

Engineer On a Disk

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Design Topics

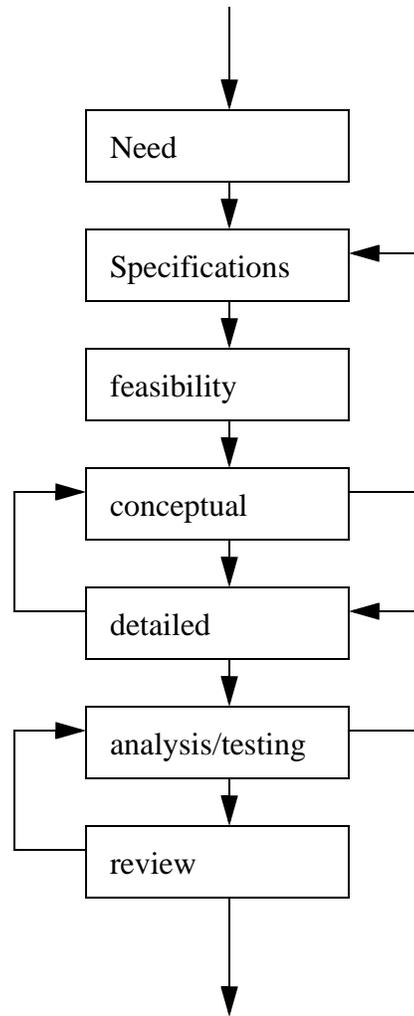
DI:2. BASIC DESIGN

- 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.

- 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 is typically referred to as having certain stages,
 - Conceptual
 - Synthesis
 - Detailed
 - Analysis

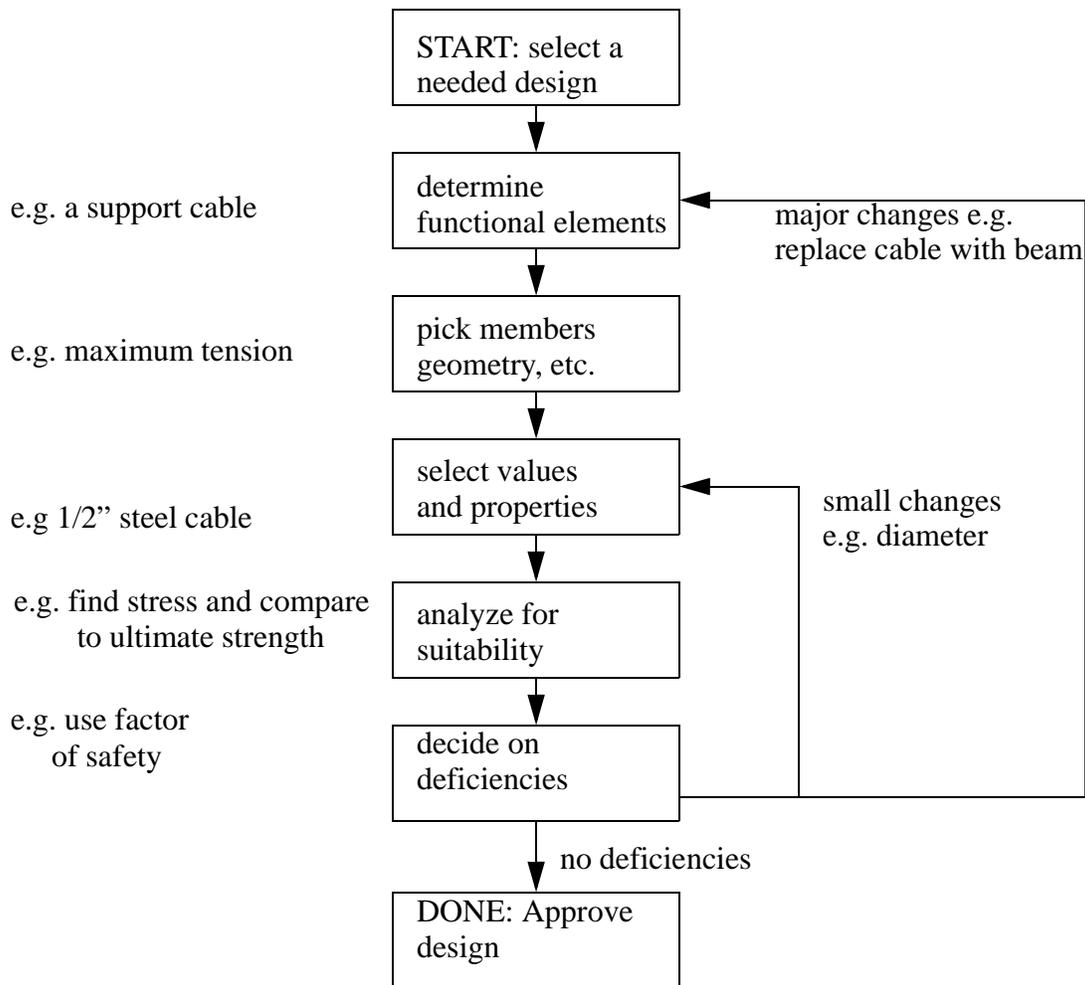
- The typical stages of design include,



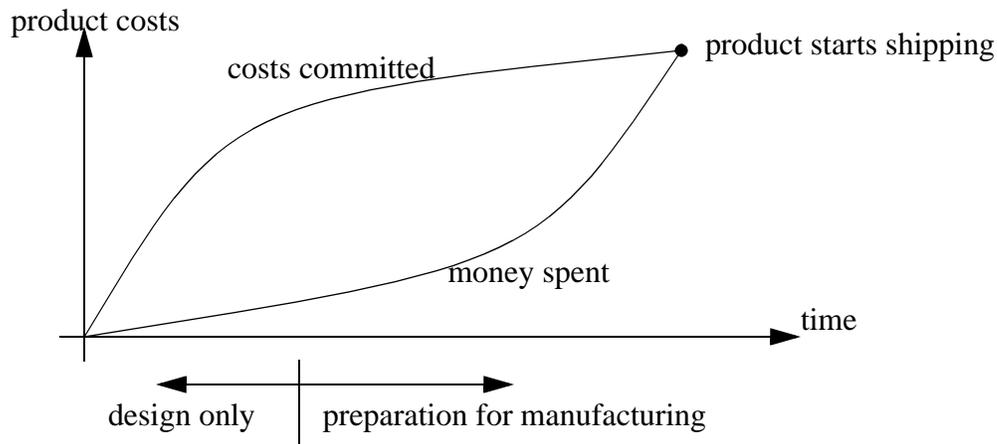
- Design factors commonly considered are,

- functional requirements
- physical constraints
- specifications
- aesthetics
- usability/user interface
- cost
- manufacturing
- evaluation/testing/analysis
- maintenance
- retirement

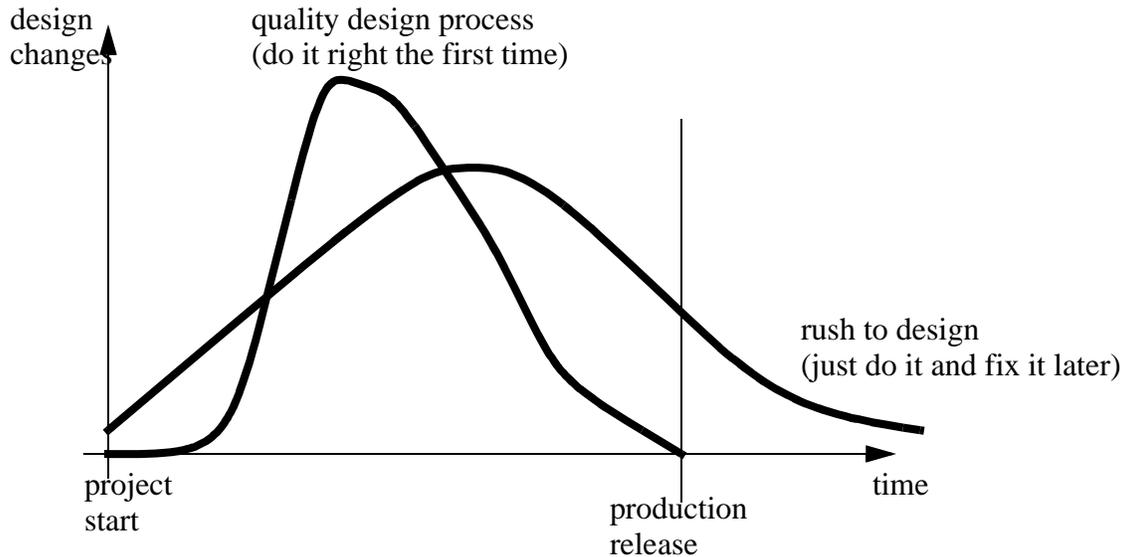
- A more detailed design sequence is shown below,



- 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.
- 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.



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



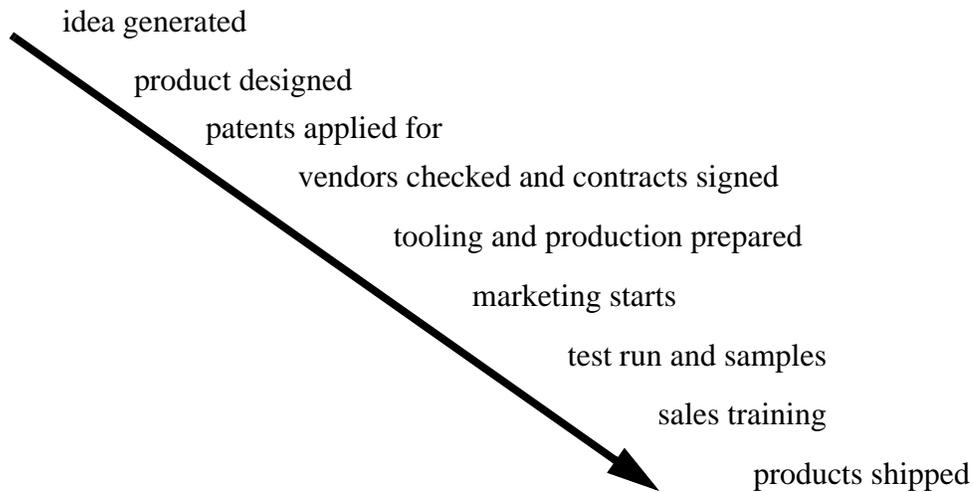
- Over-the-wall is an engineering approach that has developed because of management pressures. It helps split designs into clean stages and responsibilities. This approach does simplify management up front, but requires fire fighting as problems arise.
- A product life cycle has four phases,
 1. Identify needs, plan and design
 2. Manufacture and deliver
 3. Use, maintain, repair
 4. Retire

DI:2.1 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:3. COMMERCIAL

- The commercial view of product development typically looks like,



- Other significant functions that will be considered are,
 - documentation user/service manuals
 - maintenance/service/installation training
 - packaging
 - government forms in regulated industries
 - business plans for financing - banks or venture capital
 - market survey and testing

3.1 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:4. PRODUCT DESIGN

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

configuration	function	substituting
connection	interface	transition
components	magnifying	
copying	rearranging	
decomposing	refine	
form	reversing	

DI:4.1 LEGAL DESIGN AXIOMS

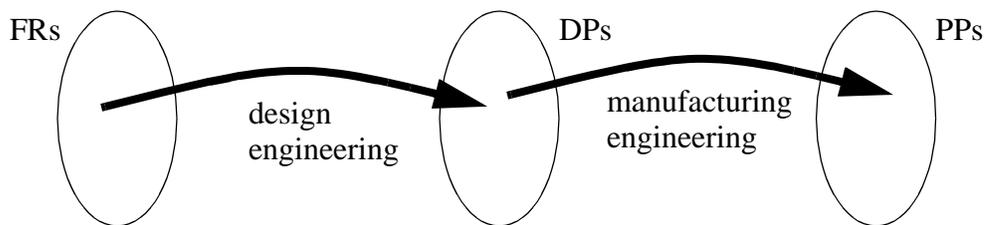
- Some rules to follow to reduce the chance/success of a law suit
 - the design process should examine hazards and probabilities (e.g., FMEA)
 - make sure that all employees conform to the current standards and legal requirements (e.g. toxicity)
 - inspection and quality control in manufacturing
 - clearly written warning labels and manuals that outline proper use and hazards
 - keep good records of all tests, inspections, etc.

4.2 REFERENCES

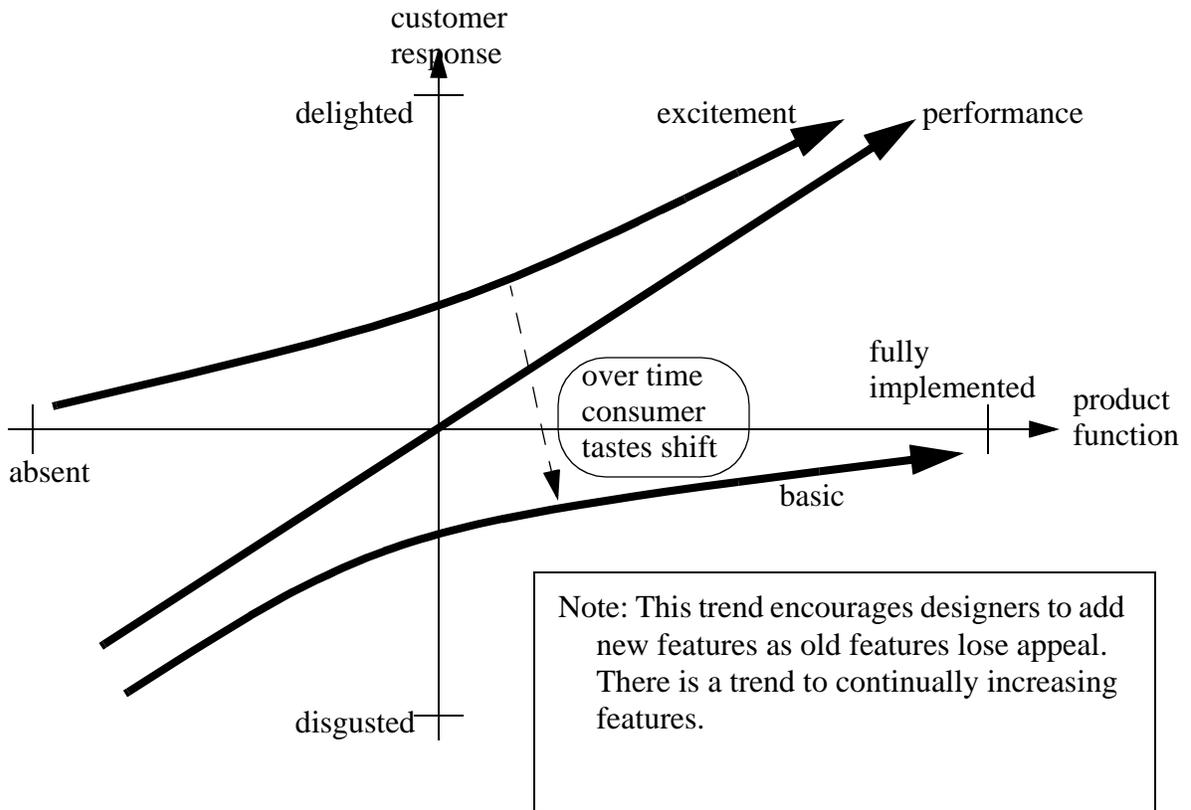
Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:5. SPECIFICATIONS

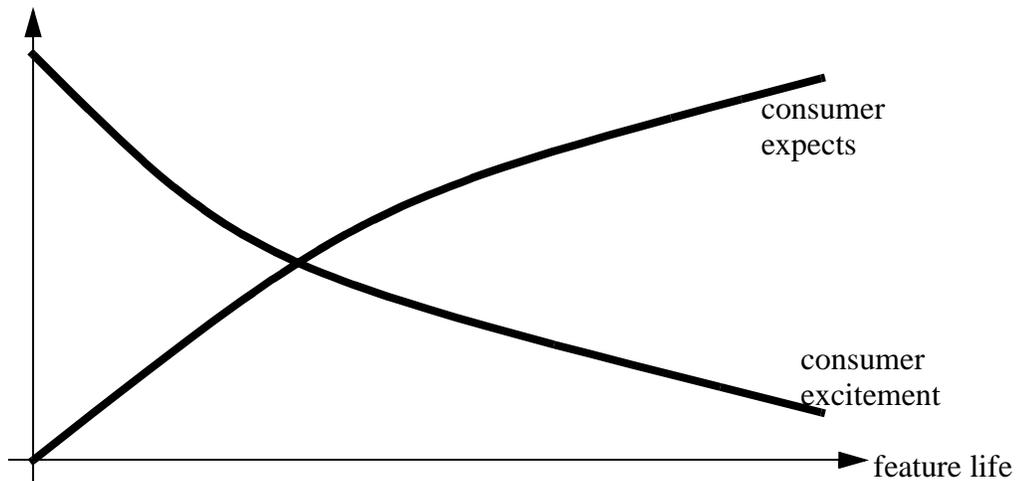
- Specifications are a brief list of functional objectives.
- These are often called Functional Requirements (FRs)
- We can look at the design process as mapping Functional Requirements (FRs) to Design Parameters (DPs). We can also look at mapping from the design parameters to the Process Parameters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



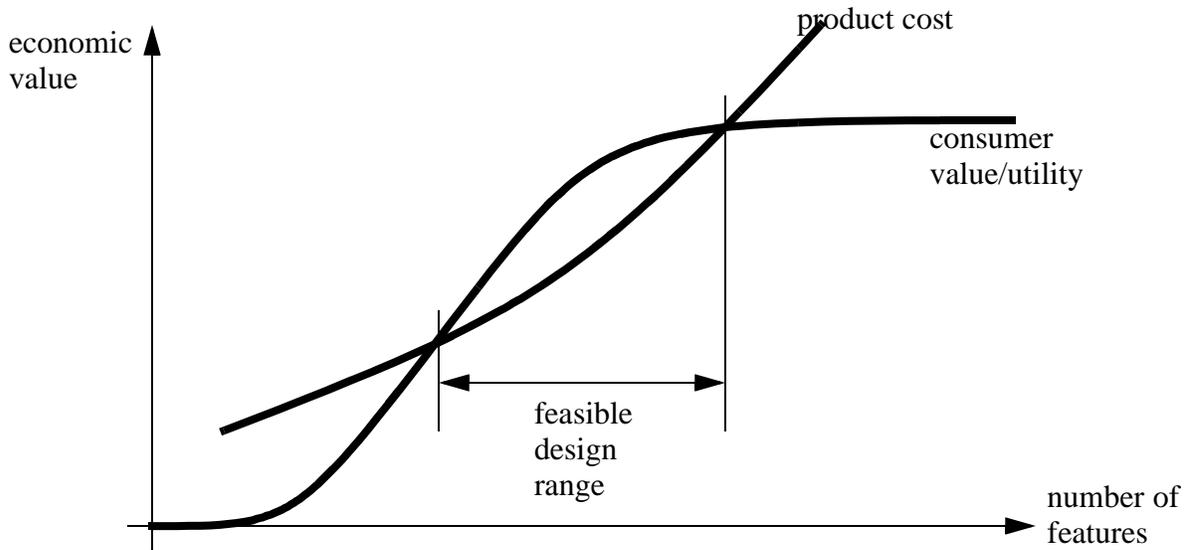
- Examples of DPs could be # of engine cylinders, or a final dimension.
- Good rules of thumb for specifications are,
 - try to talk in general terms that focus on the function instead of solution (e.g., “the automobile should be able to move on ground with a 12 inch variation in height” instead of “the 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.
- In design we should try to meet, not exceed specifications. The Kano model helps to illustrate this [Ullman],



- As an example consider the progress in the computer industry. Specifically Moore's Law - about every 2 years the number of transistors on a chip will double (implies memory doubling, speed doubling, etc) this has proven to be remarkably accurate.
- If we construct a graph we can show how the consumer response shifts as a function of time



- 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.



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

5.1 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:6. DESIGN METHODS

DI:6.1 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 dependence on the manufacturers specifications.

DI:6.2 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:7. 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.

DI:7.1 GENERATION OF CONCEPTS

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

DI:7.1.1 Brain Storming

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

DI:7.1.1.1 - Practice Problems

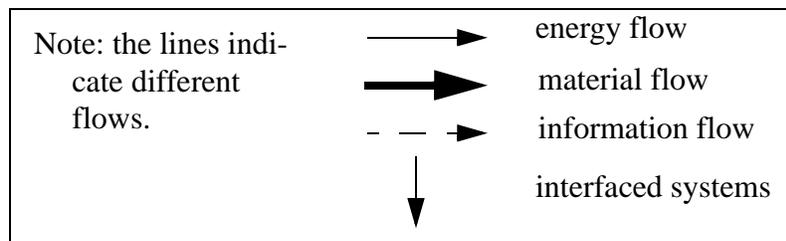
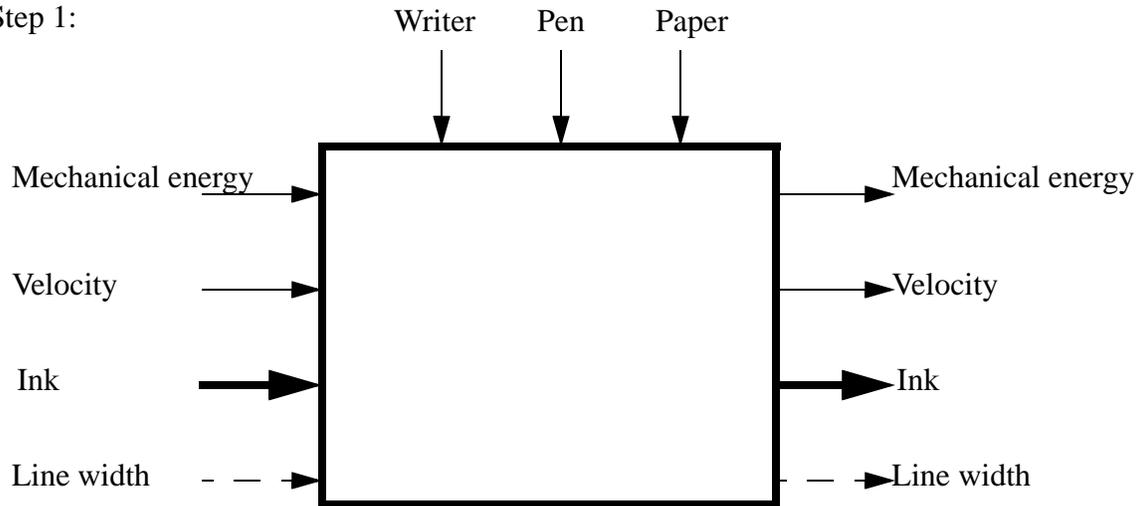
1. Use brain storming to develop concepts for putting on shoes.

DI:7.1.2 Diagramming

- We can break functions down to subfunctions shown as black boxes

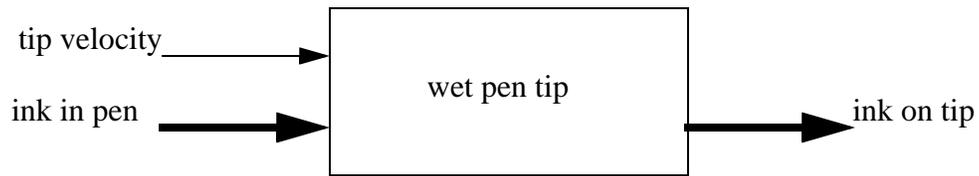
- Basically we draw functional blocks that show interfaced systems and indicating inputs and outputs of information, energy and materials.
- We can start by drawing one main box for a function (e.g., ‘a pen must draw a consistent line width)

Step 1:



- 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
- (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

Step 2:



- 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:

DI:7.1.2.1 - Practice Problems

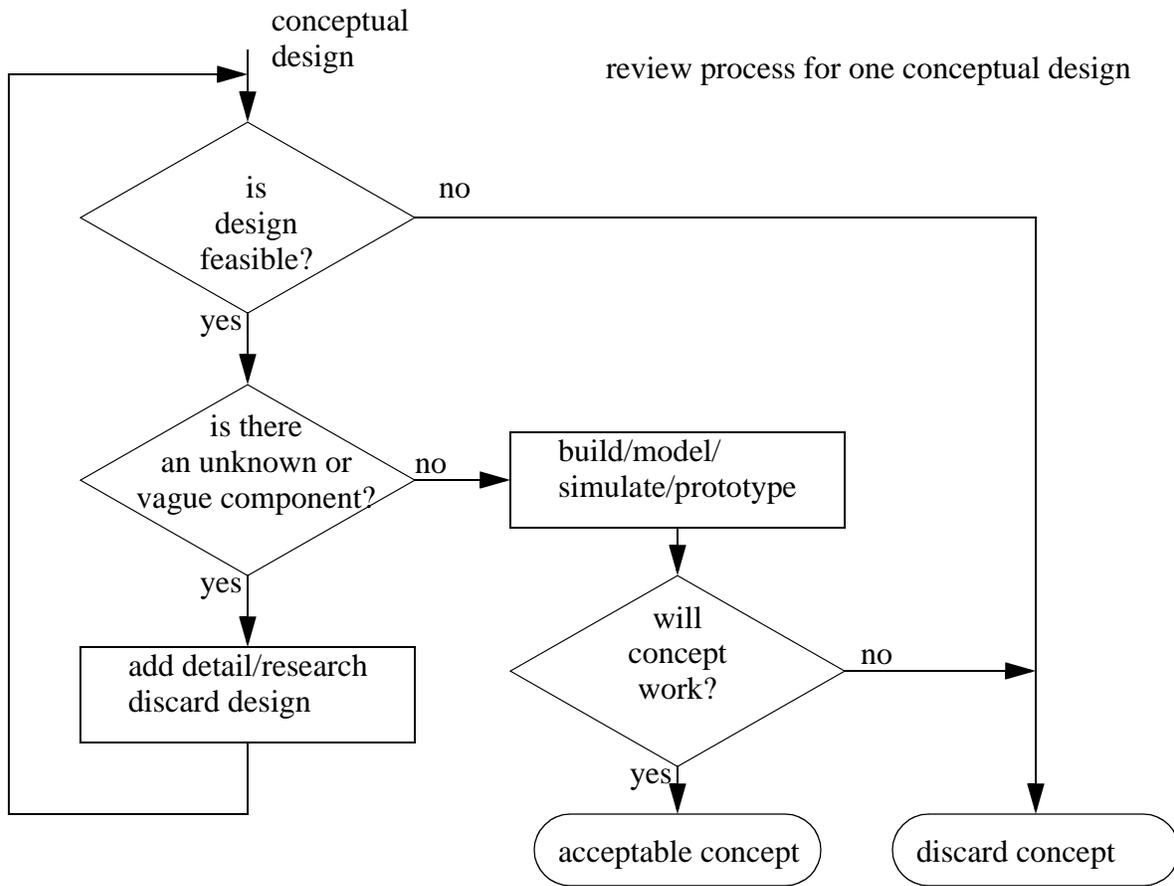
1. Considering the example started in the notes,
 - a) develop more subfunction blocks for the pen
 - b) using the previous blocks, draw a detailed functional diagram
 - c) Develop a final pen design using the final diagram.

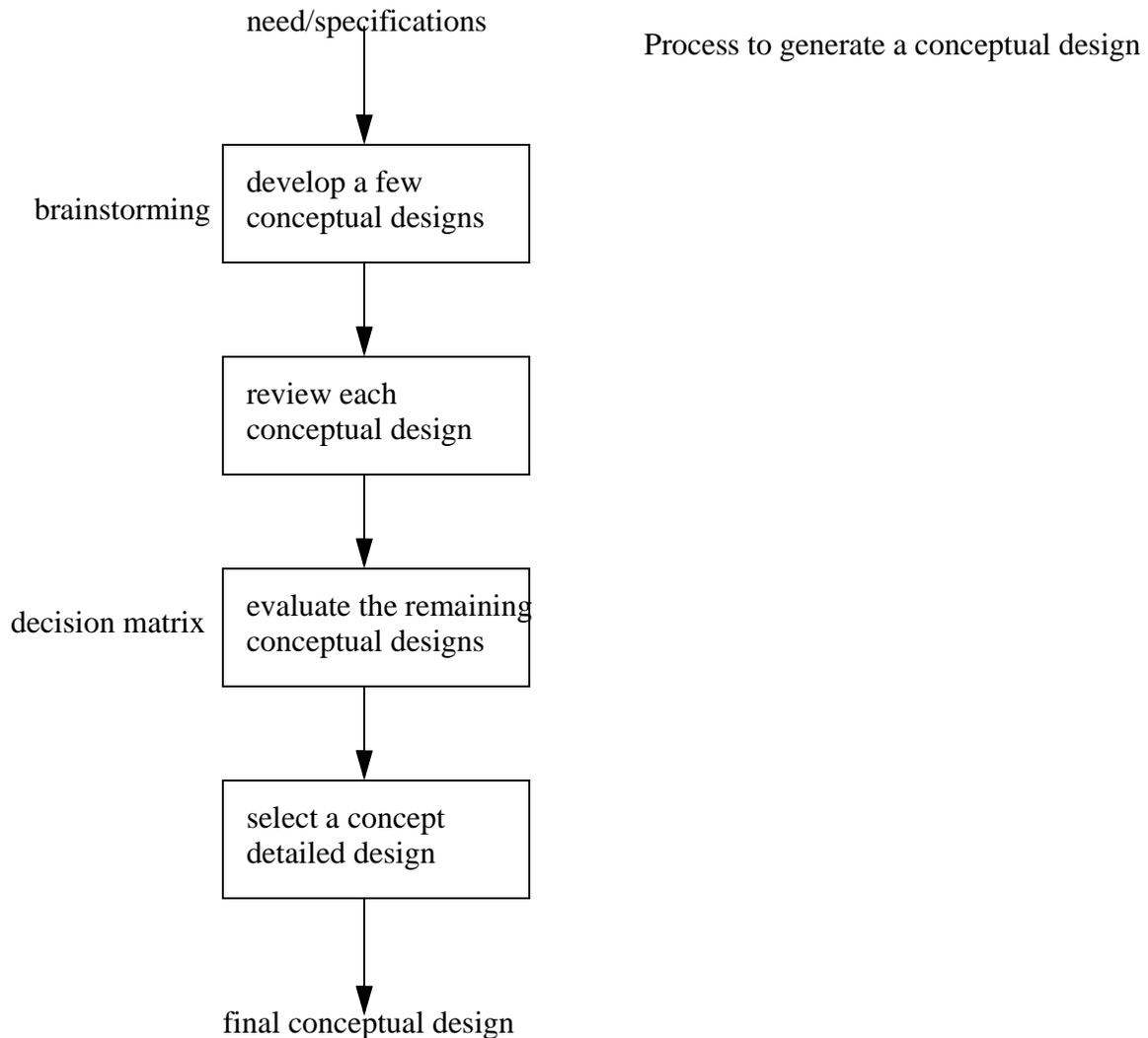
DI:7.1.3 Patents

- 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

DI:7.2 CONCEPT EVALUATION

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





DI:7.2.1 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.
 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).

7.3 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:8. HUMAN FACTORS/ERGONOMICS

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

DI:8.1 ERGONOMICS

- 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 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.)
- Typical ergonomic problems in manufacturing are listed along with possible solutions,
 - discomfort - unneeded 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.
 - 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)
 - 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
 - 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 emissions

DI:8.2 SAFETY

- It is natural for a machine to have hazardous parts/functions/flows.
- If the risk (probability) of coming in contact is high we call this danger
- Typical hazards include,
 - pinch points
 - crushing
 - collision with moving objects
 - falling from heights
 - slippery surfaces
 - explosion
 - electric shock
 - temperature/fire
 - toxicity
 - physical strain
- When possible it is best to eliminate hazards. If this is not possible we want to reduce the risk of access (hence danger).
- OSHA (Occupational Safety and Health Administration) regulates workplace procedures.
- Danger can be reduced by,
 - signs
 - safeguards (e.g. barriers)
 - policies and procedures
 - worker training
 - special protective equipment (e.g. earplugs)
- Typical additions to machines include,
 - barrier guards - physical blocks to separate operators and equipment. Interlocks are used to disable the machine when the barrier is open.
 - passive safety devices - for example seat belts
 - active safety devices - these include
 - hand pull-backs
 - dead-man controls
 - presence sensing devices

- maintenance safety devices - these additions (and procedures) ensure that the machine is still safe, even though the normal safety equipment is disabled.
 - warnings - large warning signs, buzzers, status lights, etc. are used to promote awareness.
- Note: It is important to place safety considerations at the top of the design priorities. It is so obvious that it is quite often assumed.

DI:8.2.1 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
- 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)

DI:8.2.2 MIL-STD 882B - System Safety Program Requirements

- This standard addresses the likelihood and acceptability of hazards.
- The basic tables are,

	I Catastrophic	II Critical	III Marginal	IV Negligable
A. Frequent	1	3	7	13
B. Probable	2	5	9	16
C. Occasional	4	6	11	18
D. Remote	8	10	14	19
E. Improbable	12	15	17	20

Risk Index	Criterion
1-5	unacceptable
6-9	undesirable
10-17	acceptable with review
18-20	acceptable with no review

Category	Description	Definition
I	catastrophic	death or equipment loss
II	critical	major injury, illness or system failure
III	marginal	minor injury, illness or system failure
IV	negligable	insignificant loss of function

Level	Description	Single Item	Inventory
A	frequent	happens often	allways happening
B	probable	occurs several times over life of product	occurs frequently
C	occasional	will occur sometime over life of product	occurs several times
D	remote	may occur during life of product	not often
E	improbable	rarely occurs	rarely

DI:8.3 HUMAN STRENGTH AND PROPORTIONS

- When designing we can use statistical values of human proportions to set sizes of components, forces, etc.

- These tables are available from a number of sources such as NASA. There is a set of tables in the back of the text book.

DI:8.4 EQUIPMENT INTERFACES

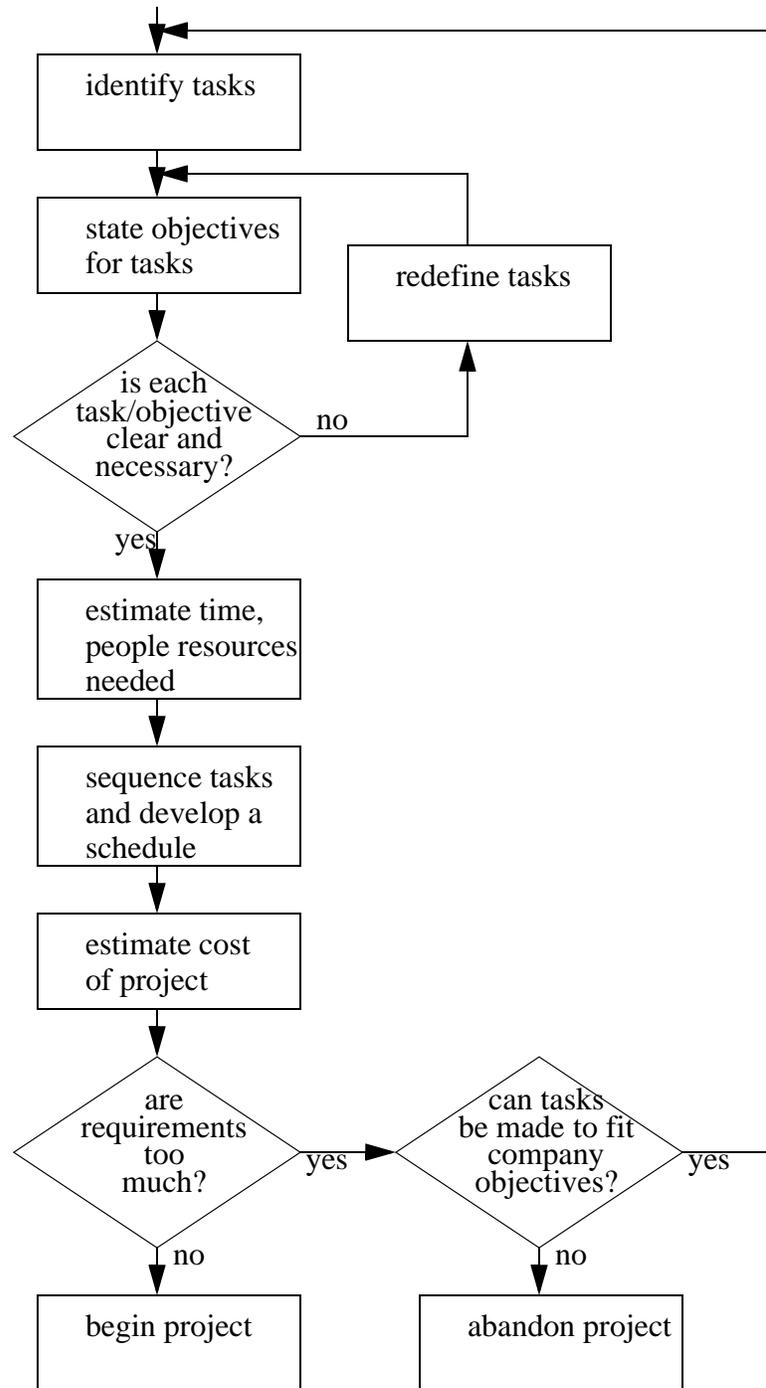
- When a human interacts with a machine they use controls to begin actions, and displays to monitor status.
- Typical controls include,
 - switches (push, toggle, touch, etc.)
 - sliders, knobs
 -
- Typical displays include
 - indicator lights
 - audible tones (buzzers, beeps, bells, etc.)
 -

8.5 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:9. MANAGEMENT

- Management differs from administration in that it sets a new course working on the policy making level - administration follows policy. There are many levels of administration and management.
- Questions that a manager will consider before putting together a design activity include,
 - Is the design for a small batch or mass production? smaller batches don't require as much effort in refining the design. The design cost becomes a significant part of the final cost.
 - Is the design an improvement or redesign of an existing product, or is it new? Product improvement/variation can be done with minimal technical effort. The amount of technical effort increases dramatically as we go to a new design.
 - What design functions are anticipated? This determines the types of roles on a design team. (These are listed in approximate order of responsibility and authority). Note: All of these roles are important in a successful design. There should be people assigned to each explicitly.
 1. Marketing/Product manager - makes major market/customer decisions
 1. Design Engineer - Makes major technical decisions and assesses results
 2. Manufacturing engineer - makes decisions about production of product
 2. Designer/Engineer - does detailed design work based on major decisions
 3. Quality control engineer - evaluates quality problems and opportunities
 3. Materials specialist - selects materials
 3. Industrial designer - makes aesthetic decisions (typically an artist)
 4. Drafter - completes drawings of parts
 4. Technician - builds, tests, evaluates product
 4. Vendor/Supplier Representative - a product manager from another company
 - How does the design naturally break into manageable parts? The team can be constant members in a static structure, or can have shifting responsibility and structure. An innovative design must allow more freedom and a dynamic structure. A well defined design should be use a clear structure and set of tasks.
 - How much time does the design require? Based on experience and some calculations a manager can set milestones for a design team. Typical tasks might include,
 - set specifications
 - generate concepts
 - test concepts with prototype/simulation
 - do detailed design
 - build full prototype
 - test and evaluate prototype
 - plan for tooling and production
 - test runs
 - full runs
- A manager will tend to follow a set of steps when planning,



DI:9.1 PRACTICE PROBLEMS

1. Consider a typical pen,
 - a) a design improvement to change one unappealing feature.

- b) to design a similar competitive product.
- c) to design a radically new, but functionally equivalent product.

9.2 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:10. DESIGN TEAMS

- Selecting team membership appropriately increased the chance of success in the design.

DI:10.1 TEAM PROFILES

- To select members of teams we must consider psychological factors and the general objectives of a design.

DI:10.1.1 Personalities

- We can develop categories of people by using some indicators of personality (this is not to be taken too seriously).

DI:10.1.1.1 - Personality Traits

- In terms of organizational behavior there are some traits (note - not strengths) that may be identified. A personality can be made up of a combination of these traits.
 - a. detail oriented - pays a great amount of attention to information. Investigative in nature. This person does not like lingering questions, etc. A large amount of time will be spent trying to prove things completely
 - b. planning/organization - looks forward and lays out steps. Prefers a well ordered sequence and wants to know/decide what will happen next and on.
 - c. innovator - breaks traditional molds. This person does not mind changing direction and will invent unexpected solutions.
 - d. concrete/constructor - A 'touchy-feely' person that move easily into implementation. This person is skills oriented and will take pleasure in the practice/methods of developing a solution.
- A good team will overall have a combination of each of these traits.
- As an exercise,
 1. pick a partner.
 2. for your partner, write down a number from 1 to 4 for the points above. The total score cannot be above 10. Don't let your partner see your numbers.
 3. write down similar numbers for yourself.
 4. talk to your partner about the numbers you got, compared to what they gave you.

DI:10.1.1.2 - Personality Types

- We can also classify individuals as,
 - introverts/extroverts
 - concept/detail oriented
 - subjective/objective
 - decisive/flexible

- When introverted individuals are encountered,
 - encourage them to speak out
 - make team members aware of the introverts message
 - use introverts to “check” extroverts

- Extroverted individuals may require,
 - slow them down and allow time for thought
 - make extroverts listen to others and repeat
 - ensure they don't “dominate” the group

- Fact oriented people,
 - need to be encouraged to think wildly
 - need to plan/set goals before starting

- Concept oriented people,
 - need to be grounded in detail and should be asked to explain in detail.
 - keep these individuals on track

- As an exercise, consider what to do with the remaining two personality types to make a design team more effective.

subjective

objective

decisive

flexible

DI:10.1.2 Team Composition

- Typical personality types found on a team might include,
 - coordinator - a natural leader
 - creator - develops new ideas
 - resource/investigator - does “leg-work”
 - shaper - problem solver
 - monitor/evaluator - has vision
 - team worker - dislikes dissent
 - implementor - uses tried methods well
 - completer/finisher - gets things done
- A good team will have some combination of all of these.

DI:10.1.3 Team Success

- Some guidelines for a successful team,
 1. Productivity - a well laid out (realistic) set of goals, purpose and methods will lead to an enthusiastic team.
 2. Composition - technically capable and well matched personalities
 3. Methods - lay out the problem solving styles and techniques
 4. Immediate Gratification - devise goals and objectives to develop frequent feelings of accomplishment
 5. Bonding - team members should spend time to develop personal relationships

10.2 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:11. ADMINISTRATION

- We need to determine the day-to-day (administration) needs of a design team.
- In terms of the design process there is a continual cycle of,
 1. identifying problems
 2. devising solutions
 3. evaluating the solutions
 4. deciding to accept, retry, terminate
- The specifications are repeatedly used to guide all phases of the design work. A design not conforming to the specs is useless.

11.1 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:12. CONCURRENT ENGINEERING

DI:12.1 OVERVIEW

Rework and summary required in this section

- Concurrent engineering is a common sense approach to product design.
- Originally (hundreds of years ago) the designer was also the person who produced the design. So during the design phase they considered production problems.
- As designs, and manufacturing methods became more complex, it became necessary to break down design and manufacture to more specific tasks.
- These areas of specialization caused different functions to arise in an enterprise. So it became common for the designer to have little, or nothing to do with production.
- For many years designs tended to be thrown over-the-wall. This was effective in big companies, but some problems arose as a result,
 - The designer did not always understand the results of his decisions
 - More time was spent trying to get a design to work right
- But, now with the aid of computers, and other information tools, we are able to close the gap between the designer, and production. Hence, concurrent engineering.
- Reasons for using the traditional design methods,
 - Product development is traditionally its own organization and is physically and organizationally isolated.
 - Process development and production operations are located together in a different organization labeled manufacturing.
 - Most emphasis is on manufacturing operations, that is, shipping product out the door.
- Problems with current design methods,
 - The design is driven by scheduled deliverable data items. There is pressure for drawings and specifications, which leads to a depth-first design search. Design alternatives are quickly eliminated in the interest of time, and one particular idea is pursued.
 - The definition of design detail is costly in labor hours. Even with CAD/CAM tools, much manual effort is needed. It would be better to delay this task until the design is somewhat optimized.
 - The design process is characterized by a rigid sequence of design decisions. The ultimate goal is usually lower cost, when the goals should include optimal performance and ease of manufacture.

- Producability and supportability issues are not considered until relatively late in the process, when a design change may be very costly.
 - Production planning, support analysis, maintenance, and reliability are considered separately from the design process. The designers are left on their own to select the particular set of utilities considered in the first design iteration.
 - Design data is fragmented. Documentation includes CAD files, dimensioned component drawings, sketches, process drawings, 3-D solid models, etc. It is difficult, if not impossible to maintain consistency at all times across these representations.
 - Information is lost as the design progresses. The design intent may be lost by the time the documentation gets to the producability experts. They then must rely on experience and luck in guessing what changes can be made to make the item producible and also functional. Ideally, the reasons for the design features would be included in the design documentation.
 - Designers are usually not aware of cost information, so they cannot intelligently set cost reduction as a realistic goal. Companies do not release cost information routinely. There are no tools for estimating costs as there are for other design domains, and when the costs are calculated, it is often too late to make major design changes.
- Some of the goals of concurrent engineering are,
 - Avoiding component features that are unnecessarily expensive to produce. This often happens because when a decision is made about a manufacturing feature, there is often a lack of information about the effect of the decision.
 - Minimizing Material Costs, and selecting better materials.
 - Concurrent Engineering means that during design, we consider more than just the design, we also consider how to make it, how to package it, and all of the other functions that were previously left-for-later.
 - The development of Concurrent engineering can be traced to 1979 Xerox, HP & Ford look at design practices, and foreign competition. Many small developments since then.
 - Important tasks for a concurrent engineering team are,
 1. Define the design concept as behavior - The design team must define exactly how a product must perform, and rank the options. This will tend to focus the multidisciplinary team.
 2. Define error recovery procedures - In effect the team must now define the challenges which the product will face. For example, if we are designing a transmission, what are the possible failure modes the transmission may face, or stacking for shipping.
 3. Define how components interact - As components are defined, and detailed, their interdependence must be considered. At this stage the power of the multidisciplinary team becomes important. If all team members participate, most problems can be eliminated before they become problems.
 4. Define product integration and testing procedures - The group as a whole define how the product will be brought together, and tested. This ensures that original design intent is present in the final product, and also the final product should be manufacturable with very little backtracking.

DI:12.2 DOING CONCURRENT ENGINEERING

[find - source]

1. From the start, include all domains of expertise as active participants in the design effort.
2. Resist making irreversible decision before they must be made.
3. Perform continuous optimization of product and process.
4. Identify product concepts that are inherently easy to manufacture.
5. Focus on component design for manufacture and assembly.
6. Integrate the manufacturing process design and product design that best match needs and requirements.
7. Convert concept to manufacturable, salable, usable design by stating all constraints.
8. Anticipate fabrication and assembly methods and problems.
9. Reduce number of parts.
10. Increase interchangeability between models.
11. Define subassemblies to allow models to differ by the subassemblies.
12. Standardize fastener types and sizes; use low-cost, irreversible fasteners only where a skilled serviceperson would work.
13. Improve robustness of product and process.
14. Identify difficult process steps for which costs and process times cannot be predicted.
15. Use existing processes and facilities so that product yield is high.
16. Break down products and processes into self-contained modules and assembly lines.
17. Adjust tolerances to eliminate failures during assembly.
18. Identify testable areas.
19. Make assembly easier by minimizing setups and reorientations.
20. Design parts for feeding and insertion.
21. Determine character of product; what design and production methods are appropriate.
22. Subject the product to a product function analysis to ensure rational design.
23. Carry out design for producability and usability study; can these two be improved without impairing function ?
24. Design fabrication and assembly process
25. Design assembly sequence
26. Identify subassemblies
27. Integrate quality control strategy with assembly.
28. Design each part so that tolerances are compatible with assembly method and fabrication costs are compatible with cost goals.
29. Design factory system to fully involve production workers in the production strategy, operate on minimum inventory, and integrate with vendor capabilities.

DI:12.3 FUTURE TOOLS FOR CONCURRENT ENGINEERING

- More computer tools are becoming available for breaking down the barriers between the 'Islands' of automation.
- Some tasks have been defined for evolving software to support concurrent engineering. [get source]
 1. Interoperable tools and tasks - Develop standards for file transfer, so that software may pass information freely between various engineering systems.
 2. Interoperable computing environment - The differences between different computers, from different vendors should be eliminated, or at least made to be insignificant. This will overcome the need for separated systems which occurs now. This also extends to other aspects of computing technology, such as User interfaces, Database interfaces, Files management systems.
 3. Data management - Basically integrate all information into a single framework, so that transferring information is no longer an issue. An example of this is a single database which would serve all software in a facility, so that there is no need for transferring designs, and other information.
 4. Process management - At present human judgement is still required to initiate any, and all processes in an automated environment. If the computers could be made to automatically review designs, or forward information the interested parties, then the computer would create an automated framework for concurrent engineering.
 5. Decision support - While most of the other 4 developments are concerned with the design information. We would eventually require tools that examine the work done by the group, and determine which aspects of the design still need to be performed, or are insufficient. In effect, the computer takes on some of the management tasks.
- As the 5 stages above develop the focus changes from data to knowledge, and from simple storage of files, to shared collaboration of data.

DI:12.4 SOFTWARE CONCURRENT ENGINEERING

- A number of software tools have been developed which make it possible to consider later stages of a product life during the design stage.
- There are some standard tools like FEA for failure analysis, but there are also tools which use knowledge about a problem domain to suggest design changes.

DI:12.5 METHODS

- Some methods have already been identified for supporting concurrent engineering, [get source]

Axiomatic Design - This topic applies methods such as Nam Suh's theories so that production costs, and problems can be eliminated in the design stage by following the rules. An example of an axiom would be "Everything being equal, conserve materials".

Design For Manufacturing (DFM) guidelines - Methods which focus on rules for simplifying manufacturing in general. An example of one of these rules is "Use known and proven vendors and suppliers".

Design For Assembly (DFA) - A method for evaluating whether designs may be assembled quickly, and effectively. An example is "Use tapers to align parts which must be mated".

Taguchi Methods - Experimental methods for determining sensitivity of design factors to change. This allows designs to be made less sensitive to variations in the production process.

Group Technology - A number is given to a part. The number tends to identify what the part is. Similar parts will have similar numbers. As a result it becomes easy to use similar designs, and process plans. The use of standards allows problems discovered before to be considered.

Failure-Mode and Effects Analysis (FMEA) - Estimates of failures, and possible outcomes can be examined before the part ever reaches production, and provisions may be made in the design phase.

Value Engineering - During the design stage, an attempt is made to evaluate all of the parts in a design, and decide what their value to the customer is. Financial costs are also considered. This allows a picture of how good the design is before the customer gets it.

Simulation - Simulation is an important aspect of product evaluation. If a production facility does not exist, or a new technology is being used, simulation allows evaluation of production times, costs, efficiencies, and problems, before any equipment is purchased, or designs are finalized. This overlaps with some elements of CAE. For example a simulation of cooling of plastics in an injection mold allow consideration of production problems.

- 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.

12.6 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:13. DESIGN FOR X (DFX)

DI:13.1 OVERVIEW

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

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

DI:13.2 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,
 - 1a. parts are purchased, and put into inventory, or storage bins.
 - 1b. 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)
 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.
- 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.

- 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%

DI:13.2.1 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.

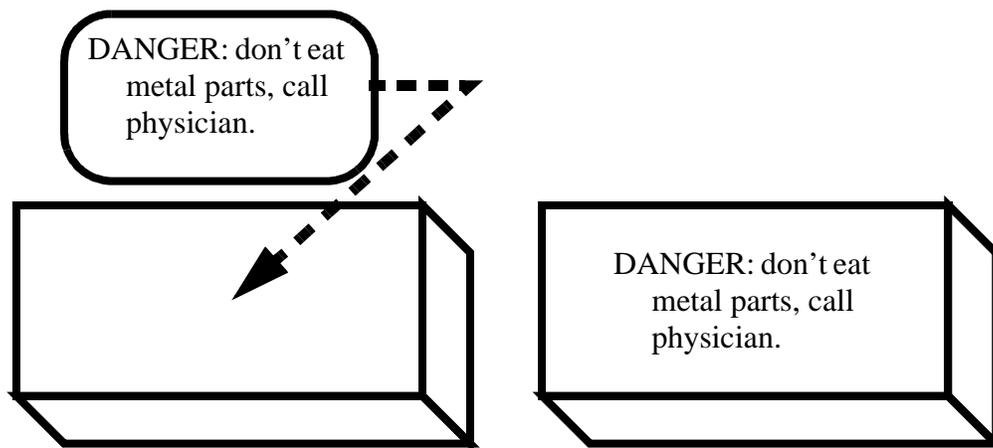
DI:13.2.2 Rules for Manual/Automatic Assembly

- 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
- 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
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

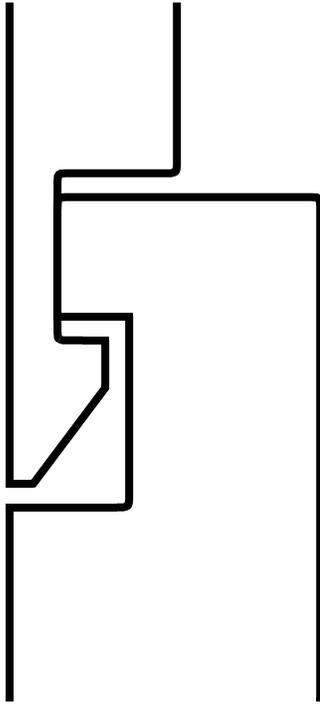
DI:13.2.3 Reducing the Number of Parts

- 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?
- 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. This completely eliminates a part, and the associated operations.

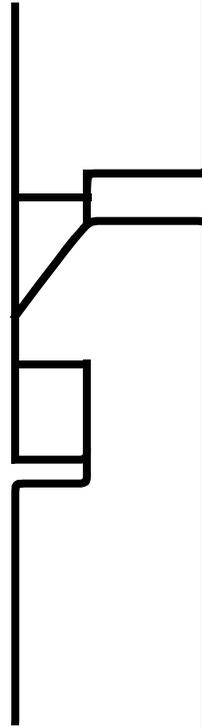


2. In sheet metal parts create features using sheet metal, instead of attaching them with other means. Some examples are,
 - instead of adding hook to a sheet metal part, cut and bend hooks out of the sheet metal
 - don't add screw standoffs to metal, but punch the metal to create a standoff, and tap the hole.

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.



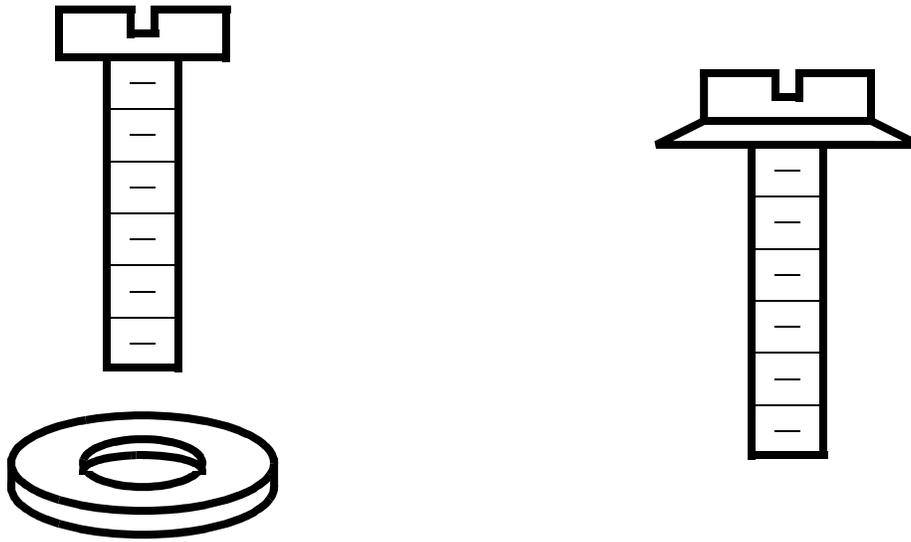
Flexible Catch



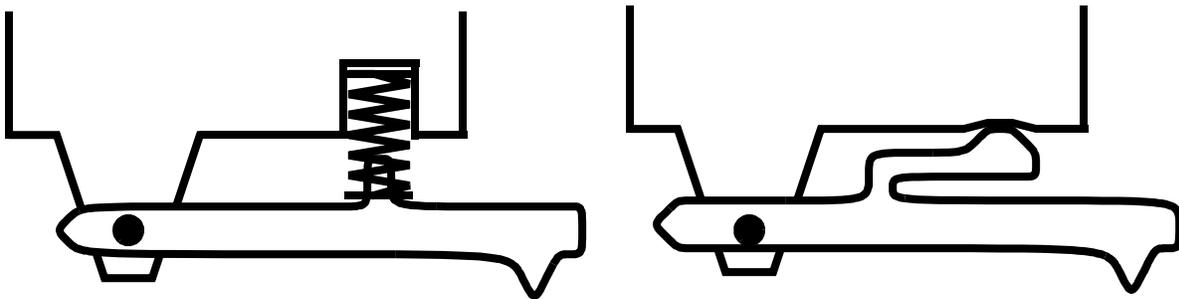
Flexible Detent

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.

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



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



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.

DI:13.2.4 Feeding and Orienting Parts

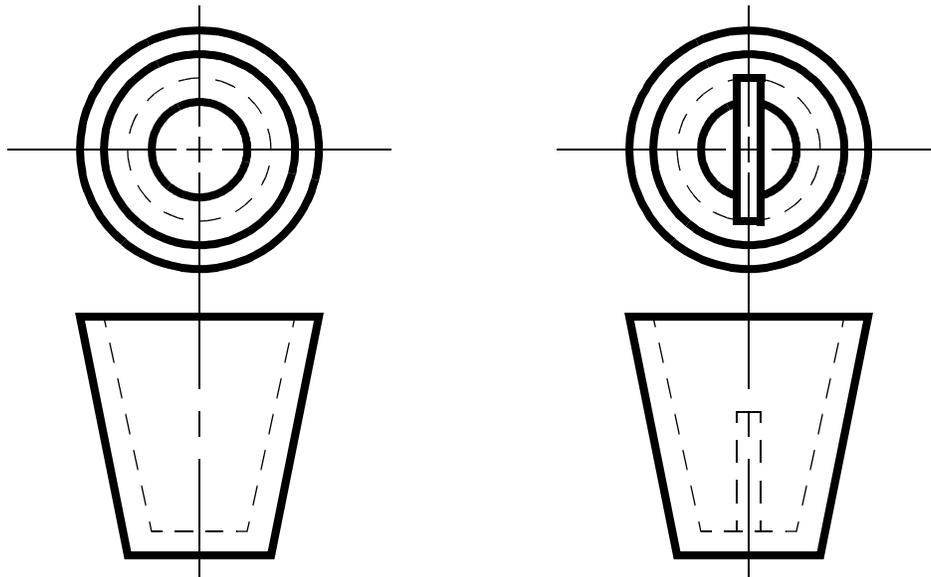
- It must be considered that more complicated parts require greater handling time to properly orient them.

DI:13.2.4.1 - 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.)
- When the parts are stored together, they can sometimes tangle or nest.
 - Tangling - the parts get looped together, making them difficult to separate
 - Nesting - one part gets stuck inside another, much like styrofoam cups.
- The obvious problem with this situation is that the parts often require additional costly human intervention to separate them, and this problem will greatly reduce the success of an automated parts feeder.
- The problems of nesting and tangling can be significantly reduced through small design modification in many cases.
- A few of the problems, and some possible solutions are shown,

PROBLEM: Two shapes can naturally nest, and in the case, suction and friction will hold them in place. [Iredale, 1964]

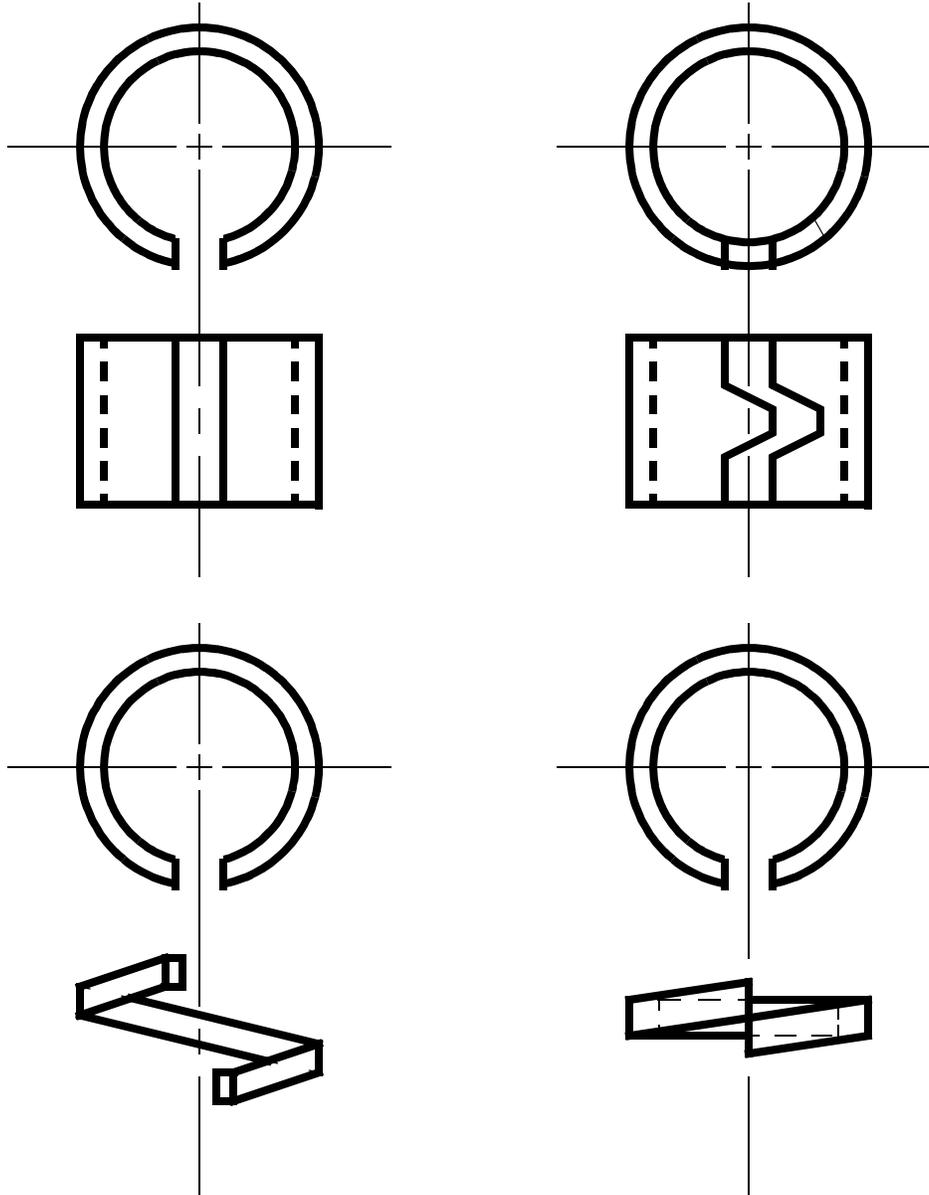
SOLUTION: Put a rib or riser in the bottom to stop the two cups from mating.



PROBLEM: Two split rings can loop over each other, and become tangled.

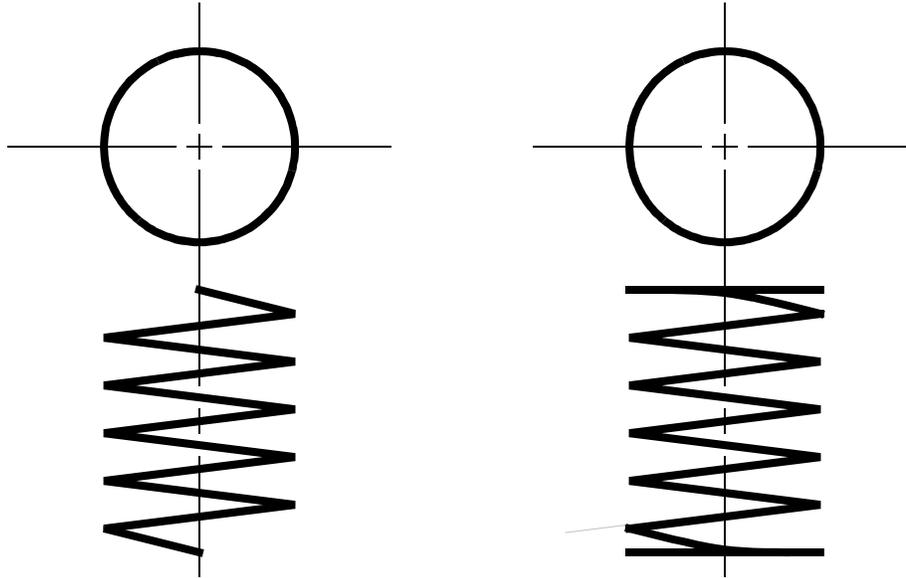
[Iredale, 1964]

SOLUTION: We can't get rid of the split (it is needed for contraction), but we can remove the large gap between the openings.



PROBLEM: Two open ended coil springs will tend to get stuck together quite easily. [Iredale, 1964]

SOLUTION: If the ends are closed, then the springs will not be coiled together except when force is applied.



DI:13.2.4.2 - Handling Parts

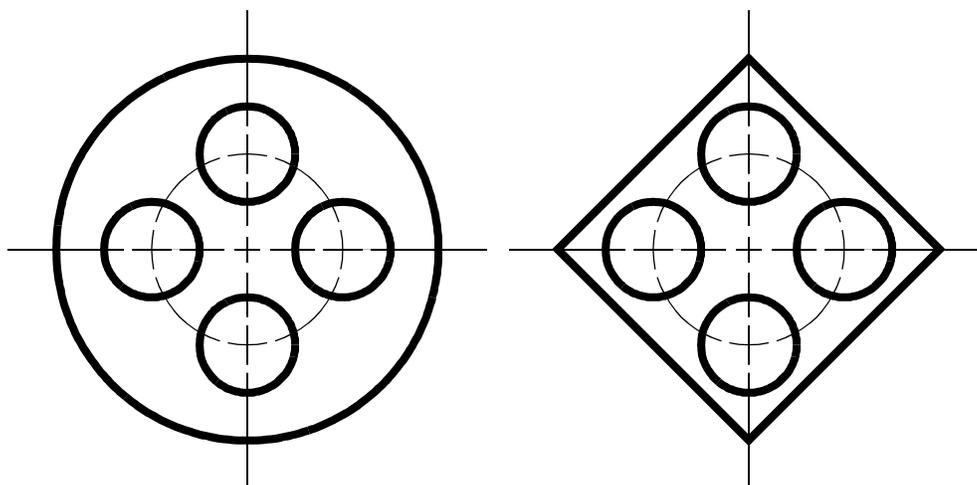
- As parts vary greatly in size we must how it is to be manipulated. The basic categories are,

CATEGORY	DESCRIPTION
One hand with tools	Very small, or delicate objects will have to be grasped with special motion amplifiers, and visual aids.
One hand	Parts can be easily picked up with a single hand
Two Hands	Parts are light enough for one hand, but a second hand is needed for untangling, support, etc.
Two hands/heavy	Both hands are needed for object bulk and/or mass
Multiple people	Two or more workers are required for bulk and/or mass
Heavy lifting tools	Equipment such as lift trucks are required to move parts.

- Other factors to consider when handling parts,
 - are the parts sticky?
 - are the parts fragile?
 - are there any sharp edges?
 - do the parts nest or tangle?
 - are there any parts or tools that the operator must leave the work station to get?

DI:13.2.4.3 - Orienting Parts

- When parts are to be fed, automatically and by human, the task is simplified if certain features are added.
- Basically, symmetry is a major problem for automated feeders.
- In general, a part is easier to orient if,
 1. The orientation is based on internal features, and there are external features that can be used for reference.
 2. Extra features are added to change the centre of mass, or create holding points for features.
- Some examples of parts orientation are,

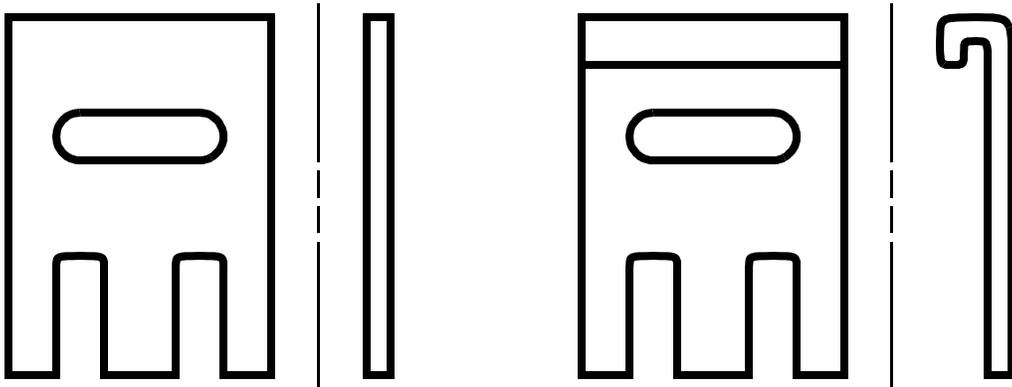


PROBLEM: The part on the left would be hard to locate

SOLUTION: If external features are added to allow orientation without examining the internal holes, the part can be fed easily.

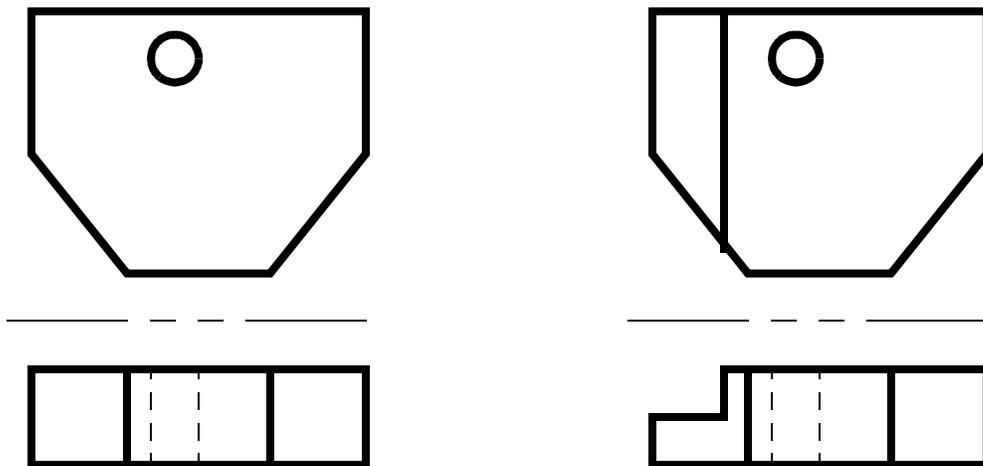
PROBLEM: The sheet metal bracket has no features that would make it easy to orient.

SOLUTION: A lip is added at the top of the part (assuming this won't affect the function), allowing the part to be oriented by suspending it by a wire for part of its travel.



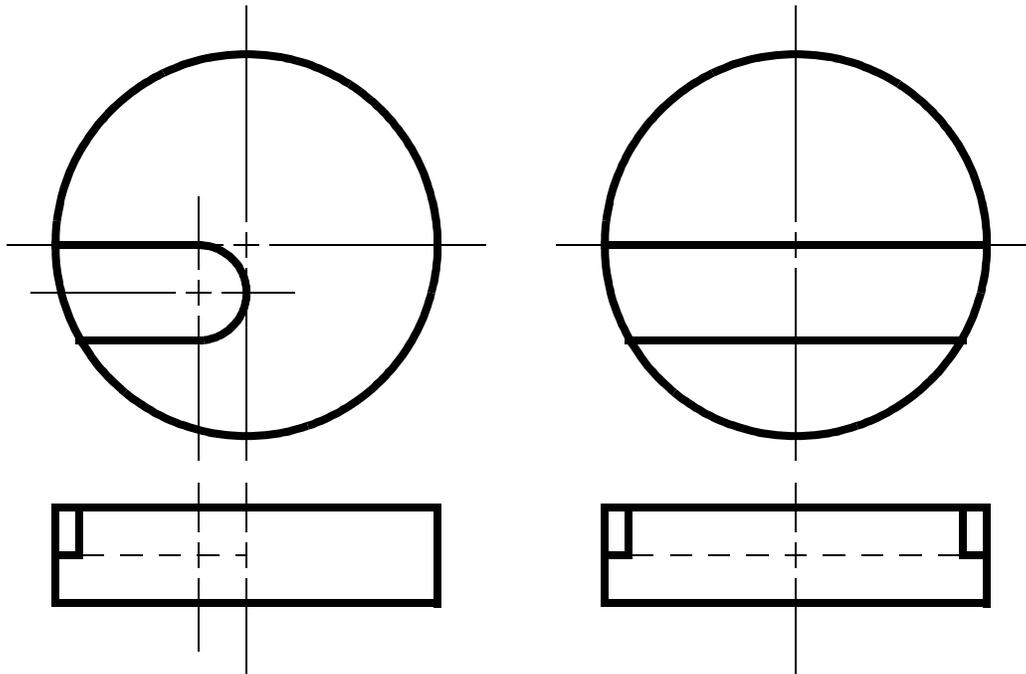
PROBLEM: The hole in the part to the left would be hard to separate locate left to right.

SOLUTION: By cutting a notch on one side, we can use a vibratory bowl feeder to sort the parts by centre of gravity or by track width.



PROBLEM: The feature on the part to the left is not prominent enough to simplify orientation techniques.

SOLUTION: The part to the right will be somewhat easier to orient.

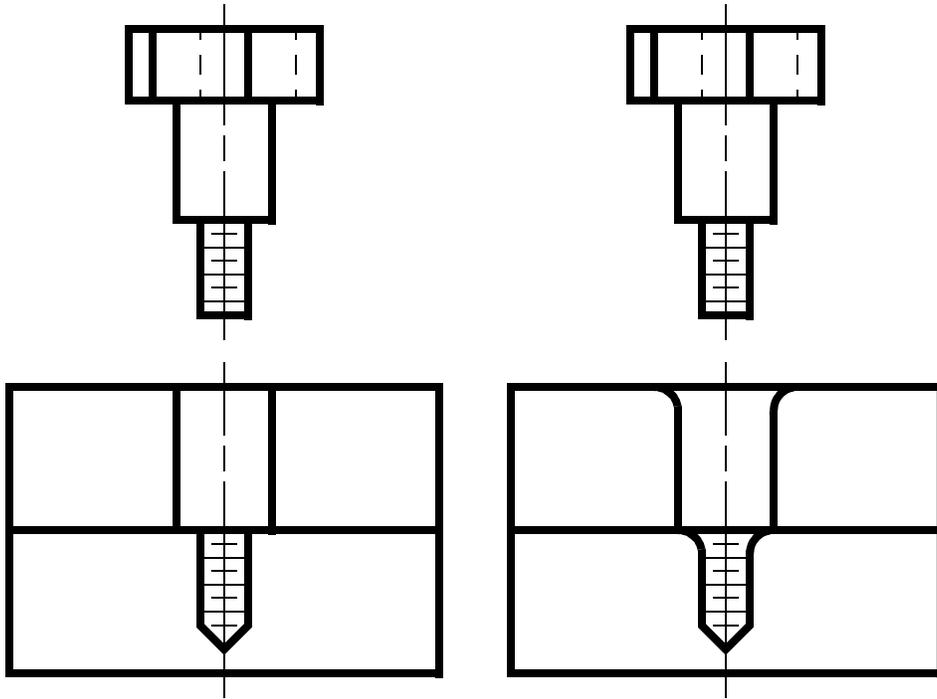


DI:13.2.4.4 - Locating and Aligning Parts

- When we try to thread a needle, the thread is smaller than the hole in the needle, but this does not make threading the hole simple. In fact the process of threading the needle is simplified by the rounded opening on the needle. If the opening of the needle were square it would greatly complicate this problem.
- Much like threading a needle, the problem of mating two parts can be simplified if the parts tend to align and locate themselves.
- If we consider that for one part to mate with another, it must travel along an approach axis. In fact, when the parts are mated the parts will have common axis. We can add guides to the parts to align the axis to be parallel, and to locate the axis so that they are colinear. Hence, the terms aligning and locating.
- Consider the cases given below, and the implications they have for alignment

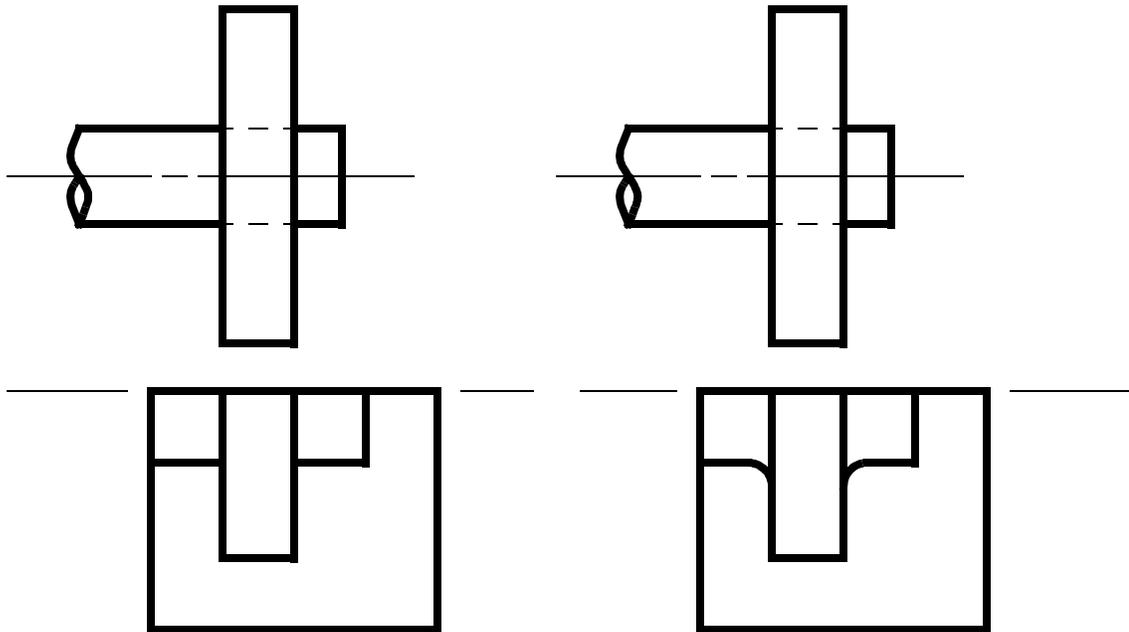
PROBLEM: We are to put a bolt (with a bearing sleeve) in a hole, but it is hard to get the bolt in the hole. At the far side, the bolt must enter a second threaded hole to secure it.

SOLUTION: Put a chamfer on any stage where the bolt must pass through, this will align it, and allow it to slip in..

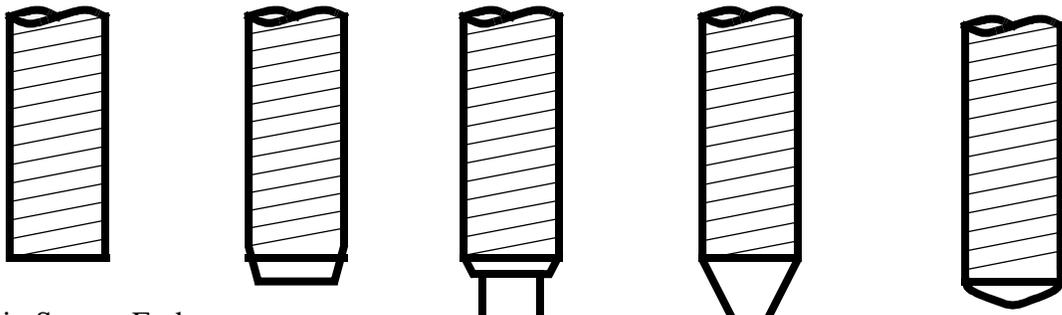


PROBLEM: A roller bearing is to be placed into a support. Just to keep things interesting, the roller bearing has already been press fit onto a shaft. But the sharp edges keep the two from mating easily.

SOLUTION: Put a chamfer on any stage where the bolt must pass through, this will align it, and allow it to slip in.



- Although screws are discouraged in DFA techniques, when they must be used, then we can add some features to help align and locate them.



Plain Square End
(not good for DFA)

Chamfer Point

Dog Point

Cone Point

Oval Point

DI:13.2.4.5 - Part Symmetry

- Perfectly symmetrical parts need no rotation to orient them, completely asymmetrical parts require at most 360° rotation followed by a second 360° to put them in the same position every time.
- There is also a recognition phase required by humans for every orientation. Therefore parts that are not symmetrical, but look as if they are upon quick inspection, will require additional inspection time.
- consider the cases below,

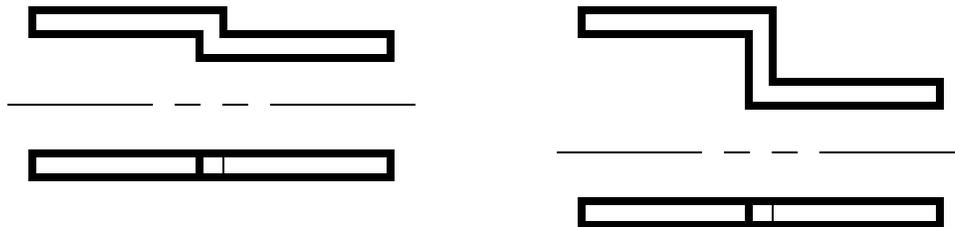
PROBLEM: The part on the left has a stepped shaft at each end, each being slightly different in length. This part can cause three problems: i) it could be installed backwards, ii) a maximum of 360° of rotation might be required, and iii) the operator would require additional time to recognize the orientation.

SOLUTION: Make the steps equal on both sides.



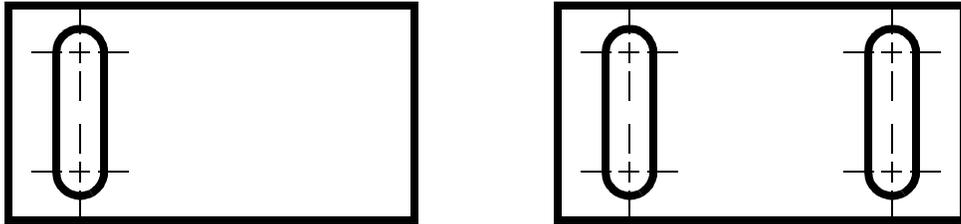
PROBLEM: The offset bar on the left is somewhat thin, and would require some time to determine left/right orientation. If it were small it would also be difficult to manipulate.

SOLUTION: Make the offset a bit larger to make the part easier to handle.



PROBLEM: The part on the left would require some time to rotate, as much as 360° , and also time to identify orientation.

SOLUTION: Put the hole on both sides, and increase symmetry.

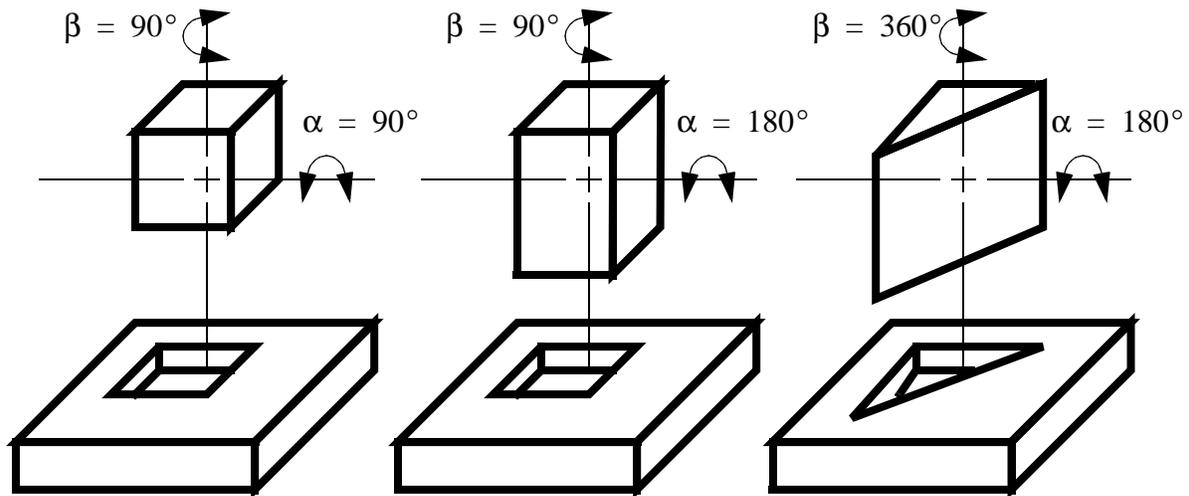


PROBLEM: The part to the left has a slot cut into it on one side. This slot would be hard to see unless the part was picked up and rotated.

SOLUTION: One possibility is to put a second slot on the other side of the piece.



- Alpha symmetry is the largest angle a part would have to be turned about an axis perpendicular to the insertion axis.
- Beta Symmetry is the largest angle the part would have to be rotated about the insertion axis for mating.
- Alpha and Beta symmetry actually range from 0 to 360° (instead of the intuitive 0 to 180°) because it is assumed that the worst case rotation is used.



Note: For the triangular wedge above there are three possible cases based on the shape of the triangle.

If all three sides are equal	$\alpha = 180^\circ$	$\beta = 120^\circ$
If two sides are equal length	$\alpha = 180^\circ$	$\beta = 360^\circ$
If no sides are equal length	$\alpha = 360^\circ$	$\beta = 360^\circ$

DI:13.2.4.6 - Part Shape, Size and Thickness

- We must consider the basic shapes of the parts being assembled. Two basic categories are prismatic and rotational.
- Rotational parts tend to roll when placed on a surface, suggesting that they will need some sort of holding fixture. This also means that during assembly, they must be supported by hand if not in a stable position when working.
- Prismatic parts tend to have at least one stable orientation that allows them to be rested on surfaces. Unlike rotational parts. If the prismatic parts are made to be stable when put in their final position, then they are much easier to fasten.

- The size of an object is generally the size of its largest major dimension, and thickness is the smallest major diameter.
- There are a number of criteria that can be used to determine how easily a part can be handled,
 - a high size/thickness can be a measure of fragility
 - large size values can indicate large weights
 - small size values can indicate the need for special tools

DI:13.2.5 Mating Parts

- There are a large number of methods for assembling parts. Generally a fastening operation is involved.
- The best rule of thumb is that all assembly work is best done by setting down a large base, and slowing dropping more parts on top of the base. Each part should be fed by gravity, and the work base should not have to be moved to put the part on.
- When mating two parts there are a number of possible combinations. The following table is an adaptation of Boothroyd [1979].

		snap fit	press fit	easy alignment, then crimping	crimping	force fit, then crimping
With open straight approach	approach from above					
	approach from side					
	approach from bottom					
inside enclosure	approach from above				Mating become more difficult	
	approach from side					
	approach from bottom					

- If a part must be supported or held down by hand while a fastening operation is done, this greatly complicates any operations. If this is the case, self securing parts should be used.
- parts may also exert some sort of resistance to insertion. If this is the case, the force should be minimized
- There are two type of obstructions that must be considered during assembly operations
 - the operator has no clear view of the assembly site
 - the assembly site is not in easy reach (i.e. the assembly axis is not clear)
- A self nesting or self fixturing part is ideal. In effect the part will hold itself in location after it has been positioned.

DI:13.2.6 Adjustments

- As an assembly is built, adjustments are commonly used to bring the shape back to proper specification. This can easily be the result of errors accumulated as parts are added in discrete steps.
- This problem can best be avoided by,
 - having parts positioned relative to one reference piece. For example pilots through layers of the work can be used for mounting parts.
 - screw hole slots, instead of holes can allow play in position.
 - loosen tolerances to the minimum levels
 -

DI:13.2.7 Modular Assemblies

- Designing in modules will allow reduction of the problems involved with any one assembly.
- Each module should be functionally separate from the other modules
- A module should have docking features to allow it to be connected to the main assembly
- advantages,
 - simplified assembly steps
 - easier quality control
 - simpler inventory
 - easier to reconfigure a system
 - suited to automatic assembly
 - fewer adjustments are required on final parts
 - simplified maintenance

DI:13.2.8 Standard Parts

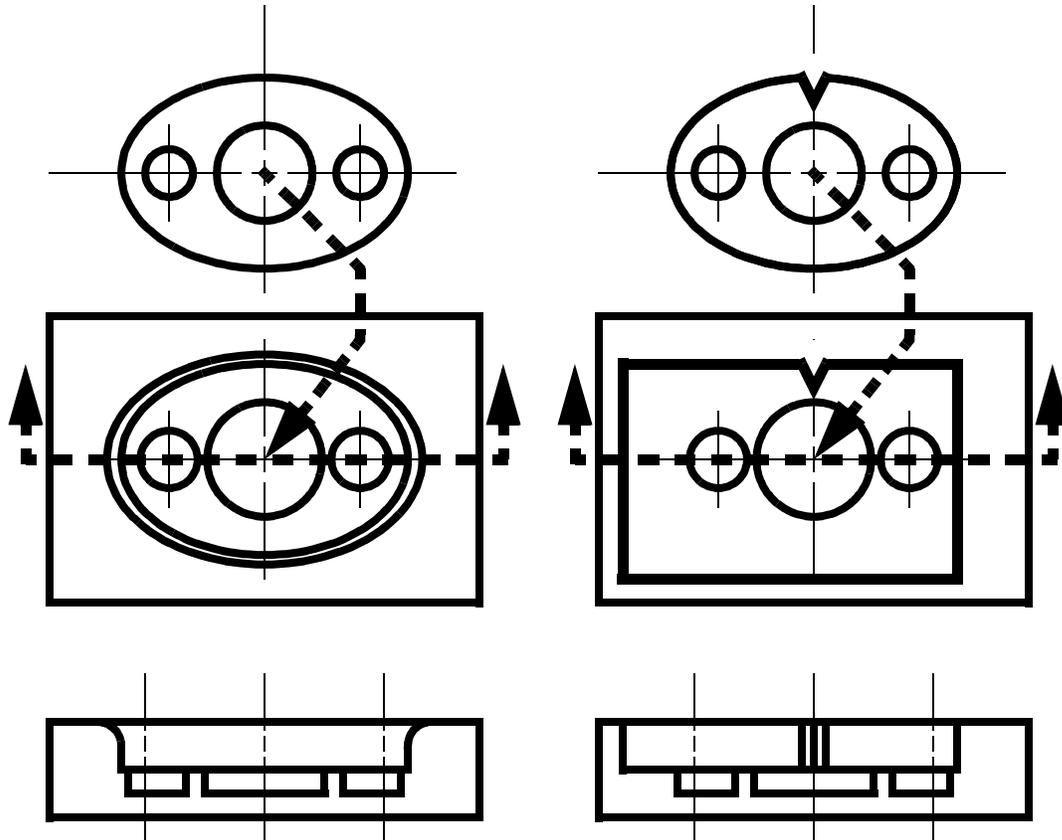
- There are a few distinct benefits to standard parts (as opposed to custom designed),
 - lower development costs
 - simple selection of vendors
 - lower production costs (no special tooling required)
 - quality levels are well established
 - these parts are easy to approve for Acceptance Sampling programs
 - automation tooling is available for many standard parts

DI:13.2.9 Part Fixtures and Jigs

- Jigs and fixtures are often used when,
 1. Doing manual assembly, with small or fragile parts
 2. doing any form of robotic assembly (at present sensors are not yet available for reliable fixtureless work).
 3. when designing self fixturing parts where the base part also acts as a form of fixture.
- When parts are mounted on fixtures, we can pretend this is another assembly step, and apply all of the normal DFA rules.
- The location of the part on the fixture is important for both alignment, and location in many cases, as the fixture has been set up as a reference.
- For high accuracy in location, we are better to have (one, two, or three) point contact between the fixture and the part. For orientation, surface/surface contact (such as chamfered hole shaft pairs) will give better results.

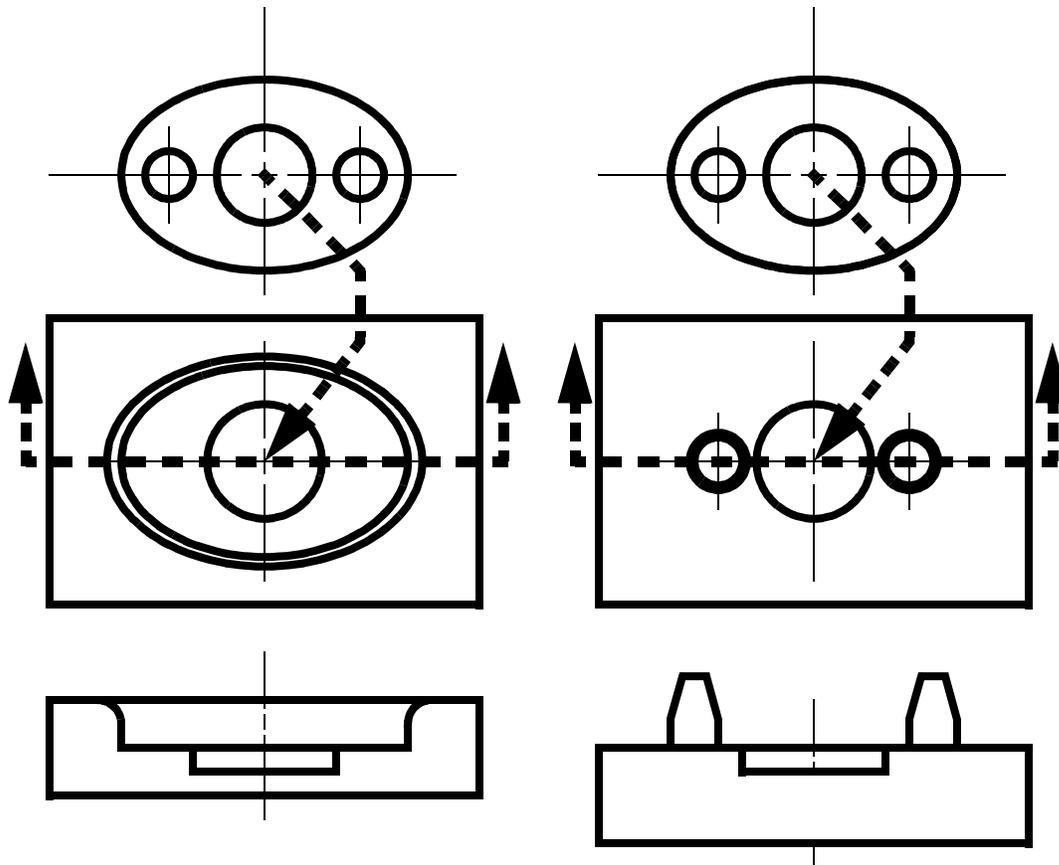
PROBLEM: We want fixture to put an oval shaped part into a fixture to insert parts into the holes, but the alignment of the part is somewhat difficult because of the rounded shape. The fixture shown has an oval shape to hold the part, a rounded opening, and holes underneath for the inserted parts to fall into.

SOLUTION: Add small alignment notches in the part, and the fixture to ease the alignment.



PROBLEM: We want to take the part below, and put it on a fixture so that the centre hole can be accessed for a press fit. But for the same problem cited for the last case this is not an easy configuration.

SOLUTION: Add tapered pegs that will go through the two side holes to locate the part.



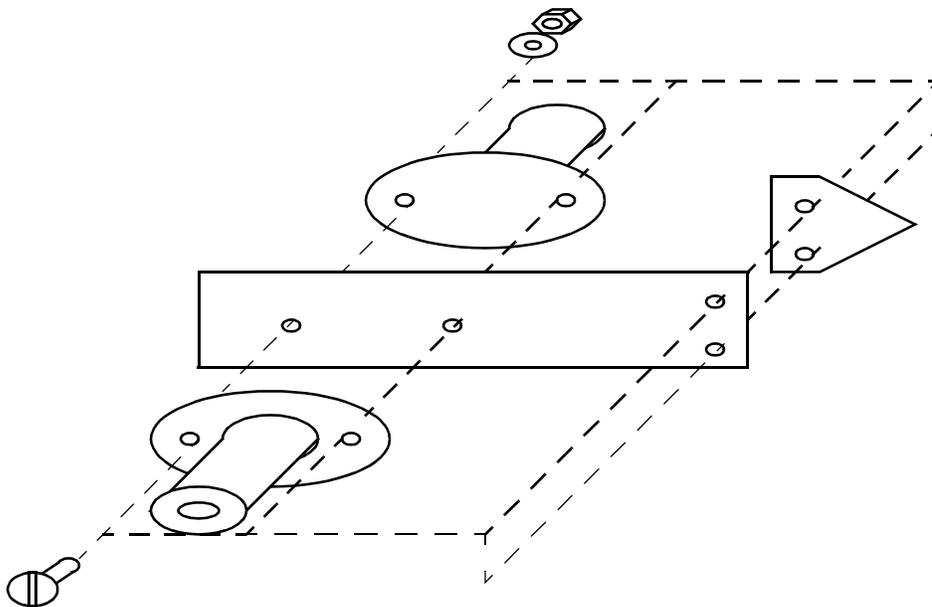
DI:13.2.10 Bottom Up Layered Assemblies

- The assembly should be done using a heavy and stable base piece at the bottom.
- As the design continues we want to add new parts in layers.
- The docking location for the new part should be a sort of mini fixture.
- Pilots should be added to locate layered pieces.

- This method also allows many parts to be put in place, and then a number of parts assembled in one assembly step.

DI:13.2.11 Examples

- First, review the DFA handbook paying special attention to the work sheets and the tables.
- Use the DFA handbook a) To do an analysis of the assembly below (assume dimensions with an overall length of about 8"). b) do a redesign of the assembly and reanalyze.



DI:13.3 DESIGN FOR MANUFACTURING (DFM)

DI:13.4 DESIGN FOR RECYCLING (DFR)

- When disassembling a product it can be very difficult to reclaim any value.

- There are three clear objectives when disassembling a product,
 - remove subassemblies that can be resold as is.
 - remove hazardous materials
 - separate the remaining materials into single materials with as little effort as possible
- By following the design for assembly rules we can actually produce a part that is relatively easy to disassemble, and with some additional rules we can obtain easy to recycle designs.
- The basic rules (above DFA) are,
 1. Use modules (consolidated parts) that can be removed and reused in other applications
 2. Mark all materials for identification that cannot be sorted easily
 3. Make parts easy to disassemble
 4. Reduce materials and energy invested in the parts.

DI:13.4.1 Reduce Materials and Energy

- When we manufacture a product it requires energy to generate the raw materials, more energy to form them, and over the life of the product energy is used.
- Ideally the perfect product last forever, and never needs to be recycled. This can be attempted through good design practices.
- Other ways to reduce the total energy/materials in the product are,
 - reduce the number of parts
 - reduce the part size
 - reduce the time to assemble
 - eliminate redundant components
 - use recycled materials where possible
 - reduce scrap
 - evaluate materials chosen for their environmental impact, and recyclability
 - minimize waste in production processes
 - packaging should be eliminated, or replace with reusable packaging
 - when reliability is a problem, make the components easy to maintain and repair.
 - avoid finishing operations that might contaminate materials
 -
- If you recycle your own products, there are potential economies of scale, and the approach to DFR will improve.

DI:13.4.2 Consolidated Parts

- Auto wreckers commonly salvage good parts from an automobile before it is scrapped. This reduces the amount of material that must be reprocessed from raw state.
- These parts are self compact modules that,
 1. can be removed and reinstalled in another machine
 2. can be rebuilt easily, if at all
 3. has a compact geometry with connectors

DI:13.4.3 Ease Of Disassembly

- One major reason not to recycle is the time required to separate materials.
- To make a product easy to disassemble you can,
 1. use snap fits that can be undone or broken easily
 2. mark the location of snap fits so that they can be separated quickly
 3. reduce the fastener count
 4. avoid threaded and permanent fasteners (eg glue)
 5. reduce the number of components to reduce the number of steps in disassembly
 6. assembly from top in layers so that parts can be picked off
 7. avoid parts with mixed materials

DI:13.4.4 Recycling Markings

- For plastics there are six symbols commonly recognized,

	Polyethylene Terephthalate
	High Density Polyethylene
	Poly vinyl Chloride
	Low Density Polyethylene
	Polypropylene
	Polystyrene

- Metals that are commonly recycled are,
 - iron/steel - this can be sorted using electromagnets
 - aluminum -
 - platinum - reclaimed from catalytic converters
- Glass is typically sorted, and is easy to melt and reuse.
- Paper can be reused, but it must be mixed with new fiber.

DI:13.5 REFERENCES

Boothroyd., G., “Design for Assembly”, Department of Mechanical Engineering, University of Massachusetts, USA, 1979.

Boothroyd, G., and Knight, W., “Design for Assembly”, Spectrum, IEEE, September 1993, pp. 53-55.

Dodd., C.W., “Design for ‘X’”, IEEE Potentials, October 1992, pp. 44-46.

Iredale, R., “Automatic Assembly - Components and Products”, Metalwork Production, April 8, 1964.

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:13.6 SAMPLE QUESTIONS

1. The theoretical minimum number of parts in a 3 prong electrical plug are,
 - a) 1-2
 - b) 3-5
 - c) 6-8
 - d) other _____ (specify, and justify your answer below)

(ans. b. 3 conductors and an insulator)

2. What features of a typical car windshield violate the principles of design for assembly (DFA)?
(ans. length to width, fragile)

3. Sketch out components of a calculator that would observe the rules of Design For Assembly

4. Redesign the part below for more efficient assembly

***** Boothroyd piston figure

DI:13.7 AXIOMATIC DESIGN

- Basically sets of rules are used to guide the design process.

DI:13.7.1 Suh's Methodology

- Relates Design Parameters (DPs) to Functional Requirements (FRs) using matrices.
- Two basic axioms,
 1. The Independence Axiom - sections of the design should be separable so that changes in one have no (or as little as possible) effect on the other.
 2. The Information Axiom - the information inherent in a product design should be minimized.
- In a simple design FRs would be the requirements of a design. This will be a discrete list of independent items. If the FRs are not independent enough then complications will arise. An example would be for a parachute,
 - FR1: The parachute will slow down a descent to prevent injury
 - FR2: When not in use it will be easily carried by a user
 - FR3: Reliability will be greater than 1 failure in 20000 users
 - FR4: The user will be able to redirect the descent vector
- If we consider DPs, we want these to be independent also. These will express how we have decided to satisfy the FRs (Note: this technique is analytical). If we consider the parachute example,
 - DP1: Material chosen for chute- weight and strength
 - DP2: Length of cords between rider and chute
 - DP3: Number of cords between rider and chute
 - DP4: Area of chute
 - DP5: Vents in chute
 - DP6: Packing and release methodology
- It is possible to relate the FRs to the DPs using a sensitivity matrix,

$$\begin{bmatrix} dFR_1 \\ dFR_2 \\ dFR_3 \\ dFR_4 \end{bmatrix} = \begin{bmatrix} \frac{dFR_1}{dDP_1} & \frac{dFR_1}{dDP_2} & \frac{dFR_1}{dDP_3} & \frac{dFR_1}{dDP_4} & \frac{dFR_1}{dDP_5} & \frac{dFR_1}{dDP_6} \\ \frac{dFR_2}{dDP_1} & \frac{dFR_2}{dDP_2} & \frac{dFR_2}{dDP_3} & \frac{dFR_2}{dDP_4} & \frac{dFR_2}{dDP_5} & \frac{dFR_2}{dDP_6} \\ \frac{dFR_3}{dDP_1} & \frac{dFR_3}{dDP_2} & \frac{dFR_3}{dDP_3} & \frac{dFR_3}{dDP_4} & \frac{dFR_3}{dDP_5} & \frac{dFR_3}{dDP_6} \\ \frac{dFR_4}{dDP_1} & \frac{dFR_4}{dDP_2} & \frac{dFR_4}{dDP_3} & \frac{dFR_4}{dDP_4} & \frac{dFR_4}{dDP_5} & \frac{dFR_4}{dDP_6} \end{bmatrix} \begin{bmatrix} dDP_1 \\ dDP_2 \\ dDP_3 \\ dDP_4 \\ dDP_5 \\ dDP_6 \end{bmatrix}$$

- Obviously the relational matrix above is non-linear, so to allow simple analysis, we consider the matrix values near the operating point, and substitute in values of small (x) and large (X) effects. As a result the previous matrix might look like,

$$\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \end{bmatrix} = \begin{bmatrix} x & & X & x \\ X & x & x & X \\ X & x & X & x & X \\ & X & & X \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \\ DP_6 \end{bmatrix}$$

- Considering the independance axiom, we want a one-to-one relationship between FRs and DPs. Ideally we would want a square identity matrix. Practically we must compromise. The corollaries give direction to changes.

Corollary 1: Decoupling - We should attempt to decouple or separate different design elements. If done using the matrix method above this would result in an identity matrix (or equivalent).

Corollary 2: Minimize FRs - If we can reduce the number of FRs it will simplify the design.

Corollary 3: Integrate Parts - When possible, without significantly compromising the other principles, we want to reduce the number of parts.

Corollary 4: Standardization - Standardized parts tend to satisfy the design axioms, and should be used when possible to reduce the information content.

Corollary 5: Symetry - When possible use symetry to reduce the information content of the product.

Corollary 6: Large Tolerances - Reduce the information content by using the largest tolerances possible.

Corollary 7: Uncouple and Minimize Information - When possible the designer should strive to minimize information and interdependence between design components.

- Ideally there are a number of objectives to follow,
 1. Strive for the same number of FRs and DPs, and have each independent.
 2. Minimize the values in the relationship matrix by reducing the information in each part.
- If we consider the parachute example, we can see the problems that must be addressed.
 1. First, FR3 has three major relationships. FR2 and FR4 have 2 major relationships. DP1 and DP4 have two major relationships. These are ideal candidates for redesign.
 2. We might consider suitability of the DPs and FRs. If they are reasonable and don't overlap, we might go farther. In this case FR3 and DP1, DP2, DP4 are prime candidates.

DI:13.7.1.1 - The Information Axiom

- Information is a measure of complexity originally developed by Shannon []
- If we think about the information content (complexity) of some modern products, the implications are obvious,
 - very pure semiconductor materials increase yield and chip sizes.
 - the number of transistors per IC is also climbing
 - the tolerances for internal combustion engines have increased - and the idea of replacing an engine is now uncommon.
- For mechanical parts (with reasonable tolerances) the information content of a part might be rated by the formula,

$$I = \sum_{i=1}^n \left[\log \left(\frac{l_i}{T_i} \right) \right]$$

where,

I = a number representing the information content

n = the number of dimensions with tolerances

li = an overall dimension for feature 'i'

Ti = the tolerance for dimension 'i'

- In another case we might have access to SPC data, and can calculate the Cpk for each feature we

might measure information with,

$$I = \sum_{i=1}^n [10 \log C_{pk_i}]$$

where,

C_{pk_i} = the process capability for feature 'i'

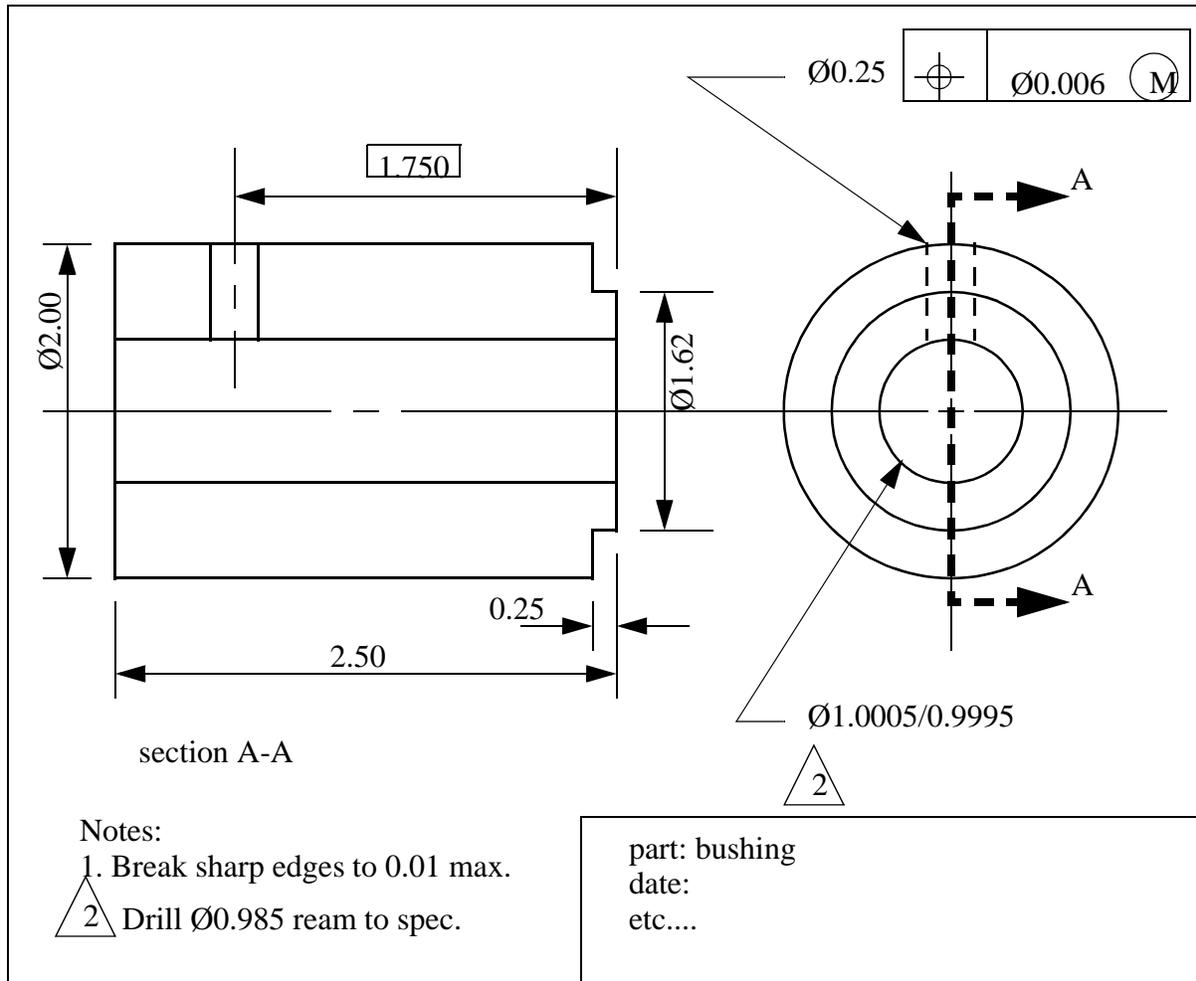
- As common sense dictates we would want to generally increase our work dimensions (to a point) and increase our tolerances whenever possible.

DI:14. DRAFTING

- Drafting was previously a set of techniques (using compasses, angles, T-squares, etc.) for creating drawings that could be understood and used in manufacturing.
- More recently drafting is focusing less on techniques and more on conventions, because of CAD systems.
- The conventions of drafting are very important because they allow us to define parts in a way that they will be understood by any engineer, machinist, technologist, etc.

DI:14.1 CONVENTIONAL DRAFTING

- The purpose of drafting is to present technical ideas in precise and concise forms.
- A properly drafted drawing should be understood by any engineer.
- A sample of a drafted drawing is given below.



DI:14.1.1 Manual Drafting

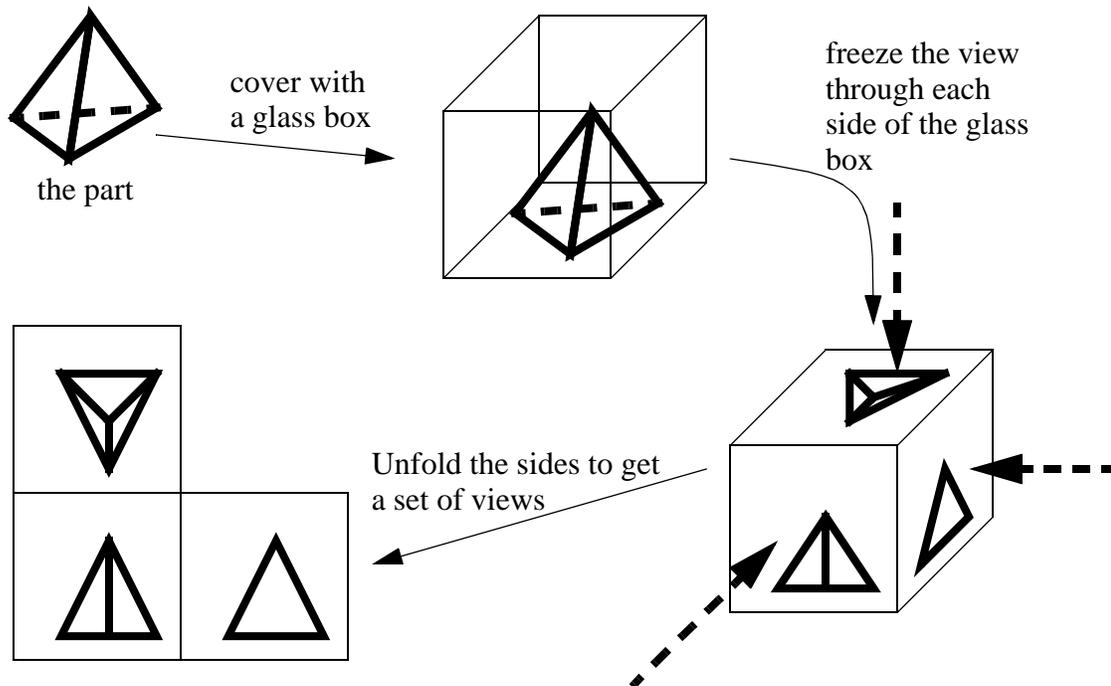
- This is the use of drafting boards, pencils, pens, and a number of specialized tools for drafting. While this method is still very popular, the techniques used in manual drafting are quickly being displaced by CAD (Computer Aided Design) systems.
- I will not cover some of the manual drawing topics list below, but more information on them appears in a large number of drafting books.
 - lettering
 - hand sketching
 - drawing ellipses
 - etc

DI:14.1.2 Turning Three Dimensions Into Two (Multi View Drawings)

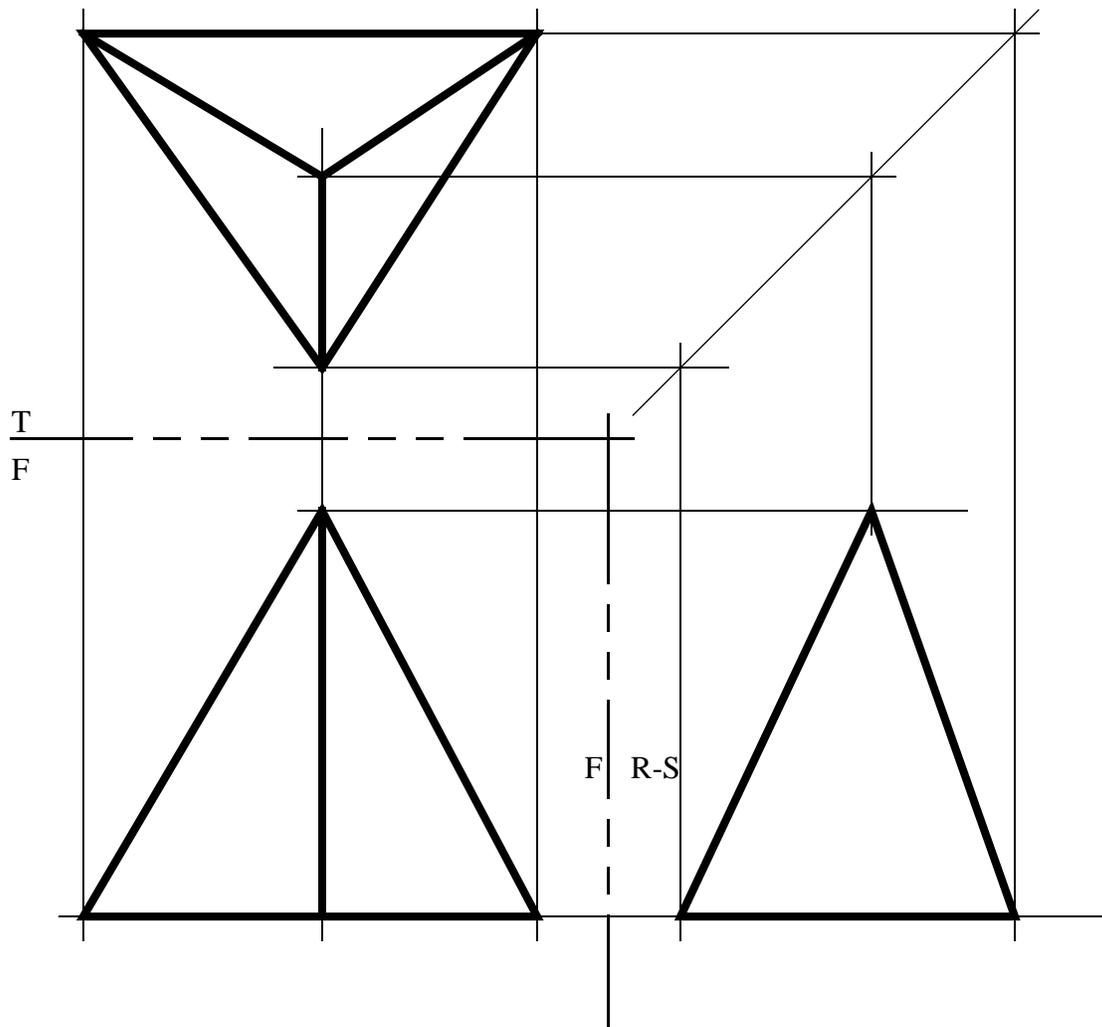
- The problem with drafting is that the paper is flat, while the object drawn is not.
- To get around this we can develop a number of views to work with.
 - Front View
 - Top View (Plan View)
 - Right Side View
 - Left Side View
- This method of developing views is known as Orthographic projection
- This method eliminates the perspective distortion in real vision, thus making it easier for technical depiction.
- In this method, object faces that are parallel to the viewing plane are shown as actual size, but objects that are not parallel are foreshortened.
- The number of views used is a function of the geometry. For a simple object such as a washer, only one view is needed. A more complicated object, such as a piston, would require at least two views.

DI:14.1.2.1 - The Glass Box

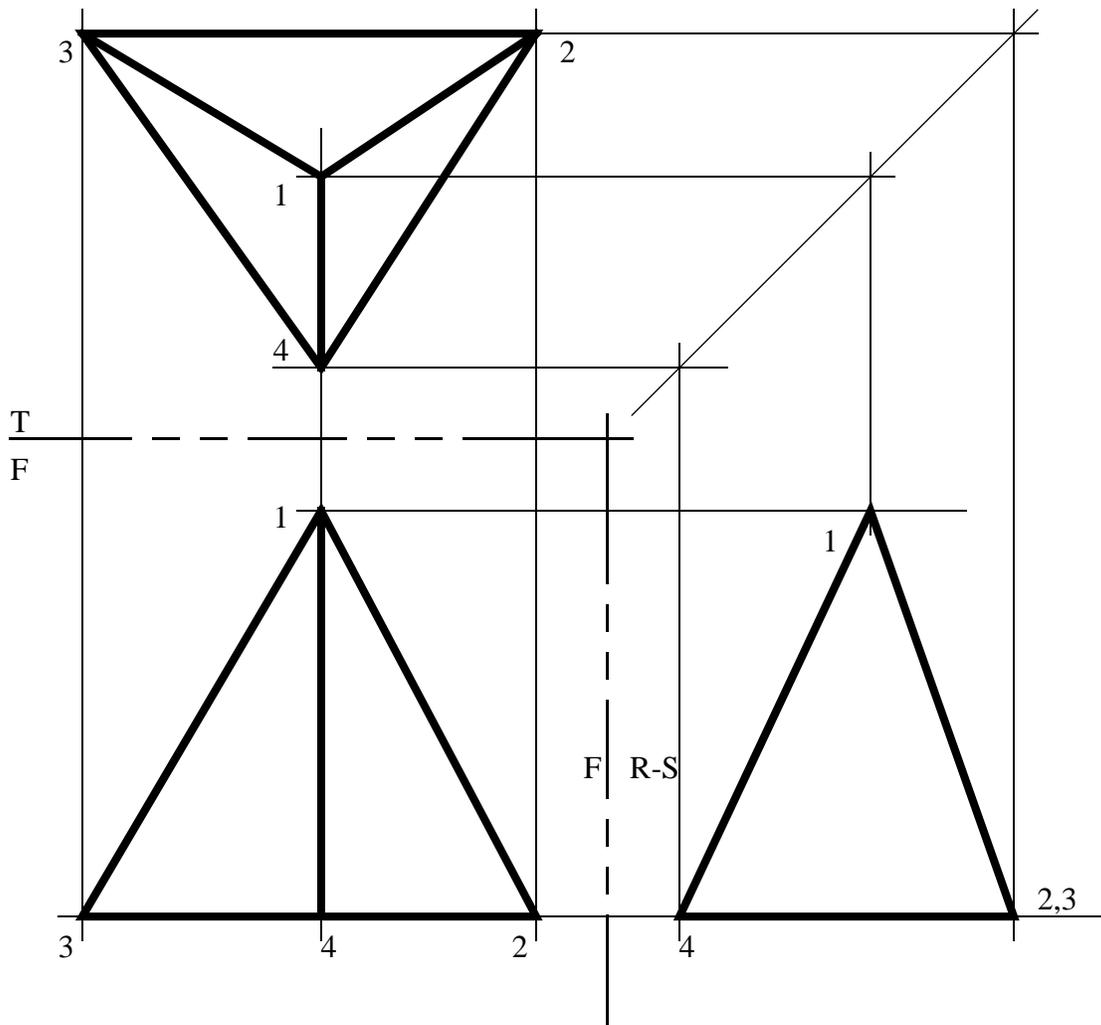
- The views are developed as if a glass box was placed over the object. The view from each direction was frozen, and when the box is unfolded, the resulting views are seen.
- Imaging the case below of a small tetrahedron (a three pointed triangle),



- The drawings are layed out with certain conventions. The example above is continued below for illustration, In the figure extra construction lines are added to show how the drawings in the different views are related. Note that the top view is related to the side view using a 45° line. These properties are a result of the 'glass box' concept. The folding lines are often shown on drawings (they have two dashes and one long). Also note that in the figure shown below, the points in the top view will be the same distance from the folding line as they are in the side view.



- The layout of the drawings is done by convention. In this drawing the right side view is to the right of the front view. If this drawing observed european standards, the right side view would be on the left hand side.
- A useful method for keeping the large number of points in a drawing sorted is to number them. For example,

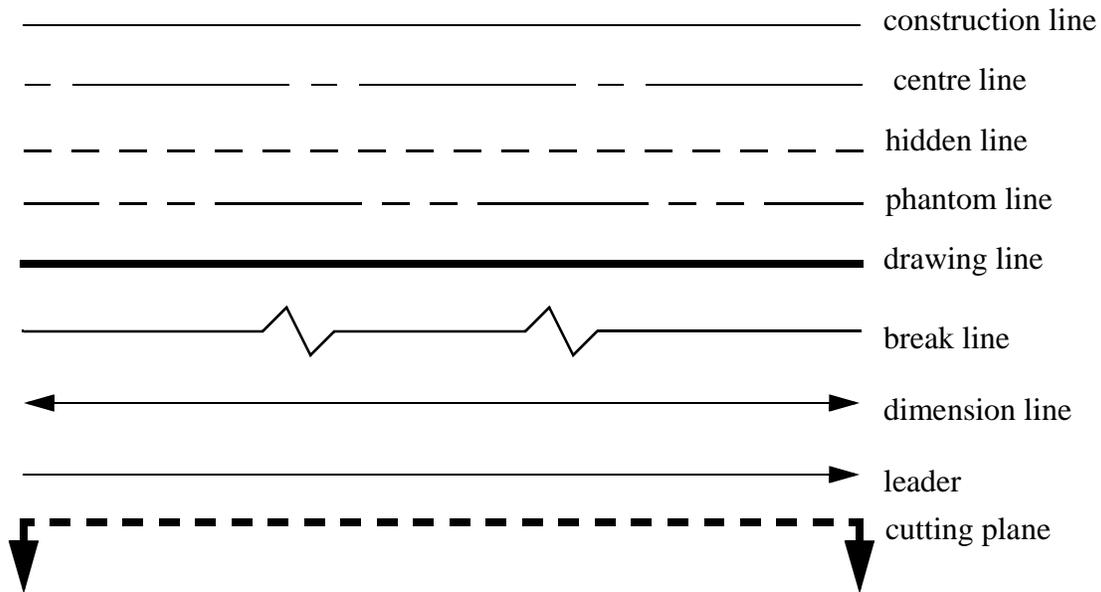


- The view that is selected as the front is arbitrary, but it should
 - be a natural front to the object.
 - be the most important view
 - appear stable
 - chosen to minimize hidden lines in other views
 - contain most of the detail

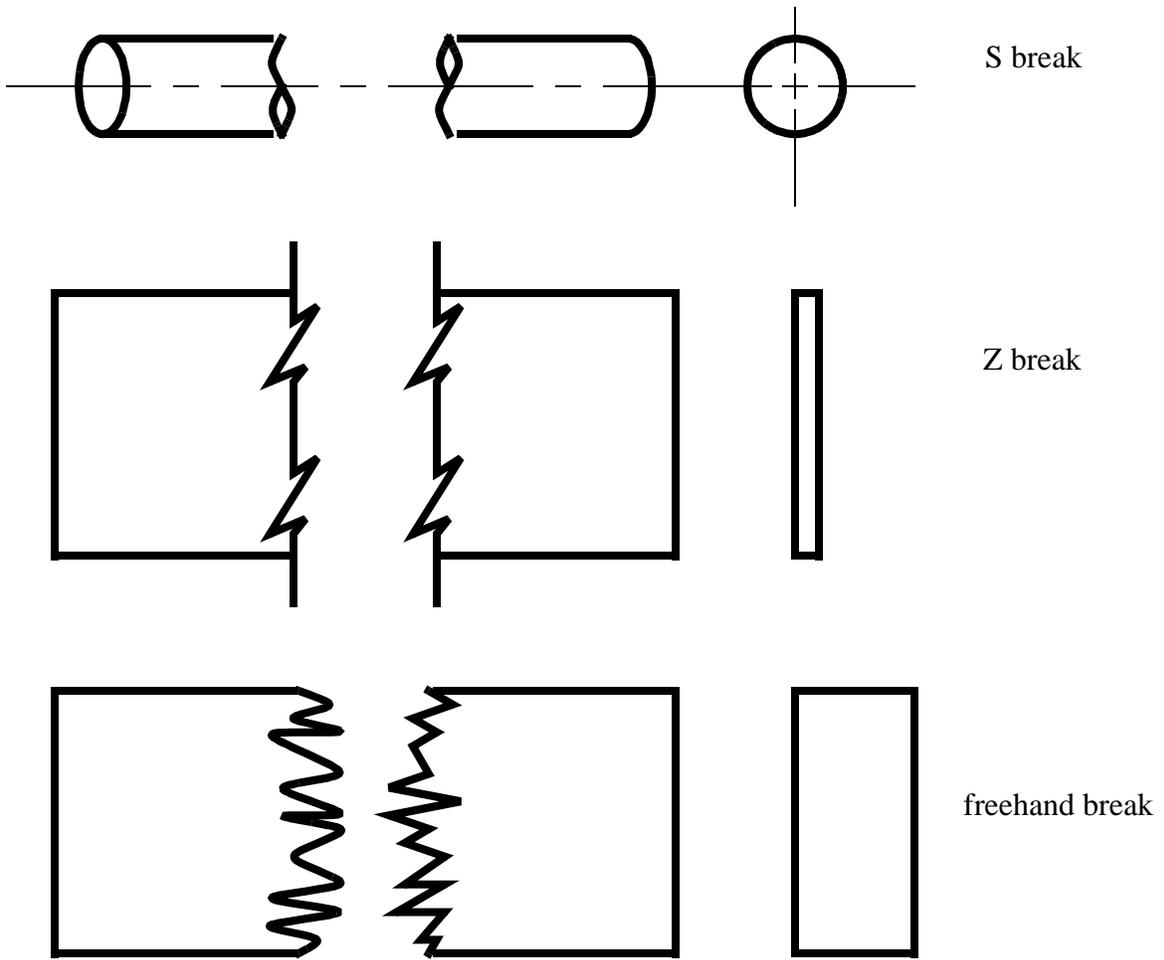
DI:14.1.3 Lines

- The number of lines on drawings will become confusing, therefore this calls for some method for differentiating between lines.
- Hidden lines are dashed lines used to show lines that not visible.

- Centre lines are used to show the axis of rotation for an object surface. These lines have long/short dashes.
- Construction lines are drawn on to help locate final drawing lines. These lines are so light that they are often not even erased when the drawing is complete.



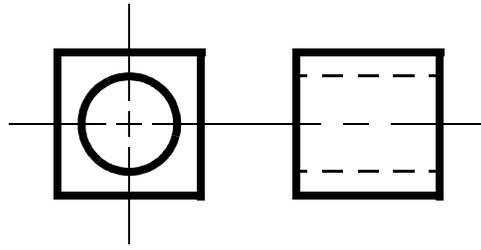
- Some objects have disproportionate dimensions. As a result, it may be necessary to ‘break’ them to show any reasonable level of detail. There are three types of breaks commonly used,
 - S breaks - for round objects
 - Z breaks - for thin long/wide objects
 - freehand breaks - for long rectangular objects



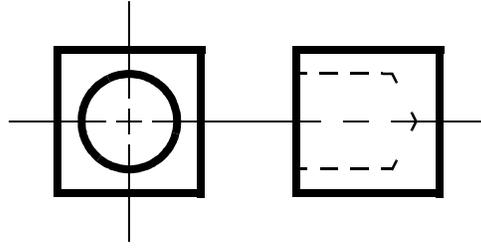
DI:14.1.4 Holes

- There are a number of holes commonly depicted in drawings,

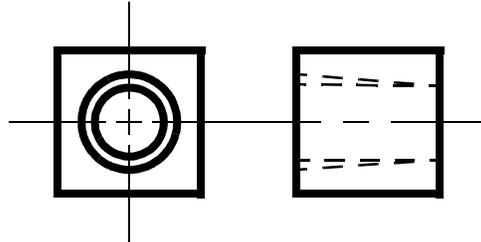
Through Holes - these are cut all the way through an object



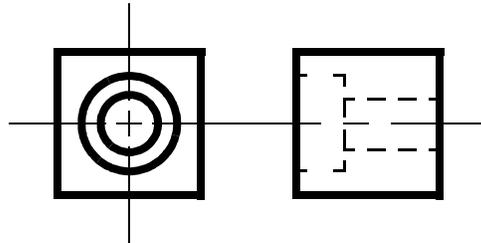
Blind Holes - these holes stop part way through an object



Tapered Holes -



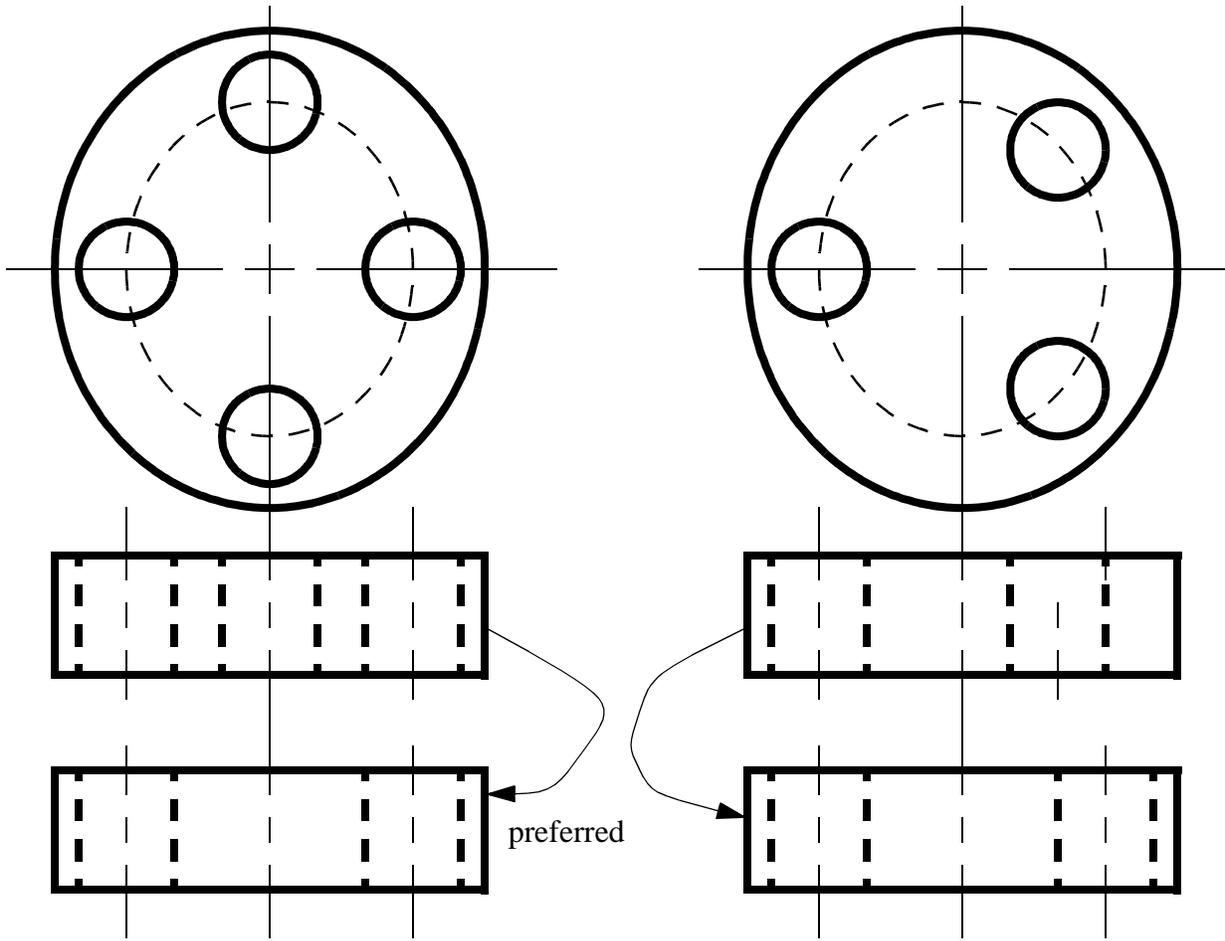
Counterbored Holes -



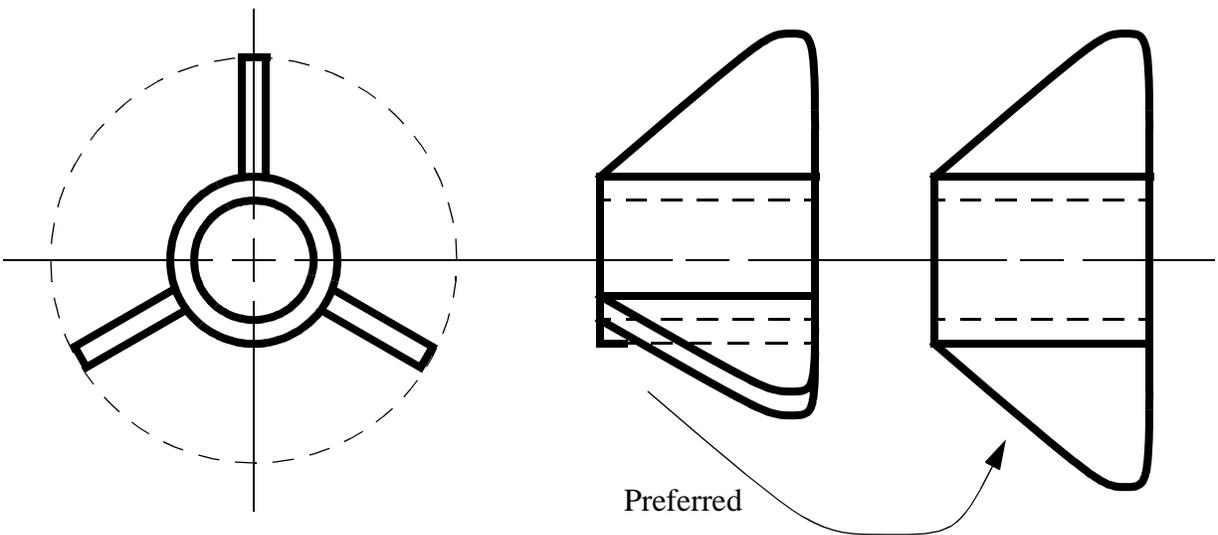
DI:14.1.5 Special Cases

DI:14.1.5.1 - Aligned Features

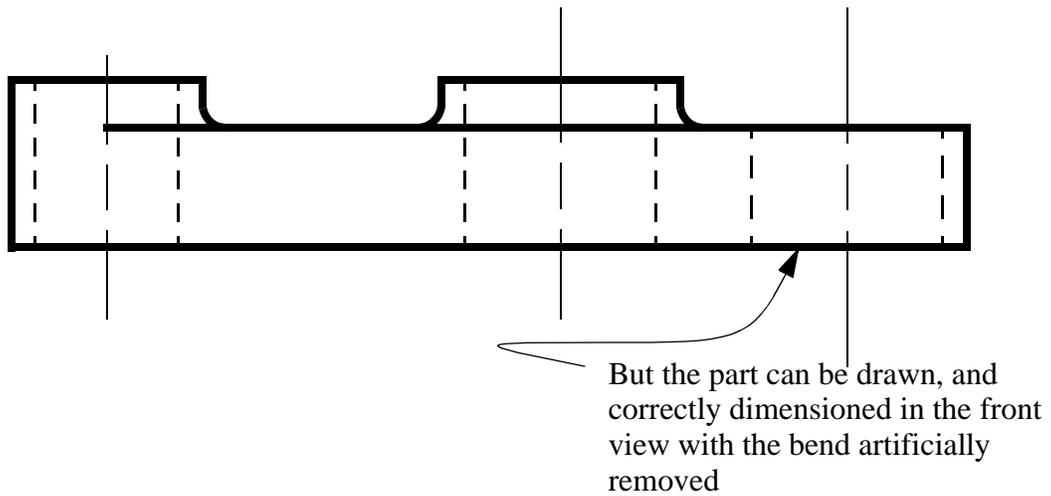
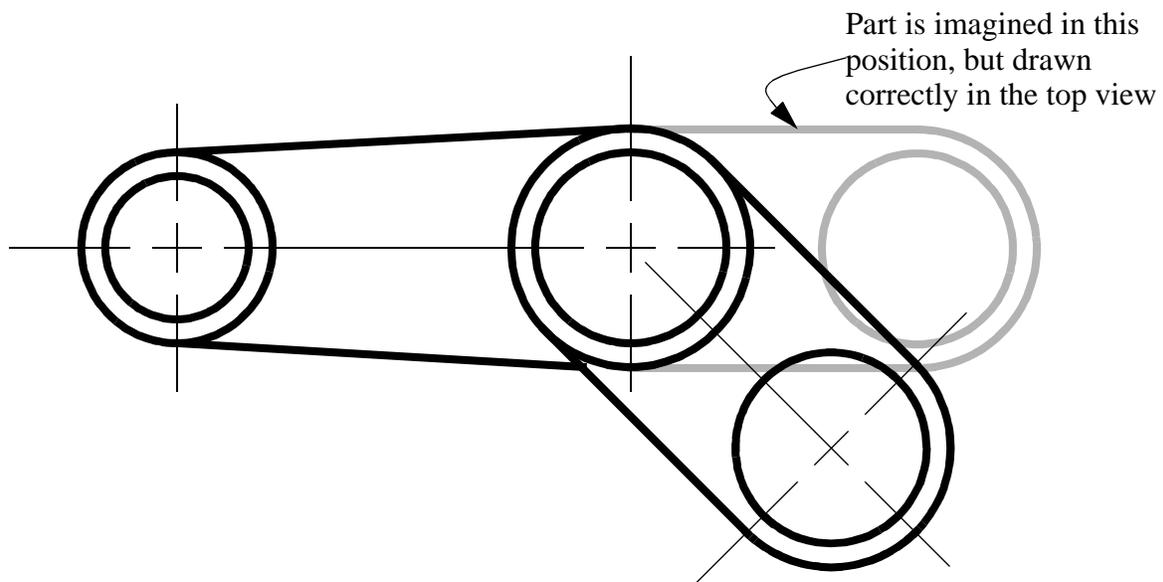
- Aligned features - in some cases, features are revolved, and shown at a consistent radial distance, but not necessarily in the correct position.
- Holes are commonly rotated to simplify views



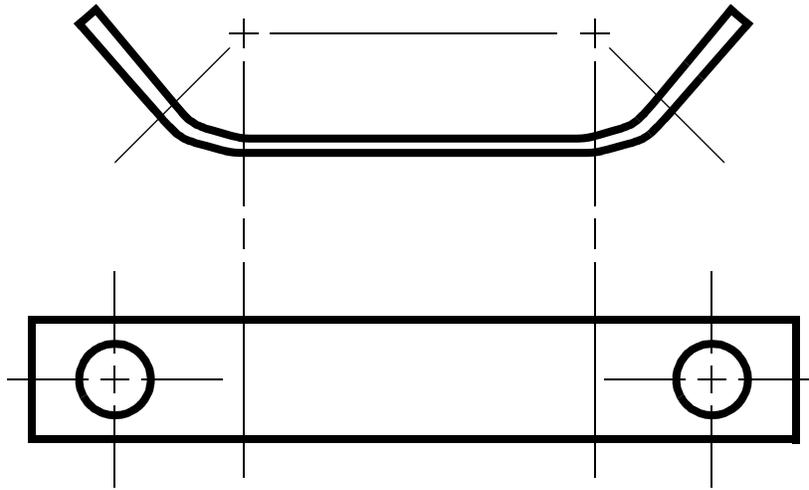
- Ribs and wings are commonly rotated to simplify views



- Large features on parts may be rotated to simplify views. small features, such as slots may also be rotated between views for clarity.

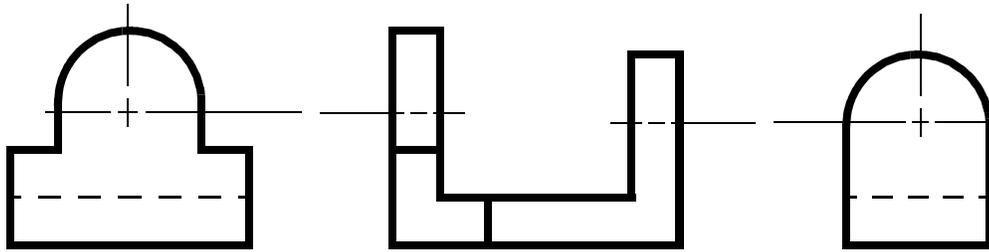
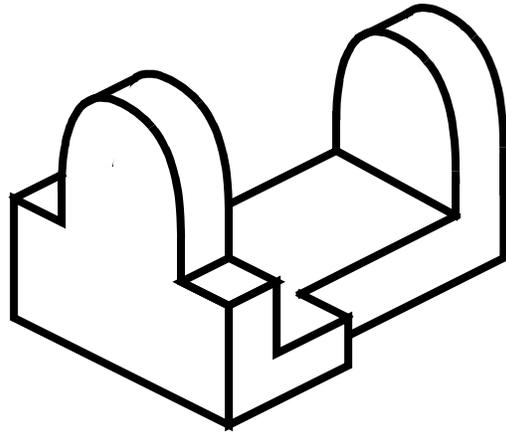


- Sheet metal parts start out flat, but are deformed to new useful shapes. Therefore it is common to draw sheet metal parts in the deformed, and the undeformed state.

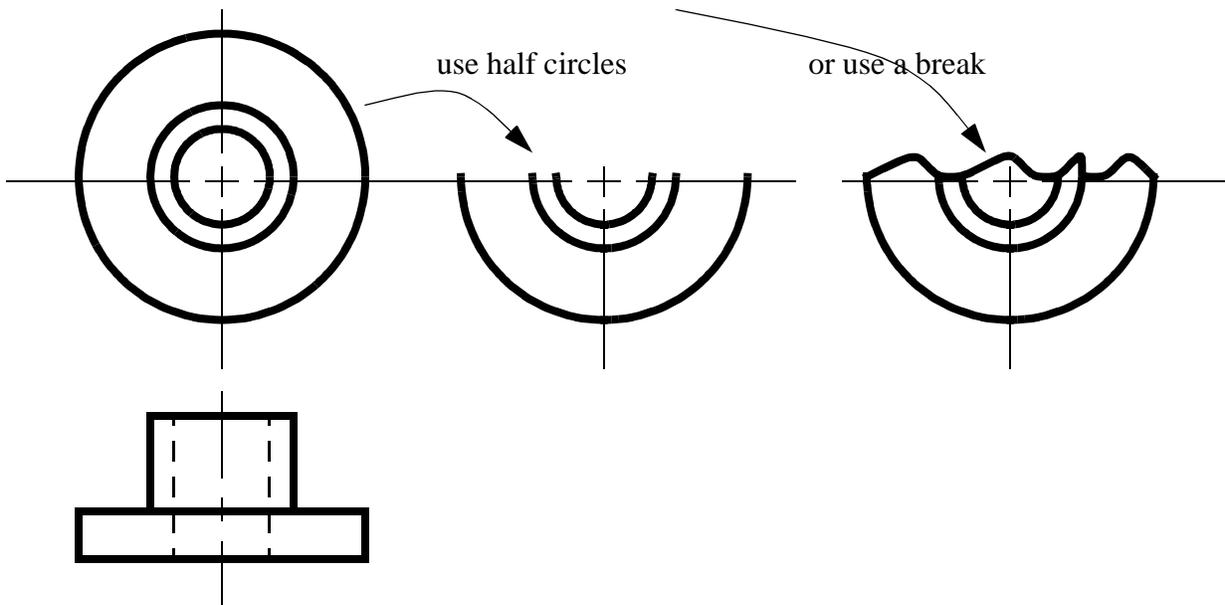


DI:14.1.5.2 - Incomplete Views

- Incomplete views - certain details can be omitted to simplify the view. This method produces drawings that are not correct, but they are commonly used in practice.
- Some views will end up having an excessive number of hidden lines. To combat this problem, we may sometimes just leave them out.



- Large radial/cylindrical parts are often cropped to save space. But, enough is shown to make the remainder of the geometry obvious.

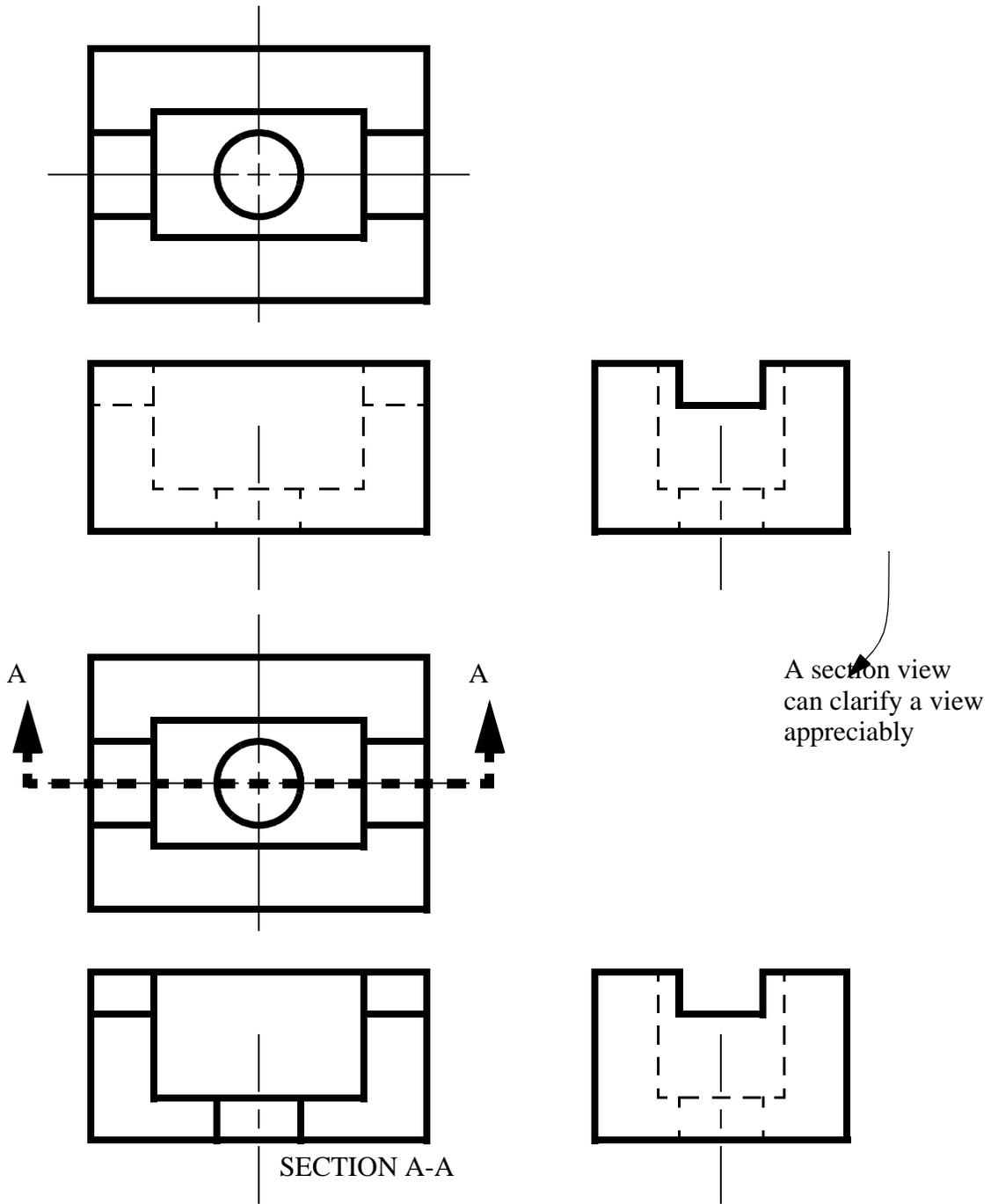


DI:14.1.6 Section Views

- when there are complicated internal features, they may be hard to identify in normal views with hidden lines. A view with some of the part “cut away” can make the internal features very easy to see, these are called section views.
- In these views hidden lines are generally not used, except for clarity in some cases.
- The cutting plane for the section is,
 - shown with thick black dashed lines.
 - has arrows at the end of the line to indicate the view direction
 - has letters placed beside the arrow heads. These will identify the section
 - does not have to be a straight line
- sections can be lined to indicate,
 - when the section plane slices through material
 - two methods for representing materials. First, use 45° lines, and refer to material in title block. If there are multiple materials, lines at 30° and 60° may be used for example. Second, use a conventional set of fill lines to represent the different types of materials.

DI:14.1.6.1 - Full Sections

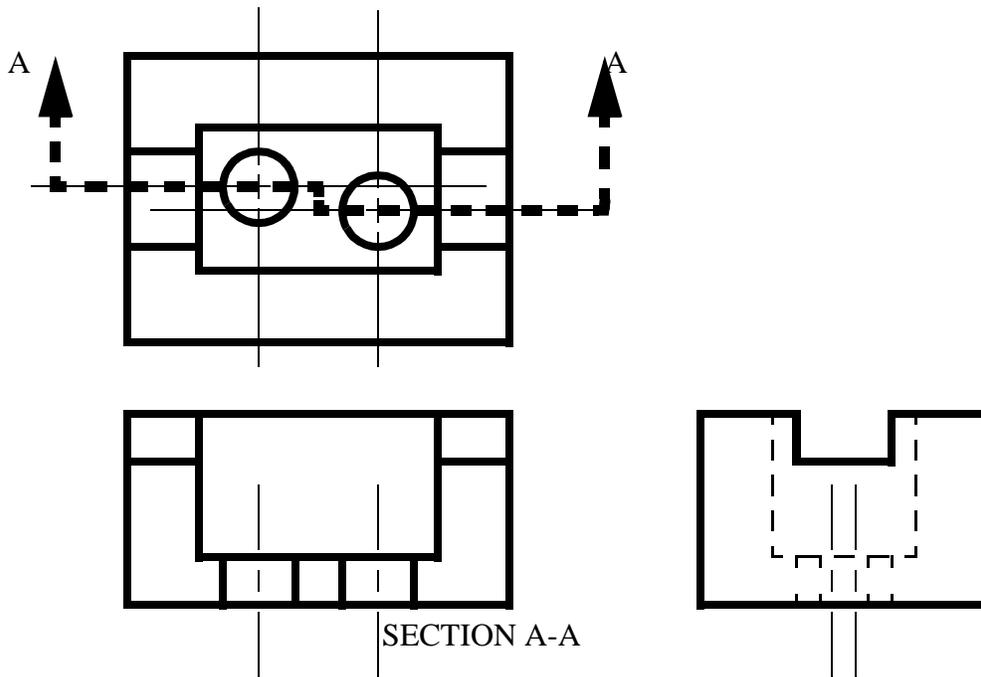
- Full sections - generally a straight section line cuts through a part to give a complete view of the inside. This section typically replaces one of the views that is confusing.



DI:14.1.6.2 - Offset Section

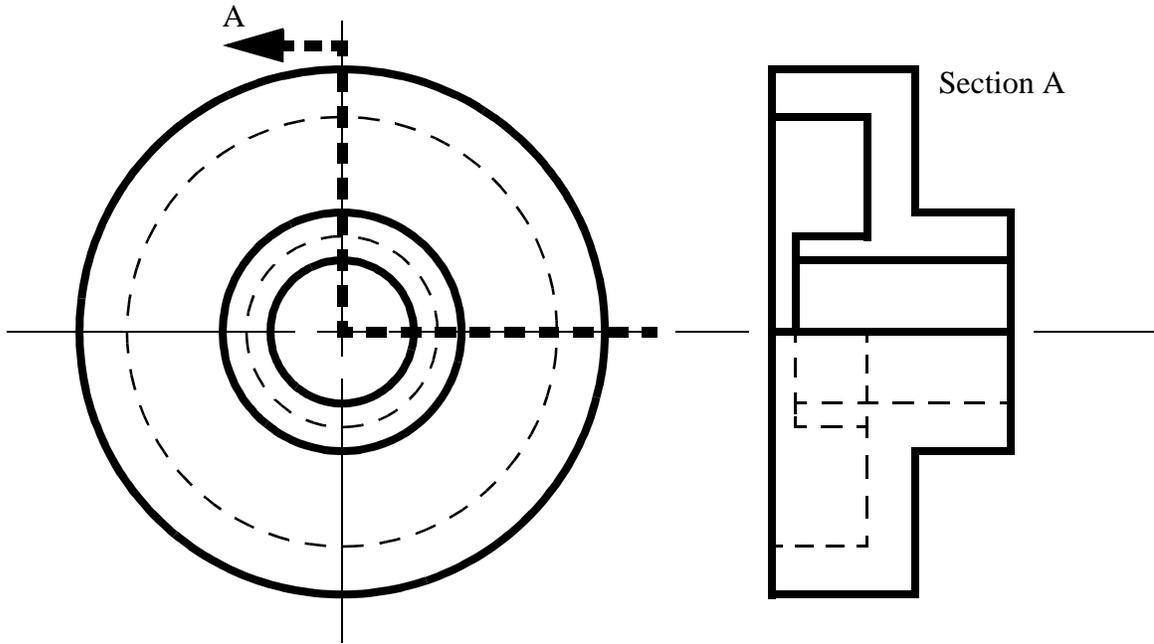
- Full sections will experience difficulties when the features do not lie along a single line.

- We can use a section line that is turned to cut through features. This view can be used to replace one of the principle views.



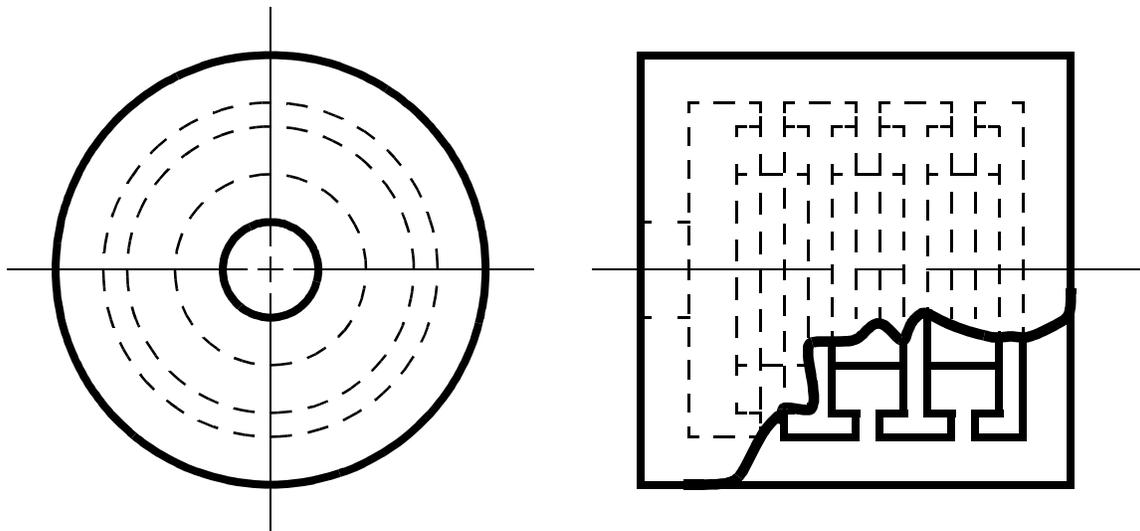
DI:14.1.6.3 - Half Section

- In some cases it is better to illustrate internal features with both a section, and a full view. In this case we can cut away only part (a quarter) of the object, and draw a view that is half normal, half section.
- this method is well suited to symmetrical parts, with the section starting at the axis of symmetry
- Take note that the section line here only has one arrow head, but the direction must be observed



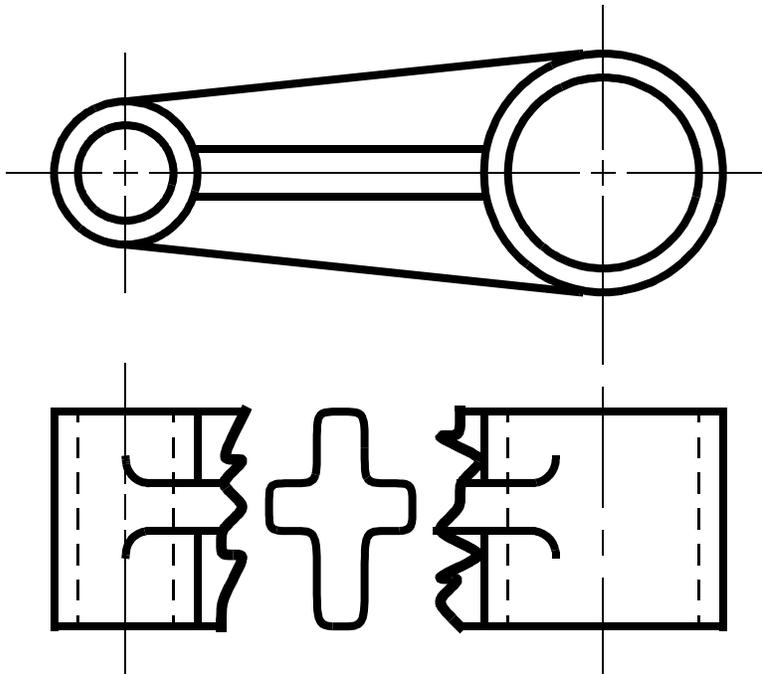
DI:14.1.6.4 - Cut Away Sections

- Instead of doing large scale sections, we can cut away a very specific region of interest.
- In this case a break line is used, and the cutting plane lines used in other cases are not applicable.



DI:14.1.6.5 - Revolved Section

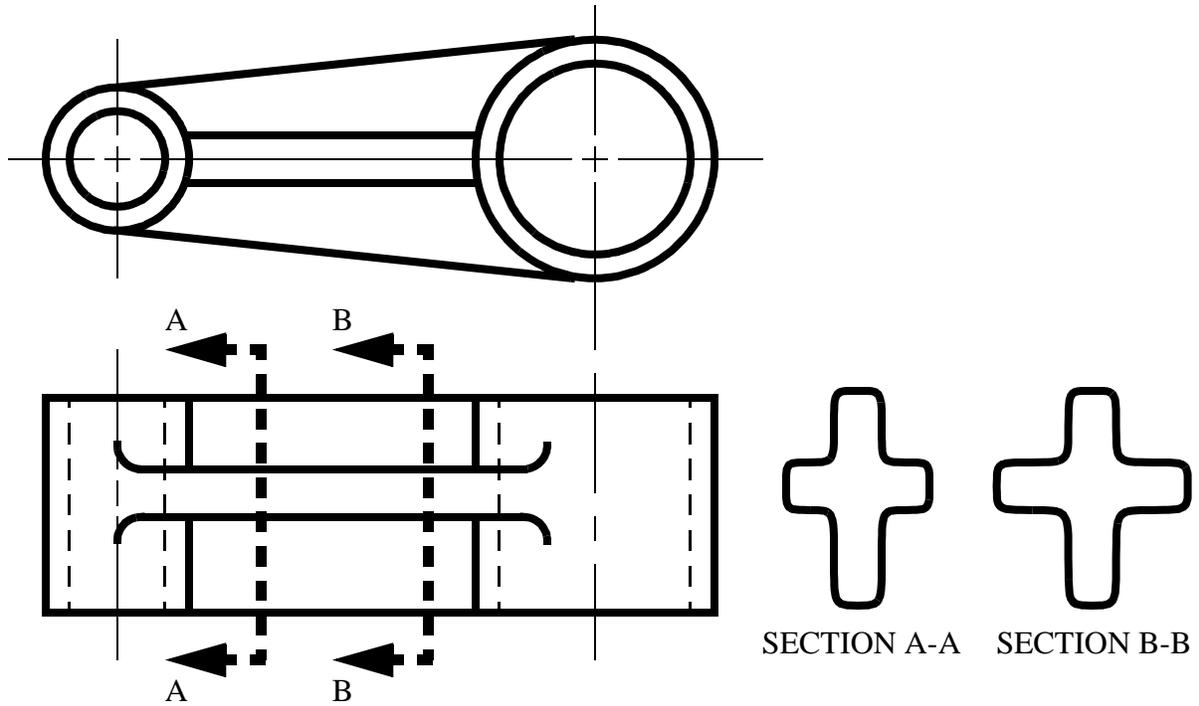
- When we have transition pieces, such as ribs, or airplane wings, we will want to show the shape, but this is not easy with conventional views, In this case we can break out a section.
- The basic procedure is to
 1. select a characteristic section, and draw cut lines to either side.
 2. in between the breaks, draw a section that is rotated 90° so that it is obvious on the drawing.
- This method is useful when space is at a premium
- The cutting plane line is not used with this technique



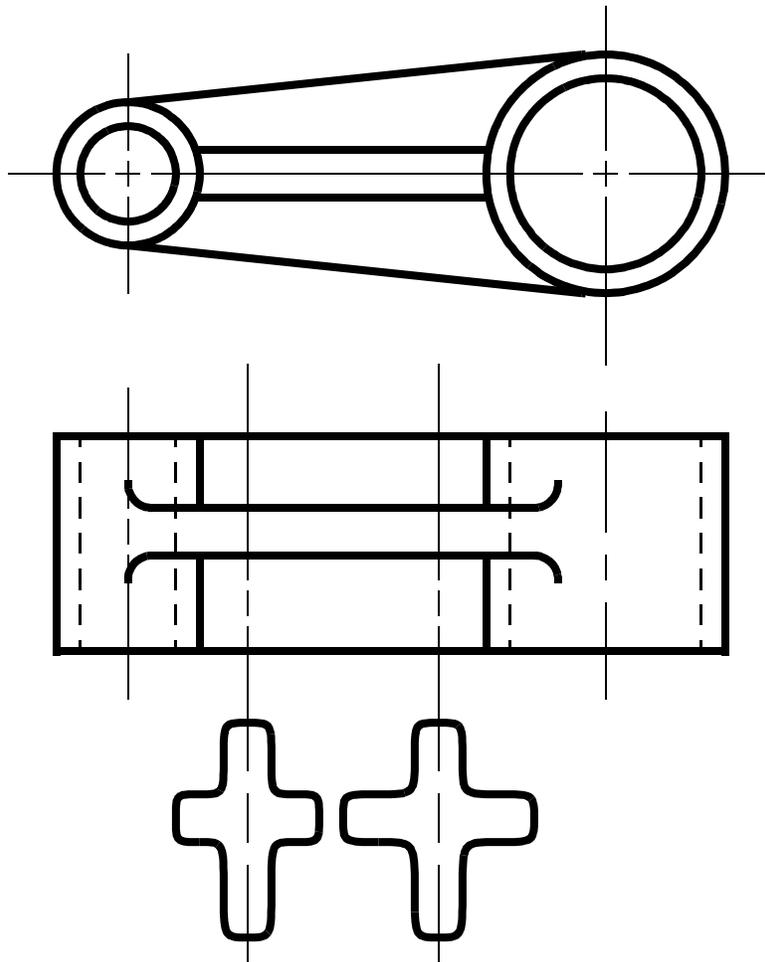
DI:14.1.6.6 - Removed Section

- this is a more exact alternative to the revolved section method.
- With this method a break is not used, but a cutting plane line is. The sections are then drawn at some other location on the page.
- The only features shown are the features of the section.

- labels such as A-A, B-B, etc are used to avoid ambiguity.
- these views are often placed at a distance and arranged in the same order as the sections.



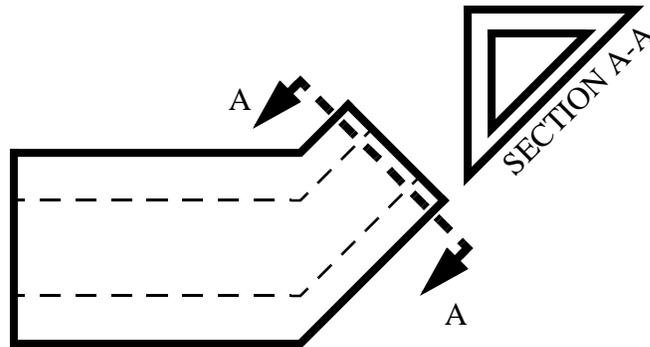
- These section may also be shown using lines extended from the object



- modified scales may also be used with appropriate notation

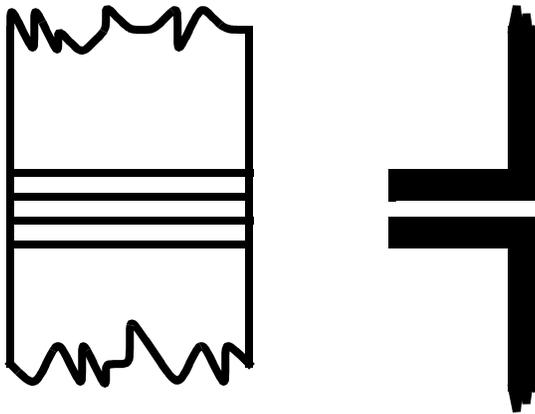
DI:14.1.6.7 - Auxiliary Section

- A section can be done that does not lie in one of the primary planes.
- This done as a normal section



DI:14.1.6.8 - Thin Wall Section

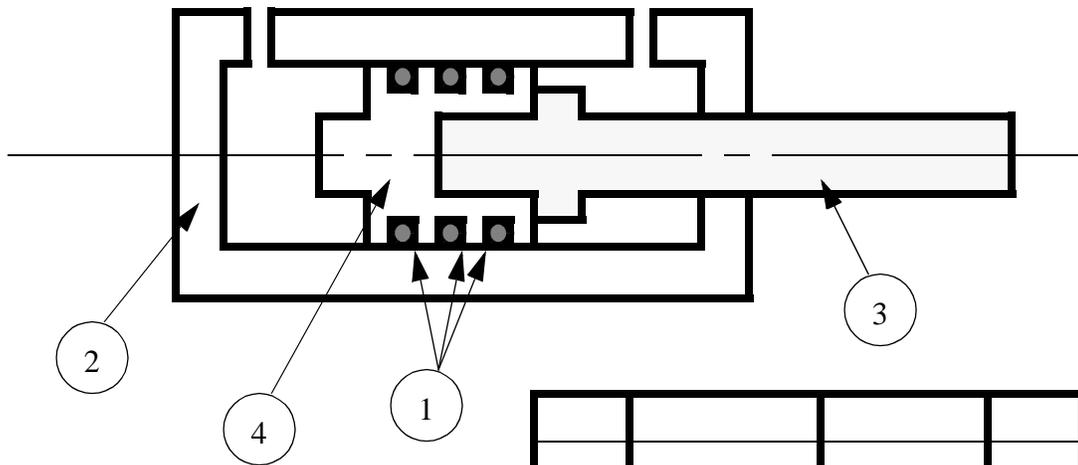
- This method is used for assemblies of thin materials, such as sheet metal.
- This illustrates how the pieces butt up against each other.
- The sections are filled with black, but a small space is left between the piece to indicate the assembled faces (operations such as crimping, spot welding, etc are used for these)



DI:14.1.6.9 - Assembly Section

- When placing parts together we want to verify that they will match, and that they can be assembled. We also want to provide assistance to the assembler. To do this a cut away assembly drawing can be used.
- There are a number of elements present in these diagrams,

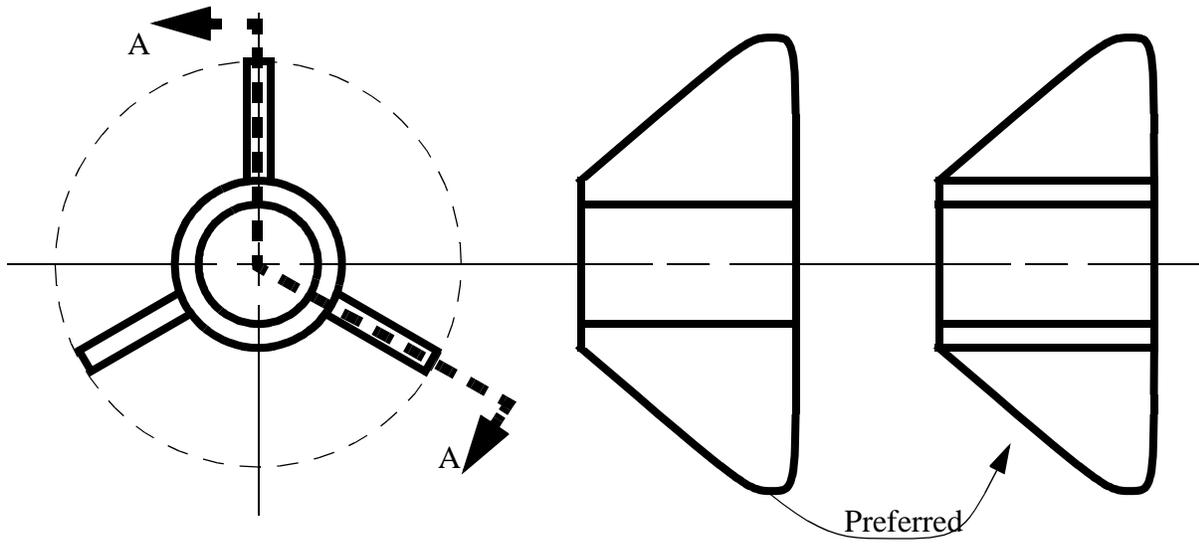
- two or more parts
- a parts list with numbered items
- generally section views are used, and oriented along the main assembly axis



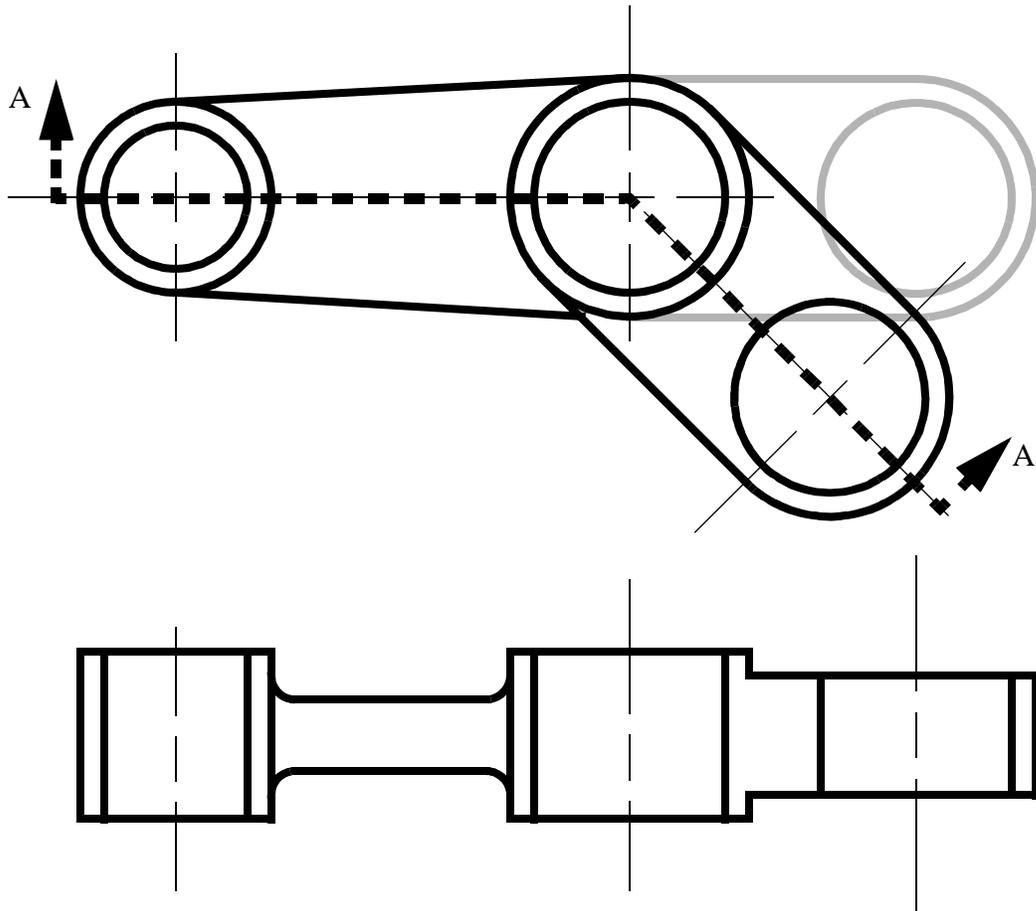
4	piston	M8765	1
3	rod	M87101	1
2	chamber	M8734	1
1	o-rings	P8703	3
ref #	description	part #	qty.

DI:14.1.6.10 - Special Cases

- Because sections are to clarify confusing features on diagrams, they are sometimes not theoretically correct.
- A few of the cases that are considered when working with sections are,
 1. cutting lines may intersect ribs, but they may be drawn offset somewhat to clarify the rib geometry.



2. sections may be aligned to clarify the views



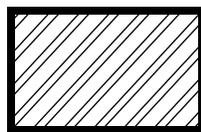
3. If a cutting plane cuts through intersecting features, the less important feature may be omitted for clarity, or to save time. For example, two rounds that intersect at an angle other than 90° would have an unusual shape, if one is not drawn, the section becomes much easier to do.

DI:14.1.6.11 - Fill Patterns

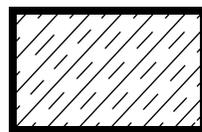
- Sections can be filled with a number of patterns to indicate different materials
- This was a common technique in the past. Some examples are given below.



cast iron and
malleable iron



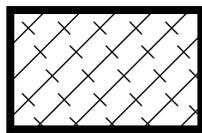
steel and
wrought iron



bronze, brass
copper



zinc, lead,
alloys



aluminum and
magnesium and
their alloys

DI:14.1.7 Auxiliary Views

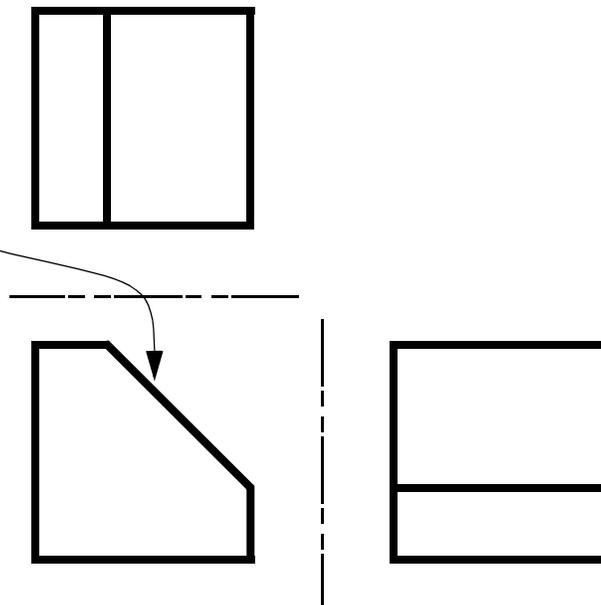
- The glass box can also be folded at odd angles. This technique produces views known as Auxiliary views.
- These views are useful when we want to draw a view of a surface that is not normal to one of the primary viewing planes.
- common terms used for this method are true size, and true shape. keep in mind that if a feature does not lie parallel to one of the primary viewing planes, it will appear distorted in every view.
- These views can be constructed from any view in a drawing. typical names for these identify the

view that they are drawn from,

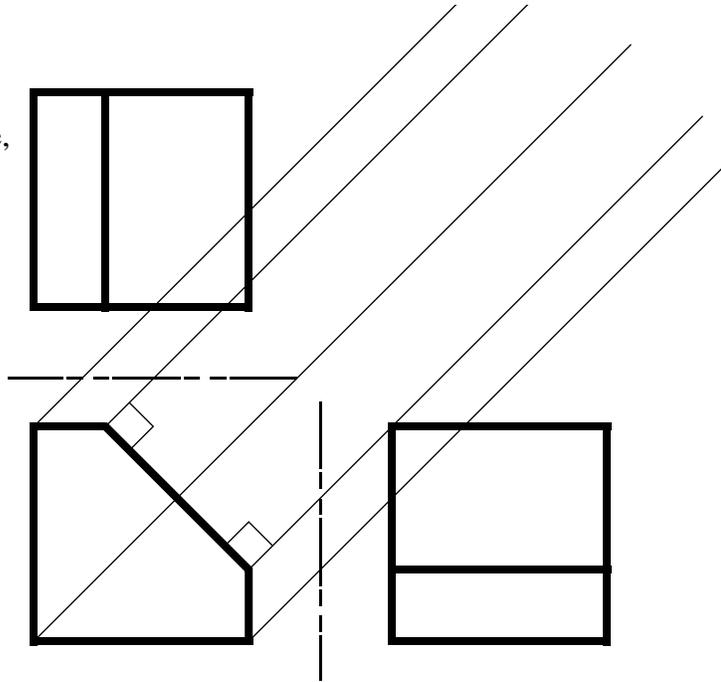
- front auxiliary view
- top auxiliary view
- side auxiliary view

- We can also use auxiliary views to project other views for geometric purposes
- hidden lines are typically not used in auxiliary views, unless needed for clarity. Also, a number of surfaces are not included because they are distorted, and of little value.
- typically steps followed to construct an auxiliary view,
 1. select the face that is to be drawn as i) a true surface, ii) a true length line, iii) an end view of a line.
 2. draw construction lines perpendicular to the surface/line/point of interest. This line should go in a direction, and far enough that leaves enough space for the view.
 3. draw a folding line at an appropriate distance. This will act as a reference plane.
 4. transfer distances from another view. This view will typically be the view adjoining the view that the auxiliary is drawn from.
 5. Complete the view.
- an example is given below, and all faces are drawn for illustration, but normally only the angled face would be drawn. Because this is the first auxiliary from the drawing, it is called the primary auxiliary view.

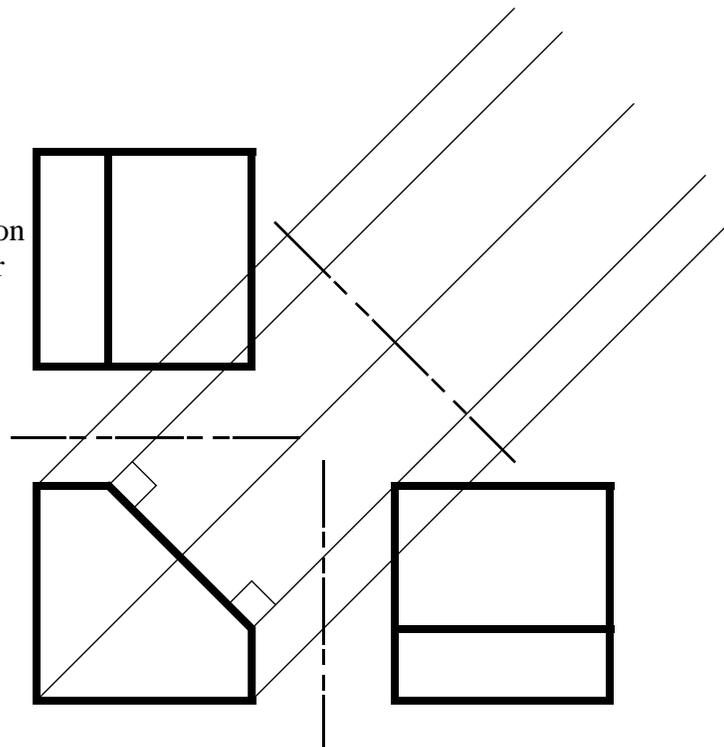
Step 1: decide to draw the angled face of the block, using the front view, because an edge view is available.



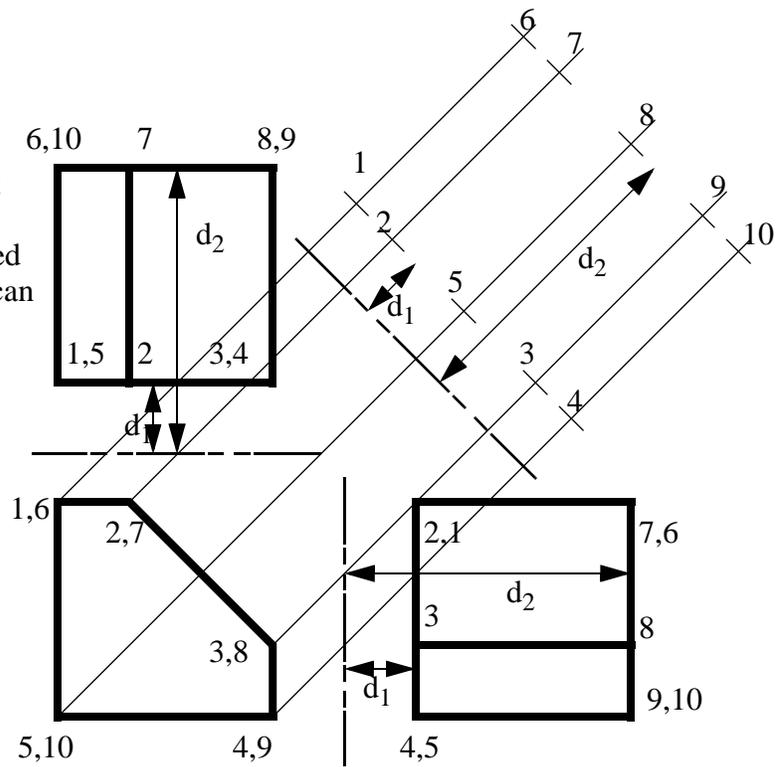
Step 2: draw construction lines perpendicular to the face, the view will be drawn in the open space in the upper right opening.



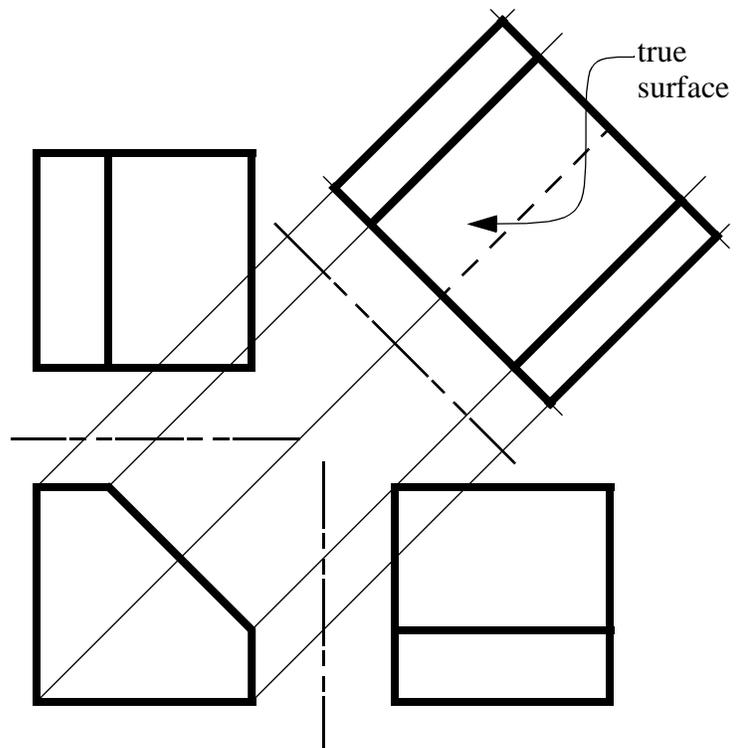
Step 3: draw the fold line in for reference. Just as a visual check, each of the construction lines should be perpendicular



Step 4: Transfer distances to find points in the auxiliary view. Here the points are numbered for the readers benefit. We can transfer the distances either from the top or side view.



Step 5: the view is completed



- There are special drafting techniques for rounded, or curved surfaces, these can be found in any drafting textbook.

DI:14.1.7.1 - Secondary Auxiliary Views

- sometimes it is necessary to make an auxiliary view, using an auxiliary view. When this is done, the first auxiliary is constructed as normal. The second auxiliary is made from the first, but the distances can only be transferred from the first auxiliary for the second auxiliary.
- These views can be needed for a number of purposes, but generally they will be needed when the object does not lie perpendicular, or parallel to any of the viewing planes.

DI:14.1.7.2 - Partial Auxiliary Views

- It is not necessary to draw entire auxiliary views, they can be draw in part, and break lines use.
- This technique allows simplified illustrations of features of interest, without full development of an auxiliary view.

DI:14.1.8 Descriptive Geometry

- The use of drafting to determine geometric properties, such as shortest distances between points and lines.
- These methods can also be used to solve statics (vector) problems, etc.
- These methods use extensions to the methods of auxiliary views that allow curved surface to be considered.
- the basic steps in these methods are,
 1. find the true lengths of a line
 2. find the end view of a line
 3. find the edge view of the surface
 4. find the true shape of the surface
- These steps will allow determination of a number of properties,
 - points can be projected into other views
 - lines can be projected into other views

- the true length of a line can be determined
- a point view of a line can be found
- distances between points and lines can be found
- distances between lines can be found
- distance between a point and plane
- angle between two planes
- edge view of a plane

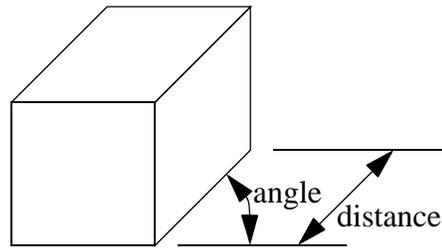
DI:14.1.9 Isometric Views

- These views are done as a way of realistically drawing objects. This is not correct, as a perspective drawing would be, but it is very good for engineering problems.
- The viewing directions are skewed so that up is still up, but straight back now goes to the left and back, and right goes to the right and back. Both of the moved axis are drawn at 30° to the horizontal.
- The values measured off these views will be accurate when measured along the axis.

DI:14.1.10 Special Techniques

- There are a number of special techniques of interest when doing manual drafting, but of declining interest in view of modern CAD systems. A list of these techniques are given below, and are described in good detail in most drafting books,
 - drawing ellipses
 - drawing with circles
 - drawing with revolution
 - drawing with four centres
 - isometric drawing
 - using $30^\circ/60^\circ$ angles
 - using special paper
 - Oblique views
 - cavalier (45° , with full depth size)
 - cabinet ($0-90^\circ$, with half depth size)
 - general ($0-90^\circ$, with between half and full depth size)

a unit cube is shown for illustration



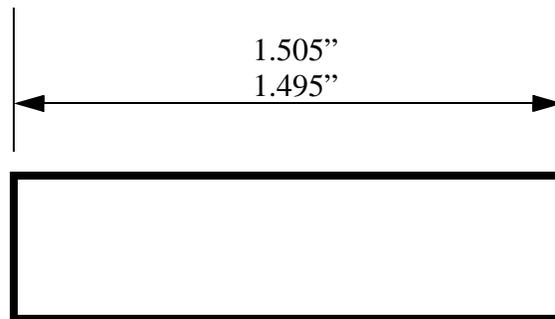
DI:14.2 NOTATIONS

- Typically these are a number of notations added to drawings to describe features, or explain operations.
- Some abbreviated terms are given below,

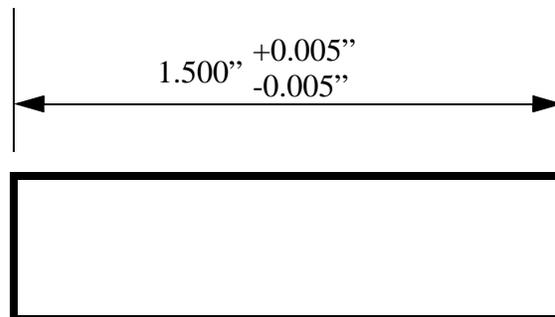
Abrev.	Description
CBORE	counterbore
CSK	countersink
DIA	diameter
HDN	case harden
L	lead
LH	left hand
NC	national course
NF	national fine
P	pitch
R	radius
Rc	Rockwell C hardness
RH	right hand
THD	thread(s)
TIR	total indicated runout
TPI	threads per inch
UNC	unified national course
UNF	unified national fine

DI:14.2.1 Basic Dimensions and Tolerances

- The size of an object, and the required accuracy can have a significant bearing on the cost
- Unilateral Tolerances
- Bilateral Tolerances
- Limits can be used to exactly define the size boundaries of a feature.



- Tolerances use a nominal dimension and differences.



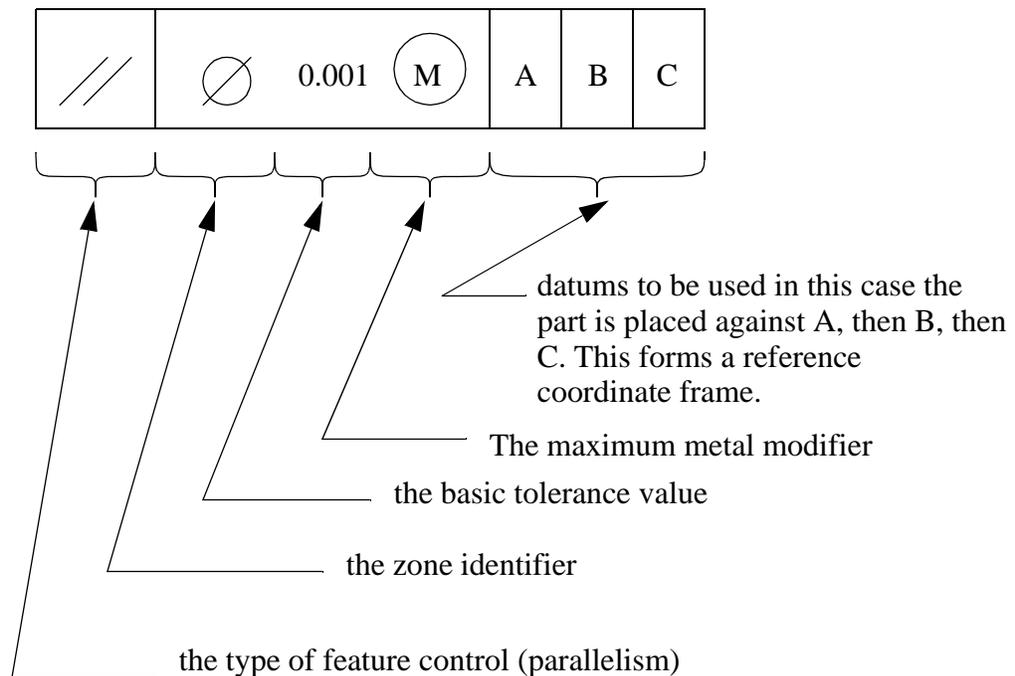
DI:14.2.2 Geometric Dimensioning and Tolerancing (GD & T)

- Specified in standard ANSI Y14.5 (1983).
- Combines rules and independent symbols in addition to the normal tolerancing symbols
- Allows old style tolerances, but adds new methods that cover geometrical forms.
- Allows easy specifications of datums, etc.

- Advantages of this method are,
 - makes drawings clearer and more unambiguous
 - allows separated features to be related
 - uses symbols instead of words to reduce language translation problems
 - the method helps specify manufacturing and metrology methods
- The main purpose of GD&T is to ensure,
 - size - the overall dimensions are as specified
 - form - the shapes specified must have the correct geometrical form
 - fit - two parts must mate as specified
 - function - the product conforms to performance specification

DI:14.2.2.1 - Feature Control Symbols

- The basic of GD&T is the feature control symbol.
- This indicates what the tolerance is, its value, the reference datums, and any modifiers needed.
- An example of a feature control is given below,



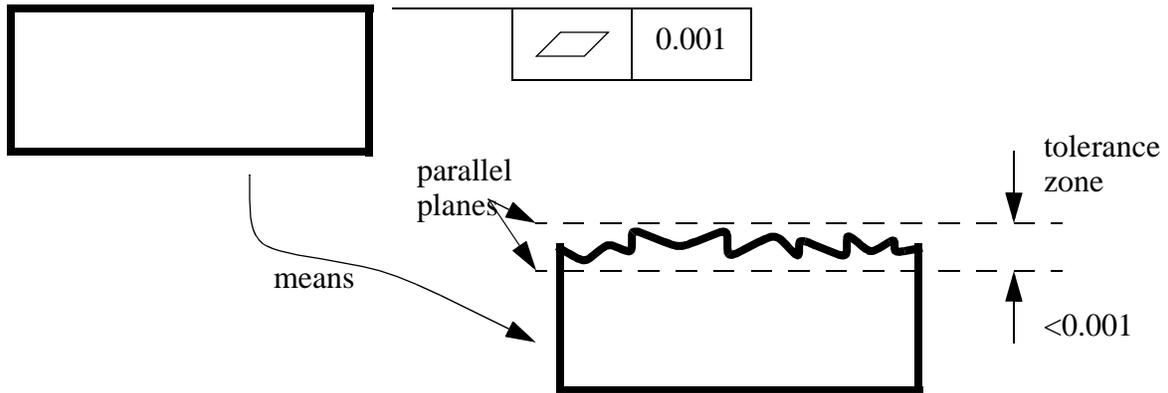
- not all of these symbols/categories will be used on a regular basis, but they provide the designer added flexibility in how they specify tolerances.

DI:14.2.2.2 - Symbols and Meaning

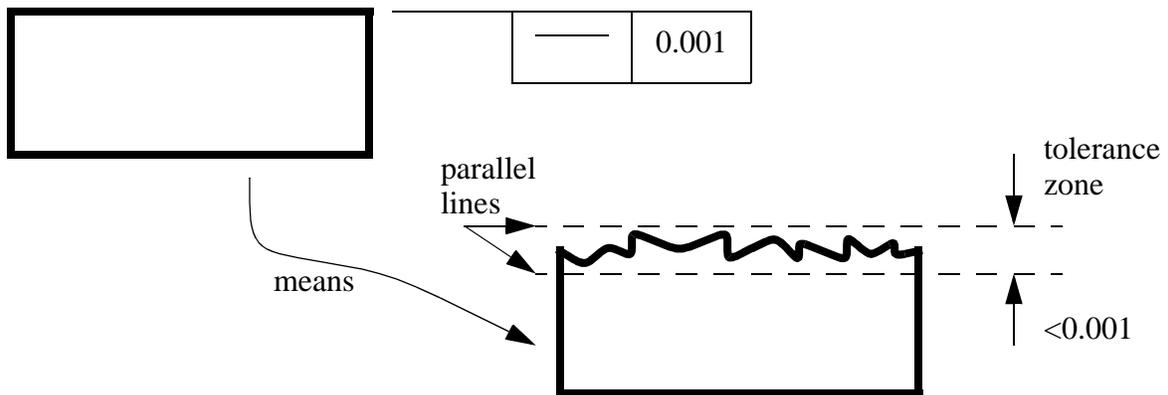
- The basic symbols are shown below,

	tolerance type	characteristic	symbol
individual features	form	straightness	
		flatness	
		circularity	
		cylindricity	
for individual or related features	profile	profile of a line	
		profile of a surface	
related features	orientation	angularity	
		perpendicularity	
		parallelism	
	location	position	
		concentricity	
	runout	circular runout	
		total runout	

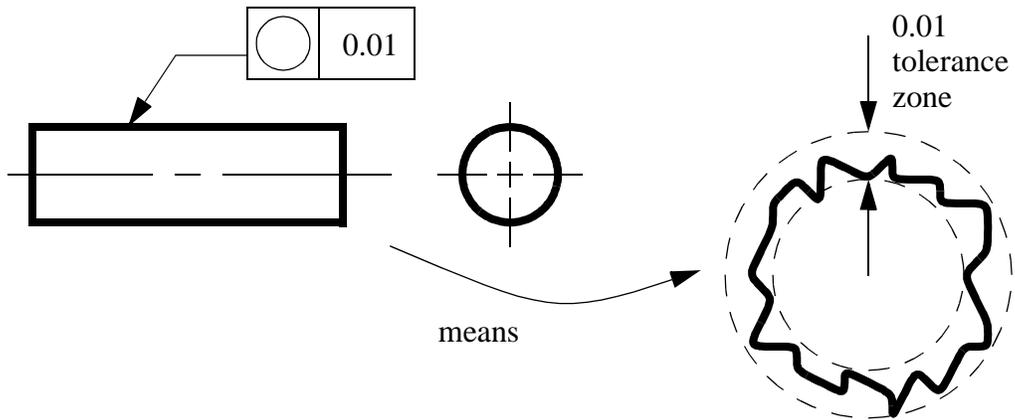
- Flatness - basically, all the surface elements are constrained to lie within two parallel surface places, separated by the tolerance



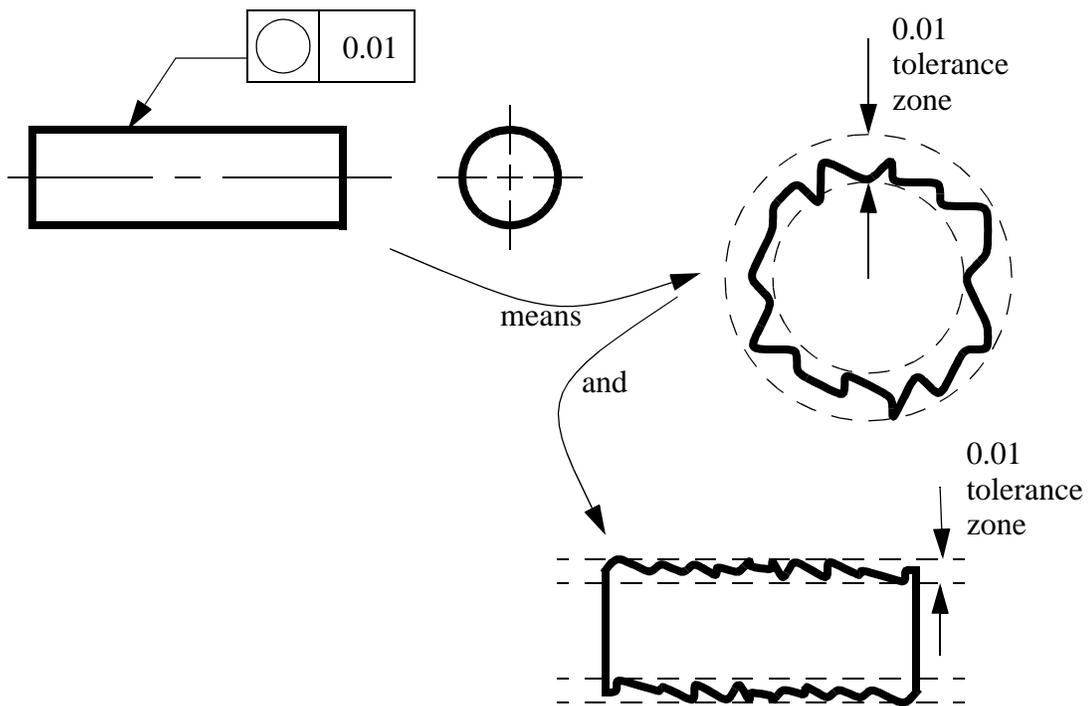
- Straightness - basically, one the surface elements is constrained to lie within two parallel surface places, separated by the tolerance. In effect, this means that if any line across the surface is within two parallel lines, the part is acceptable. This can be tested by running a comparator across the surface (using a reference plane)



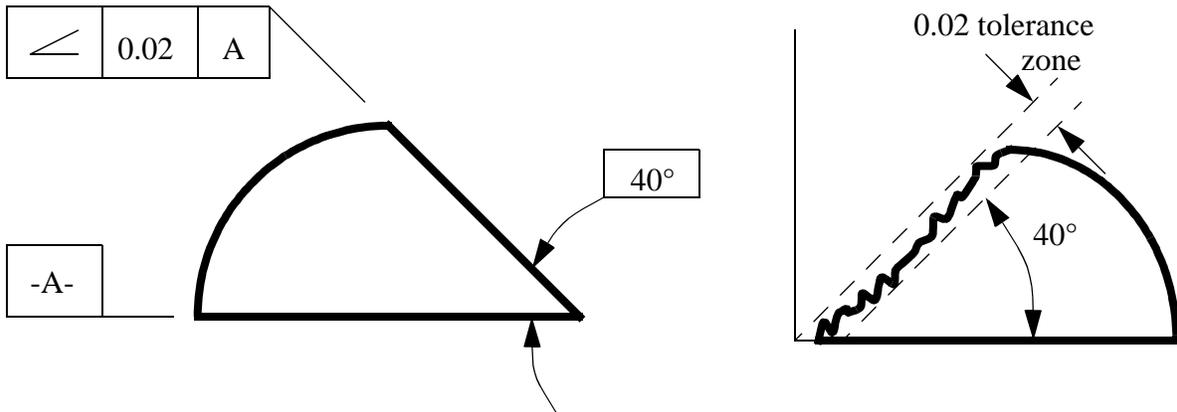
- Circularity - all of the points on a cylindrical surface are constrained to lie within two circles. This can be tested with a talyrond.



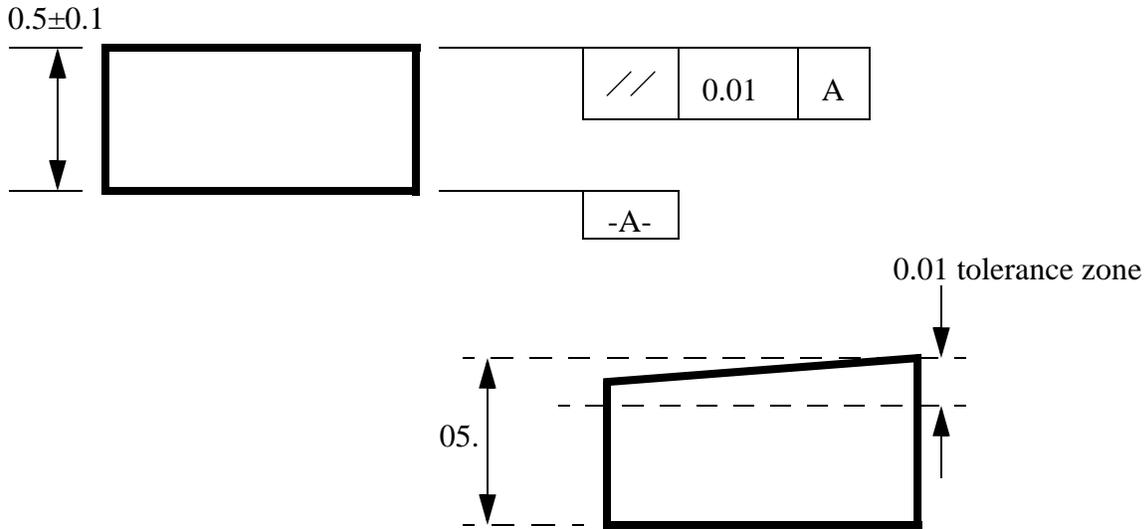
- Cylindricity - an extension to circularity that specifies the tolerance along the cylinder.



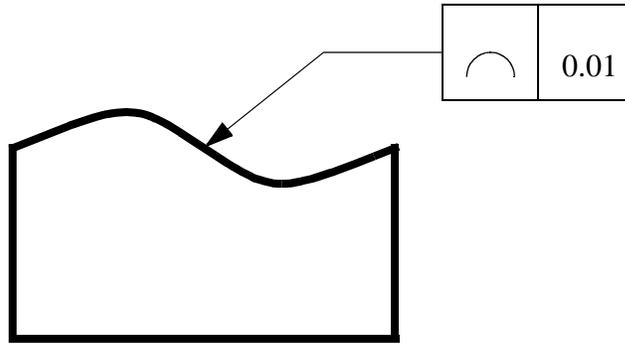
- Concentricity -
- Angularity - requires that all points on a specified feature must form an angle with a datum. This could be measured with a sine bar and a height comparator.



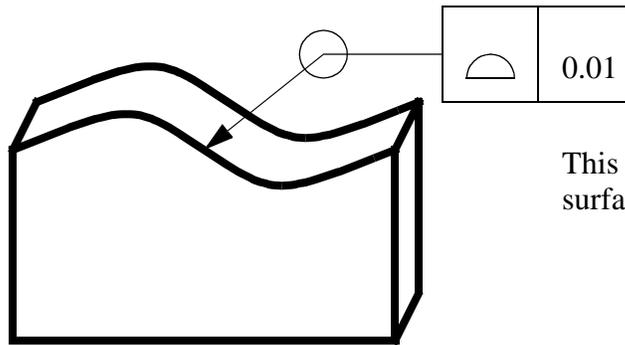
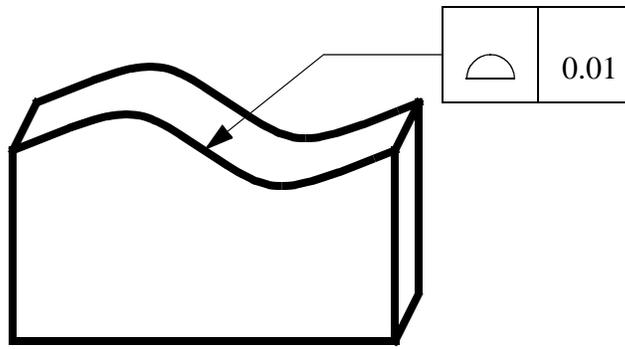
- Perpendicularity - this has the same meaning as angularity, but it is specifically applied to 90° angles. This could be measured with squares and reference plates.
- Symmetry -
- Parallelism - all points on a surface are to be parallel to a given datum, within a specified tolerance



- Line Profile - the amount of deviation that is allowed (typically for irregular lines)

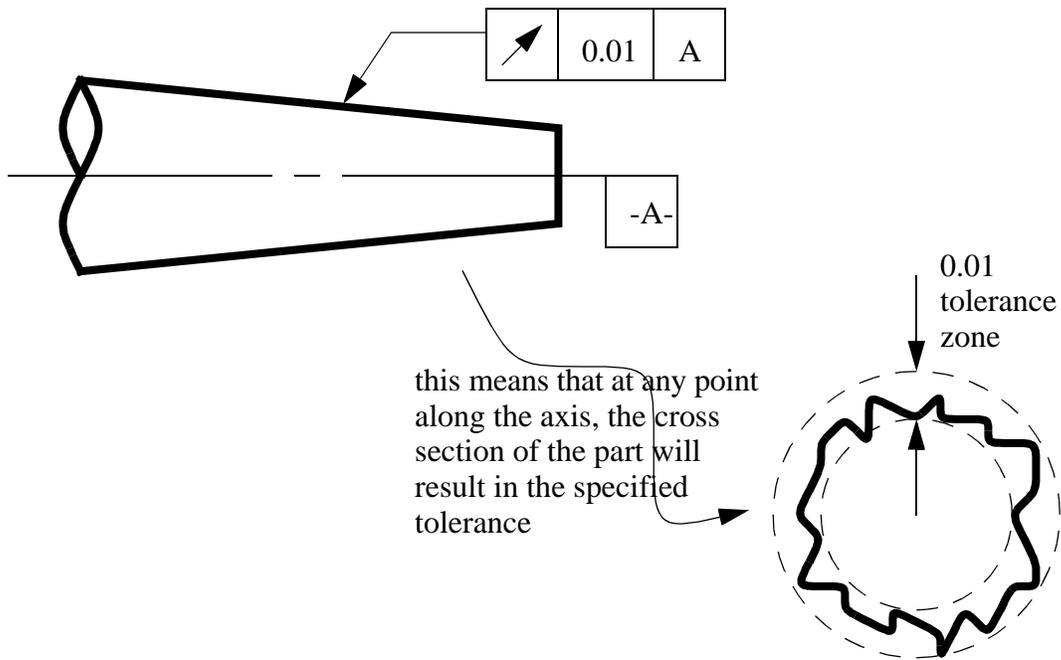


- Surface Profile - the amount of deviation that is allowed for a surface



This means over the entire surface

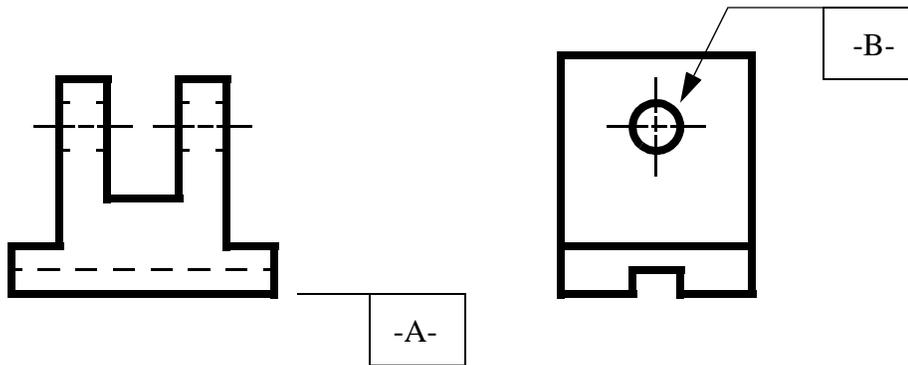
- Circular Runout - when dealing with a surface of revolution, this determines the amount of deviation allowed from the central axis. This specifically refers to a specific point



- Total Runout - similar to circular runout, but this applies to the entire part. In effect, circular runout uses two circles, whereas total runout uses two surface planes.

DI:14.2.2.3 - Datums

- These are reference features, that other features are to be measured against.
- These can be used when setting up parts, for manufacturing or production
- Typical features used are,
 - axes
 - cylinders
 - planes
 - lines
 - points
- A datum reference frame can be constructed with,
 - three perpendicular planes
 - 3 contact points in the primary plane, 2 in the secondary plane, and 1 in the tertiary
- A datum is specified with a boxed letter with two dashes,



DI:14.2.2.4 - Modifiers

- to overcome shortcomings in symbols, modifiers can be added to change their meanings.
- in particular,

(M)

Maximum material condition - the tolerance is at the extreme that would result if too little material was cut off, and the maximum material remains.

(L)

Least (Minimum) material condition - the tolerance is at the extreme that would result if too much material was cut off, and the minimum material remains.

(S)

Regardless of features size (RFS) - this indicates that the tolerance must be maintained, regardless of variations in this size of the object.

(P)

Projected tolerance zone - a tolerance zone can be extended beyond a surface. To do this the basic surface must be specified as a datum.

***** Include an example of tolerances using GD&T

DI:14.3 WORKING DRAWINGS

- The basic skills/topics discussed below lead up to preparing, and understanding a complete set of drawings.
- The purpose of working drawings is to,
 - describe the exact geometry of parts
 - indicate other details associated with drawings (for example, material)
 - show how parts are assembled
 - indicate manufacturing preferences
- generally, the drawing package will include a number of items,
 - a drawing (one a separate sheet with a separate title block) for each part
 - a bill of materials
 - an assembly drawing
- a typical working drawing package will contain,
 - a design layout
 - assembly drawings (and a Bill of Materials)
 - subassembly drawings
 - detailed drawing
 - purchased parts
 - modified purchased parts

DI:14.3.1 Drawing Elements

DI:14.3.1.1 - Title Blocks

- Most of the important details are put in this block. Each block is individualized to a company, but generally they include,
 - company name, and division if applicable
 - machine or department name
 - part name
 - drawing number
 - part number
 - the number of parts required
 - the scale

- drafter name/date
- drawing checker name/date
- material
- tolerances
- finishing details
- units of drawing

- The block is typically located in the bottom right hand corner of the drawing
- The drawing title, and drawing number are commonly printed in large fonts

DI:14.3.1.2 - Drawing Checking

- this is a process whereby a drawing is reviewed for completeness, accuracy, etc.
- modern CAD systems, especially solid modeler should reduce the emphasis on checking the drawings. Some of the main features checked for in manual drawings are,
 - appearance - this can be a large issue for hand drawn work
 - within standards - legal and corporate
 - clarity - all description, dimensions, etc should be well understood
 - completeness - sufficient dimensions, etc should be present for production
 - redundancy - redundant information should be eliminated unless essential
 - manufacturability - the cost and feasibility of production should be considered. are tolerances sufficient/excessive, are other steps sufficient for product life.
 -

DI:14.3.1.3 - Drawing Revisions

- When a drawing has reached production, it is considered final, but changes are frequently made.
- It is very important that drawing changes are dealt with properly. This means,
 - all changes are recorded on the drawing, and new drawings made
 - all old drawing must be collected, or marked void (failure to do this can lead to very expensive mistakes)
 - when a drawing has been changed a number of times, it should be redrafted.
- Computer CAD systems still do not sufficiently deal with problems such as these, and often rely on the previous manual drafting systems to process these updates. But, software is available, and is being developed for product information management (PIM) that will deal with these changes in a manner suitable for CAD.

DI:14.3.1.4 - Bill of Materials (BOM)

- An important list on most drawings is a Bill of Materials, this is a list of all required materials/ parts required to make to part depicted in the drawing.
- This list contains,
 - all part numbers
 - all part names
 - quantity of parts required
 - materials required
 - source
- This is sometimes given on separate sheets, or on the drawing itself
- The typical (but not the only) order for listing parts on a BOM is,
 1. produced in-house
 2. specialty purchase (e.g. roller bearings)
 3. standard purchased hardware (e.g., washers)
 4. bulk items (e.g. lubricants)

DI:14.3.2 Drawing Types

DI:14.3.2.1 - Assembly Drawings

- These are used to specify an assembly with,
 - a drawing of the assembled part
- Hidden lines are typically omitted from these drawings. Details may also be omitted if they have no bearing on the product
- assembly instructions may also be included in these drawings to guide workers
- full section assembly drawings are often used
- dimensions not included unless essential
- Small blow-up bubbles are often used to emphasize details
- The parts can be identified using,

- numbers with arrows and a block list of parts including,
 - quantity
 - part name
 - part source
 - part number
 - reference number
 - drawing number
- arrows and descriptions
 - quantity
 - part name
 - part source
 - part number
 - drawing number

DI:14.3.2.2 - Subassembly Drawings

- these are basically the same as assembly drawings, except that there are components that have already been assembled.
- Modern equipment is complex and is assembled in stages. The final assembly might be something like an automotive body welding shop, whereas a sub-assembly might be the car radio.

DI:14.3.2.3 - Exploded Assembly Drawings

- these are drawings that show each piece separated, and indicates their assembly paths. This can help when determining,
 - which part goes where
 - the orientation of the part
 - the part of approach
 - the order of assembly

DI:14.3.2.4 - Detailed Drawings

- These drawings use the techniques discussed earlier in this section to depict, and dimension parts.

***** INCLUDE A COMPLETE DRAWING PACKAGE TO ILLUSTRATE

DI:14.4 PRACTICE PROBLEMS

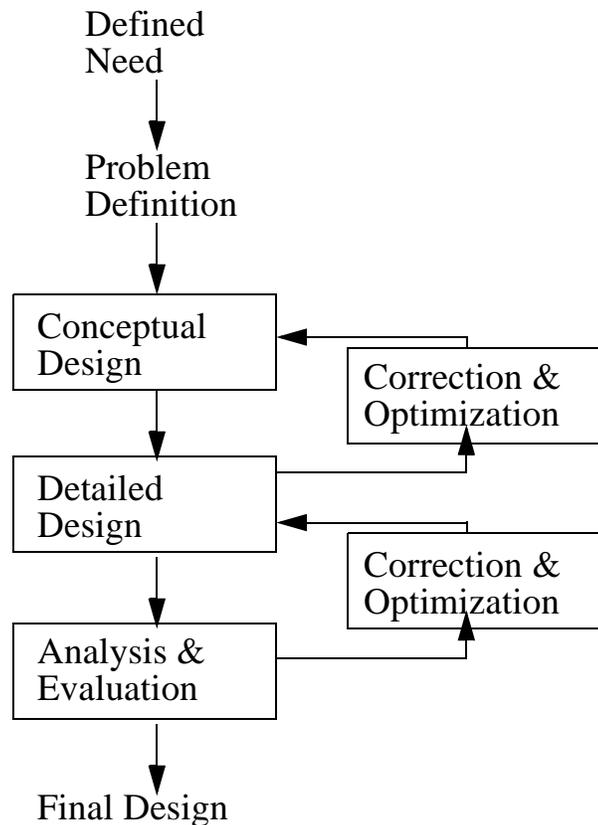
14.5 REFERENCES

Ullman, D.G., The Mechanical Design Process, McGraw-Hill, 1997.

DI:15. COMPUTER AIDED DESIGN (CAD)

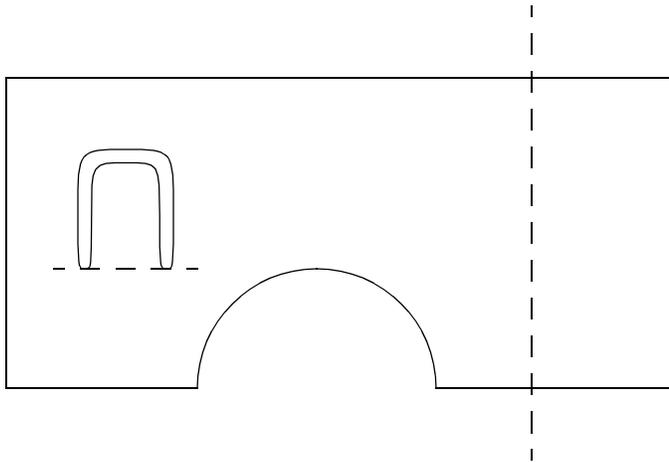
DI:15.1 DESIGN

- Recall the basic process of design (or at least one of the many)



- The important phases of this diagram are,
 - The ongoing refinement of the overall design
 - The ongoing refinement of the detailed design
 - The analysis of the design
- This diagram (or at least the main concepts) form the basis for CAD systems. A complete CAD system will provide as much of the structure above as possible.
- Some of the tools provided in a CAD environment are,
 - Innovative and conceptual design
 - Qualitative design analysis
 - Structuring of part (eg. assemblies)
 - Knowledge based/intelligent design tools
 - Engineering design information (standards lookup, or electronic catalogues)

- Optimization
- Design interfaces, and tools
- Some applications are well suited to 2D CAD systems,
 - PCBs (Printed Circuit Board Design)
 - ICs (Integrated Circuit Design)
 - Mapping (road maps, topographical maps)
- Consider the example of a sheet metal layout



- 3D CAD systems are becoming widely used for Mechanical design in a number of businesses these days including,
 - Aircraft Design
 - Automotive
 - Consumer electronics
 - etc.
- CAD systems provide advantages such as,
 - Visualization
 - Minimizes design errors
 - Graphical display of hard to visualize information (eg. 3D warping of plastic part)
 - Standardized drawings, and documents
 - Faster lead time
 - Customer perception is improved
 - Productivity improvement over time
 - Developing alternate concepts
 - Evaluation of alternate concepts

- Analytical investigation of parts
- Experimental investigation
- Detailed drawings and specifications
- Preliminary 'construction' of design prototype
- Easy bridge to prototype construction
- Easy to change designs
- Optimization

DI:15.2 CAD HISTORY

- A very brief history of CAD development is listed
 - 1940s - First digital computer developed
 - 1950s - Commercial computers become available
 - 1955 - CRTs begin being used in military projects
 - 1957 - APT II (Automatic Programmed Tool) developed for generating NC control. Automated NC used in industry.
 - 1959 - Stromberk Carlson develops a system to interpret graphics on tape, then output them to a screen, or print on special paper
 - 1963 - Ivan Sutherland presents a paper on "Sketchpad" which allows interactive graphics
 - 1965 - Lockheed introduces a CAD/CAM system, and a FEM system. McDonnell introduces CADD
 - 1966 - Business world sees Wall Street Journal title "Electronic Sketching; Engineers Focus on Screen to Design Visually via Computer; Keyboard Enlarges, Rotates 'Drawings'; Lockheed, GM Enthusiastic About Uses"
 - 1971 - David Prince writes first book on computer graphics
 - 1975 - ICAM (Integrated Computer Aided Manufacturing) project is begun by US Airforce
 - 1976 - Color raster graphics technology begins to develop.
 - 1979 - Development of IGES begins
 - 1980 - Introduction of PCs revolutionizes all markets
 - 1980s - Solid Modeling on UNIX
 - 1990s - Solid Modeling on low end systems

DI:15.3 BASIC REQUIREMENTS OF CAD SYSTEMS

- A CAD System must,
 - Allow a user to input geometry, and other information
 - Provide methods for manipulating the geometry
 - Provide for display output for the user
 - Allow storage of the design in formats which can be used in other CAD and CAM packages

- There are other features of great value to a CAD system,
 - Don't forget the manuals, They can help get through the tough times. If not, you may spend a lot of money calling help lines.

DI:15.4 EDITING AND CREATING

- Each CAD package allows us to manipulate the geometrical model using various interactive techniques.
- Editing Geometry depends upon the representation the geometry is stored with.
- If an elemental (remember: lines, circles, arcs, etc.) geometric model is used, then the methods are much different than a B-Rep model.
- The major editing methods used are for Elemental, Surfaces, and CSG.

DI:15.4.1 2D Curves and Lines

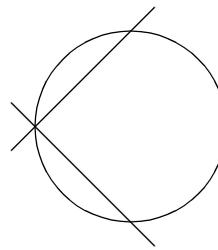
- A number of functions must be provided to allow editing of 2D geometrical entities, such as lines, circles, arcs.
- Some of the basic editing functions are listed below,
 - Basic Entity Creation (lines/ circles/ arcs/ etc)
 - create using exact coordinates
 - two screen points for line ends, circle radius/centre/diameter/etc
 - Line Trimming
 - trim lines back to intersection
 - extend lines to intersection
 - trim line to perpendicular point
 - cut a circle/arc on one side of an intersection
 - Point Creation
 - screen position
 - exact numerical coordinate
 - nearest tangent of line to an arc
 - nearest end of a line
 - midpoint of nearest line
 - centre of nearest arc
 - nearest grid point
 - Arc Creation
 - intersection of circle with another line

- Special Techniques
 - offset of a line
 - extend lines to intersection
 - trim line to perpendicular point
 - delete entities
- etc

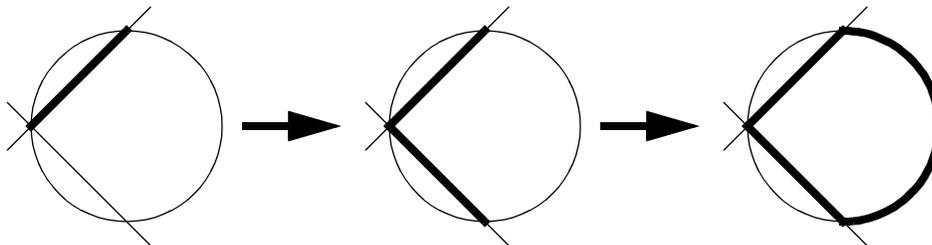
• There are a number of ways (philosophies) for creating drawings using the basic elemental editing techniques. A few popular methods are listed below.

- Construction Lines - A set of construction lines are set up, then segments of the lines are selected for the actual drawing

Step 1: Construct a basic set of lines to lay out the shape to be drawn.

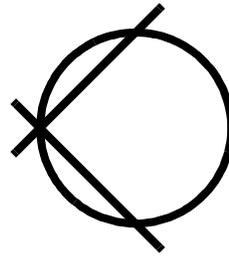


Step 2: Pick parts of the construction lines to darken.

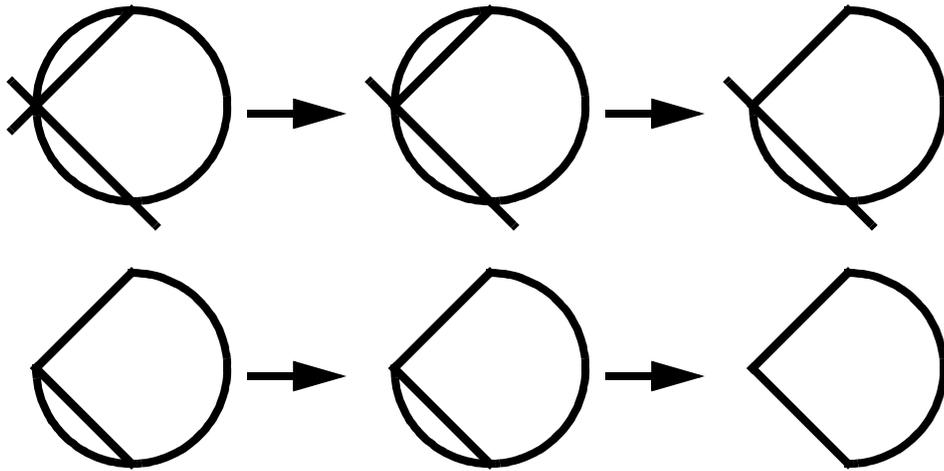


- Trimming - The construction lines are all drawn, then the unwanted parts are trimmed off

Step 1: Construct a basic set of lines to lay out the shape to be drawn.

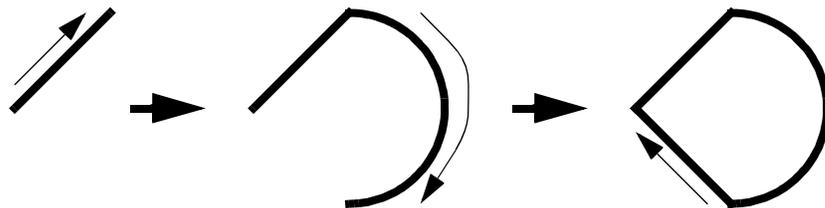


Step 2: Pick parts of the construction lines to delete.



- Navigation - A line figure is built up using successive line segments.

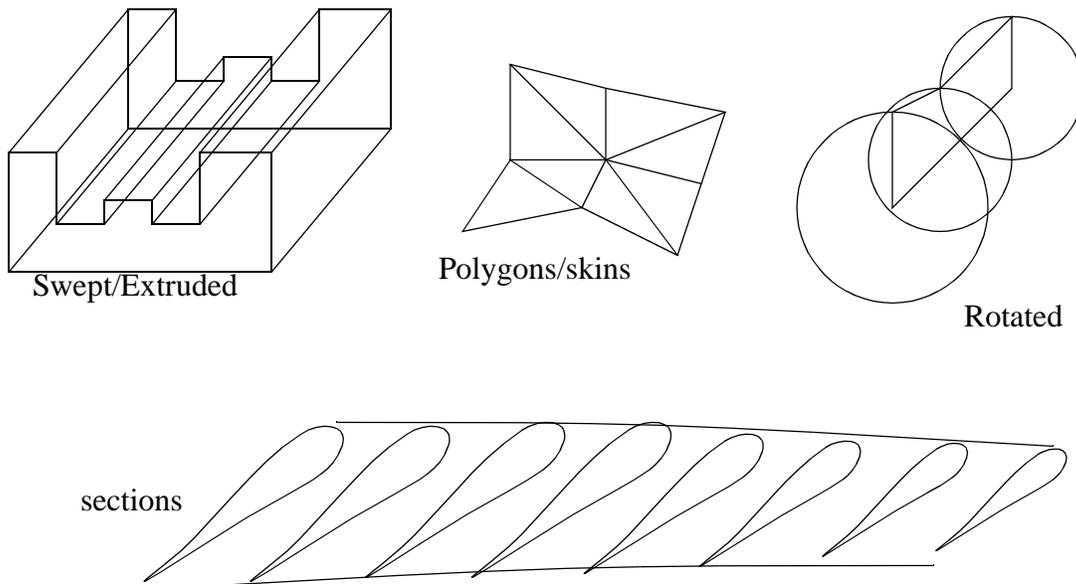
Step 1: Starting from one point, select the type of element, and build the shape in sequence.



- Parametrization - Objects such as rectangles, circles, arcs, etc. are created using their dimensions, then positioned with traditional methods.

DI:15.4.2 Surfaces

- Most surface modelling packages rely on the elemental definition of lines, and points.
- There are a number of basic philosophies for creating surfaces,
 - Swept profiles - a profile, and a path in space are used to sweep out a surface.
 - Rotated Profiles - a Profile is created then swept about an arbitrary axis
 - Extruded Profiles - a profile is created, then grown in one direction.
 - Skins (Splines) - a direct creation of points, then the splines that connect them
 - Polygon Approximation - polygons are defined which join up to define a surface
 - Sections - sections are defined for different points along a path, which then allow generation of complex transition geometries.

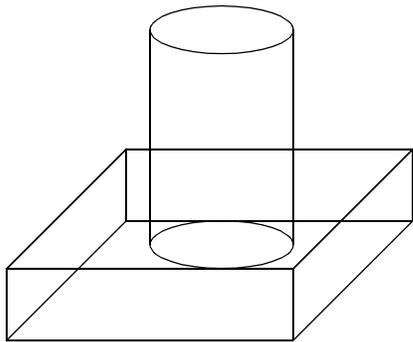


- Once surfaces have been created, they may be operated on by boolean operations.
- This method is often used as a preliminary stage to CSG editing.

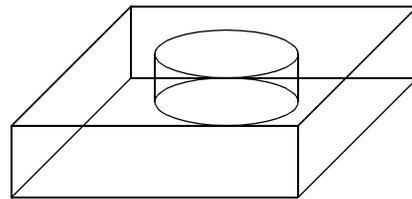
DI:15.4.3 CSG

- This is by far the simplest method
- Solid Primitives are progressively cut and joined to form new shapes.

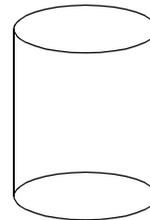
- Primitives may come from,
 - Traditional Sources - Blocks, Spheres, Wedges, etc.
 - Surfaces - A Volume is assigned to a surface model
 - Previous operations
 - others ?
- CSG editing requires storage of the results of operations. This is because a part may be used many times to cut another part, for example a chamfered hole for a sunken screw.
- The fundamental CSG operations are,
 - Union - both parts joined as one
 - Intersection - Only where two parts overlap
 - Subtraction - only where parts do not overlap, One of the parts is typically discarded.



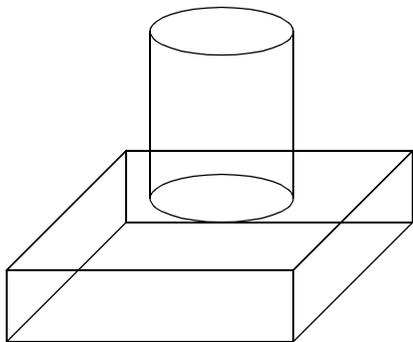
two primitives before the operation



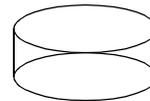
Subtraction case A (cuts hole in block)



Subtraction case B (cuts off end of cylinder)



Union (both shapes merged into one)



Intersection (bottom of cylinder remains)

DI:15.5 USER INTERPRETATION OF THE GEOMETRIC MODEL

- Every CAD system uses a graphical display for user interpretation of the final part.
- The display methods discussed in the computer graphics section are all used in CAD packages. (Please refer to that section for examples, and explanation of how each display method affects the user).
- There are many techniques possible with computer graphics that make on screen designs easier to understand.
 - Dimensioning
 - Placed manually, but updates when dimensions change.
 - Annotation - the user may add comments to drawings
 - text with a leader pointing to something
 - text alone
 - tolerances
 - Drawing information
 - Graphics effects
 - Fill Styles - hatching and other patterns selected
 - Line Styles - such as hidden, shadow, phantom, etc.
 - Color - helps differentiate when there are many lines

DI:15.6 USER DIRECTED CHANGES TO THE GEOMETRIC MODEL

- This feature is of the greatest importance to a user
- Some onscreen input selection features are,
 - Boxes - a good example of this method is the zoom boxes
 - Types - all objects of a certain type are selected
 - Last - last object created
 - All - all visible objects
 - Names - in some systems parts are named, and these can be used for reference.
 - Markers - symbolic markers can be placed on the screen to allow easy differentiation between object (like in Ideas)
 - Layers - drawings can be layered up, which allows easy separation of distinctive parts. One example is a factory layout, including separate layers for machines, plumbing, electrical, HVAC, etc.
- Objects often require manipulation on the screen, and certain parameters defined by a number of techniques,
 - Translation
 - select two points (they define a translation vector)
 - angle and distance
 - select a line (a direction vector)

- move a point to a point
- interpolate
- etc.
- Rotation
 - about a pivot point by 1 angle (2 angles for 3D)
 - about an axis by an angle
- Mirroring
 - mirror over a line/plane
- Magnification
 - a magnification about a point by a factor
- Copying
 - a simple copy
 - a copy with an offset for each copy
 - a copy with a rotation for each copy

DI:15.6.1 Modern Hardware for CAD Systems

- The CRT is taken for granted now, but previously CAD systems underwent many metamorphosis.
- The array of current and previous hardware input devices are,
 - keyboard
 - mouse
 - tablet
 - button/dial boxes
 - light pen
 - touch screen
 - track balls
 - joy sticks
 - punched cards
 - CMMs
 - scanners
 - 3D scanners

Device	Resolution	Speed	Cost	Fatigue
Mouse	Medium	High	Low	Medium
Keyboard	Exact	Low	Low	Medium
Tablet	High	High	High	Low
Position Joystick	Medium	High	Low	Low
Velocity Joystick	High	Medium	Low	Low
Light pen	Low	High	Low	High

- Future hardware input devices include,
 - virtual reality gloves
 - voice
 - scanned input and recognition
 - vision systems

- Previous output devices include,
 - Text printers
 - Graphics printers
 - Plotters
 - CRT
 - Rapid prototyping
 - Virtual reality vision systems

DI:15.7 SELECTING A CAD SYSTEM

- While this apparently seems easy, it is a very complex decision

- There are a number of factors which affect how the system is received,
 - Current computer use by employees
 - Perceived role of computer by employees
 - Cost of computer system and software
 - Available training for staff
 - Maintenance requirements for computer
 - Required number of users
 - Design complexity
 - Availability of CAM Facilities
 - Successful implementation in similar facilities
 - Management philosophy
 - Redundancy of design

- Major mistakes are,
 - Assuming more expensive is better
 - Assuming it will be well received because it will make work easier
 - Assuming that high tech means easier to use
 - Failing to get the potential users interested and involved in the decision to buy/selection/implementation
 - Neglecting the break in period
 - Not thoroughly examining the existing manual/computerized system which **ALREADY WORKS**
 - Forgetting that accountants want numbers plus a rate of return.

DI:15.7.1 An Example Plan for Selecting a CAD system

1. Examine the existing situation. Involve staff to find out what they perceive as problems, and possible solutions. This establishes allies required for whatever decision you choose. (Expect some who will resist, but they can become allies if handled properly).
2. Identify key people with an interest in the system, and get them involved with selection.
3. Devise a definite list of requirements, to support existing functions, and problems which exist, and possible solutions.
4. Get the accountant on your side by consulting them about costs, budgets, etc.
5. Gather information about existing systems by visiting trade shows, reading magazines, talking to others using systems.
6. Talk to Salesmen and companies of interest.
7. Get the salesmen to present to the CAD selection group
8. Narrow the possible vendors to about three.
9. Talk to their other customers about their system problems, and advantages, support, etc.
10. Pick a package using the CAD selection group and management.
11. Prepare budget, using help from accounting, and include a large portion of the budget for training, and maintenance.
12. Schedule training and implementation dates. Ensure that implementation is gradual, and does not overlap with the busiest times
13. Propose the budget and schedule to management, and request approval.
14. Give a general announcement to all concerned, and those partially concerned. A General meeting will help. The more information the better.
15. Follow schedule, and evaluate after each stage of implementation.

DI:15.7.2 A Checklist of CAD/CAM System Features

- A list below is suggested for hardware, but in light of recent advances in consumer computing, most of the previous concerns, such as special plotter papers, are no longer problems.

- Hardware

- Computer

- Type

- Personal Computer

- Unix Workstation

- Proprietary

- Network ready

- Backup capabilities

- Disk space

- CPU performance

- Uninterruptable power supply (UPS)

- Monitor

- Screen resolution (768*1024 or 1024*1280 are suggested)

- screen size (14" is absolute minimum)

dual monitors

I/O Devices

Drawing output
plotter
laser printer (color?)
ink jet printer

Input Devices

mouse
tablet
track ball/roller ball

• System Software

Operating System

Unix
MS-Dos/Windows 3.1,95,NT/etc.
Apple
Other ? (VMS, ???)

• CAD Software

Geometrical model

2D/3D
Exact or faceted with planar polygons
Mass properties

Editing

Parametric

Object Organization

Named Objects
Layers
Part libraries

Drawing Output

Drafting module

Analysis Module

Finite Elements
Plastic Flow
Kinematics/Collisions
Dynamics

Importing/Exporting

Surface formats: IGES, DXF, CDL
Solid Formats: PDES/STEP, SAT
Files for systems such as NASTRAN
Can be linked to a user written program

Rendering

Hidden line
Shaded Image
Ray Tracing
Real Time Rotations

DI:15.8 DESIGN

- Design interfaces have been continuously improving over the years,
 - ASCII Text Files
 - Keyboard Entry, with printed output
 - Keyboard Entry with graphic terminal output
 - Icon and Menu Driven with on-screen graphics
 - Fully windowed interfaces
- As computers become cheaper, and more powerful, the only interfaces of real importance are the Graphical User Interfaces (GUI).
- An example of novel technology is the visual scanner available for 3D input.

DI:15.8.1 Graphical User Interfaces

- The current demands on user interfaces are,
 - on-line help
 - adaptive dialog/response
 - feedback
 - ability to interrupt processes
 - consistent modules
 - a logical display layout
 - deal with many processes simultaneously
- The common trend is to adopt a user interface which often have,
 - Icons
 - A pointer device (such as a mouse)
 - Full color
 - Support for multiple windows, which run programs simultaneously
 - Popup menus
 - Windows can be moved, scaled, moved forward/back, etc.
- The history behind these machines are,
 - Development of Mouse based graphical interface at Xerox Palo-Alto Research park (70s)
 - Personal Computers began providing graphical programs for system management, games, etc (Early 80s)
 - MacIntosh, Sun, Apollo, Silicon Graphics, and others introduced mouse driven, fully windowed computers (Mid 80s)

- MacIntosh Competitor IBM PC gets OS/2 and Microsoft Windows (Late 80s). Marking massive movement to Windowed environment by all players in scientific computing.
 - X-Windows becomes a new, and widely accepted standard on workstations (Late 80s)
 - Microsoft introduces Windows, bringing windowed interfaces to the last major computer platform.
- Some Concepts in GUIs are,
 - button** - An item which is shown within a window. When a user points at it, and presses a mouse button, it initiates an action.
 - icon** - A small graphical symbol on the screen which can be opened to expose a window
 - menu** - A pop up menu which stays hidden until called up by mouse. This simplifies problems of crowded screens.
 - mouse** - a very popular input device for graphics programs. The user can point and choose an item. Contemporary alternatives are track-balls, joy-stick, dial boxes, tablets, etc.
 - scrollbars** - At this side of some graphical, and text windows are bars which can be used to move the window around, to see previous text, or hidden areas of a graphics screen.
 - slider** - A bar chart type of input, where the user can use the mouse to pull the slider along, and change an input value
 - window** - A panel for keyboard and mouse I/O, which can be layered on a screen with other windows, like paper on a desk. The user often selects to work in a specific window by pointing the mouse into it. A Window may be closed, to become an icon
- Popular window systems are (not a complete list),
 - OS/2** - IBMs attempt to take control of the operating system used on the IBM PCs, and bring full capability to PC architecture.
 - Windows 3.1** - Microsoft's answer to the MacIntosh interface
 - Windows 95** - Microsoft's answer to Windows 3.1 - adds a true multitasking environment.
 - Windows NT** - Microsoft's answer to Windows 95 - adds more capable network and file security issues.
 - MacIntosh Interface** - The proprietary windowed operating system, considered one of the forerunners in user friendly systems.
 - Sunview** - The original windowed systems used on Sun computers
 - X-Windows** - A defacto standard for newly developed windowed operating systems.
 - Openwindows** - Sun's new windowed operating system which is a superset of X-Windows
 - Motif** - A competitor to Openwindows, also based on the X-Windows standards
- The Implications of X-Windows will be very important in future computer purposes. Some of the X-Windows Features are,
 - intended for networking, including display of programs across a network. The implication of this is that I may sit at a Sun computer in my office, and run Ideas across the network from the SGI lab.

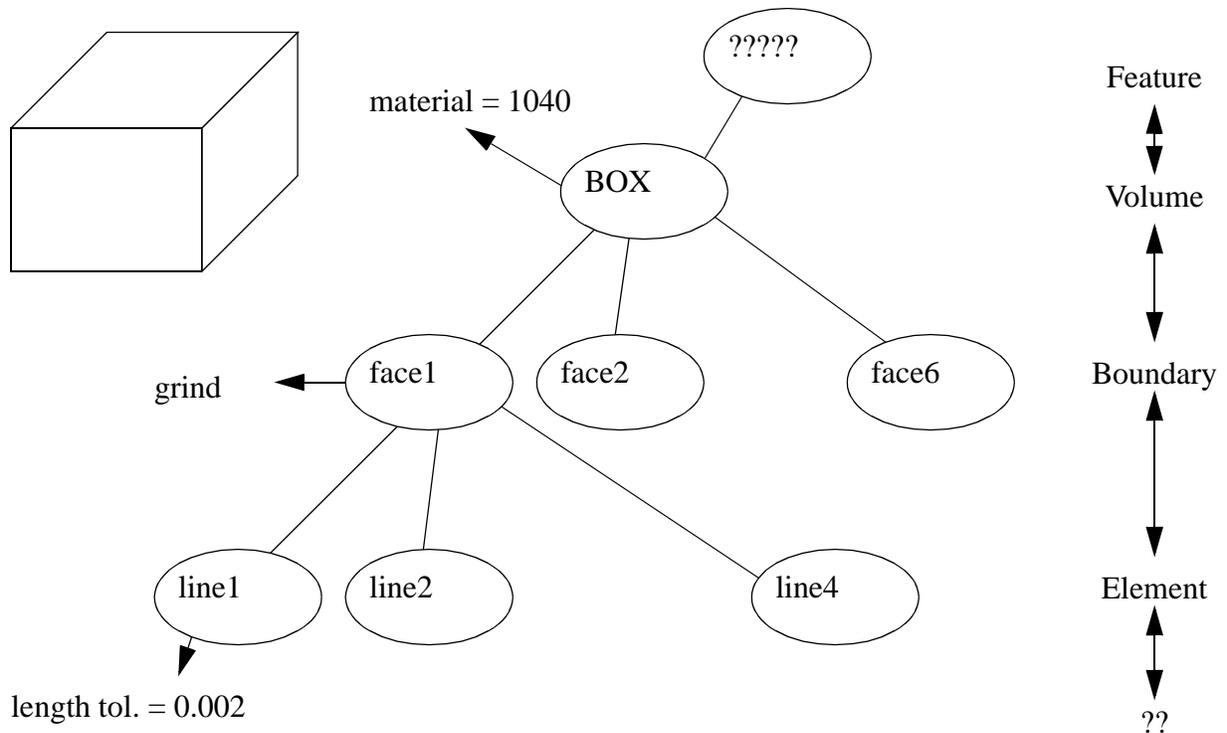
- Shared definitions makes software very portable between machines. (The quantity of public domain software is huge).
 - The user interface is very similar when going between different X-Windows based machines.
 - Easy to Customize for an individual user
 - The differences between systems like Motif and Openwindows are mainly based on definitions of things like buttons, fonts, etc.
 - When using X-Windows, a program (called the X server) runs which controls all the windowed graphics. Programs that use X are written to let it set up buttons, get input, call functions, etc.
 - etc.
- Windows NT is not yet as capable as X-Windows, but if the trend continues it will become more similar over time.
 - Automatic GUI generators are available on commercial systems. One example is given for a system which allows window layout, then automatic program generation.

DI:15.9 PRACTICE PROBLEMS

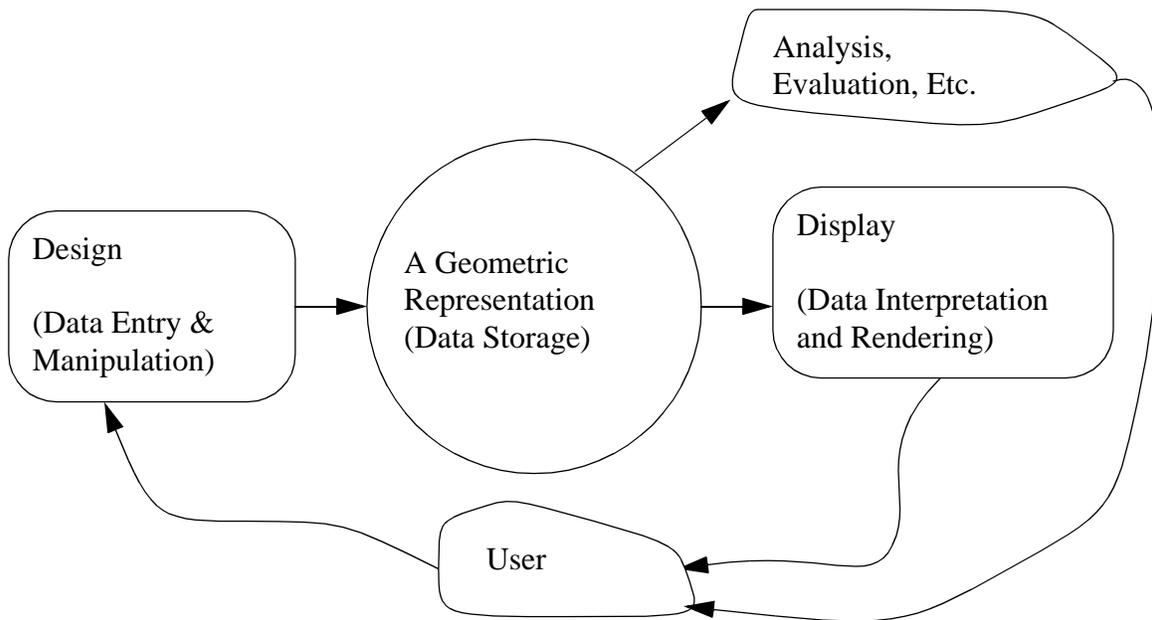
DQ:16. GEOMETRICAL MODELLING OF PARTS

DQ:16.1 OVERVIEW

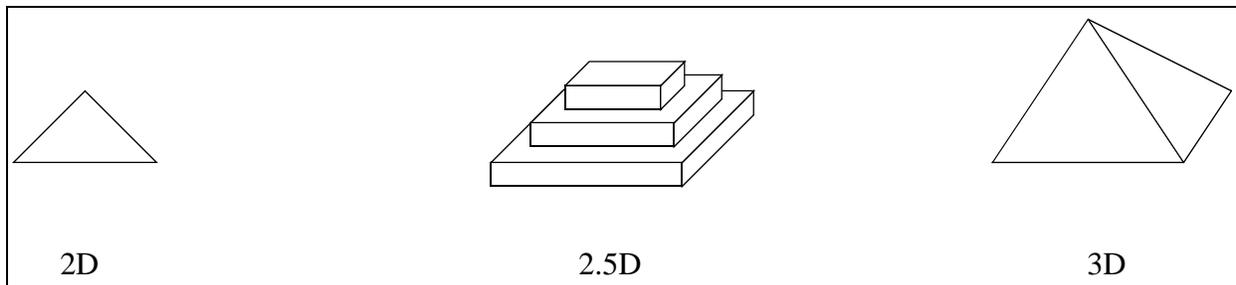
- A model is used to mathematically capture some aspect of the real world so that it may be manipulated, studied, tested, etc.
- To computerize a design we will capture a very explicit model of a part in a computer program.
- Geometry is by far, the most important part of any design. It is used as a reference for tolerances, processes, functions, materials, assemblies, etc.



- Three major functions in geometric modelling,



- The Geometric Representation determines what a system can do.
- There are a number of methods of representing geometry, 1D, 2D, 2.5D, 3D
 - 2D - All in one dimension, such as a side view of a part
 - 2.5D - Points have an x, y coordinate, and height. This is a special case which can describe raised surfaces like buildings.
 - 3D - Full spatial dimensions



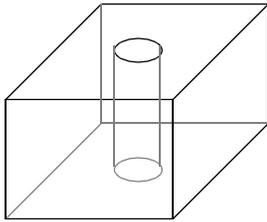
- 2D models are quickly becoming obsolete, 2.5D models were an early compromise, but 3D models are quickly becoming the standard.

DQ:16.2 GEOMETRIC MODELS

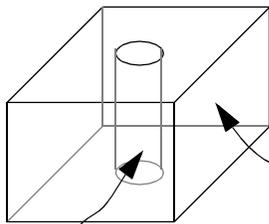
- There are many ways to model a part, the major categories are,

- Elemental (using lines and points like drafting)
- Surfaces (such as polygons used in ES 206)
- Solids - Swept
- Solids - BRep
- Solids - CSG
- Features

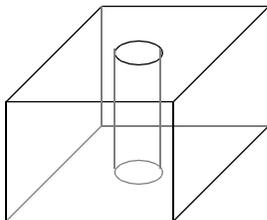
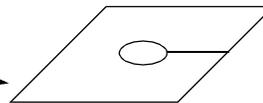
- If describing a block with a hole in it, each of the methods above will result in different descriptions



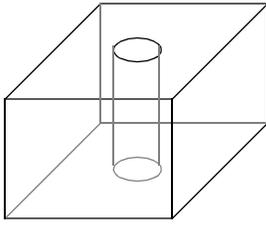
Elemental: 14 Lines
 2 Circles



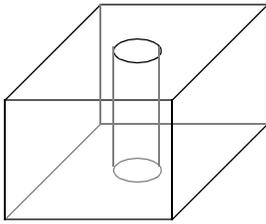
Surfaces: 4 Square polygons for sides
 Many rectangular polygons for inside hole
 2 Odd shaped polygons for top and bottom



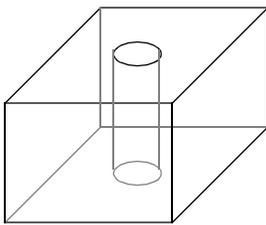
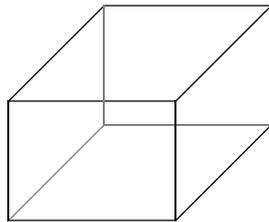
Solids Swept: 1 Base block
 1 Circular profile
 1 Straight path to sweep the cutting circle
 through the block



Solids BRep: 7 Faces
8 Vertices
14 Edges



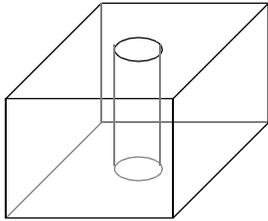
Solids CSG: 1 Block primitive
1 Cylinder primitive
1 Equation: Block - Cylinder



Features: 1 Block from stock
1 Bored hole

- Which is best???? all of them in the right situations.
- Each method has its particular advantages, and disadvantages.
- The best software and hardware supports a combination of all methods.
- It is assumed that other information is used to describe the geometries above, like,
 - Position
 - Orientation
 - Dimensions
- The geometries can also be used to associate other information,

- Materials
- Tolerances
- Finishes
- Inspection information

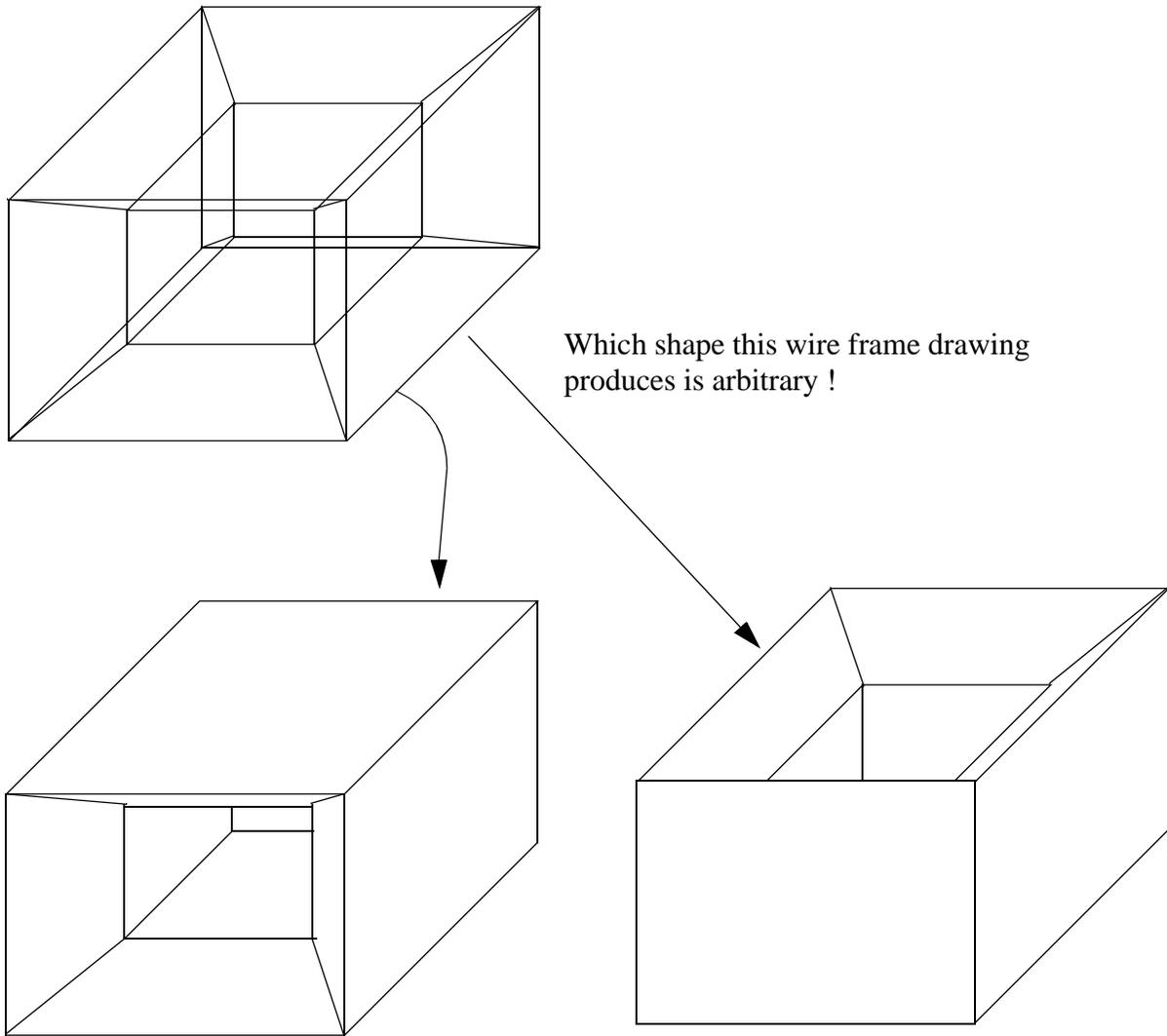


BLOCK
HOLE

```
HOLE = {  
    radius = .5 inches  
    height = 3 inches  
    x_position = 1.5 inches  
    y_position = 1.5 inches  
    x_rotation = 90 degrees  
    radius_tolerance = 0.001 inches  
}
```

DQ:16.2.1 Elemental Depiction:

- Depicted with the simplest of details (lines, points arcs, etc.)
- Advantages,
 - very easy to store and alter
 - well suited to line based problems
 - does not require a powerful computer
 - easy to perform traditional drafting
- Disadvantages,
 - not capable of carrying complex information
 - ambiguous
 - complex items require long time to model
 - requires repetition
 - very hard to connect to programs for FEM, etc.
- Typically used in older CAD systems like AUTOCAD, CADKEY, etc.
- A classic demonstration of the arbitrary nature is shown below,



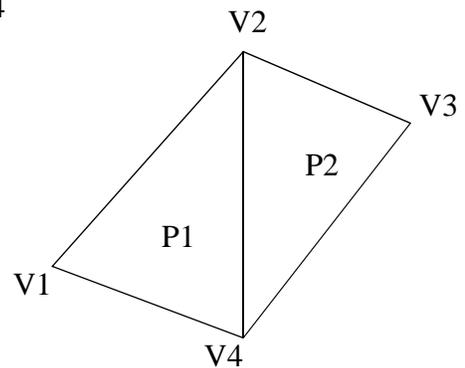
DO:16.2.2 Surface Description

- The geometry is described with polygons which **should** represent an entire surface of an object.
- Generally these polygons do not indicate which side a volume lies on, but inside/outside is defined with tricks like defining polygon vertices so that counter-clockwise is out.
- STL is a good example of an engineering use of this surface representation.
- This method is also used in computer games where speed is important, and the overhead of the

full solid information is not desired.

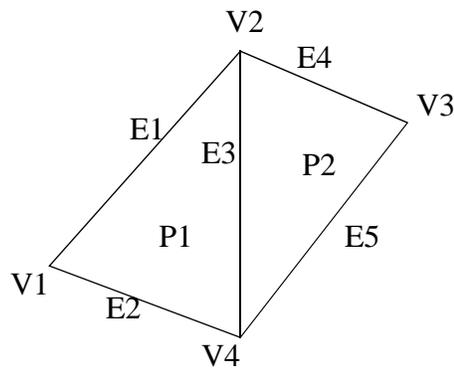
- Advantages,
 - gives appearance of solids.
 - well known, and fast software and hardware for drawing.
- Disadvantages,
 - because objects are not solid, they may be subject to ambiguities
 - hard to pass data to other systems, like FEA
 - not well suited to CAD
 - polygon selection is problematic
- Commonly used in graphics packages like HOOPS, PHIGS, CORE, etc. Also acts as the basis for the SGI computer graphics.
- An example of the polygon meshes is given below.

Vertex #	Location	Polygon #	Vertices
V1	0,5, 0	P1	V1,V2,V4
V2	4,15,0	P2	V2,V3,V4
V3	4,10,0		
V4	8,0,0		



- We can also define these geometries using edge meshes.

Vertex #	Location	Edge #	Vertices	Polygon #	Edges
V1	0,5, 0	E1	V1,V2	P1	E1,E3,E2
V2	4,15,0	E2	V1,V4	P2	E3,E4,E5
V3	4,10,0	E3	V2,V4		
V4	8,0,0	E4	V2,V3		
		E5	V3,V4		

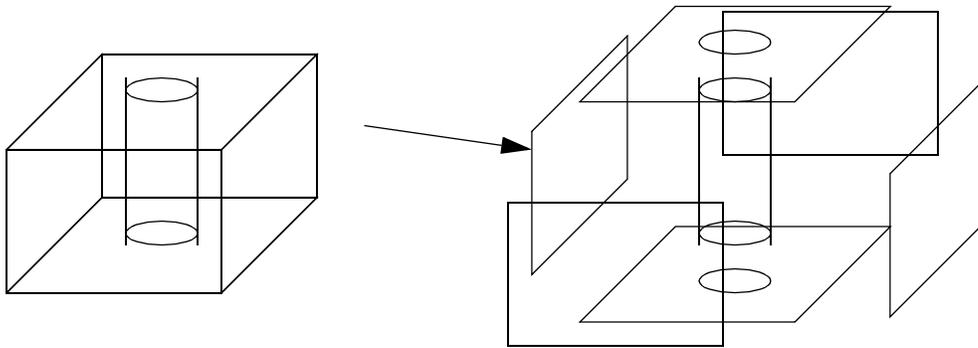


DO:16.2.3 Solid - Swept

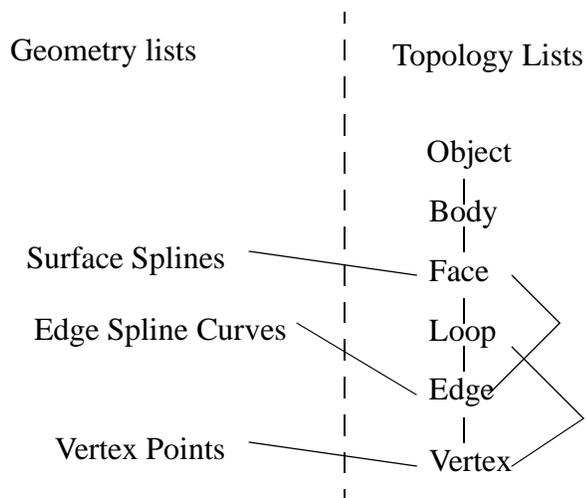
- A profile is created in 2D, and then swept along a path to create a volume, or to cut a volume.
- The path may be straight, rotating about an axis, rotation along a helix, following a curved twisting path.
- Advantages,
 - Can make very complex parts quickly
- Disadvantages,
 - Requires a powerful computer
 - Some operations difficult

DO:16.2.4 Solid - B-Rep (Boundary Representation)

- This still bears a remote resemblance to Surface Modelling.
- Major differences are that,
 - inside/outside is defined for each surface
 - the edges, and vertices of touching faces are defined
- Advantages,
 - can store very complex geometries
 - easy to propagate changes to faces, edges and vertices
 - can easily generate and store complex surfaces
 - many systems support this method, such as PARASOLIDS, ACIS, etc.
 - can be used to mimic CSG
- Disadvantages,
 - high Level information is still not present in model
 - requires a powerful computer
 - hard to recognize some simple features like a block
- A BRep object is pictured below,

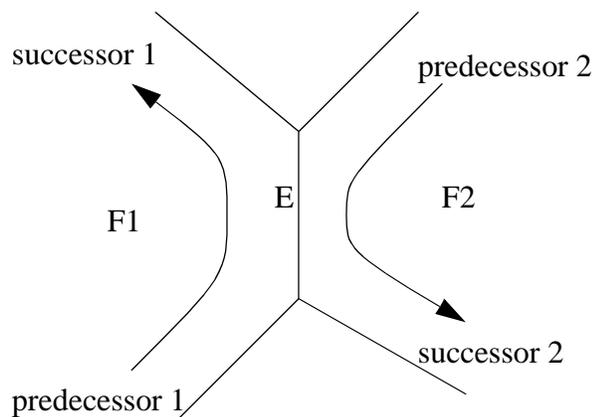


- Each feature in a B-Rep object can be varied independently
- Geometry is kept in parallel with the object topology. One example of a data structure is seen below.



- A common data focus uses the edges of an object to define the shape (vertices and faces can also be used)

Winged-edge data structure



- Euler operations can be used to build an object.
- We can check to see if the solid model is valid using the basic Euler equation, or the more involved Euler-Poincare topological equation. These equations must be satisfied for the models to be valid.

$$V - E + F = 2$$

where,

V = number of vertices

E = number of edges

F = number of faces

$$V - E + F - (L - F) - 2(S - G) = 0$$

where,

L = number of edge loops

S = number of shells

G = genus of solid (holes)

- When developing solid modelers we can use the Euler operations to ensure that the model stays topographically valid at all times.

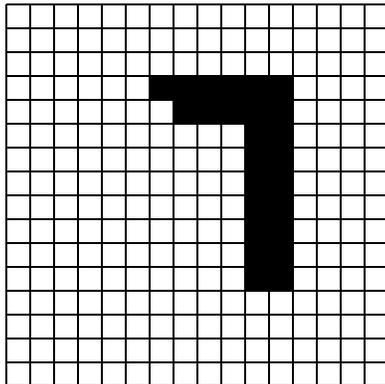
DQ:16.2.5 Solid - CSG

- Does not calculate lines/vertices/faces when storing part geometries
- Uses primitive shapes such as planes, blocks, spheres, cylinders, wedges, torii, etc. to model shapes
- The primitives can be rescaled to meet requirements
- Uses a basic set of operators to combine or cut with the primitives,
 - Union - Both primitives are joined into one (boolean OR)
 - Intersection - The part of the primitives which overlaps (boolean AND)
 - Not - The inverse of a shape
 - Assemble - Parts may overlap without being joined
 - Difference - The area of one primitive is removed from another
- Basic common primitives are,
 - blocks
 - cylinders
 - wedges
 - tetrahedrons
 - spheres
 - torii
 - cones

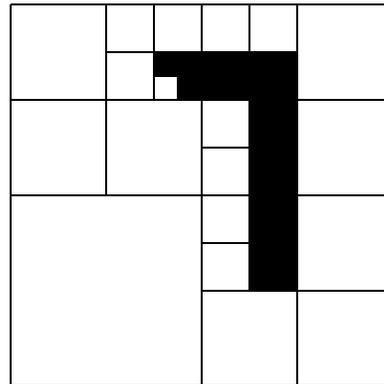
- Advantages,
 - Very compact representation
 - Primitive shapes match human thought processes
 - Very fast when creating parts with standard geometrical features
- Disadvantages,
 - Slow because all interpretation is done at once
 - may be difficult to incorporate irregular surfaces
- Used in systems like PADL2, Romulus, Build, etc.
- CSG designs can be stored in trees
- Various types of CSG operators are possible based on closure of sets. In particular we can consider two boxes that touch, but don't overlap.
- Halfspaces can be used for defining boundaries of an object.

DQ:16.2.6 Tessellated Models

- Space is broken down as a regular/irregular grid.



This evenly tessellated space is divided down into 256 squares



This space is broken down into 28 squares for an equivalent representation

- locations in space are marked as occupied/empty/partially filled.
- this method is most common when using scanners such as CAT and MRI that collect data in

voxels (these are small rectangular volumes)

DQ:16.2.7 Features

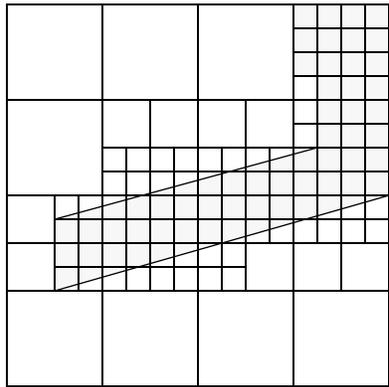
- The designer would simply define a part in terms of fundamental manufacturing features, such as chamfers, through slots, blind slots, etc.
- Very high level, but can complicate additions of unanticipated features, like a ridge in a car hood.
- Advantages,
 - very intuitive and easy to use
 - can simplify other aspects of CIM (eg. If a standard feature is used there will be a standard process plan to make that feature).
 - emphasizes the use of standard components.
- Disadvantages,
 - restrictive when dealing with nonstandard features
 - interaction of features can be hard to estimate
 - a complete set of all possible features would be very large
- There are two levels of features commonly used in these systems,
 - micro
 - macro
- A set of standard features for rotational parts might be,
 - Macro Features,
 - cylinder
 - taper
 - External Features
 - rotational fillet
 - thread
 - square neck
 - chamfer
 - shoulder
 - external radius
 - key seat
 - spline
 - flat
 - thread
 - Internal Features
 - internal taper
 - internal slot]

- internal tapered radial slot
 - internal round slot
 - countersink
 - internal spline
 - woodruff keyseat
- A set of prismatic features might be,
 - Macro Features,
 - box
 - External Features
 - linear chamfer
 - linear round
 - linear v slot
 - linear slot
 - linear round slot
 - linear t-slot
 - Internal features
 - rectangular pocket
 - linear fillet

DO:16.3 SOLID MODELERS

DO:16.4 MASS PROPERTIES

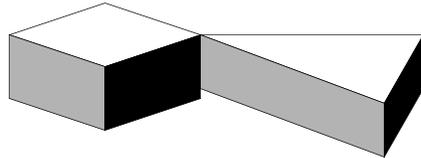
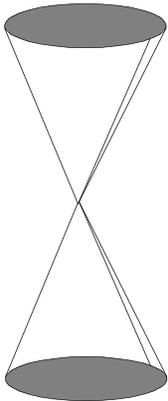
- A Numerical integration may be done on the geometry of a part by examining its components. From this mass, Polar and Cartesian moments of inertia, and centre of mass may be determined.
- An approximate division of space is often used called oct-trees. In this case the volume of the object is recursively broken down into finite parts. Other methods use an even division of space.



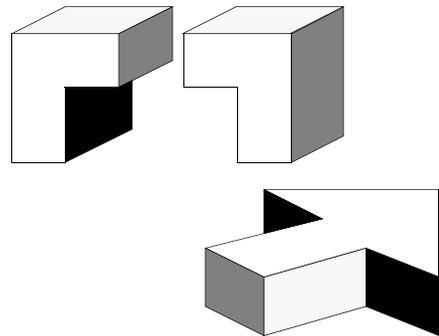
- Is most successful with solids models.

DO:16.5 NON-MANIFOLD PARTS

- A manifold part makes sense mathematically. A non-manifold part may be interpreted in a number of ways, when dealing with general cases.
- Some examples below show manifold/non-manifold shapes



Non-Manifold / Open Parts



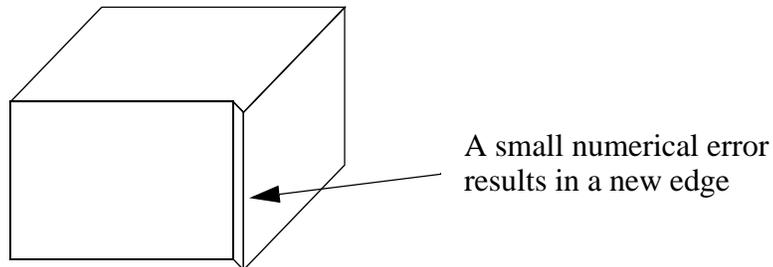
Manifold Parts

- Non-manifold parts have,
 - vertices with less than 3 adjoining faces
 - edges with more or less than two adjoining faces
 - etc.

- Non-manifold parts are required for,
 - composite material modeling in a single part
 - assembly modeling where parts touch or overlap (press fit)
 - other Future Applications ????

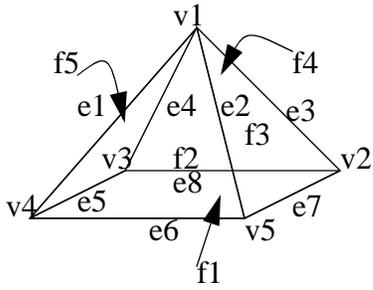
DO:16.6 NUMERICAL ACCURACY

- Many CAD systems experience numerical problems based upon the nature of floating point arithmetic.
- This can result in points, and surfaces being distorted, and this may cause errors during comparison.
- To overcome the problem, most systems will allow a “point tolerance” value to be used to numerically compare, and join separated point.



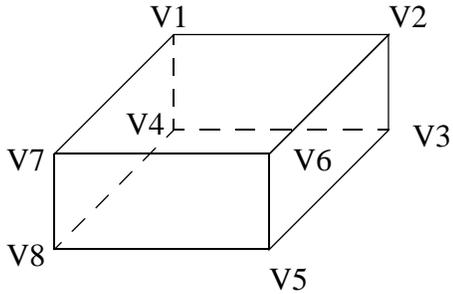
DO:16.7 PRACTICE PROBLEMS

1. Discuss the statement “Line trimming can be essential when constructing solid models”.
2. a) For the part below, describe how it would be represented with a winged edge B-Rep data structure. Draw the winged edges, then create data arrays.



b) For the model in part a) suggest how tolerances could be added to the arrays.

3. Draw a B-rep solid model representation for the box below. Vertices have been drawn, you will need to add the other data elements to complete the model.

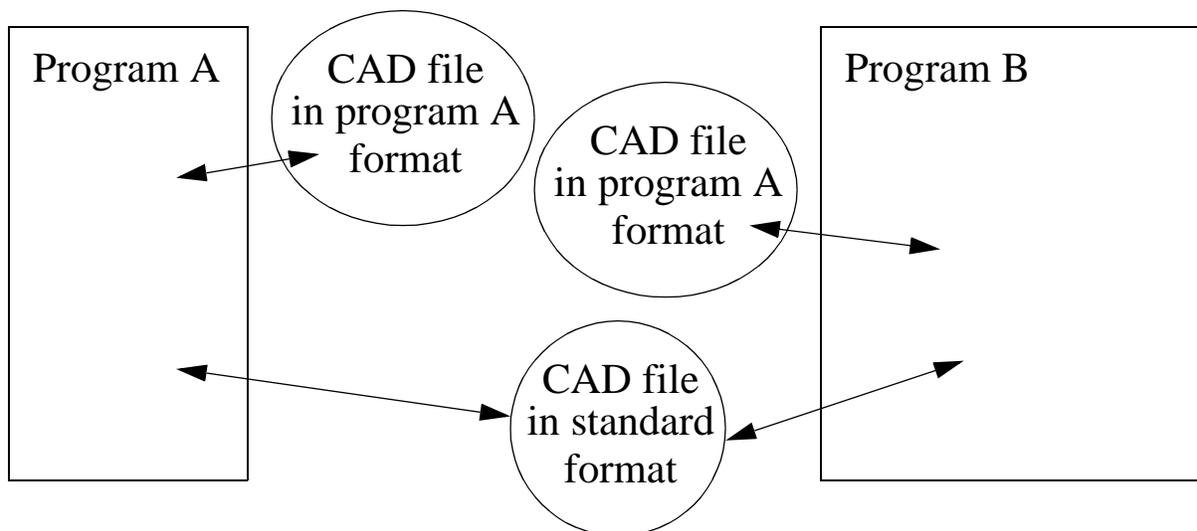


4.

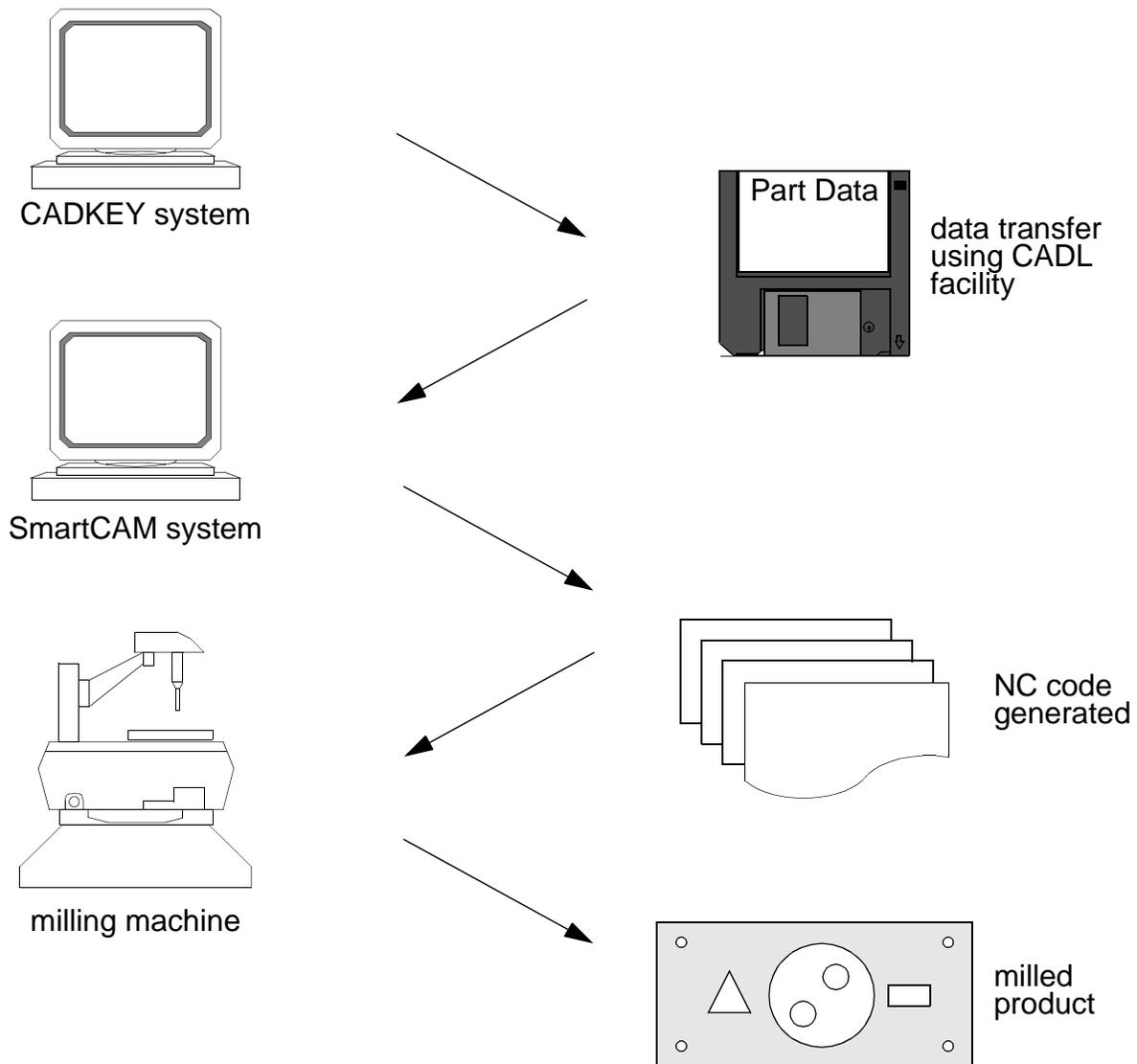
DM:17. GEOMETRICAL MODELLING FOR DESIGN

DG:18. CAD FILE FORMATS

- Every CAD package stores information internally in a format that it best suited for that package. When the user is done this information is written to files on the hard drive.
- These proprietary formats can only be read by the specific program (and version of software), and are virtually useless to other programs.
- For most modern engineering applications it is necessary to be able to transfer CAD models between dissimilar computer programs.
- Standard file formats are the best method for storing and transferring CAD geometries (and other information) between dissimilar programs.
- Files are mainly stored on disks as ASCII, or binary with a structure that has been agreed upon by organizations that represent various interest groups in the CAD/CAM sectors.
- When standard formats are used data should be easily transported between systems. Although beware, some vendors do not conform fully to these standards.
- The basic structure of programs using standard files is shown below



- An example of data transfer is a prototype part drawn using CADKEY and then transferred to SmartCAM (via CADL) so that it can generate the NC code to manufacture the part. Finally it is transferred to the milling machine using 'G-Code'.



- Reasons to use non-standard files are listed below. Note: some software offers standards that are non-compliant - these should be treated as non-standard files.
 - Standard files are compromises, therefore they may limit the ability of certain software
 - Standards do not always exist, and may lag behind their need.
 - Prevent your customers from using other CAD, etc software (e.g., Microsoft and IBM have made an art of this process)
- Why use standard files?
 - Universally readable allowing easy data transfer
 - Generally more dependable than proprietary formats (better thought out)

DG:18.1 GRAPHICS FORMATS

- Some Graphics formats are intended for graphical display,
 - GIF - (Graphics Interchange Format) A compact graphic format
 - JPG - (Joint Photographic experts Group) A compressed format
 - MPEG - (Motion Pictures Experts Group) Compressed Animation
- Some graphics formats are intended for output on hardcopy devices
 - HPGL - Hewlett Packard Graphics Language - An ASCII language devised to drive pen plotters
 - PostScript - A VERY popular graphics format which typically drives laser printers, but can also be displayed on devices like color screens

DG:18.2 CAD FORMATS

- Some types are
 - CGM - A US defense department product, related to polygon modeling
 - CIF - For Integrated Circuit Design by layered polygon definition
 - DMC - Digital Mapping for Customers - for transmitting maps
 - DXF - Primarily developed by Autodesk (for Autocad) to transfer geometry using ASCII definitions
 - EDIF - Electronic Design Interchange Format supports VLSI design, and is expected to incorporate Circuit Boards soon
 - IISF - A format Developed by Intergraph for their CAD systems
 - SET - Standard d'Echange et de Transfert - Made to be more compact than IGES
 - STEP and PDES (Standard for the Exchange of Product model data and Product Data Exchange Specification) An attempt to model other attributes of a product, in addition to geometry, such as tolerancing. This is the emerging standard, but it is not widely available yet.
 - VDA-FS (DIN 66301) A German approach for modelling surfaces
 - VDA-IS - A German subset of IGES for the auto industry
 - UNV - Ideas Universal File

DG:18.2.1 Proprietary “Standard” Formats

- As mentioned before, these should be treated as non-standard formats, but they will increase some of the transferability of data.
- For marketing reasons most major vendors of CAD systems attempt to define their own “standards”. Examples include ‘DXF’ for Autocad, ‘CADL’ for Cadkey, ‘SAT’ for ACIS.

- An example of a proprietary format is the CADL file produced by Cadkey for transferring geometric entities through the use of an ASCII file. Such entities may be lines, points, arcs, splines, etc.

```
LINE      0.0, 0.0, 0.0, 1.0, 1.0, 1.0, 1, 1, 0, 0, 1
```

└──────────────────┘ └──────────────────┘

start pt. end pt.

DG:18.2.2 Standard Formats

- A device independent format is based on public standards that are controlled by non-commercial bodies.
- examples of these include
 - STEP (Standard for Exchange of Product Data)
 - SET (Standard d'Exchange et de Transfer)
 - PDES (Product Data Exchange Specification)
 - IGES (Initial Graphics Exchange Specification)

DG:18.2.2.1 - IGES

- IGES was first developed by the National Bureau of Standards, Boeing Corporation, and General Electric Corporation and published by the National Bureau of Standards in 1980.
- Initially the only data that could be exchanged were basic entity types such as points, lines, arcs, and circles.
- September 1981, IGES version 2.0 was approved by the American National Standards Institute as ANSI standard Y14.26M for CAD/CAM communications.
- More recent versions of IGES contain the ability to transfer constructive solid geometry and boundary representations of solid models.
- The IGES can be in either binary or ASCII format. In ASCII the file is easy to read and modify by hand but it tends to be larger.
- There are two formats
 - a fixed 80 character line length format

- a compressed line length free format.

- In the fixed formatted data, there are several sections that must be entered in a highly structured approach. Data must be right justified within the specified column locations, and these locations must occupy the columns between 1 and 80, inclusive. The following is a brief outline of some rules that must be followed in creating the IGES file.

1. *Blanks*: Blanks are only significant in string constants. A numeric field of blanks is considered to denote the default value for that field. No blanks are allowed between the beginning of a numeric constant and the end of that constant. Leading blanks in numeric constants are ignored. Blanks between the end of any constant and the delimiter following the constant are not allowed.

2. *Numeric Constants*: Embedded commas in numeric constants are not permitted. The absolute magnitude of a numeric constant may not exceed the value of

$2^{(N-1)} - 1$, where N is the number of bits used to represent an integer of a real value. Real constants may be double or single precision. Valid integer constants can be expressed as:

1 150 -24567 23457 +23456.

Valid real constants can be expressed as:

346.098 0. -.34 0.1E-3 1.E+4.

3. *String Constants*: A string constant is defined as an arbitrary sequence of ASCII characters. Blanks, commas, and numbers are treated as characters within the string. String constants are represented in Hollerith notation. This form consists of a non-zero integer constant (i.e. the number of characters in the string), followed immediately by the letter H, followed by the character string. Valid string constants can be expressed as:

3Hr45 12H Hello There 9Htime;.erw

4. *Sequence numbers*: A sequence number is a string of up to seven digits and is used for indexing the lines within the various sections of the IGES file. Sequence numbers begin at 1, (i.e. 0000001) in each section and continue sequentially without interruption to the end of that section. This is primarily used to indicate the number of physical lines of the particular section, or may be thought of as section line counters. Sequence numbers must be used in each section of the IGES file. These numbers are right justified in the columns 74 to 80. Sequence numbers may have leading zeros (0) or blanks.

- An IGES file consists of six (6) sub-sections that must appear as follows:
 1. flag section
 2. start section
 3. global section
 4. directory entry section

- 5. parameter data section
- 6. terminate section

DG:18.2.2.1.1 - Flag section (optional)

- This section identifies whether the IGES file is written as a bit string binary file, or as a “compressed” ASCII file. If this section is ignored, then the default format for the IGES file is ASCII.

DG:18.2.2.1.2 - Start section

- This section of the IGES file is to provide a readable prologue to the file. There must be at least one (1) start record. All records must have the letter “S” in the 73rd column and a sequence number in columns 74 to 80. Information in columns 1 to 72 are ASCII characters. Figure 3

1		72	73	80
THIS IS A READABLE SECTION OF THE IGES FILE.			S0000001	
Only the ASCII character set is used in this space.			S0000002	
.			.	
.			.	
Characters occupy columns 1 to 72.			S	N

DG:18.2.2.2 - Global section

- The global section contains information regarding the IGES pre-processor, and any information that is required by the IGES post-processor. There are 24 parameters that must be entered. These include:

Parameter	Data Type	Description
1	string	parameter delimiter character
2	string	record delimiter character
3	string	product ID from sending system
4	string	file name
5	string	system ID
6	string	IGES pre-processor version
7	integer	no. of bits for integers
8	integer	single precision magnitude
9	integer	single precision significance
10	integer	double precision magnitude

11	integer	double precision significance
12	string	product ID for receiving system
13	real	model space scale
14	integer	unit flag
15	string	unit description (mm, m, in, etc.)
16	integer	no. of line weight gradations
17	real	size of max. line width
18	string	data and time of file generation
19	real	min. user intended resolution
20	real	approx. max. coordinate value
21	string	name of author of file
22	string	name of organization
23	integer	IGES version
24	integer	applicable drafting standard

• Parameters of the global section (All string constants are represents in Hollerith notation).

1. *Parameter delimiter character*: Indicates which character is used to separate values in free formatted data (including the global section). Default is a comma (,).
2. *Record delimiter*: Indicates which character is used to indicate the end of a list of parameters in free formatted data sections (including the global section). Default is a period (.
3. *Product ID from sending system*: Name of the product as referenced from the sending system.
4. *File name*: Name of the IGES file.
5. *System ID*: Name and version of software containing the pre-processor which created the IGES file.
6. *IGES pre-processor version*: Version of the pre-processor which created the IGES file.
7. *No. of bits for integers*: No. of bits present in the integer representation of the sending system.
8. *Single precision magnitude*: Maximum power of 10 which may be represented as a single precision floating point number from the sending system.
9. *Single precision significance*: No. of significant digits of a single precision floating point number on the sending system.
10. *Double precision magnitude*: Maximum power of 10 which may be represented as a double precision floating point number from the sending system.
11. *Double precision significance*: No. of significant digits of a double precision floating point number on the sending system.
12. *Product ID for receiver*: Name of product intended to be used by the receiving system.
13. *Model space scale*: Ratio of model space to real space (e.g. 0.125 indicates a ratio of 1 unit model space to 8 units real space).
14. *Unit flag*: Integer value denoting the measuring system used in the file.
 - unit flag = 1 (inches)
 - = 2 (millimeters)
 - = 3 (see parameter 15 for name of units)
 - = 4 (feet)
 - = 5 (miles)

- = 6 (metres)
- = 7 (kilometers)
- = 8 (mils, i.e. 0.001 inches)
- = 9 (microns)
- = 10 (centimeters)
- = 11 (microinches)

A value of “3” should only be used when the receiving system is using the same units. In this case, parameter 15 must be used to provide additional information as to those units.

15. *Unit description:* A string constant naming the units in the system.

- 2HIN or 4HINCH (model units are inches)
- 2HMM (model units are millimeters)
- 2HFT (model units are feet)
- 2HMI (model units are miles)
- 1HM (model units are metres)
- 2HKM (model units are kilometers)
- 3HMIL (model units are mils)
- 2HUM (model units are microns)
- 2HCM (model units are centimeters)
- 3HUIN (model units are microinches)

When a unit flag of “3” is used, the string constant naming the desired unit should conform to MIL-STD-12D (DOD12D), or ANSI/IEEE 260 (IEEE260).

16. *Maximum no. of line weight gradations:* Number of equal subdivisions of line thickness.

17. *Size of Max. line width:* Width of the thickest line possible in the (scaled) file.

18. *Date and time of file generation:* Time stamp of when the file was created.

19. *Minimum user intended resolution:* Smallest distance in model space units that is discernible by the system.

20. *Approximate Max. coordinate value:* Upper bound on the values of all coordinate data occurring in this model.

21. *Name of author of file:* Name of person who generated the data contained in the IGES file.

22. *Name of organization:* Name of organization who generated the data contained in the IGES file.

23. *IGES version:* Integer number representing the corresponding version of IGES used to create the file.

- 1 - IGES version 1.0
- 2 - ANSI Y14.26M-1981,
- 3 - IGES version 2.0
- 4 - IGES version 3.0

Default is 3 (i.e. IGES version 2.0).

24. *Applicable drafting standard:* Integer number representing the drafting standard to which the data in the IGES file was specified.

- 0 - no standard
- 1 - ISO (International Organization for Standardization)
- 2 - AFNOR (French Association for Standardization)

- 3 - ANSI (American National Standards Institute)
- 4 - BSI (British Standards Institute)
- 5 - CSA (Canadian Standards Association)
- 6 - DIN (German Institute for Standardization)
- 7 - JIS (Japanese Institute for Standardization)

• A sample of the global section is given below,

1	72	73	80
, , 8HGear.prt, 8HGear.prt, 15HMCS.Cadkey 3.02, 23HGear Desi		G0000001	
gn Version 1.0, 16, 8, 24, 11, 53, 8HGear.prt, 1. , 2, 2HMM, 1, 1. ,		G0000002	
13H890206.100000, .0005, , 12H Douglas Lee, 15HES 488b CAD/		G0000003	
CAM, 4, 0;		G0000004	

DG:18.2.2.3 - Directory entry sections

- provides attribute information for each entity entered in the parameter section
- each directory entry consists of two, 80 character, fixed formatted lines
- An example is given below,

1	8	9	16	17	24	25	32	33	40	41	48	49	56	57	64	65	72	73	80
1		2		3		4		5		6		7		8		9		10	
11		12		13		14		15		16		17		18		19		20	

1. *Entity type number*: An integer value identifying the type of geometric entity.
2. *Parameter data*: Sequence number of the parameter data record for this entity.
3. *Structure*: Not discussed here. For more information, consult the IGES text.
4. *Line font pattern*: Integer value indicating the pattern to be used in displaying the geometric entity.
 - 1 - solid
 - 2 - dashed

3 - phantom

4 - centreline

5. *Level*: An integer value indicating the graphic display level, or layer, to be associated with the entity.
6. *View*: Specifies the type of entity view desired. This value is a pointer to the directory entry of a view entity (type 410). It can also be a pointer to an associativity instance. A value of zero (0) indicates the entity is displayed with the same characteristics in all views.
7. *Transformation matrix*: This value is either a pointer to the directory entry of a transformation matrix used in defining this entity, or a zero indicating the identity matrix used in defining this entity, or a zero indicating the identity matrix for rotation (zero rotation) and zero translation.
8. *Label display associativity*: Pointer to the directory entry of a label display associativity which defines how the entity's label and subscript are to be displayed in different view.
9. *Status number*: This is an 8 digit number relaying 4 pieces of entity information, described as follows:
 - Blank status - defines whether the entity is meant to be visible on the output device of the receiving system. A value of 00 implies the entity is displayed, a value of 01 indicates the entity is not to be displayed.
 - Subordinate entity switch - indicates if an entity is referenced by another entity in the file. A value of 00 indicates the entity is independent, and not referenced by other entities. A value of 01 indicates the entity is dependent on some other parent entity. A dependent on some other entity. A dependent entity cannot exist without its parent entity.
 - Entity use flag - indicates the use of the entity. A value of 00 indicates the geometry, 01 indicates annotation (descriptive purposes), 02 indicates an entity used in definition of structures of data, 03 indicates all other used for entities such as defining structural features in the file, 04 indicates logical or positional entities and 05 indicates 2D parametric entities defined by a mathematical parametric equation.
 - Hierarchy - indicates the relationship between entities in a hierarchical structure and is used to determine which entity's directory entry attributes should be applied. Applies to line font, view, entity level, blank status, line weight, and color number. A value of 00 indicates all the above directory entry attributes apply to this entity.
10. *Sequence number*: The sequence number for the position of the directory entry line in the IGES file. This sequence number will always be an odd number.
11. *Entity type number*: Same as in 1.
12. *Line weight number*: Denotes the width for which an entity is to be displayed. Largest line thickness is specified in global parameter 16, smallest thickness is specified in global parameter 17. A value of zero (0) indicates the default line weight as specified by the receiving system.
13. *Color number*: This value specifies the color of the entity.
 - 1 - black
 - 2 - red

- 3 - green
- 4 - blue
- 5 - yellow
- 6 - magenta
- 7 - cyan
- 8 - white
- 0 - no color specified

- 14. *Parameter line count number*: The number of lines in the parameter data section which contain the entity whose attributes are described in the directory entry section.
- 15. *Form number*: A value of zero (0) causes individual interpretation of the entity type entered in the parameter data section.
- 16. *Reserved field*: This field is reserved for future use and should be left blank.
- 17. *Reserved field*: Same as 16.
- 18. *Entity label*: This is an alphanumeric identified for the particular entity type in consideration.
- 19. *Entity subscript number*: A numeric qualifier for the entity label in 18.
- 20. *Sequence number*: The sequence number for the position of the directory entry line in the IGES file. This sequence number will always be even.

• A sample of a directory section is given below,

1	8	9	16	17	24	25	32	33	40	41	48	49	56	57	64	65	72	73	80
110		1				1		5		0		0				00000000		D	1
110		0		8		1		0						line				D	2
110		2				1		5		0		0				00000000		D	3
110		0		8		1		0						line				D	4
116		3				1		1		0		0				00000000		D	5
116		0		3		1		0						point				D	6
116		4				1		1		0		0				00000000		D	7
116		0		3		1		0						point				D	8

DG:18.2.2.4 - Parameter entry section

• This section of the IGES file provides entity identification and coordinates to be plotted on the receiving system. The following is a partial list of some common entities:

Entity Type No.	Entity Type
100	circular arc
102	composite curve
108	plane
110	line

112	parametric spline curve
114	parametric spline surface
116	point
124	transformation matrix
126	rational B-spline curve
128	rational B-spline surface
136	finite element

- The structure is a free formatted data entry from columns 1 to 64. Each line of free formatted data consists of the entity type number followed by the parameter data describing the entity. Columns 65 to 72 are reserved for a parameter data index which is an odd number counter, right justified in the field, which begins at the number 1 and progresses in odd increments for each entity entered. Column 73 is reserved for the letter 'P' to indicate the data element belongs to the parameter data section. Columns 74 to 80 are reserved for the sequence number. Each line of data corresponds to the entity type as specified in the global section. For example, the first entity element of the global section corresponds to the first line of coordinates in the parameter data section. Each portion of data in the global section is matched with its coordinate counterpart in the parameter data section.

- Circular arc entity parameter data:

Index	Name	Type	Description
1	zt	real	parallel zt displace. of arc from xt, yt plane
2	x1	real	arc centre x coordinate
3	y1	real	arc centre y coordinate
4	x2	real	start point x coordinate
5	y2	real	start point y coordinate
6	x3	real	terminate point x coordinate
7	y3	real	terminate point y coordinate

- Line entity parameter data:

Index	Name	Type	Description
1	x1	real	start point x coordinate
2	y1	real	start point y coordinate
3	z1	real	start point z coordinate
4	x2	real	terminate point x coordinate
5	y2	real	terminate point y coordinate
6	z2	real	terminate point z coordinate

- Point entity parameter data:

Index	Name	Type	Description
1	x	real	x coordinate of point
2	y	real	y coordinate of point
3	z	real	z coordinate of point
4	PTR	pointer	pointer to directory entry of subfigure insta-

nce specifying the display symbol. If zero (0), then no display symbol is specified.

- A sample of a data section is given below,

1	72	73	80
100,0.0,0.0,0.0,20.0,20.0,0.0;	1	P0000001	
110,5.0,5.0,0.0,10.0,10.0,0.0;	3	P0000002	
116,5.0,10.0,0.0,0.0;	5	P0000003	

DG:18.2.2.5 - Terminate section

- This section provides information needed by the post-processor to properly signal the end of the IGES file. The information that is relayed to the receiving system is the number of lines in each of the sections of the IGES file.
- A sample of the termination section is given below,

1	8	9	16	17	24	25	32	33	40	41	48	49	56	57	64	65	72	73	80
No. of 'S' lines	No. of 'G' lines	No. of 'D' lines	No. of 'P' lines	not used												T0000001			

DG:18.2.2.6 - A Sample IGES File

- A Sample IGES File (Note: the columns are out of alignment)

```

This is a sample IGES file generated from a drawing done using CADKEY. S      1
This is simply a drawing of a two boxes: one larger box and one smaller S      2
box placed on top of the larger one. The size of the larger box is S      3
100x150x50 and the size of the smaller box is 80x60x50 units. S      4
Viewed from the top view, the origin is located on the top of the large S      5
r box. S      6
, ,7Hbox.prt,7Hbox.prt,14HMCS.CADKEY 3.0,9HC2IG 3.0B,16,8,24,11,53, G      1
7Hbox.prt,1.,2,2HMM,1,1.,13H911001.075746,.0005,,17HDouglas M. A. Lee, G      2
33HTThe University of Western Ontario,4,0; G      3
124 1 1 0 0 0 01000000D 1
124 0 0 1 0 0 Matrix D 2
124 2 1 0 0 0 01000000D 3
124 0 0 1 0 0 Matrix D 4
124 3 1 0 0 0 01000000D 5
124 0 0 2 0 0 Matrix D 6
124 5 1 0 0 0 01000000D 7
    
```


124,6.125742E-017,0.,-1.,0.,-1.,6.125742E-017,-6.125742E-017,0.,	11P	9
6.125742E-017,1.,3.752472E-033,0.;	11P	10
124.,.707107,-.408202,.577383,0.,.707107,.408202,-.577383,0.,	13P	11
-4.331554E-017,.816543,.577285,0.;	13P	12
124.,.5,.5,.707107,0.,-.853553,.146447,.5,0.,.146447,-.853553,.5,	15P	13
0.;	15P	14
110,0.,0.,0.,100.,0.,0.;	17P	15
110,100.,0.,0.,100.,150.,0.;	19P	16
110,100.,150.,0.,0.,150.,0.;	21P	17
110,0.,150.,0.,0.,0.,0.;	23P	18
110,0.,0.,-50.,100.,0.,-50.;	25P	19
110,0.,0.,0.,0.,0.,-50.;	27P	20
110,100.,0.,0.,100.,0.,-50.;	29P	21
110,100.,0.,-50.,100.,150.,-50.;	31P	22
110,100.,150.,0.,100.,150.,-50.;	33P	23
110,100.,150.,-50.,0.,150.,-50.;	35P	24
110,0.,150.,0.,0.,150.,-50.;	37P	25
110,0.,150.,-50.,0.,0.,-50.;	39P	26
110,10.,70.,0.,90.,70.,0.;	41P	27
110,90.,70.,0.,90.,130.,0.;	43P	28
110,90.,130.,0.,10.,130.,0.;	45P	29
110,10.,130.,0.,10.,70.,0.;	47P	30
110,10.,70.,50.,90.,70.,50.;	49P	31
110,10.,70.,0.,10.,70.,50.;	51P	32
110,90.,70.,0.,90.,70.,50.;	53P	33
110,90.,70.,50.,90.,130.,50.;	55P	34
110,90.,130.,0.,90.,130.,50.;	57P	35
110,90.,130.,50.,10.,130.,50.;	59P	36
110,10.,130.,0.,10.,130.,50.;	61P	37
110,10.,130.,50.,10.,70.,50.;	63P	38
S 6G 3D 64P 38	T	1

LINE	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	1	1	1	0	0	1	1
LINE	100.0000	0.0000	0.0000	100.0000	150.0000	0.0000	1	1	1	0	0	1	1
LINE	100.0000	150.0000	0.0000	0.0000	150.0000	0.0000	1	1	1	0	0	1	1
LINE	0.0000	150.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	1
LINE	0.0000	0.0000	-50.0000	100.0000	0.0000	-50.0000	1	1	1	0	0	1	1
LINE	0.0000	0.0000	0.0000	0.0000	0.0000	-50.0000	1	1	1	0	0	1	1
LINE	100.0000	0.0000	0.0000	100.0000	0.0000	-50.0000	1	1	1	0	0	1	1
LINE	100.0000	0.0000	-50.0000	100.0000	150.0000	-50.0000	1	1	1	0	0	1	1
LINE	100.0000	150.0000	0.0000	100.0000	150.0000	-50.0000	1	1	1	0	0	1	1
LINE	100.0000	150.0000	-50.0000	0.0000	150.0000	-50.0000	1	1	1	0	0	1	1
LINE	0.0000	150.0000	0.0000	0.0000	150.0000	-50.0000	1	1	1	0	0	1	1
LINE	0.0000	150.0000	-50.0000	0.0000	0.0000	-50.0000	1	1	1	0	0	1	1
LINE	10.0000	70.0000	0.0000	90.0000	70.0000	0.0000	1	1	1	0	0	1	1
LINE	90.0000	70.0000	0.0000	90.0000	130.0000	0.0000	1	1	1	0	0	1	1
LINE	90.0000	130.0000	0.0000	10.0000	130.0000	0.0000	1	1	1	0	0	1	1
LINE	10.0000	130.0000	0.0000	10.0000	70.0000	0.0000	1	1	1	0	0	1	1
LINE	10.0000	70.0000	50.0000	90.0000	70.0000	50.0000	1	1	1	0	0	1	1
LINE	10.0000	70.0000	0.0000	10.0000	70.0000	50.0000	1	1	1	0	0	1	1
LINE	90.0000	70.0000	0.0000	90.0000	70.0000	50.0000	1	1	1	0	0	1	1
LINE	90.0000	70.0000	50.0000	90.0000	130.0000	50.0000	1	1	1	0	0	1	1
LINE	90.0000	130.0000	0.0000	90.0000	130.0000	50.0000	1	1	1	0	0	1	1
LINE	90.0000	130.0000	50.0000	10.0000	130.0000	50.0000	1	1	1	0	0	1	1
LINE	10.0000	130.0000	0.0000	10.0000	130.0000	50.0000	1	1	1	0	0	1	1
LINE	10.0000	130.0000	50.0000	10.0000	70.0000	50.0000	1	1	1	0	0	1	1

DG:18.2.3 A DXF File

• The DXF file below is shown only for illustration (Not for casual reading)

```

0          61.230339      8          20.403206      38          0
SECTION   38          0          11          0.000000      10
2         0.000000      10          0.000000      0          155.563492
HEADER    0          70.710678      21          LINE         20
0         LINE        20          -40.827133      8          16.328091
ENDSEC    8          -81.647354      38          0          11
0         0          11          0.000000      10          155.563492
SECTION   10          176.776688      0          56.568542      21
2         106.066017      21          LINE         20          57.155220
TABLES    20          -20.417019      8          65.319267      38
0         61.230339      38          0          11          0.000000
ENDSEC    11          0.000000      10          113.137085      0
0         0.000000      0          56.568542      21          LINE
SECTION   21          LINE        20          32.663086      8
2         0.000000      8          24.492136      38          0
BLOCKS    38          0          11          0.000000      10
0         0.000000      10          113.137085      0          155.563492
ENDSEC    0          176.776688      21          LINE         20
0         LINE        20          -8.164045      8          57.155220
SECTION   8          20.410112      38          0          11
2         0          11          0.000000      10          98.994949
ENTITIES  10          176.776688      0          56.568542      21
0         0.000000      21          LINE         20          89.811401
LINE      20          -20.417019      8          24.492136      38
8         -40.827133      38          0          11          0.000000
0         11          0.000000      10          56.568542      0
10        70.710678      0          113.137085      21          LINE
0.000000  21          LINE        20          65.319267      8
20        -81.647354      8          -8.164045      38          0
0.000000  38          0          11          0.000000      10
11        0.000000      10          155.563492      0          98.994949
70.710678 0          176.776688      21          LINE         20
21        LINE        20          16.328091      8          48.984272
-40.820225 8          -20.417019      38          0          11
38        0          11          0.000000      10          98.994949
0.000000  10          106.066017      0          113.137085      21
0         0.000000      21          LINE         20          89.811401
LINE      20          20.403206      8          -8.164045      38
8         0.000000      38          0          11          0.000000
0         11          0.000000      10          113.137085      0
10        0.000000      0          155.563492      21          LINE
70.710678 21          LINE        20          32.663086      8
20        -40.827133      8          16.328091      38          0
-40.820225 38          0          11          0.000000      10
11        0.000000      10          98.994949      0          98.994949
176.776688 0          106.066017      21          LINE         20
21        LINE        20          48.984272      8          89.811401
20.410112 8          61.230339      38          0          11
38        0          11          0.000000      10          56.568542
0.000000  10          106.066017      0          113.137085      21
0         70.710678      21          LINE         20          65.319267
LINE      20          20.403206      8          32.663086      38
8         -40.820225      38          0          11          0.000000
0         11          0.000000      10          155.563492      0
10        70.710678      0          98.994949      21          ENDSEC
176.776688 21          LINE        20          57.155220      0
20        -81.647354      8          48.984272      38          EOF
20.410112 38          0          11          0.000000      ?
11        0.000000      10          56.568542      0
106.066017 0          106.066017      21          LINE
21        LINE        20          24.492136      8

```

DG:18.3 PDES/STEP

- PDES (using STEP) is the result of an international effort to develop a standard product design standard.
- This format attempts to incorporate all aspects of product modeling including,
 - geometry (B-Rep, CSG, Features)
 - tolerances
 - electrical/electronics
 - function information
 - process plans
 - etc

DG:18.4 PRACTICE PROBLEMS

1. Given the following IGES file, draw the part it contains.

```

A Test file for the IND807 final exam 1995                               S      1
,,7Hbox.prt,7Hbox.prt,14HMCS.CADKEY 3.0,9HC2IG 3.0B,16,8,24,11,53,     G      1
7Hbox.prt,1.,2,2HMM,1,1.,13H911001.075746,.0005,,9HHugh Jack,         G      2
30HRyerson Polytechnic University,4,0;                                G      3
  110      1      1      1      1      0      0      00000000D      1
  110      0      3      1      0      0      0      Line      D      2
  110      2      1      1      0      0      0      00000000D      3
  110      0      3      1      0      0      0      Line      D      4
  110      3      1      1      0      0      0      00000000D      5
  110      0      3      1      0      0      0      Line      D      6
  110      4      1      1      0      0      0      00000000D      7
  110      0      3      1      0      0      0      Line      D      8
  110      5      1      1      0      0      0      00000000D      9
  110      0      3      1      0      0      0      Line      D     10
  110      6      1      1      0      0      0      00000000D     11
  110      0      3      1      0      0      0      Line      D     12
  110      7      1      1      0      0      0      00000000D     13
  110      0      3      1      0      0      0      Line      D     14
  110      8      1      1      0      0      0      00000000D     15
  110      0      3      1      0      0      0      Line      D     16
  110      9      1      1      0      0      0      00000000D     17
  110      0      3      1      0      0      0      Line      D     18
  110     10      1      1      0      0      0      00000000D     19
  110      0      3      1      0      0      0      Line      D     20
  110     11      1      1      0      0      0      00000000D     21
  110      0      3      1      0      0      0      Line      D     22
  110     12      1      1      0      0      0      00000000D     23
  110      0      3      1      0      0      0      Line      D     24
  110     13      1      1      0      0      0      00000000D     25
  110      0      3      1      0      0      0      Line      D     26
110,0.,75.,0.,0.,100.,0.;                                           1P      1
110,50.,100.,0.,25.,100.,0.;                                         3P      2
110,25.,100.,0.,25.,75.,0.;                                           5P      3
110,25.,75.,0.,50.,75.,0.;                                           7P      4
110,50.,75.,0.,50.,50.,0.;                                           9P      5
110,25.,50.,0.,50.,50.,0.;                                          11P     6
110,0.,0.,0.,100.,100.,100.;                                         13P     7

```

110,50.,0.,0.,50.,50.,0.;
110,75.,0.,0.,100.,0.,0.;
110,100.,0.,0.,100.,25.,0.;
110,75.,25.,0.,100.,25.,0.;
110,75.,25.,0.,75.,50.,0.;
110,75.,50.,0.,100.,50.,0.;
1S 3G 26D 13P

38

15P 8
17P 9
19P 10
21P 11
23P 12
25P 13
T 1

DC:19. COMPUTER AIDED ENGINEERING (CAE)

- One of the fundamental features of Engineering is to make trade-offs to get optimal designs
- If we overdesign, then all designs become simple, but more expensive, and more difficult to manufacture
- If we underdesign, then our design will not fulfill our requirements
- Therefore we use knowledge and tools to achieve designs which are ‘just right’.
- There are many physical factors which can affect the quality of a design,
 - Yield stress failure
 - Excessive deformation
 - Insufficient heat transfer
 - Kinematic interference
 - Too much/little air drag
 - Resonance at wrong frequency
 - Electromagnetic interference effects
 - Non uniform cooling effects (eg. warping in plastic parts)
 - etc.

DC:19.1 FINITE ELEMENT ANALYSIS (FEA)

- Why?: When we have to find an effect (stress, strain, flux, etc) which is distributed throughout a volume, and is too difficult to calculate by hand.
- How: Break a part into discrete chunks (elements), Apply driving functions, constraints, etc., then solve for physical effects.
- Elements
 - different types of elements may be used in a FEM mesh
 - elements that are too deformed will yield poorer results
 - if a field variable will be subject to a large change over an area, then smaller elements should be used to improve the approximation.
- CAD systems will often allow a user to manually, and automatically mesh a part.
- Generative meshing algorithms will
 - mesh a part roughly,
 - solve the problem using the rough mesh,

- identify elements with large errors,
 - reduce the element sizes in the critical areas,
 - resolve the problem to obtain a more accurate result.
- Errors of 10% or more are easy to get using FEA systems. Care must be taken when examining results.
 - Boundary conditions used in FEA systems include,
 - x, y, and/or z positions fixed
 - x, y, and/or z axis rotations fixed.
 - applied force
 - applied moment
 - Automeshing
 - Still a research topic, and many various methods are available
 - Generally the computer breaks geometry into subsections

***** Include Automeshing figure

***** Include Ideas FEM notes

***** Include my FEM notes

DC:19.2 ASSEMBLY AND KINEMATICS

- It is difficult for the computer to distinguish between two or more parts, and how they are related
- Assemblies tend to have a hierarchy of sub-assemblies and parts
- Another important concept is an instance. For example, a bolt is a single part in a CAD system, but there may be 10 instances of the bolt in a product.
- Each instance of a part has,
 - a position
 - an orientation
 - a unique identification
 - other information the designer chooses to associate
- It is also important to define instances in an assembly as a chain of kinematic entities. Some

common joints are,

- slider
- rotary
- spherical
- universal
- ground (a special case for kinematic solutions)

- Assembly planning requires some representation of a precedence for assembly mating. The example that follows shows some of the data structures which may be used for describing an assembly.

DC:19.2.1 Tolerancing

- The real value of tolerancing becomes obvious when we begin to consider assemblies.
- The obvious methods of tolerancing are,
 - dimensional tolerancing
 - geometrical tolerancing
- There are many methods for dealing with tolerances when working by hand (eg. Maximum metal condition)
- The trade off to be handled by tolerancing is tighter tolerances increase quality, but they slow production, and increase cost.
- As tolerances are stacked up, accumulated errors occur. It is hard to predict what effects these errors will have.
- The ability to obtain a tolerance can also be effected by the manufacturing method chosen.
- A popular computer based method for tolerance analysis is the Monte Carlo simulation. In effect, each tolerance has a random distribution, and it is varied randomly. The effect is noted, and statistics are gathered from the model. The basic process is outlined below.
- Monte Carlo Tolerance Evaluation,
 1. Generate a candidate instance of an as-manufactured part using a normal (or other) distribution random number generator to perturb the vertices of the part within the specified size tolerance zone.
 2. Check if the part instance meets the specified form tolerances. This is needed because form tolerances may be tighter than size tolerances, and because normal distribution may, in rare cases, generate perturbations with standard deviations beyond the size tolerance zone.
 3. If one or more of the vertices of the part instance are found out of zones of form tolerances, the part instance is rejected. If all vertices are inside the zone, the part

instance may be accepted.

4. Repeat steps 1 to 3 for all other parts in the assembly.
5. Use the solid modeler to create the assembly instance using all the instances created in step 4. These instances are positioned relative to datums established by part features.
6. Check if the assembly instance from step 5 satisfies the design constraints. If yes, the assembly is accepted. If not, the assembly is rejected.
7. Repeat steps 1 to 6 as many times as the desired sample size (number of assembly instances) is used to calculate the statistics. The larger the sample size the better, and the more confidence we have in the results.

DC:19.3 ASSEMBLIES

- While assemblies apparently look simple, they pose intersection problems
- The dilemma is that two points in a modelled assembly may occupy the same point in space, a physical impossibility.
- In some cases this may be simply ignored, but when doing interference checks, or joining models, the two assembled parts may become one part, then change the results when doing FEM, kinematic, and vibration analysis.
- Some methods to deal with this are,
 - Explicitly store, and manipulate parts of an assembly separately
 - To use complex graphics boundaries called s-sets (still research)

DC:19.4 OPTIMIZATION

- One of the most important aspects of engineering

***** Add in optimization notes