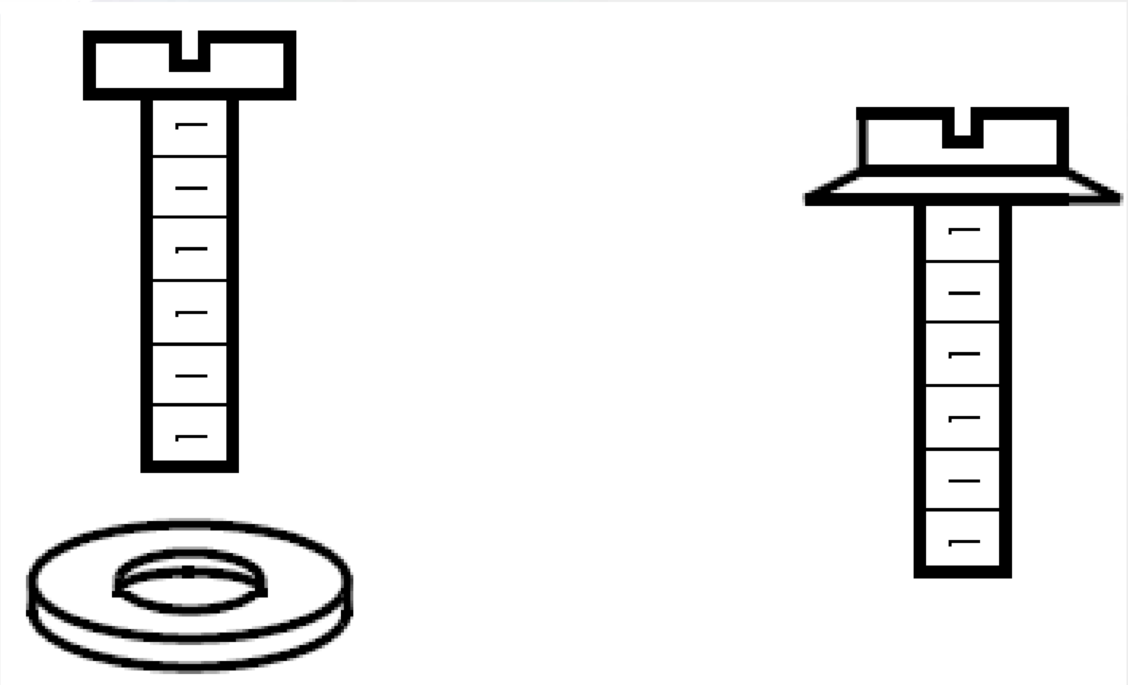
Snap fittings

ASIDE:

Basically these catches are designed to be deflected during assembly, but to not have any forces on them after assembly. This will prevent creep of the plastic. Care must be exercised during design to make sure the plastic is not permanently deformed.

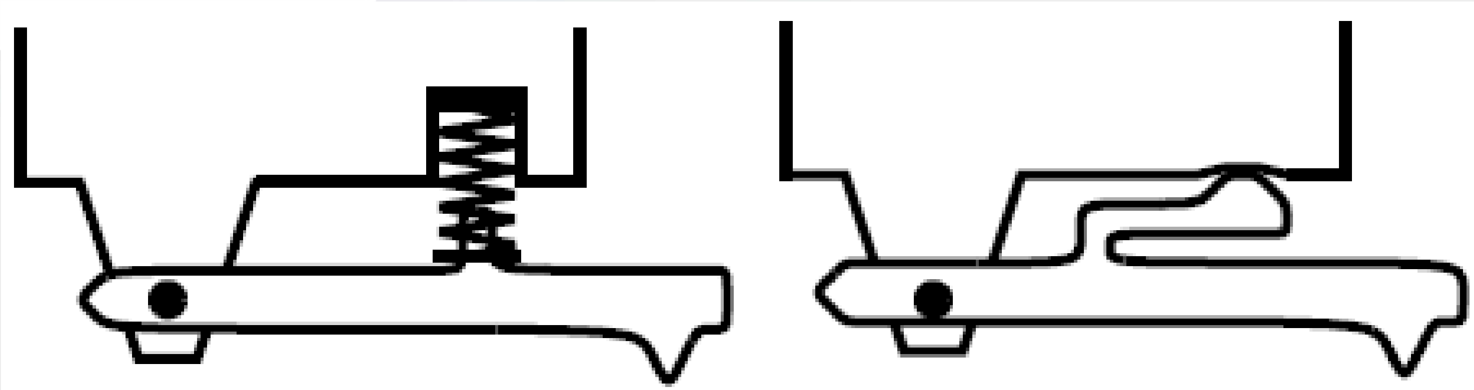
Reducing the Number of Parts

4. If screws must be used try integrating washers with the screw heads, this will eliminate at least one part.



Reducing the Number of Parts

5. Replace separate springs with parts with thin sections that act as springs.



Reducing the Number of Parts

6. When screws are required (often for maintenance) try to reduce the number to a minimum.
7. Cables can be eliminated for a reduction in cost, and an increase in reliability, and access for maintenance. Card edge connectors, and PCBs will be slightly higher in material costs, but the boards are simply plugged together. If cables are strung between boards and other boards/components, they will require additional time for soldering, be the source of soldering quality problems, and make the boards tricky to orient, etc.

Feeding and Orienting Parts

- It must be considered that more complicated parts require greater handling time to properly orient them.

- Part Tangling/Nesting
- It should be considered that when small parts are shipped, they come in bulk lots. (large/more expensive parts are often shipped in pallets, or separately.