Design Process

An Overview

Boeing India University Relations
Industry Ready Engineer
Curriculum Enhancement Program

August 2023

Content

Total 2 hrs

Design Process (2 hours)

- Design conceptualization
- Preparation of conceptual layouts
- Guidelines from Industrial-standards pertaining to the design requirements
  - MIL, ASTM, ASME, SAE, ISO, DIN, BS & FAR’s.
- Finalizing a layout design
- Sizing of components from the finalized layout design
- Materials, heat treatment and finishes
- Preparation of detail and assembly drawings
  - GD&T
  - Tolerance stack up
  - Types of fits
- Design review, feedback and update – PDR (Preliminary design review)
- Final review and update – CDR (Critical design review)
- Uploading in PLM database – Enovia / Team center
- Release of drawings for production – Design certification and approvals.

Group Exercise (2 hour) – Come up with format

Design Process Flow

Requirements

- Performance characteristics
- Customer Requirements
- Regulatory Requirements

Feasibility Study

- Can met the requirements with major/minor modification
- Comparison study
- Estimation

Detail Specification

- Capacity
- Limitations
- Product life

Design Development

- Concept Design
- Trade offs considerations
- Preliminary sizing

Configuration

- Configuration Selection
- Product Layout

Verification

- Analysis
- Testing

Design Complete

- Design Approval
- Release

Design conceptualization

Idea generation and design innovation concepts

- Eliminate

- Combine

- Separate

- Copy

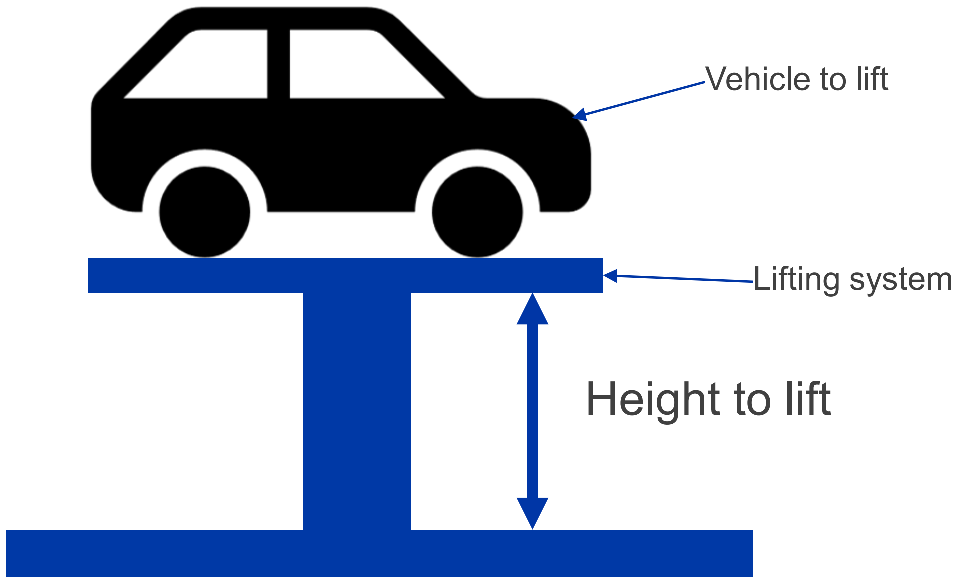
- Segment

- Vary

Preparation of conceptual layouts

- The preparation of design conceptual layouts will be based on below factors:
- Functional requirements
- Spatial constraints
- Geometric constraints
- Environmental requirements
- Mechanism synthesis
- Load requirements
- Weight constraints
- Accessibility provisions
- Maintainability

Design concepts of lifting mechanism

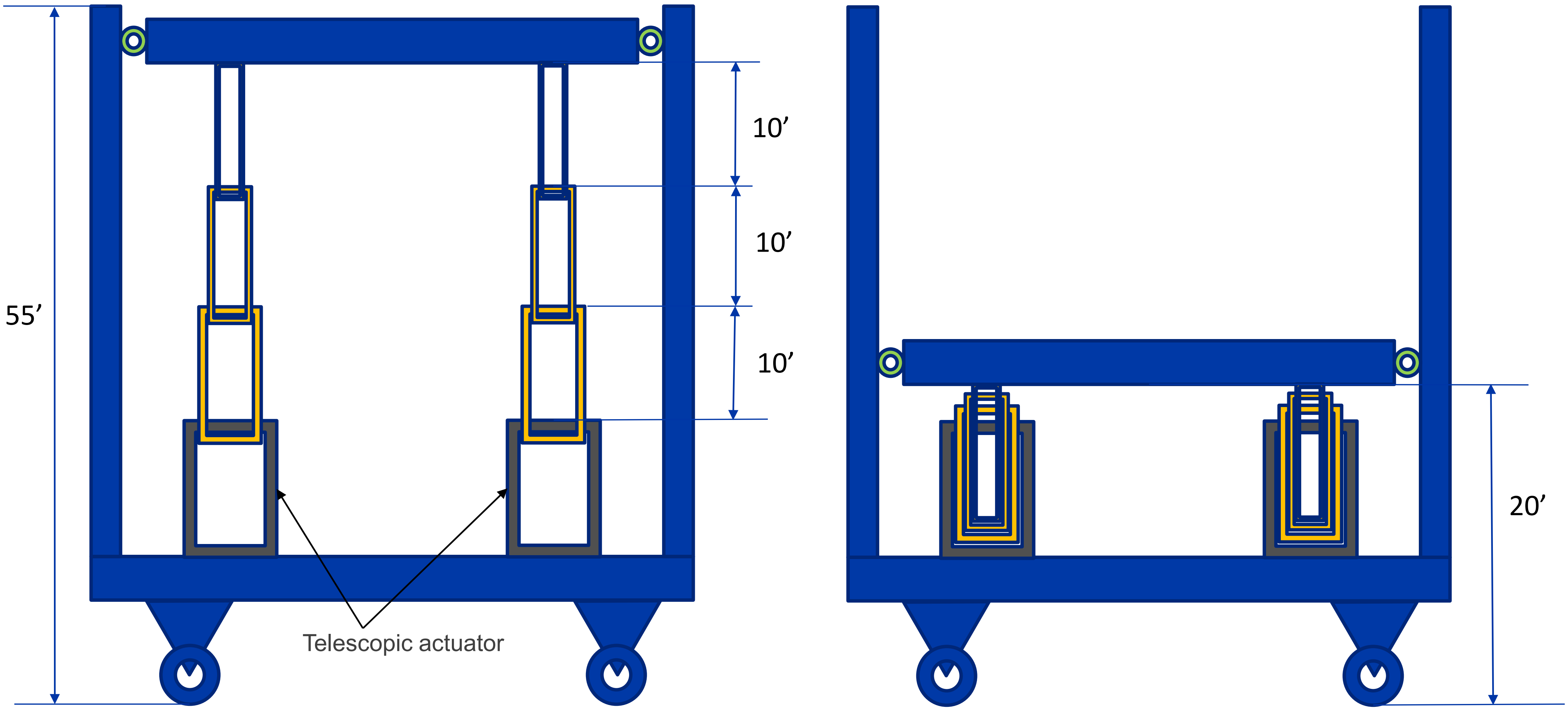


Requirements for Design

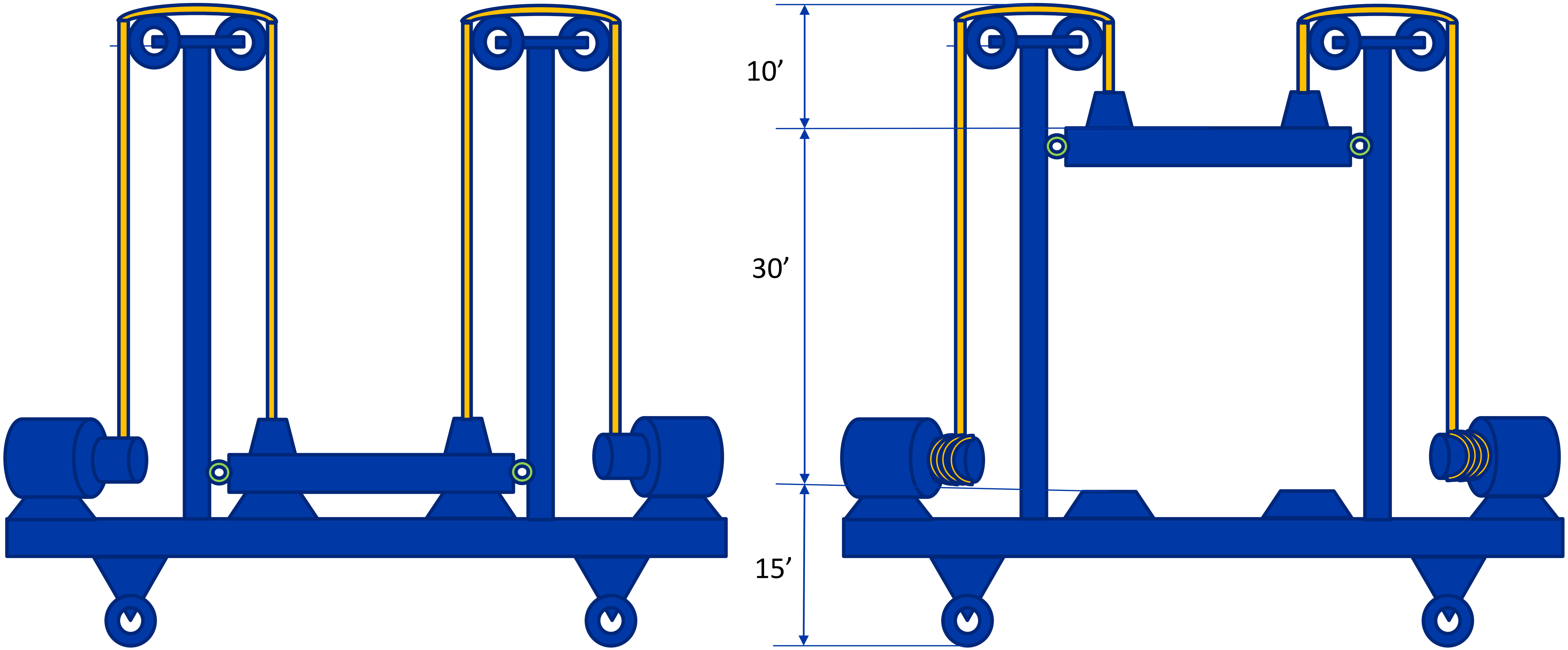
ID	Requirement	Parent
	Tier 1	
T1-R-1	Car shall undergo periodic maintenance as recommended by manufacturer.	-
T1-R-2	For maintenance, shall have easy access to the underside of the car.	T1-R-1
T1-R-3	Maintenance shall ensure safety and reliability standards.	T1-R-1
T1-R-4	During maintenance the car shall not be damaged	T1-R-1
	Tier 2	
T2-R-1	The workshop shall have the capability to service the underside of the car.	T1-R-2
T2-R-2	The workshop shall capability to lift the car to a height of 2.15m.	T1-R-2 T2-R-1
T2-R-3	The lift shall ensure clear access to the underside of the car.	T1-R-2 T2-R-1 T2-R-2
T2-R-4	The tires of the car shall interface with the lift bed.	T1-R-2 T2-R-1 T2-R-2
T2-R-5	The lift shall have mechanism to arrest the motion of the car on top of the lift bed.	T1-R-4 T2-R-4
T2-R-6	The lifting time shall be less than 30sec.	T1-R-2 T2-R-1
T2-R-7	The lowering time shall be more than 1min but less than 2.	T1-R-3 T1-R-4
T2-R-8	The lift shall be designed to fail safe.	T1-R-3 T1-R-4
T2-R-9	The overall envelope of the lift shall be as shown in figure ***************	T2-R-1 T2-R-2
T2-R-10	Lift shall be capable of lifting a 2800 kg car, with 50% additional allowance.	T2-R-1 T2-R-2

ID	Requirement	Parent
	Tier 3	
	Check Valve	
T3-R-CV1	The function of the unit shall be to allow Hydraulic System Fluid to free flow/minimum resistance in one direction only, and prevent flow in the opposite direction.	T2-R-1 T2-R-10
T3-R-CV2	It shall contain a minimum number of individual parts, consistent with the stated functional requirements.	T3-R-CV1
T3-R-CV3	The product shall be manufactured using material and process as per industry standard.	T1-R-3
T3-R-CV4	The unit shall meet all applicable environmental requirements without degradation during and after exposure to the following conditions.	T1-R-3
T3-R-CV5	The weight of the unit shall not exceed 500g.	T2-R-9
T3-R-CV6	Reseating of the valve shall occur between the limits of 55.16 kpa forward pressure and zero pressure	T2-R-6/7/8
T3-R-CV7	Cracking pressure of the valve shall be not less than 13.8 kpa nor greater than 55.16 kpa.	T2-R-6/7/8
T3-R-CV8	The unit shall be designed for rated flow of 0.1136 m^3/min.	T2-R-6/7/8
T3-R-CV9	The pressure drop shall not exceed 344.738 kpa at 0.1136 m^3/min flow at a temperature of 40 deg.C +/-30 deg.C.	T2-R-6/7/8
T3-R-CV10	Internal leakage in the reverse flow direction, measured after a two minute seating period shall be zero when subjected to pressure of 13790 kpa and 34.5 kpa consecutively.	T2-R-6/7/8
T3-R-CV11	No external leakage shall be seen when subjected to proof pressure of 1.5 times the max operating pressure.	T2-R-6/7/8

iDEA-1 : Telescopic Actuation system



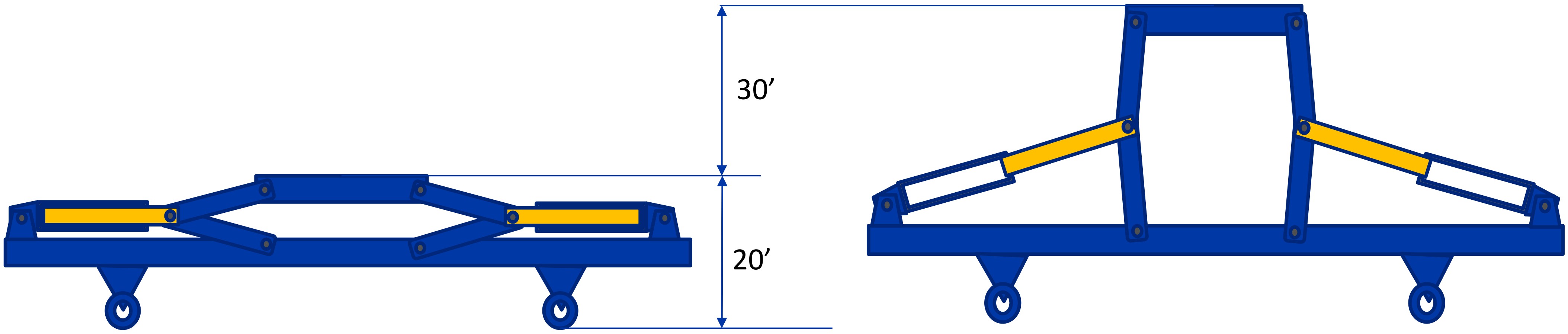
iDEA-2 : Crane lifting system



https://www.knelectric.com/cable-drums/

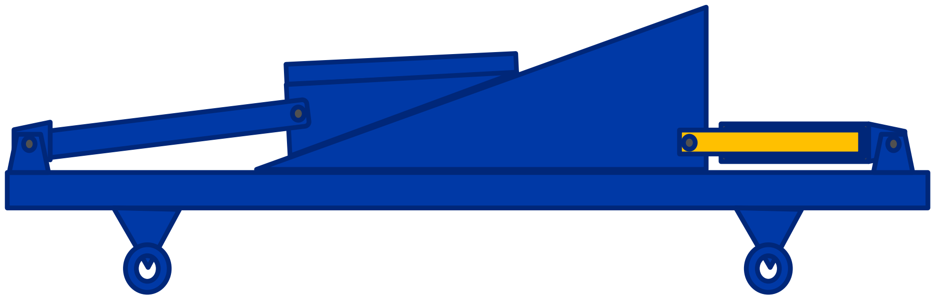
https://www.petheind.com/

iDEA-3 : Articulated Actuation Lift System

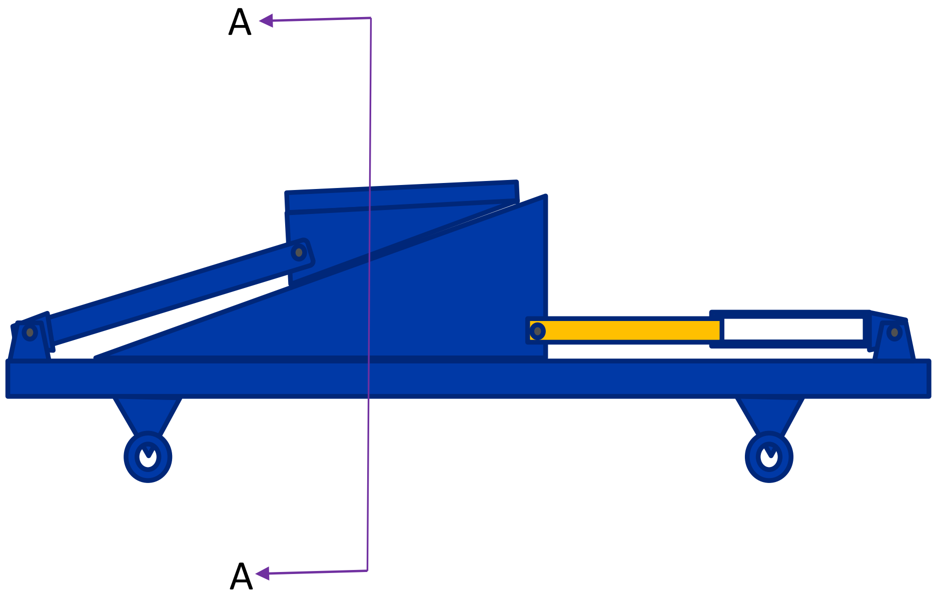


1. Actuator stroke can be 20’.
2. Each link can be 20’ length.
3. May need a lock rod after lifting is done.

iDEA-4 : Ram lift system

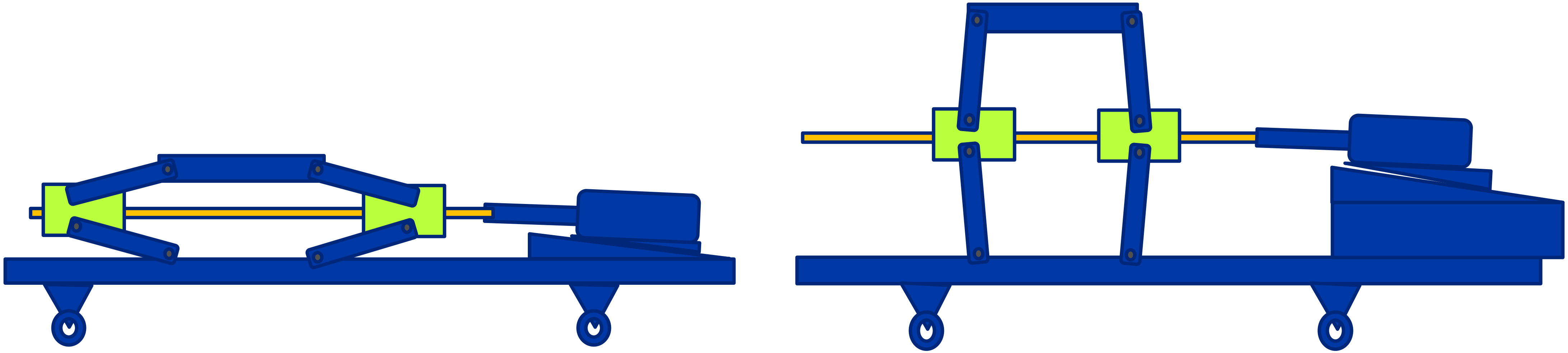


Section A-A
Option 1 with V-groove sliding as in lathe bed



Section A-A
Option 2 with wheels and rail groove

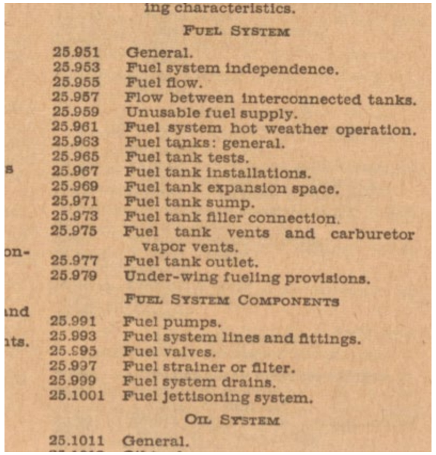
iDEA-5 : Scissor with lead screw Actuation system



Guidelines from Industrial-standards pertaining to the design requirements

Industrial standards: Mentioned about generic mechanical design controls and guides on design parameters & standard usage.

- MIL standards
- ASTM
- SAE
- ASME
- ISO standards
- DIN standards
- British standards etc.



ing characteristics.

FUEL SYSTEM

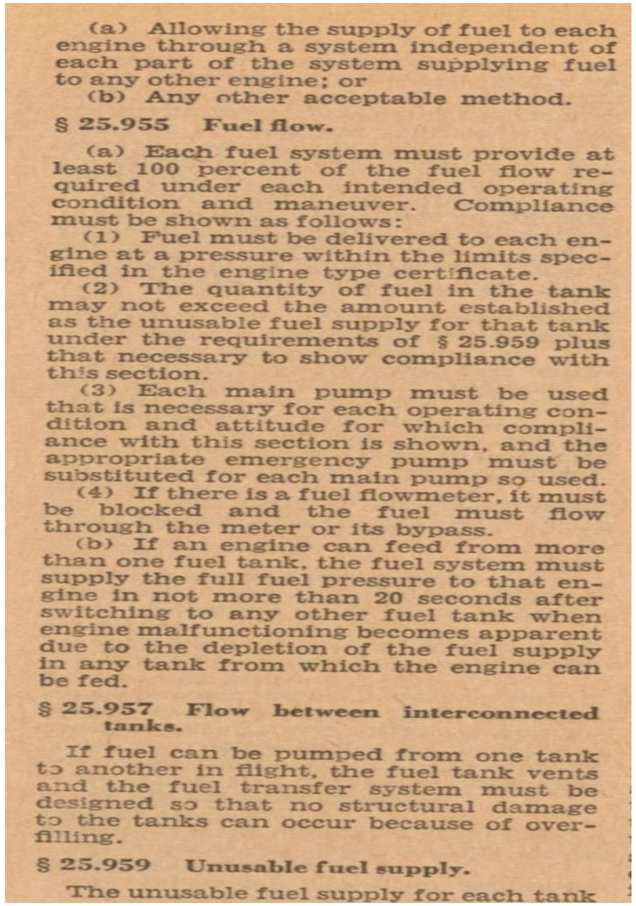
25.951	General.
25.953	Fuel system independence.
25.955	Fuel flow.
25.957	Flow between interconnected tanks.
25.959	Unusable fuel supply.
25.961	Fuel system hot weather operation.
25.963	Fuel tanks: general.
25.965	Fuel tank tests.
25.967	Fuel tank installations.
25.969	Fuel tank expansion space.
25.971	Fuel tank sump.
25.973	Fuel tank filler connection.
25.975	Fuel tank vents and carburetor vapor vents.
25.977	Fuel tank outlet.
25.979	Under-wing fueling provisions.

FUEL SYSTEM COMPONENTS

25.991	Fuel pumps.
25.993	Fuel system lines and fittings.
25.995	Fuel valves.
25.997	Fuel strainer or filter.
25.999	Fuel system drains.
25.1001	Fuel jettisoning system.

OIL SYSTEM

25.1011	General.



(a) Allowing the supply of fuel to each engine through a system independent of each part of the system supplying fuel to any other engine; or

(b) Any other acceptable method.

§ 25.955 Fuel flow.

(a) Each fuel system must provide at least 100 percent of the fuel flow required under each intended operating condition and maneuver. Compliance must be shown as follows:

(1) Fuel must be delivered to each engine at a pressure within the limits specified in the engine type certificate.

(2) The quantity of fuel in the tank may not exceed the amount established as the unusable fuel supply for that tank under the requirements of § 25.959 plus that necessary to show compliance with this section.

(3) Each main pump must be used that is necessary for each operating condition and attitude for which compliance with this section is shown, and the appropriate emergency pump must be substituted for each main pump so used.

(4) If there is a fuel flowmeter, it must be blocked and the fuel must flow through the meter or its bypass.

(b) If an engine can feed from more than one fuel tank, the fuel system must supply the full fuel pressure to that engine in not more than 20 seconds after switching to any other fuel tank when engine malfunctioning becomes apparent due to the depletion of the fuel supply in any tank from which the engine can be fed.

§ 25.957 Flow between interconnected tanks.

If fuel can be pumped from one tank to another in flight, the fuel tank vents and the fuel transfer system must be designed so that no structural damage to the tanks can occur because of overfilling.

§ 25.959 Unusable fuel supply.

The unusable fuel supply for each tank

FAR regulations

- Mentioned about aerospace design controls and guides on design parameters.

https://www.govinfo.gov/content/pkg/FR-1964-12-24/pdf/FR-1964-12-24.pdf

Pugh Matrix

Pugh matrix is a decision model or decision matrix or problem solving matrix, which helps to choose between list of different alternatives.

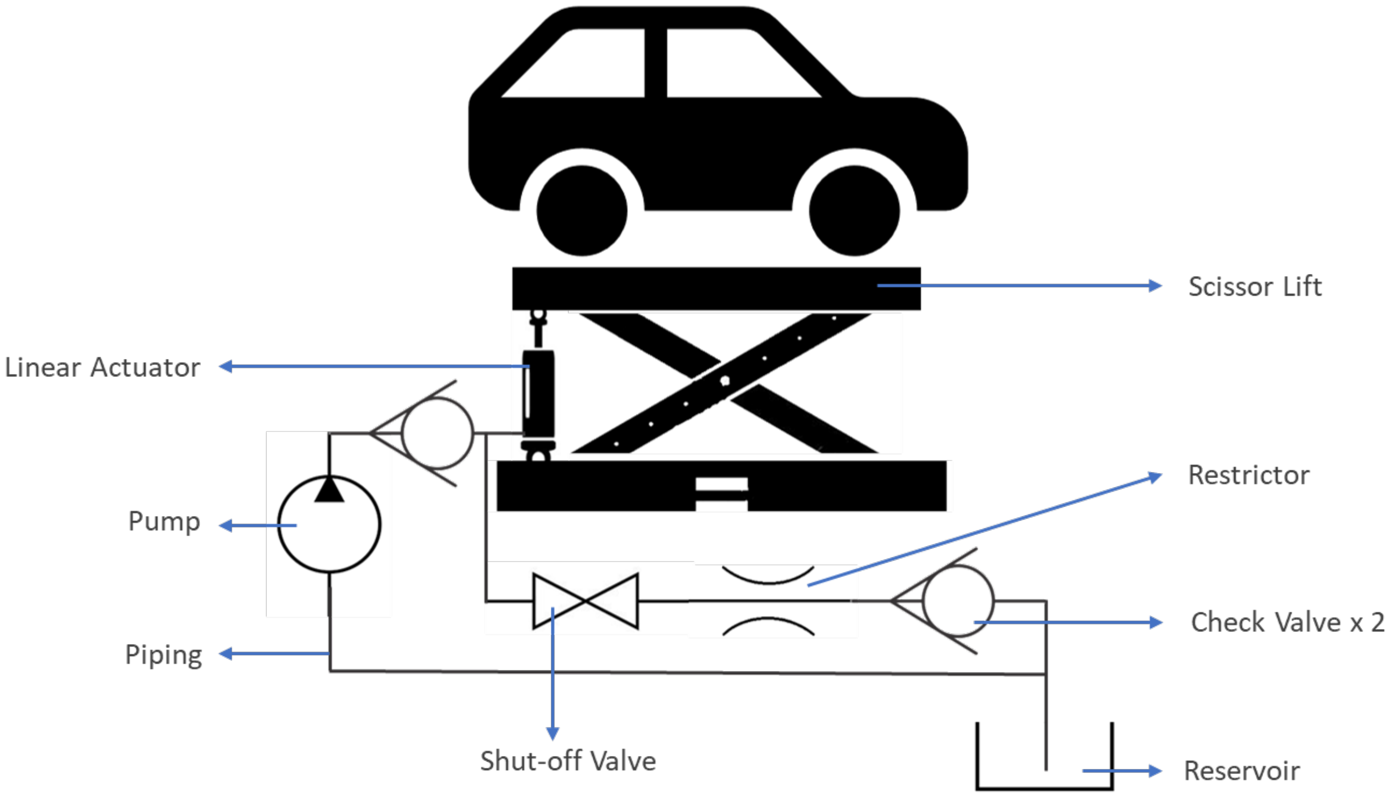
- Can be evaluated against a baseline – like if the new suppliers are better or worse than the current one based on established criteria.
  - For each criterion, rate each other alternative in comparison to the baseline, using scores of worse (–1), same (0), or better (+1).
  - Finer rating scales can be used, such as 2, 1, 0, –1, –2 for a five-point scale or 3, 2, 1, 0, –1, –2, –3 for a seven-point scale.
- Or without a baseline a set of options can be evaluated consistently based on established rating scale for each criterion.
  - Word the criteria and set the scales so that the high end of the scale (5 or 3) is always the rating that would tend to make you select that option: most impact on customers, greatest importance, least difficulty, greatest likelihood of success
    - 1, 2, 3 (1 = slight extent, 2 = some extent, 3 = great extent)
    - 1, 2, 3 (1 = low, 2 = medium, 3 = high)
    - 1, 2, 3, 4, 5 (1 = little to 5 = great)
    - 1, 4, 9 (1 = low, 4 = moderate, 9 = high)

Finalizing a layout design – Pugh Matrix

S. No	Design concepts	Durable Function	Safety	Quality	Producibility	Cost	Schedule	Score	Rank
1	Telescopic Actuation system	4	4	4	3	3	3	21	2
2	Crane lifting system	3	1	3	3	3	4	17	3
3	Articulated Actuation Lift System	5	5	5	5	4	5	29	1
4	Ram lift system	2	2	2	3	2	3	14	4
5	Scissor with lead screw Actuation system	1	2	2	3	1	3	12	5

- This is a Pugh Matrix without baseline.
- Max rating score is 5 with the best outcome
- Thus the articulated actuation lift system concept is chosen, best suited to the application and further progressed for the detail design and development.
- Best design concepts approved is further developed to present the geometric envelop and critical parameters for the refinement of M&P process leading to detail designing.

Selected Design Concept- Final layout design



Design & Develop

1 Scissor Lift
2 Restrictor
3 Check Valve
4 Shut-off Valve
5 Linear Actuator

COTS Selection

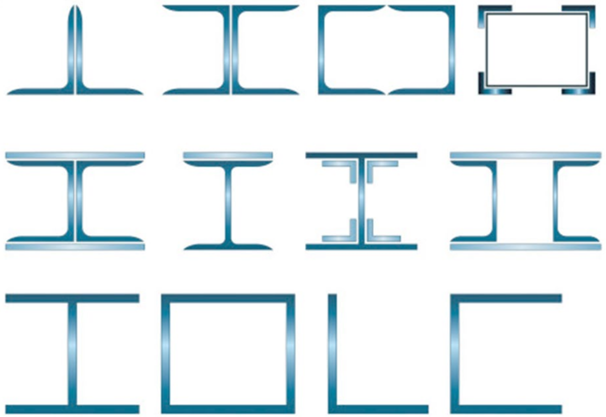
1 Pump
2 Piping
3 Reservoir
4 Hydraulic Fluid

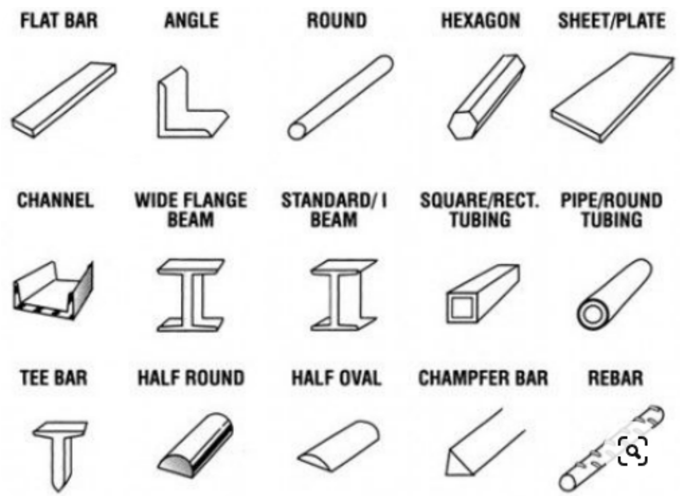
Integrate all components per workshop lift schematic & layout

Sizing of components from the finalized layout design

The sizing of components and detail design will be carried out based on following factors

- Type of load acting on the system
    - Bending
    - Compression
    - Torsion
    - Impact
    - Fatigue
    - Concentrated load
    - Distributed loads
    - Buckling
- Workability
- Symmetricity of the structural member





Sizing of components from the finalized layout design

- Design of mechanical components and structures
    - Bending equation and torsion equation

- Design of springs
    - Standard spring design steps

- Design of hydraulic components
    - Fluid properties and flow equations

- Design of mechanical linkages
    - Functional path and laws (ex. Grashafs law)

- Standard parts
    - Fasteners, seals etc.

Materials, heat treatment and finishes

- Material selection based on properties and function
- Heat treatment
- Finishes and types

Materials Requirements

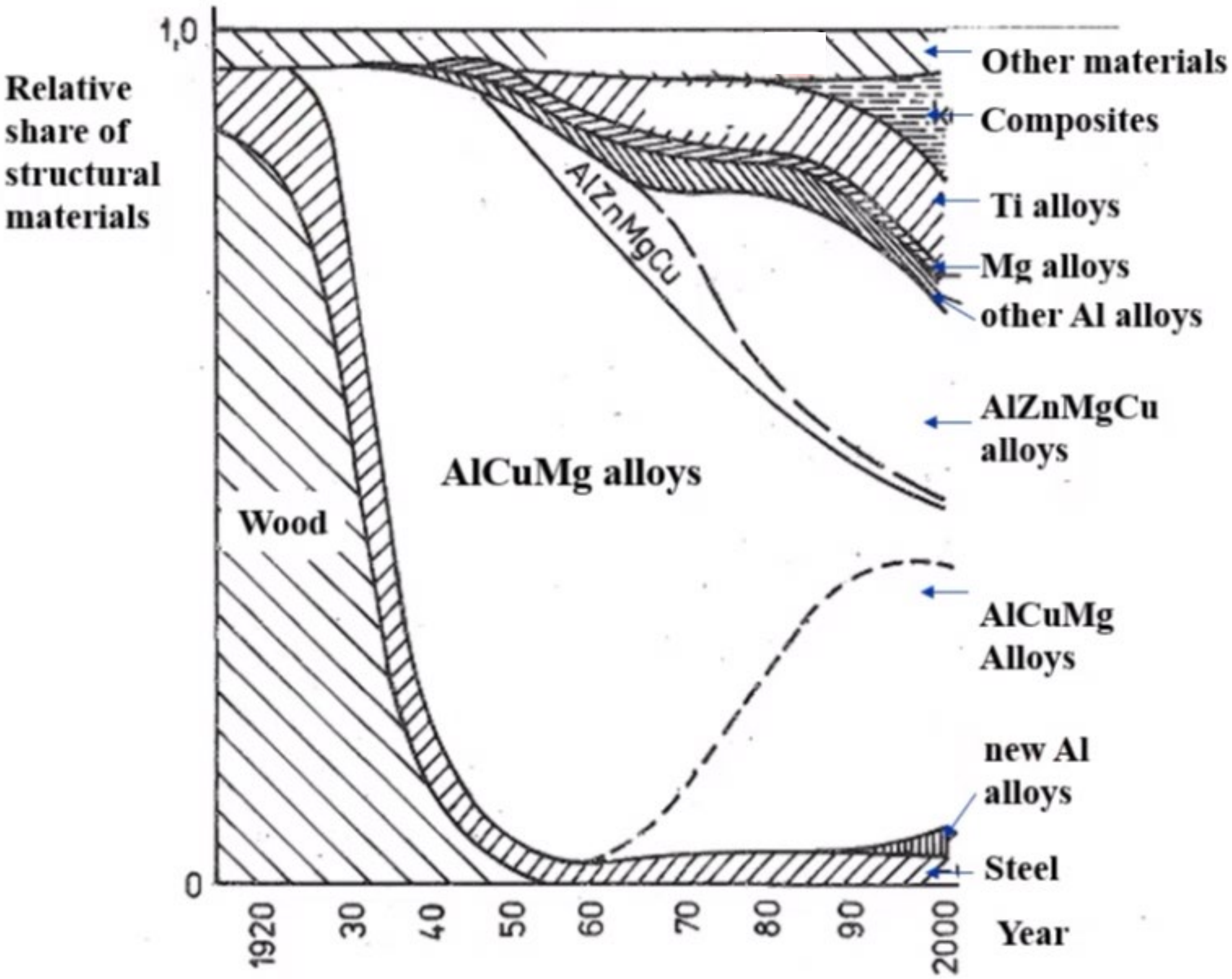
Basic requirements

- High strength and stiffness
- Low density, high specific properties e.g. strength/density, yield strength/density, E/density
- High corrossion resistance
- Fatigue resistance and damage tolerance
- Good technological properties (formability, machinability, weldability)
- Special aerospace standards and specifications

Specialist requirements

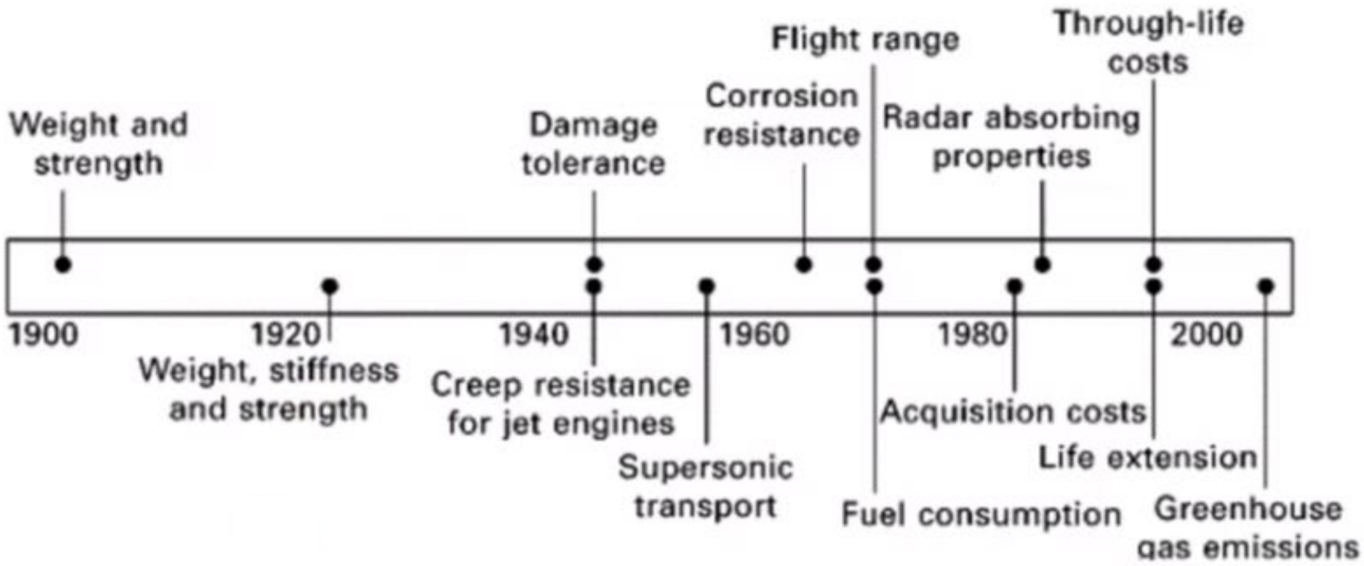
- Electrical conductivity - for materials used in the outer skin of aircraft
- Thermal conductivity - high-temperature applications such as heat shields and engine components
- Thermal expansion - for high-temperature materials.
- Flammability is a consideration for materials where there is the risk of fire - aircraft cabin & jet engines
- Stealth is an important property for materials used in the external surface of covert military aircraft.

Development of materials for basic structures



Material selection criteria

- Strength
- Durability
- Flexibility
- Weight
- Resistance to heat and corrosion
- Ability to cast
- Ability to welded or harden
- Machinability
- Electrical conductivity



Historical timeline indicating materials selection criteria introduced into aircraft design

Ref. Introduction to Aerospace Materials, Book, 2012, Elsevier

Heat treatments

What is heat treatment?

Heat treatment is a manufacturing process in which a material, generally a metal or alloy, is altered by heating and cooling cycles under complex thermal boundary conditions and wide temperature ranges. Heat treatment defines the quality of a product in terms of microstructure, mechanical properties, residual stress, and dimensional accuracy

The basics of heat treatment

The heat treatment process can be applied to ferrous metals such as cast-iron, AHSS, stainless steel and other alloy steels, as well as non-ferrous metals such as aluminum, magnesium, titanium, copper, or brass.

Heat treatment processes require the following three main steps:

1. Heating the material to a specific temperature (in the range of up to 2400 °F / 1316 °C)
2. Soaking, or maintaining the specific temperature for a certain amount of time (varying from seconds to more than 60 hours)
3. Cooling at a suitable rate following prescribed methods. The material can be cooled rapidly, slowly (in the furnace), or can be quenched (using water, brine, oils, polymer solutions, salts, or gases)

Heat treatment methods

Heat treatment generally consists of controlled heating, soaking and cooling steps.

There are five techniques used for the heat treatment of materials. Here is an overview of these principal heat treatment processes and how they affect the material.

Normalizing

This process consists of homogenization or grain refinement to obtain uniformity in the material microstructure. The material is heated to a temperature above the upper critical line of the iron carbide phase diagram to produce a homogeneous austenitic phase. This is then followed by a cooling phase in slightly agitated air to form ferrite. Normalizing is typically applied to ingots prior to working and steel casings prior to hardening. Normalizing reduces hardness and increases ductility and is usually used after other processes have unintentionally increased hardness and reduced ductility.

Heat treatments

Annealing

In this process, the material is heated beyond its upper critical point (the temperature above which austenite forms), soaked there and then cooled at a slow rate. This process is mainly used for relieving internal stresses, softening and refining the grain structure of metals. This results in changes in the mechanical and electrical properties of the metal. Benefits of annealing include improvement of machinability, ease of cold work, and increasing in the dimensional stability. This process is typically used for steels and steel alloys.

Surface Hardening

This is also known as case hardening. It includes over a dozen treatments in which the surface of the material is hardened creating a hard 'case' while the core remains tough or soft. This provides improved wear resistance for parts such as gears, cams and sleeves. This process is one of the most common for steel and iron.

Hardening

This process consists of heating the material above the critical point, where austenite is formed, followed by cooling. The material can be cooled rapidly in air, oil, water or others. This rapid cooling process is known as **quenching** and is generally applied to stainless and high-alloy steels, primarily to produce controlled amounts of martensite in the microstructure and obtain increased hardness. Hardening is often used in cast-irons and steels alloyed with metals such as nickel and magnesium.

Age Hardening

Also known as precipitation hardening, this hardening process develops high strength in metals by alloying with elements such as copper, titanium, or aluminum. This process is generally applied to stainless steels with the effect of increasing corrosion and oxidation resistance.

Tempering

This process follows a previous hardening process and consists of heating the material to a temperature below the lower critical point followed by cooling at a suitable rate. It is used mainly to increase ductility and toughness and to increase the grain size of the matrix. For example, metals such as steel are often harder and more brittle than desired. Tempering reduces internal stresses and brittleness. This process is mainly used in steels and aluminum-based alloys.

Typical Heat treatment designations for Aluminum Alloys

Suffix letter "F," "O," "H," "T," or "W," indicates basic treatment condition	First suffix digit indicates secondary treatment used to influence properties	Second suffix digit for condition H only indicates residual hardening
F—As-fabricated		
O—Annealed-wrought products only		
H—Cold worked, strain hardened		
	1—Cold worked only	2—1/4 hard
	2—Cold worked and partially annealed	4—1/2 hard
		6—3/4 hard
	3—Cold worked and stabilized	8—Hard
		9—Extra hard
W—Solution heat treated		
T—Heat treated, stable		
T1—Cooled from an elevated-temperature shaping operation + natural aged		
T2—Cooled from an elevated-temperature shaping operation + cold worked + natural aged		
T3—Solution treated + cold worked + natural aged		
T4—Solution treated + natural aged		
T5—Cooled from an elevated-temperature shaping operation + artifical aged		
T6—Solution treated + artificial aged		
T7—Solution treated + overaged		
T8—Solution treated + cold worked + artificial aged		
T9—Solution treated + artificial aged + cold worked		
T10—Cooled from an elevated-temperature shaping operation + cold worked + artificial aged		

Finishes and Types

Metal processing and finishing is the last step in the manufacturing process and describes an array of processes that alters the surface of metal products and components to improve their durability, appearance, and environmental protection. To further improve the aesthetics of the finished product, metal processing and finishing services also include cleaning and polishing processes.

Different Types of Metal Processing & Finishing

1. Electroplating
2. Electroless Plating
3. Passivation
4. Hot Blackening
5. Powder Coating
6. Phosphate Coating
7. Electropolishing
8. Buff Polishing
9. Abrasive Blasting

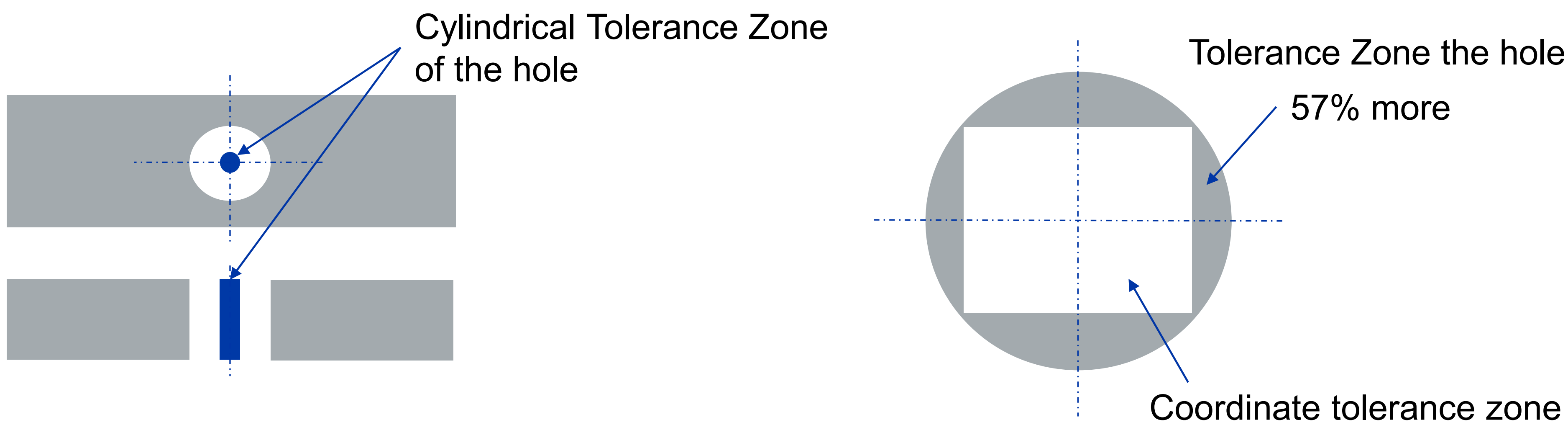
Preparation of detail and assembly drawings

- GD&T as per
  - ASME Y14.5-2018 standard
- Types of Fits
  - Clearance fit,
  - transition fit
  - interference fit
- Tolerance stack up

Geometric Dimensioning and Tolerancing

Benefits of using GD&T

- <u>Geometric Tolerance Zones</u>
  - GD&T defines tolerance zones with consideration of the geometric shape of the feature where the tolerance is applied.
  - Additional tolerance area compared to a rectangular coordinate tolerance zone



Benefits of using GD&T

- Material condition modifiers
  - Material modifiers applied to the geometric tolerance, increasing the size of tolerance zone when the actual feature size departs from applied material condition. This increase the part acceptance and reduce the rejections
    - Maximum Material condition
    - Least material condition
    - RFS
- Datum
  - Establishes a Datum Reference Frame (DRF), consisting of three mutually perpendicular datum planes. This in turn:
    - a. Serves as the origin of the measurement system, and
    - b. Limits the part's Degrees of Freedom (DOF). This may be accomplished physically with a tool, or virtually with software.
  - Minimizes the variation in a tolerance path during a tolerance analysis by identifying indexing features of two mating parts as Datum features, known as functional datum.

Fundamental Rules

- Each dimension shall have a tolerance, except for those dimensions specifically identified as reference, maximum, minimum, or stock (commercial stock size).
- The drawing should define a part without specifying manufacturing methods. Thus, only the diameter of a hole is given without indicating whether it is to be drilled, reamed, punched, or made by any other operation.
- Unless otherwise specified, all dimensions and tolerances are applicable at 20°C (68°F)
- Unless otherwise specified, all tolerances apply for full depth, length, and width of the feature.
- Dimensions and tolerances apply only at the drawing level where they are specified.
- A 90° basic angle applies where center lines of features in a pattern or surfaces shown at right angles on a 2D orthographic drawing are located or defined by basic dimensions and no angle is specified.

Inch and Millimeter tolerances

		Millimeter	Inch	
Unilateral	No trailing zeros on nominals or zeros	32 $^{0}_{-0.02}$	.500 $^{+.005}_{-.000}$	No leading zeros, and precision matches between noms and tols on direct dimensions
Bilateral	Plus & Minus have same number of decimal places Leading zeros on fractions, but trailing zeros only when equalizing tols	32 $^{+0.25}_{-0.10}$	.500 $^{+.005}_{-.010}$	No leading zeros, and precision matches between noms and tols on direct dimensions
Limit	Min's and Max's have same number of decimal places	25.45 25.00	.750 .748	Min's and Max's have same number of decimal places No leading zeros
Basics	No requirement for basic dimension precision to match the geometric tol precision. With | ⌖ | Ø0.15Ⓜ | A | B | C | Leading zeros for values less than 1mm No trailing zeros	$\boxed{25}$ **not** $\boxed{25.00}$	**New in 2009**	No requirement for basic dimension precision to match the geometric tol precision. But, not a problem if it does. $\boxed{1.000}$ or $\boxed{1.00}$ with | ⌖ | Ø.005Ⓜ | A | B | C |

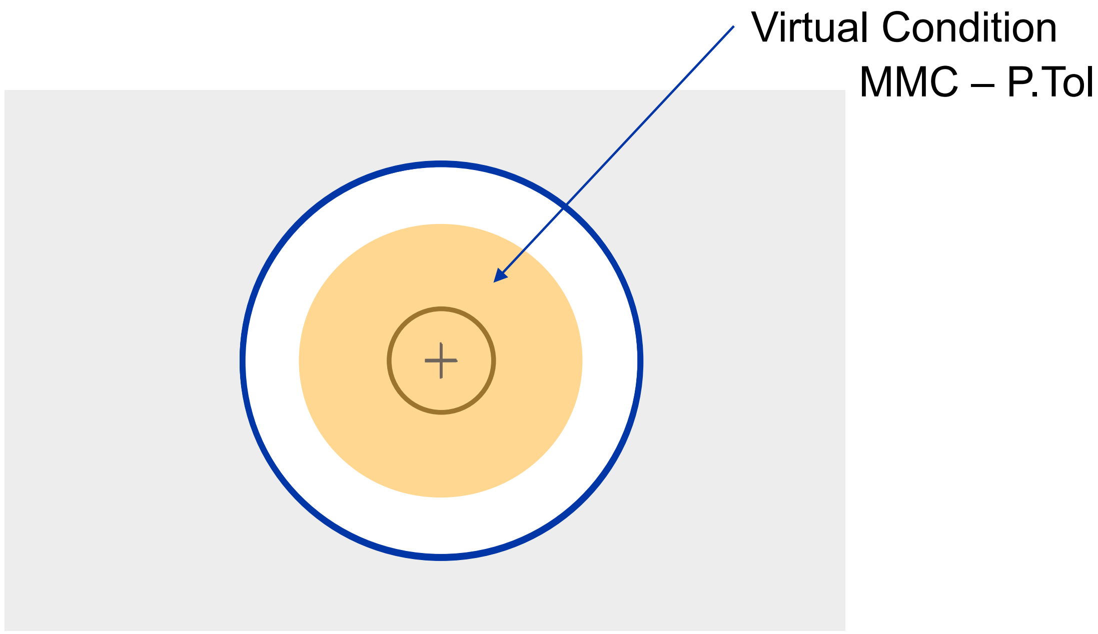
Geometric characteristic and modifiers

Application	Tolerance Type	Characteristic	Symbol	Application of Additional Tolerance Modifiers	See para
Individual Features	Form	Straightness	⏤	RFS or MMC ***	5.4.1 - 5.4.1.2
		Flatness	⏥	RFS, MMC or LMC ***	5.4.2 - 5.4.2.1
		Circularity	○	RFS only	5.4.3
		Cylindricity	⌭		5.4.4
Individual or Related Features	Profile	Profile of a Line	⌒		8.2.1.2
		Profile of a Surface	⌓		8.2.1.1
Related Features	Orientation	Angularity	∠	RFS, MMC or LMC	6.3.1
		Perpendicularity	⊥		6.3.3
		Parallelism	//		6.3.2
	Location	Position**	⌖		7.2
		Concentricity	◎	RFS only	7.6.4
		Symmetry	⌯		7.7.2
	Runout	Circular Runout	↗ *		9.4.1
		Total Runout	⌰ *		9.4.2
*Arrowheads may be filled or not filled.					
**May be related or unrelated to datums.					
***May apply MMC or LMC when applied to a diameter or width size specification.					

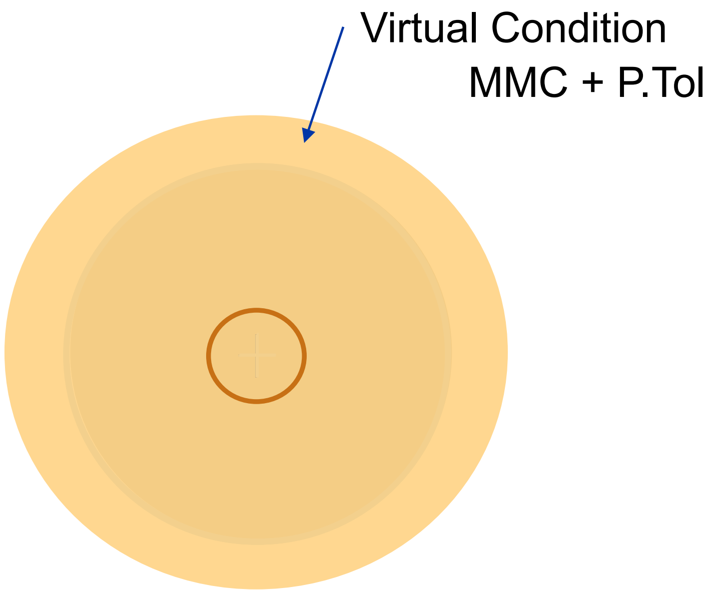
Gone in 2018 standard

Virtual Condition

- A constant boundary generated by the collective effects of a considered feature of size's specified MMC or LMC and the geometric tolerance for that material condition.



Hole @ MMC

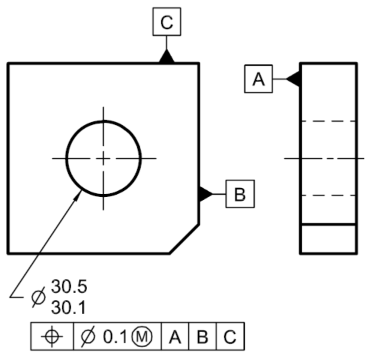


PIN @ MMC

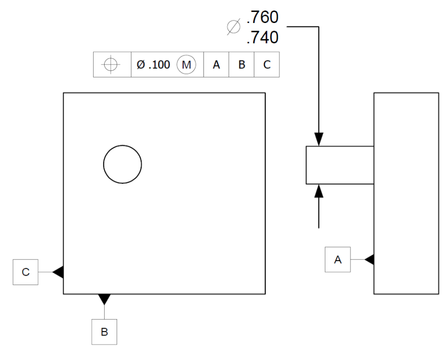
Virtual Condition

- Virtual condition
  - ensures parts produced will fit together and function upon assembly. To ensure this, the allowable extreme inner and outer boundaries of mating parts must be determined;
  - used by gauge manufactures to find the gauge dimensions
  - used by product inspectors to check these extreme conditions.

Feature	Material Modifier	Calculation
Internal Features (Hole)	MMC	MMC – Geo.Tol
	LMC	LMC + Geo.Tol
External features (Pin)	MMC	MMC + Geo.Tol
	LMC	LMC - Geo.Tol



Hole VC 30



PIN VC 0.860

Bonus Tolerance

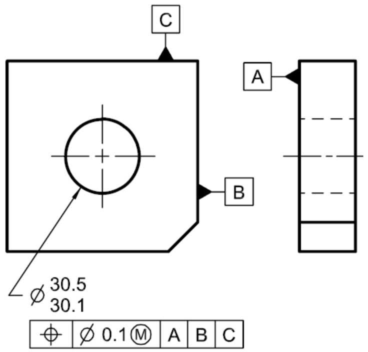
- When Geo.Tol @ MMC or LMC

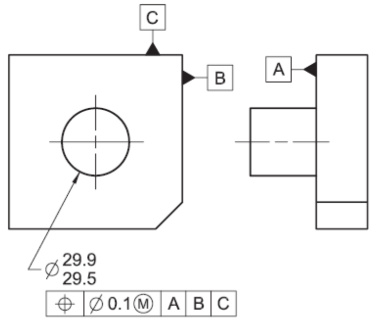
  Bonus Geo. Tol = Max Deviation FOS from Specified

  Total Geo. Tol = Specified + Bonus

- Total Geo. Tolerance is based on VC.

Feature	Material Modifier	Total Geo. Tol
Internal Features (Hole)	MMC or LMC	VC- Actual FOS
External features (Pin)	MMC or LMC	VC+ Actual FOS





	⌀ HOLE	⌀ TOL	VC
LMC	30.5	0.5	
	30.4	0.4	
	30.3	0.3	30
	30.2	0.2	
MMC	30.1	0.1	

	⌀ PIN	⌀ TOL	VC
MMC	29.9	0.1	
	29.8	0.2	
	29.7	0.3	30
	29.6	0.4	
LMC	29.5	0.5	

Types of Fits

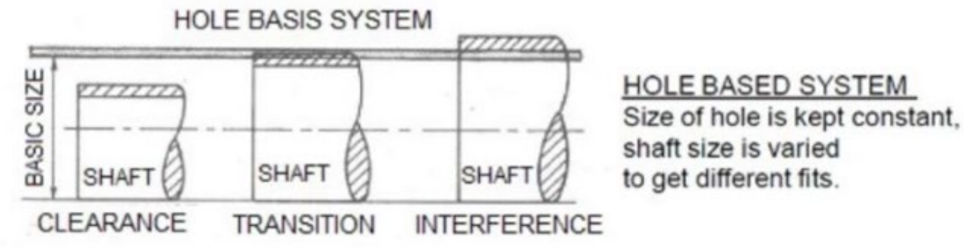
Types of FITs

https://amesweb.info/fits-tolerances/ansi-limits-fits-calculator.aspx

Clearance fit: - it is the difference b/w the size of hole & the size of shaft which is always positive.
(i.e. Hole size is always bigger than shaft size)

Types of Clearance Fits:
The most commonly used fits of the clearance type are.

1. **Slide fit**
2. **Running Fit**
3. **Slack running Fits**
4. **Easy Slide**
5. **Loose Running Fits**



Slide-Fit:
Slide fit has a very small clearance between two mating parts i.e. almost to zero
By this, we can say that the sliding fit is too closed to a transitions fit.

An example of a Slide fit is the tailstock spindle in a lathe machine.

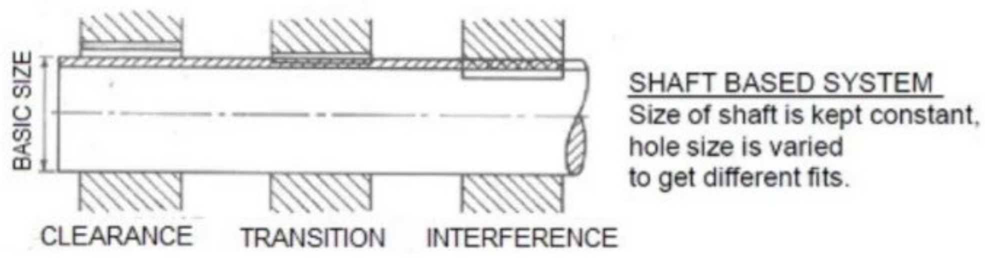
Running Fit:
At moderate speeds, the running fit is employed in engineering for rotation of components. The clearance provides the required space for couplings.
For Example, couplings**,** Gears, etc.
Easy Slide Fit:
As the name implies, it provides a small clearance between the shaft and hole.
It is applicable for slow regular motion and non-regular motions
For Example, Piston.

Loose Running Fits:
As the name implies, Loose Running fits have the largest clearance and employed for rotation at high speeds of the components.
For Example, Plummer block, Idler Pulleys, etc.

Types of FITs

Interference fit: - it is the difference b/w the size of hole & the size of shaft before assembly which is always negative. (I.e. Shaft size is always bigger than hole size).

Interference fit:



Types of Interference Fits:
Interference Fit is further Classified into the following types.

1. **Force Fit**
2. **Tight Fit**
3. **Shrink Fit**

The explanation for the types of Interference fits are as follows.

Force Fit:
The force fits are employed for mating parts.

Example of a Force fit include Forging machine and the gears on the shaft of a concrete mixer.

Tight Fit:
Tight fits provide less interference than force fits.

Example of a Tight fit include Cylindrical grinding machine, stepped pulleys of a conveyor.

Shrink Fit:
There is negative allowance in Shrink fit and more amount of force is required for assembling the parts.
This is the explanation on **Types of Interference Fits**. Let's look at Transition Fit in a detailed way.

Types of FITs

Transition fit: - Fit that lies b/w the clearance and interference fit

Types of Transition Fits:
The transition fit is classified into two types:

1. **Wringing Fit**
2. **Push-fit**

The explanation on Types of Transition Fits is as follows.

Wringing Fit:
In machines, where the parts can be replaced without any difficulty, there wringing fit is used.

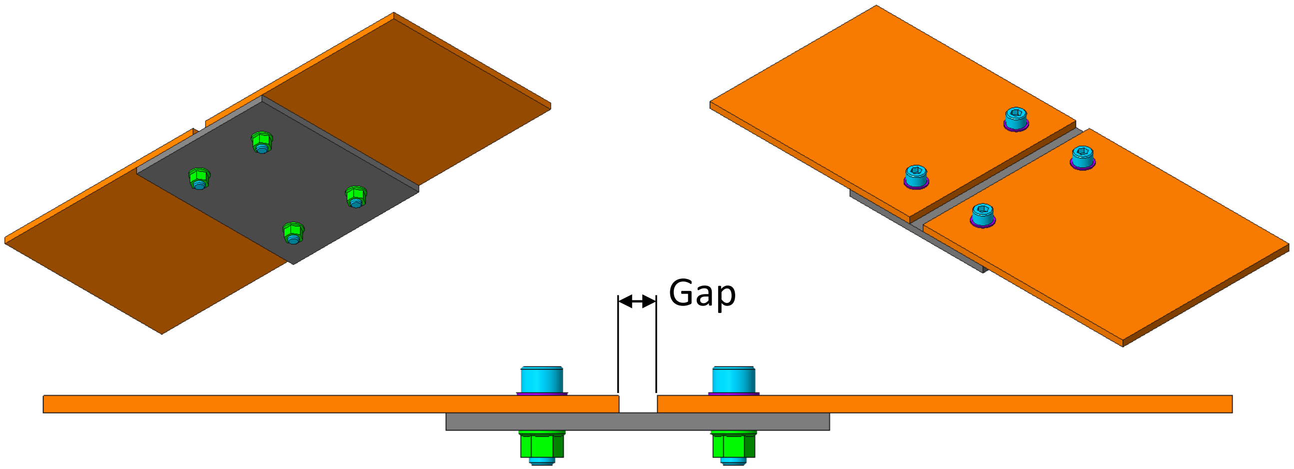
Example of Wringing Fit include gears of machine tools.

Push-Fit:
It is characterized by its clearance. An example of Push-fit is Gear Slip bushing.
It is used for producing non-mating assemblies like fit between Piston and Piston rings of IC engine, coupling, and coupling rings, etc.

Tolerance stack up

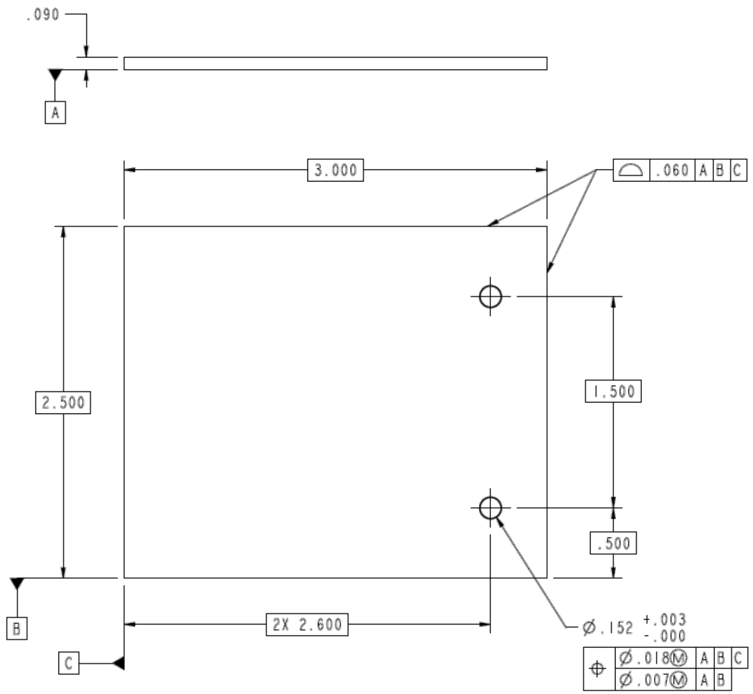
Example : Three-Plate Assembly Shift

- Problem Statement: The plates below are to be assembled as shown with the 4X cap screws and nuts. It is desired that engineering knows the minimum and maximum gaps between the two plates to ensure the plates cannot touch or that the gap is not too large
- Given Information: Cap Screw shank diameter: .138 +.000/-.005
- Assumptions:
  - Although there are 4 fasteners, the stack up will be done through a cross section with only two fastener through A-A
- Objective:
  - Determine Worst Case results for min and max gaps

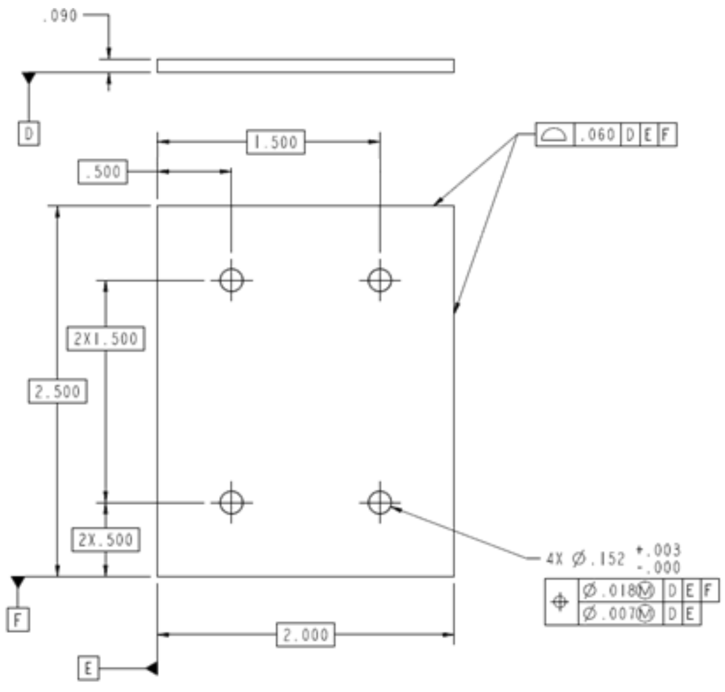


Example: Three-Plate Assembly Shift

- The engineering drawings for both plates are given below.



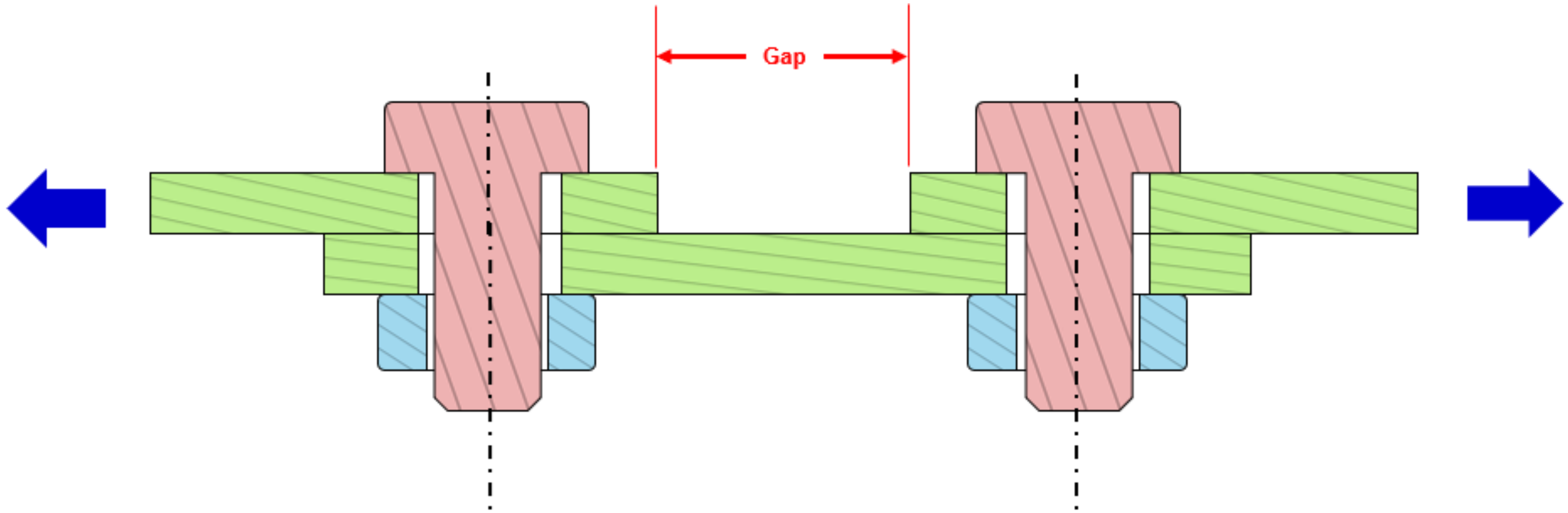
-1 & -2 CONFIG



-3 CONFIG

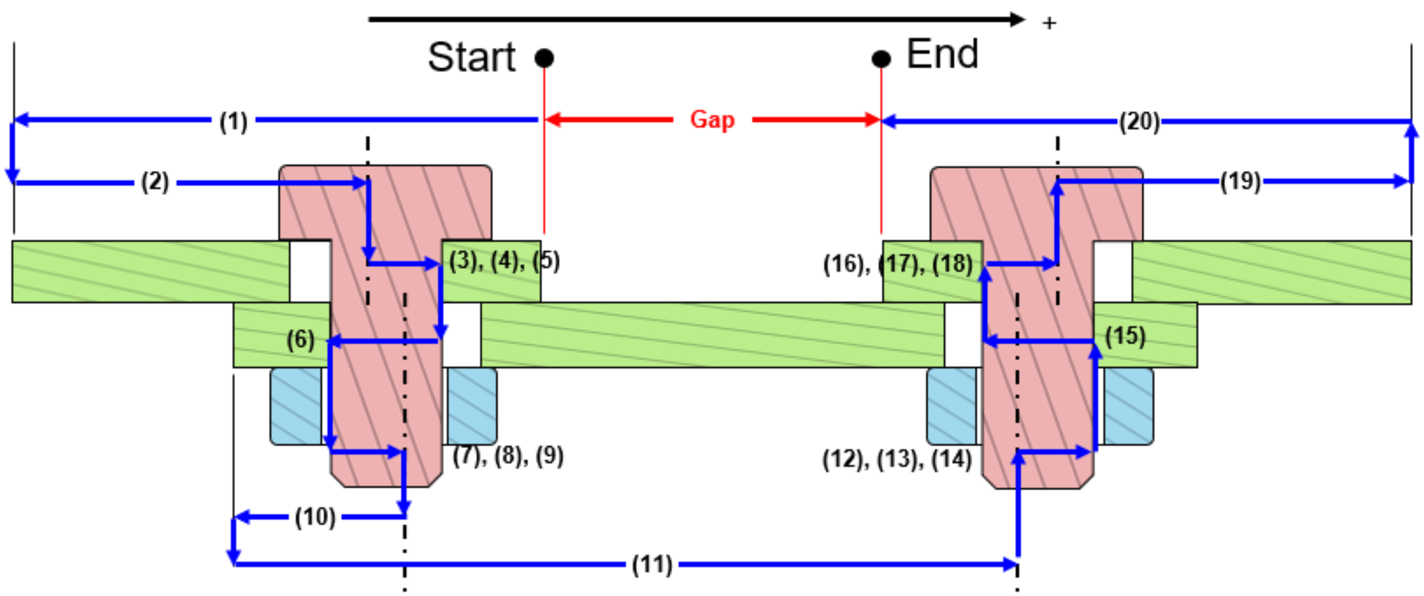
Example: Three-Plate Assembly Shift

- For this example, we will look at finding the maximum gap between the two plates
- As a first step, we will look at the part with everything centered as shown below. To find the max gap for this assembly, we want to take out all of the assembly float in such a way that causes the gap to be a maximum.
- This would be pulling the plates at the two blue arrows to yield the result on the next slide
  - We are “taking the slack” out of the assembly and biasing everything to the max gap



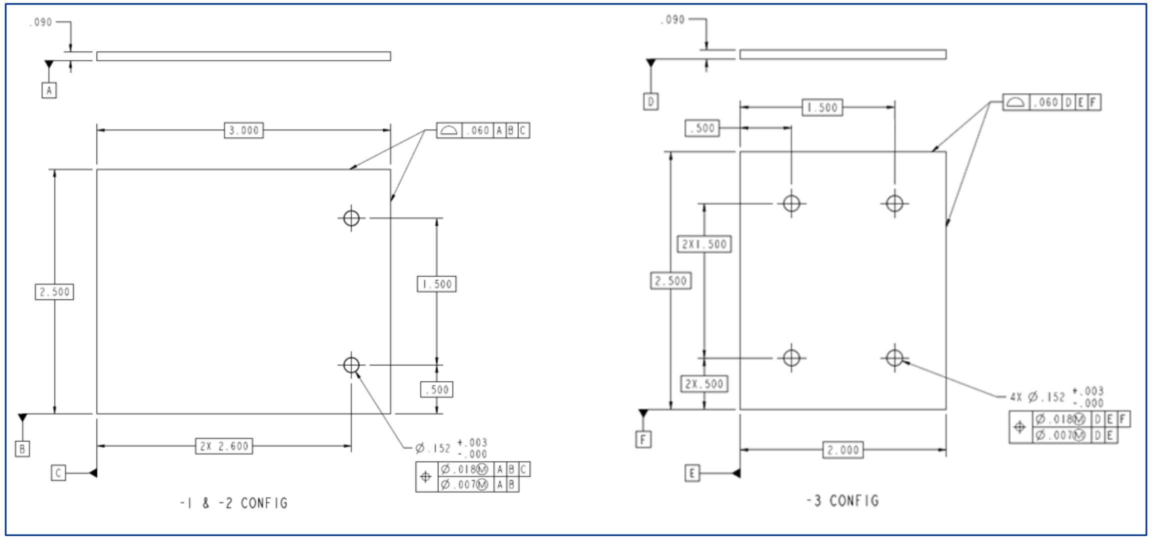
Example: Three-Plate Assembly Shift

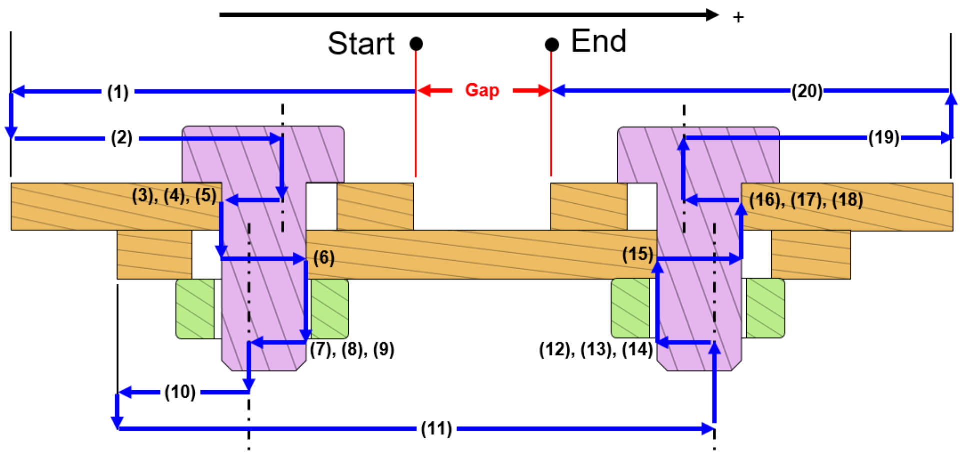
After the parts are "pulled apart", the assembly will look like what is shown below. We can now generate our loop diagram and equations as shown below



$$Gap_{max} = -(1) + (2) + (3) + (4) + (5) - (6) + (7) + (8) + (9) - (10) + (11) + (12) + (13) + (14) - (15) + (16) + (17) + (18) + (19) - (20)$$

Example: Three-Plate Assembly Shift





Example: Three-Plate Assembly Shift

As seen by viewing the two analyses, true minimums and maximums are the values that correspond to the assembly shift direction. Values circled in blue are the equation items showed previously that have sign differences, requiring different analysis sheets
Note that the other values in blue are not true min or max values for the entire assy. Although they do not represent what the designer is looking for, they are still physically significant and represent the following:

Minimum gap in an assembly shift state biased towards the max gap
Maximum gap in an assembly shift state biased towards the min gap

Row QTY 20	Description of Component/Assy	Description	Target Dims	Tolerances USL	Tolerances LSL	Weight (+/-)
1	Plate -1	Basic Dim with Profile	3.0000	0.0300	0.0300	-1.000
2	Plate -1	Basic Dim of hole to datums	2.6000	0.0000	0.0000	+1.000
3	Plate -1	Hole Size	0.1520	0.0030	0.0000	+0.500
4	Plate -1	Hole Pos Tol		0.0180	0.0180	+0.500
5	Plate -1	Hole Bonus Tol		0.0030	0.0000	+0.500
6	Fastener	Fastener Size	0.1380	0.0000	0.0050	-1.000
7	Plate -3	Hole Size	0.1520	0.0030	0.0000	+0.500
8	Plate -3	Hole Pos Tol		0.0180	0.0180	+0.500
9	Plate -3	Hole Bonus Tol		0.0030	0.0000	+0.500
10	Plate -3	Basic location of hole to Datum	0.5000	0.0000	0.0000	-1.000
11	Plate -3	Basic location of hole to Datum	1.5000	0.0000	0.0000	+1.000
12	Plate -3	Hole Size	0.1520	0.0030	0.0000	+0.500
13	Plate -3	Hole Pos Tol		0.0180	0.0180	+0.500
14	Plate -3	Hole Bonus Tol		0.0030	0.0000	+0.500
15	Fastener	Fastener Size	0.1380	0.0000	0.0050	-1.000
16	Plate -2	Hole Size	0.1520	0.0030	0.0000	+0.500
17	Plate -2	Hole Pos Tol		0.0180	0.0180	+0.500
18	Plate -2	Hole Bonus Tol		0.0030	0.0000	+0.500
19	Plate -2	Basic Dim of hole to datums	2.6000	0.0000	0.0000	+1.000
20	Plate -2	Basic Dim with Profile	3.0000	0.0300	0.0300	-1.000

Inputs for stackup with assy shift biased towards max gap

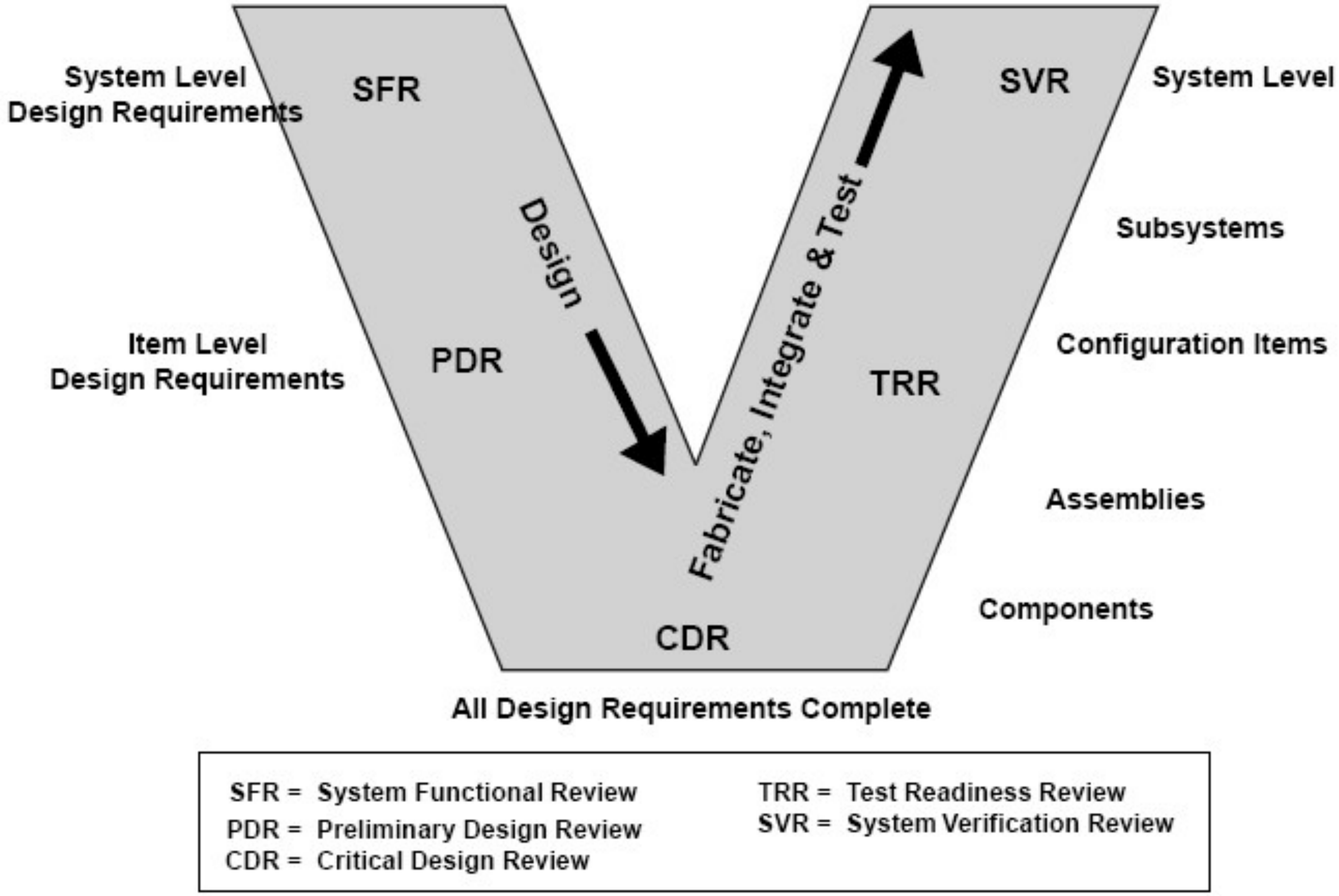
Min / Max	
Min	Max
0.1320	0.3460
0.1696	0.3084

Worst Case Values

Max distance = 0.3460”

System Development Process

- V-model is a graphical representation of a systems development lifecycle.
- V-model summarizes the main steps to be taken in conjunction with the corresponding deliverables within project life cycle development.



PDR (Preliminary design review)

- Submission of PDR packages (Preliminary Draft)
  - Drawings, CAD models
  - Bill of Materials
  - Assembly instructions (Part Lists)
  - Tolerance stack up sheets
  - Design substantiation reports
  - Stress analysis reports
  - Test plans etc.

- Getting Reviewer comments (DEA, Stress, ME, M&PT, GROUP)

- Capturing Reviewer comments in a action log.

DE – Design Engineer
DEA – Design Engineer Approval
ME- Manufacturing Engineer
M&PT- Materials and process engineer.
Group-Systems group engineer

CDR (Critical design review)

- Submission of CDR packages (Final Draft)
  - Drawings, CAD models
  - Bill of Materials
  - Assembly instructions (Part Lists)
  - Tolerance stack up sheets
  - Design substantiation reports
  - Stress analysis reports
  - Test plans etc.

- Getting Reviewer comments (DEA, Stress, ME, M&PT, GROUP)
- Capturing Reviewer comments in a action log.

Note:- Reviewers will check if all the comments from PDR is implemented and if there were any review miss in PDR it will be covered during CDR.

Testing

Coupon test : coupons are **small samples that are removed from the existing structure and are used for subsequent analysis and testing**. Coupons are required for both tensile and chemical testing. Coupon tests are low in cost, simple to conduct, and **allow the simultaneous evaluation of numerous materials and variations of a single material.**

Component test: The primary objective of component testing is **to validate the behavior of the individual component, as per specified requirements**.
Ex: The Check valve of the system is tested to confirm its functional and performance requirements.

Sub-assembly test: Sub-assembly is a critical part of the manufacturing process. It reduces the complexity of the assembly process by breaking it down into smaller tasks that can be completed more efficiently. Sub-assemblies are also beneficial in terms of quality and cost control. By manufacturing sub-assemblies, manufacturers can ensure that their products meet the highest quality standards.
Ex: The Hydraulic circuit of the system is tested to confirm its functional and performance requirements.

Final product test: The Final product test is performed will **ensure that the product meets established specifications and that these specifications account for its structural integrity, safety, perseverance and efficiency**.
Ex: The Complete system is tested to confirm its functional and performance requirements.

Exemplary

Qualification/Testing

Qualification Plan:

Design Review	Analysis	Testing	Similarity to available test Data	Inspection
• Material and Processes • Interchangeability • Marking • Lubrication • Mechanical Integrity • Mechanical Requirements • General Hydraulic design requirements	• Altitude • Humidity • Temperature cycle • Acceleration • Waterproofness • Fluid Susceptibility# • Sand and Dust • Fungus Resistance • Icing • Abuse loads • Fire protection • Thermal Shock • Operational, Removal, and Schedule Reliability • FMEA % • Service Life • Storage Life • Maintainability Notes: * Test may required depending on Natural frequency. # May include test, analysis and similarity % By Qualitative comparative analysis	ATP • Proof Pressure ^ • Cracking Pressure ^ • Reseating Pressure ^ • Pressure Drop ^ • Leakage Qual • Vibration • Salt Spray • Burst Pressure • Extreme Temperature performance (High and Low) • Stability • Port Endurance • Endurance Life • Impulse fatigue • Limit load & Ultimate Load • Bench Handling Shock • Shipping Container Shock • Contaminated fluid ^ Part of Acceptance testing		• Preparation for Delivery of Production Parts • Workmanship • Envelop & Interface • Weight ^ ^ Part of Acceptance testing

Exemplary

Certification/Qualification/Testing

- Testing – Acceptance Test Procedure (ATP)

- ATP document defines acceptance testing
  - ATP is based on Acceptance Test Plan Requirements from Design

- ATP testing to be performed.
  - ATP will include (as a minimum):
    - Proof Pressure and External Leakage
    - Cracking Pressure
    - Reseat Pressure
    - Pressure Drop
    - Weight and envelop dimension checks

Exemplary

Certification/Qualification/Testing

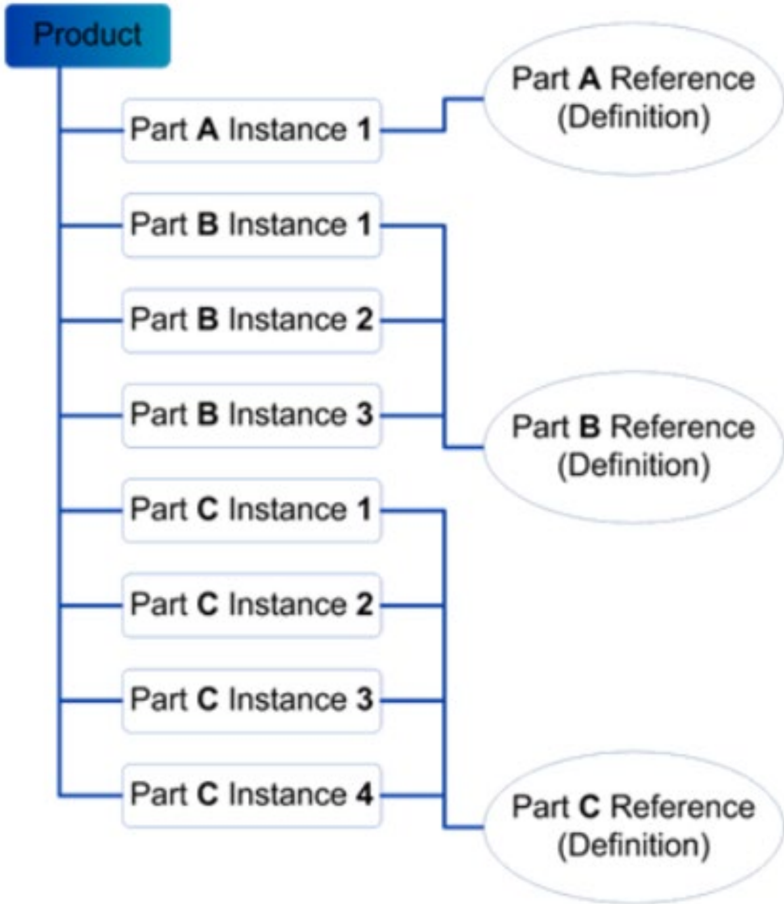
- Testing – Development Test Procedure (DTP)

- DTP document defines development testing on prototype design
  - DTP is based on Development Test Plan Requirements from Design

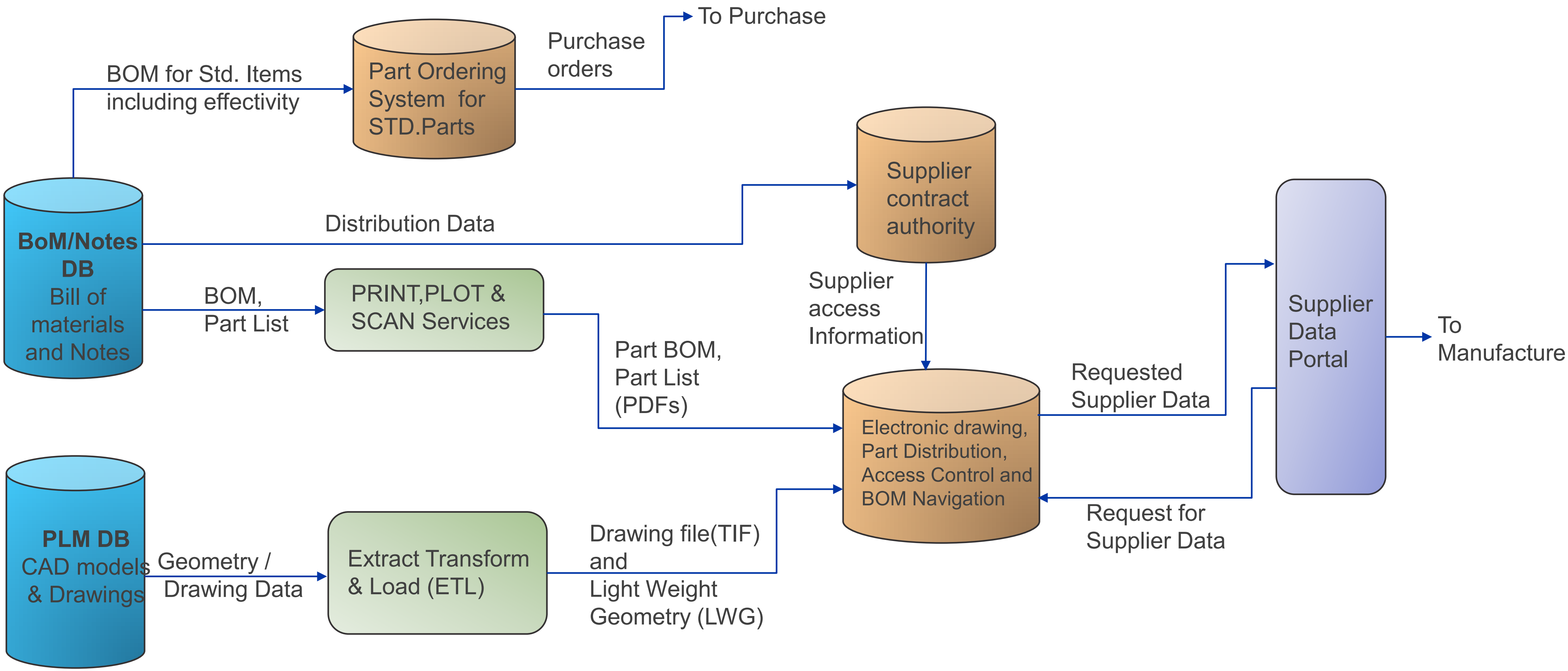
- DTP testing to be performed.
  - DTP will include (as a minimum): Functional tests (ATP),
    - Proof Pressure and External Leakage
    - Cracking Pressure
    - Reseat Pressure
    - High and low temperature Performance

Configuration Management in PLM database

- Enovia / Team center/PDM



Release of drawings for production



Thank You