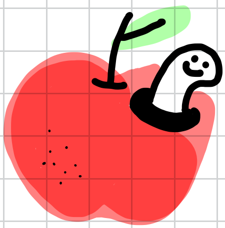
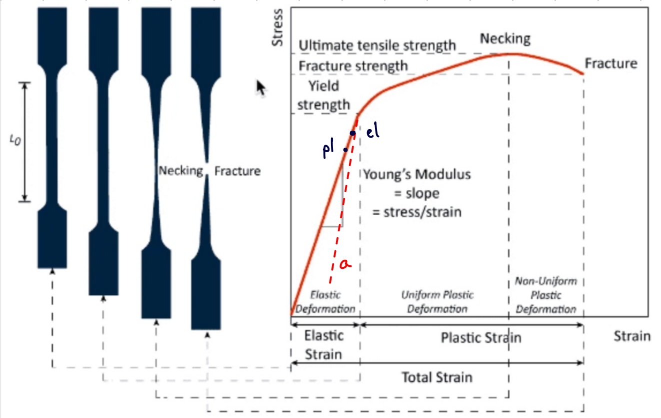
Materials Science



Stress + Strain

Definitions

FOS: $\frac{\text{ultimate strength}}{\text{allowable stress}}$



$$\sigma = \frac{F}{A}$$ F: force, A: cross section area

$$\varepsilon = \frac{l - l_0}{l_0}$$ l: final length, l_0: initial

Elastic Region: slope in elastic region measures stiffness E (young mod)
- High E means stiffer material
- Elastic deformation is reversible material returns to original shape
- (pl) Proportional Limit · max point where σ ε are directly proportional.

Yeild Point: stress @ which permanent (plastic) deformation occurs.
- Some materials have distinct yeild point others you can find using the offset method (a) (eg. 0.2% strain) to find yeild strength.

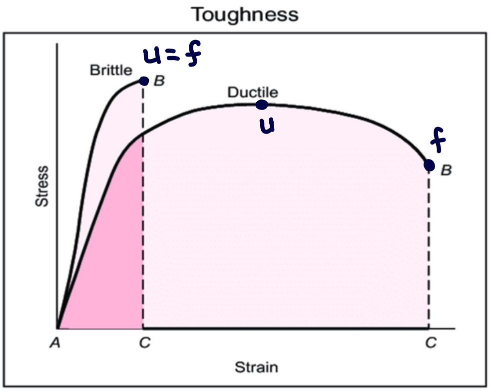
Plastic Region: irreversable deformation when material stressed beyond yield

Ultimate Tensile Strength: max stress before necking will occur.

Necking: localized reduction in cross sectional area before fracture

Fracture: the point at breakage. Brittle fracture little to no plastic deform. Ductile has sig plastic deform before fail.

Ductile vs Brittle stress strain curves:



Toughness = the ability to absorb energy up to fracture
= the total area under the strain-stress curve up to fracture

Ductile

Hookes law

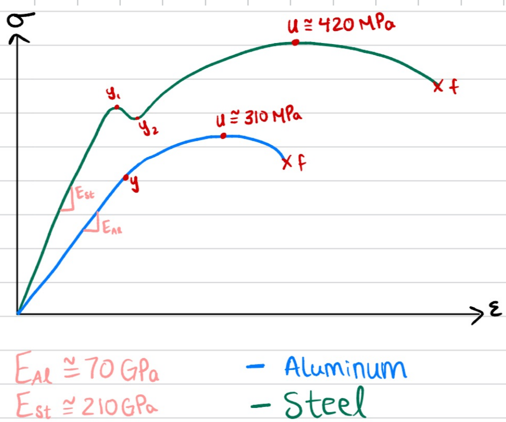
Elastic region: linear slope up to yeild point

Plastic region: stress remains const as strain ↑ then stress ↑ as material strengthens due to defor then localized thinning precedes fracture

Brittle Material:

Elastic region linear until sudden fracture with no plastic
Low strain to failure (remember what ε formula is)

Aluminum vs Steel SS Curve



Aluminum:

- Lightweight 1/3 density of steel
- Lower stiffness and strength
- Lower YM simplifies forming
- Density: 7.85 g/cm^3
- Losses strength at temps >200°C
- Naturally forms protective oxide layer

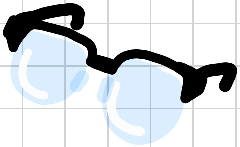
Steel:

- Higher strain hardening as deforms plastic
- Higher elongation before fracture

- Most mild/low carbon steels exhibit yeild point phenomenon YPP.

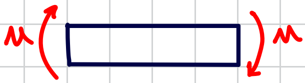
- YPP occurs bc carbon atoms at interstitial sites of steel microstructure that require high stress to slip (y_1) but stress falls after dislocation lines move past y_1

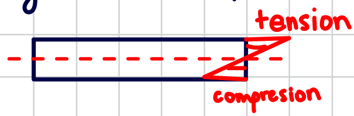
MODS



Beam Bending

: when a mechanical member is subjected to pure bending due to an applied load





Flexture Formula:

$$\sigma = -\frac{My}{I}$$

σ : bending stress
M : moment due to load
I : second moment of inertia

Moment of Inertia : denoted as I quantifies resistance of cross sectional area to bending or rotation.

→ for rectangular geometry:

$$I = \frac{bh^3}{12}$$

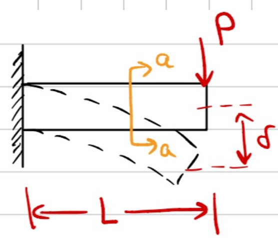
since h is cubed it has larger effect on I

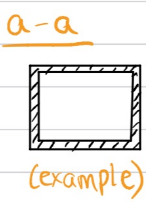
→ Parallel Axis Theorem: allows you to calculcte moment of inertia of cross sectional area about axis parallel of centroidal one.

$$I_{parallel} = I_{centroid} + Ad^2$$

Ex rect beam has width 100mm height h=200. Calc moment inerita about base of rect.

Deflection of Cantilevered Beam





P: applied force
L: beam length
E: Youngs Modulus
I: Second Moment of Area
δ: deflection

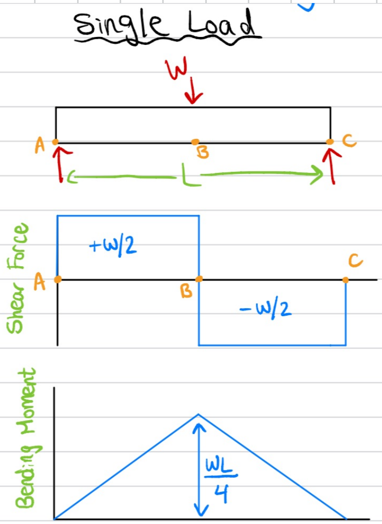
$$\delta_{max} = \frac{PL^3}{3EI}$$ Point load @ free end — stiffness $= \frac{3EI}{L^3}$

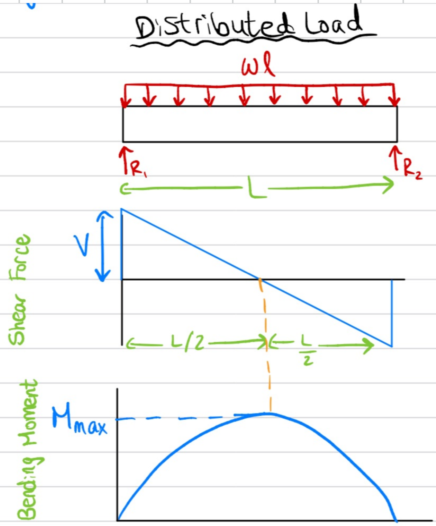
$$\delta_{max} = \frac{wL^4}{8EI}$$ uniformly dist load — $K = \frac{8EI}{L^4}$

$$\delta_{max} = \frac{ML^2}{2EI}$$ applied moment @ free end

You can reduce δ by: ↓P ↓L ↑E ↑I

Shear Force and Bending Moment Diagrams

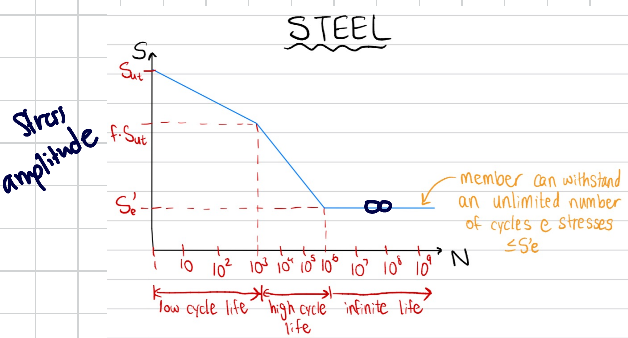


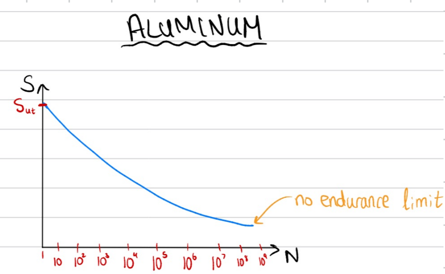


Cyclical Loading : Fatigue

- Fatigue is the progressive and localized structural damage that occurs when material is subject to repeated loading and unloading cycles.

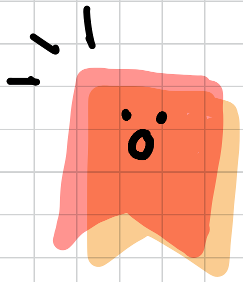
- We can use stress life curves to predict # of cycles (N) a steel member can endure at given cyclical stress (S)





Aluminum doesn't distribute an endurance limit but tapers off at ~ 5×10^8 cycles

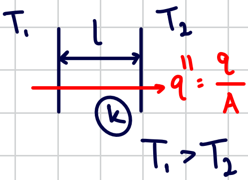
Heat Transfer



Modes of Heat Transfer

Conduction

1D heat transfer through material



k : thermal conductivity

Fourier's Law

$$q_k = \frac{kA}{L}(T_1 - T_2)$$

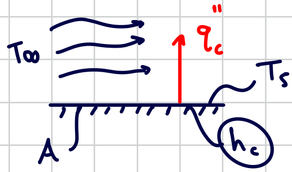
Thermal Resistance

$$q_k = \frac{T_1 - T_2}{R_k}$$

$$R_k = \frac{L}{kA}$$

Convection

heat transfer from surface to moving fluid



$\bar{h}_c$: avg convective heat transfer

Newton's cooling law

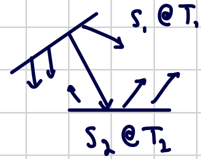
$$q_c = \bar{h}_c A (T_s - T_\infty)$$

$$q_c = \frac{T_s - T_\infty}{R_c}$$

$$R_c = \frac{1}{\bar{h}_c A}$$

Radiation

heat transfer through electromagnetic waves to one surface to another



$T_1 > T_2$

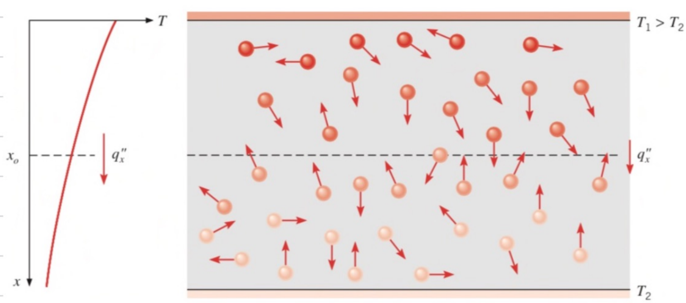
$$q_r = A_1 F_{1-2}\, \sigma (T_1^4 - T_2^4) = \frac{T_1 - T_2}{R_r}$$

$$R_r = \frac{T_1 - T_2}{A_1 F_{1-2}\, \sigma (T_1^4 - T_2^4)}$$

q = heat transfer rate (W)

Conduction : heat transfer from more energetic to less energetic particles

heat transfer across this medium in contact



Fourier's Law: $q''_k = -k\frac{dT}{dx}$

- q''_k → heat flux (W/m^2)
- k → thermal conductivity
- $\frac{dT}{dx}$ → temp. gradient
- $-$ → -ve due to ht in direction of ↓ temp.

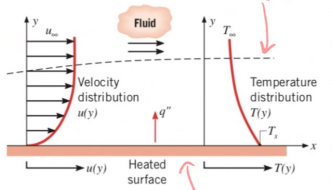
But... under SS conditions, temp. is linear so → $q''_k = -k\frac{T_2 - T_1}{L}$

1.2.2 - Convection

Comprised of:

① Random molecular motion (diffusion) ② Bulk, macroscopic motion of fluid

boundary layer



surface (u=0): random motion only

if $T_s > T_\infty$:

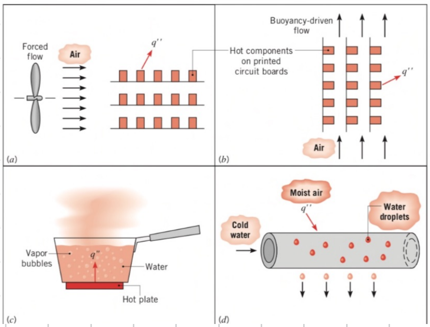
↳ ht via convection occurs from surface to fluid

$q'' = h(T_s - T_\infty)$

- q'' → heat flux (W/m^2)
- h → convection heat transfer (W/m^2K)
- $(T_s - T_\infty)$ → temp.

Forced vs. Natural Convection

a → forced convection
b → natural convection
c → boiling
d → condensation



3 laws thermodynamics

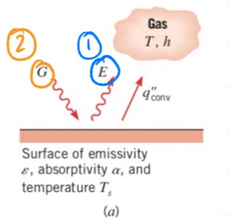
① conservation of energy · used to find energy heat loss efficiency

② disorder increases. As disorder ↑ energy transformed into less usable forms. Efficiency will be always <100%

③ molecular movement stops @ absolute zero -273°C. At this temp perfect crystal no disorder.

1.2.3 - Radiation

- energy emitted by matter @ non-zero temp.
- energy transported by EM waves
- doesn't require a material medium



①: radiation emitted from surface

$$E = \varepsilon \sigma T_s^4$$

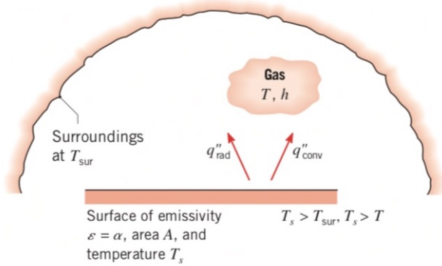
- E → emissive power
- ε → emissivity $(0 \le \varepsilon \le 1)$
- σ → Stefan-Boltzman constant $(\sigma = 5.67 \times 10^{-8}\ W/m^2K)$
- T_s → Surface temp.

if $\varepsilon = 1$ → blackbody

②: radiation incident on a surface from surroundings

$$G_{abs} = \alpha G$$

- G_{abs} → irradiation absorbed by surface
- α → absorptivity $(0 \le \alpha \le 1)$



$T_{surr} \neq T_s$

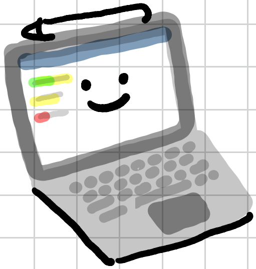
- T_{surr} → open surroundings
- T_s → enclosed surface

Radiation Eqn: $q''_{rad} = \frac{q}{A} = \varepsilon E_b(T_s) - \alpha G = \varepsilon\sigma(T_s^4 - T_{surr}^4)$

q''_{rad} → net radiation heat transfer from surface

$$q''_{rad} = \varepsilon\sigma(T_s^4 - T_{surr}^4)$$

GD&T

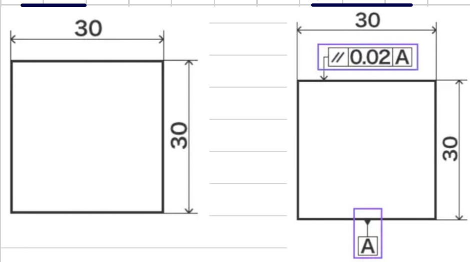


GD&T:

system to define and communicate tolerances on engineering drawings. It provides info on shape, size, positional relationship and allowable error for form and position.

Difference between coordinate/size and geometric tolerance:

Size | **geometric**



Modifier GD&T Symbols

TERM	4.5 2018
Maximum Material Condition	Ⓜ
Maximum Material Boundary	Ⓜ
Least Material Condition	Ⓛ
Least Material Boundary	Ⓛ
Translation	▷
Projected Tolerance Zone	Ⓟ
Free State	Ⓕ
Tangent Plane	Ⓣ
Unequally Disposed Profile	Ⓤ
Independency	Ⓘ
Statistical Tolerance	(ST)

Independency	Ⓘ
Statistical Tolerance	(ST)
Continuous Feature	(CF)
Diameter	Ø
Spherical Diameter	SØ
Square	□
Between	↔
All Around	⌀ (leader with circle)
All Over	⌀ (leader with double circle)
Dynamic Profile	△
From - To	→

Geometric Characteristic Symols

SYMBOL	GEOMETRIC CHARACTERISTIC	TOLERANCE TYPE	CONTROL SUMMARY
⏥	FLATNESS	FORM (NO RELATION BETWEEN FEATURES)	CONTROLS FORM (SHAPE) OF SURFACES AND CAN ALSO CONTROL FORM OF AN AXIS OR MEDIAN PLANE. DATUM REFERENCE IS NOT ALLOWED
—	STRAIGHTNESS		
⌭	CYLINDRICITY		
○	CIRCULARITY (ROUNDNESS)		
⊥	PERPENDICULARITY	ORIENTATION (NO RELATION BETWEEN FEATURES)	CONTROLS ORIENTATION (TILT) OF SURFACES, AXES, OR MEDIAN PLANES FOR SIZE AND NON-SIZE FEATURES. DATUM REFERENCE REQUIRED
//	PARALLELISM		
∠	ANGULARITY		
⌖	POSITION	LOCATION	LOCATES CENTER POINTS, AXES, AND MEDIAN PLANES FOR SIZE FEATURES. ALSO CONTROLS ORIENTATION
⌓	PROFILE OF A SURFACE		LOCATES SURFACES. ALSO CONTROLS SIZE, FORM, AND ORIENTATION OF SURFACES BASED ON DATUM REFERENCE
⌒	PROFILE OF A LINE		
⌰	TOTAL RUNOUT	RUNOUT	CONTROLS SURFACE COAXIALITY. ALSO CONTROLS FORM AND ORIENTATION OF SURFACES
↗	CIRCULAR RUNOUT		
◎	CONCENTRICITY	LOCATION (DERIVED MEDIAN POINTS)	LOCATES DERIVED MEDIAN POINTS OF A FEATURE. *NOT COMMON...CONSIDER USING POSITION, RUNOUT, OR PROFILE*
⌯	SYMMETRY		

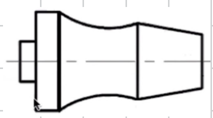
Form: Individual features application
↳ doesn't depend on neighboring features

Orientation: Related Features application

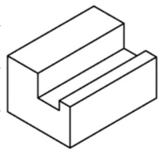
Location: I/R

Runout / Location (derived median points): R

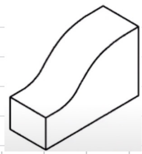
Types of Parts



Axis symmetry parts



Prismatic parts
- planar surfaces



3-D Contour Parts
- linear + circular surfaces

> Based on type of part, we must choose 1/14 symbols to fabricate it →

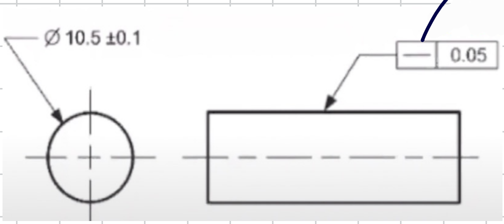
Form Control (4 Symbols)

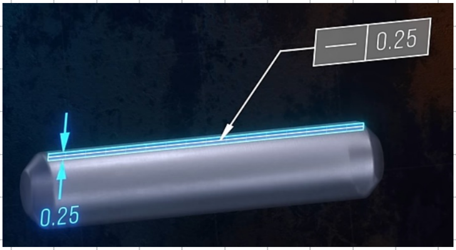
① Straightness

2 types: surface straightness and axis straightness

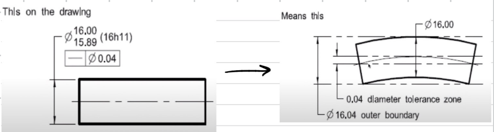
Surface

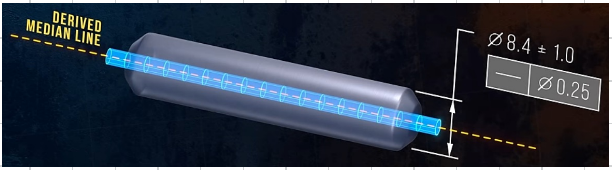
feature control frame





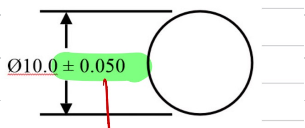
Axis





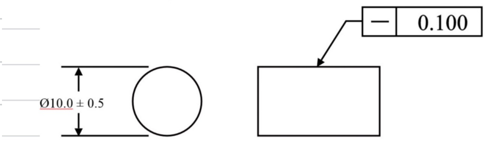
Example

straightness without GD&T:



very expensive for such a simple part

Straightness with GD&T



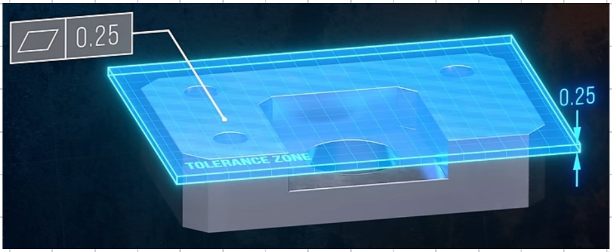
Use Case: designing pipes that must be straight

Maximum Material Condition Ⓜ

- Use mmc when part function depends on fit and assy clearance

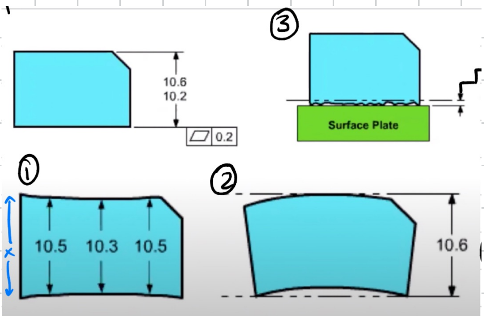
Ⓛ when part function depend on strength material, or minimum wall thickness

Flatness : only applied to prismatic parts where you have planar surface

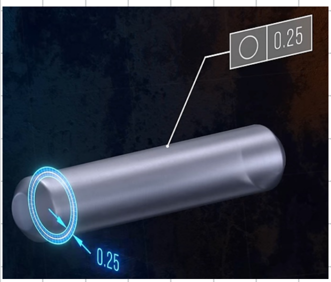


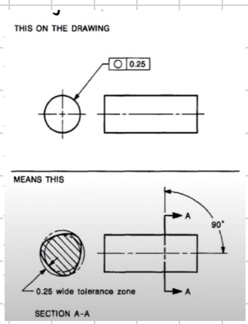
3 Step Verification

1. Size within drawing limits
2. Part has to be in boundary of max material condition
3. Peak & valley difference

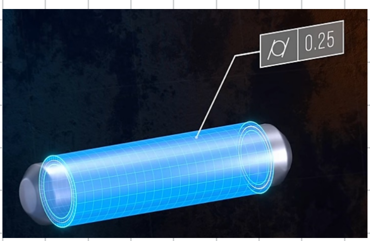


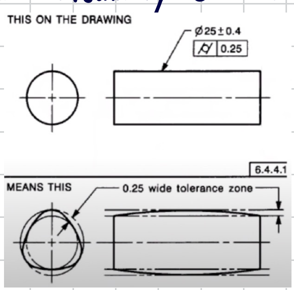
Circularity : only applied to axis symmetry parts w/ circular x-section





Cylindricity : Straightness and circularity both for axis symmetry part





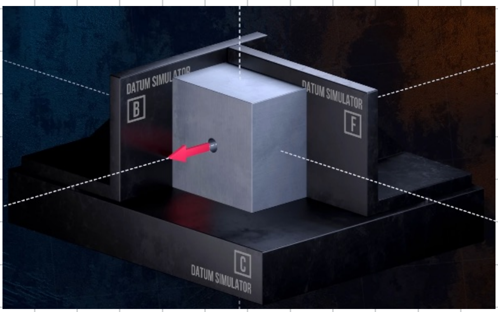
Orientation Control (3 symbols)

Datum: Used to create a relationship between surface we want to control and existing surface

Datum Feature: Feature on the object that is restrained

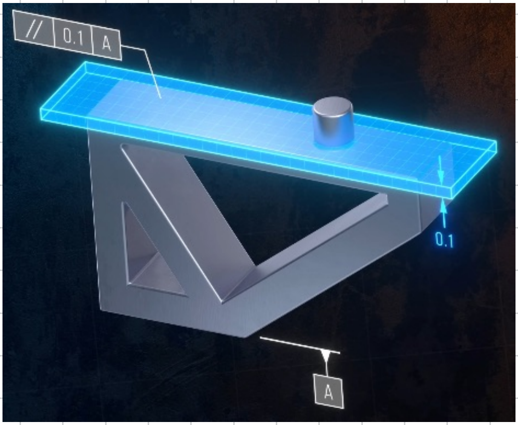
Datum: theoretical perfect surface corresponding to the feature

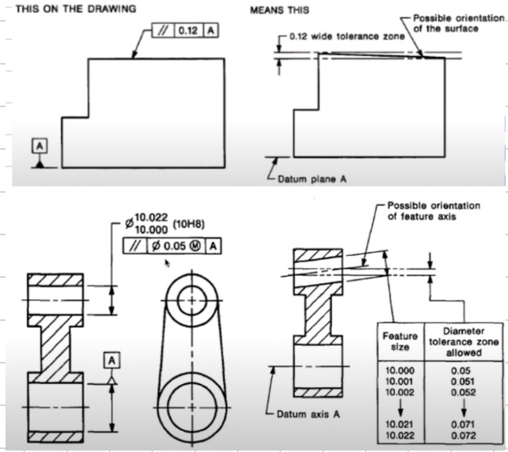
Datum Simulator: real imperfect surface used to imobalize part to approx perfect datum



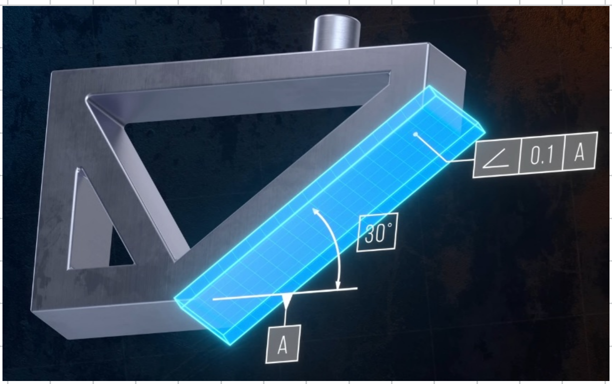
- Part in space has 6 degrees freedom
- If you hold datum feature against datum sim 3 DOF are constrained
- Hold against two sims then 5 DOF X
- Hold against 3 sims then part imobile
- Datums establish datum reference frame (coord syst to inspect feature)
- Order of which datums applied matters bc all real surfaces are imperfect.

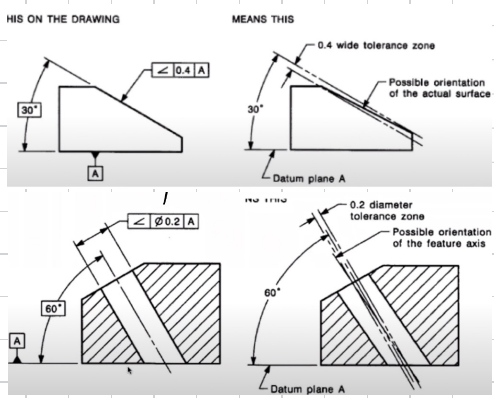
① **Parallelism** : controls how close feature is to being parallel with a datum



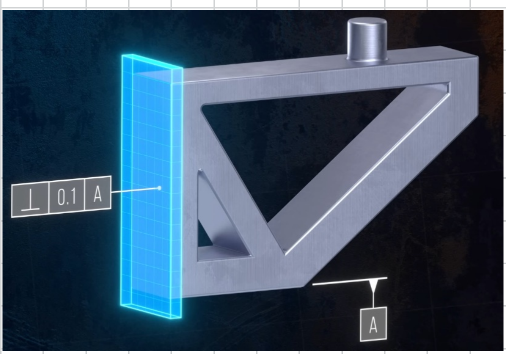


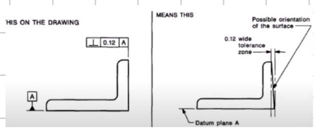
② **Angularity** :



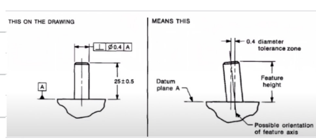


Perpendicularity : same as parallelism but 90°

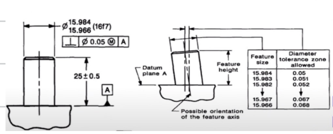




→ controlling surface wrt datum



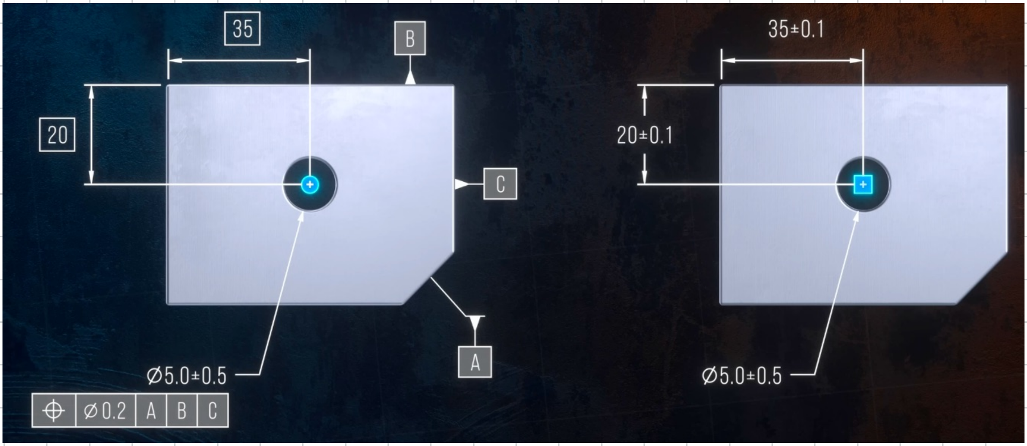
→ controlling axis wrt datum



→ using angularity w/ MMC, Ⓜ
↳ toleance zone changes based on feature size

Location Control (3 symbols) (position best)

Position: defines maximum distance a plane or axis can be away from theoretically exact position used to define location of holes

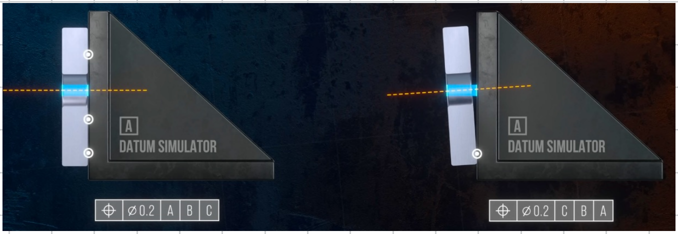


<u>True Position</u>: theoretically exact position of the feature called out by basic dimen

<u>3 Problems w/ coordinate dimensioning</u>

1. Rectangular tolerance zone 57% larger
2. tolerance can't change using Ⓜ based on feature size
3. doesn't give you reference to measure from

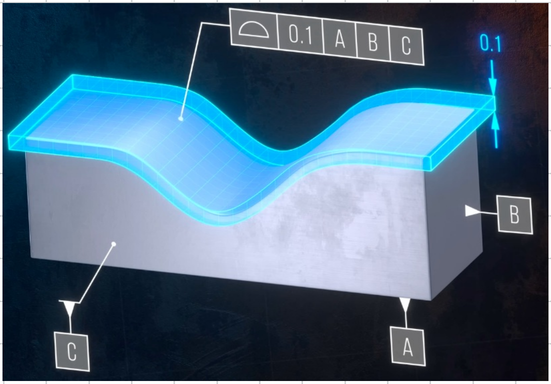
Another advantage of GD&T is that allows you to explicitly define relevant datums and what order they should be considered.



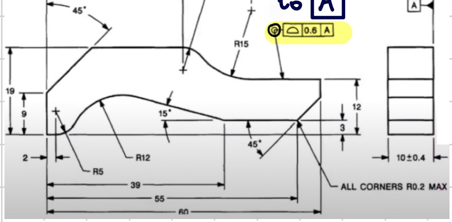
- Primary datum is usually chosen as the one perpendicular to axis of hole.

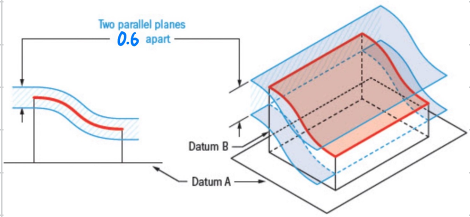
Profile of a Surface

: follows the shape of the feature with width of specified tolerance



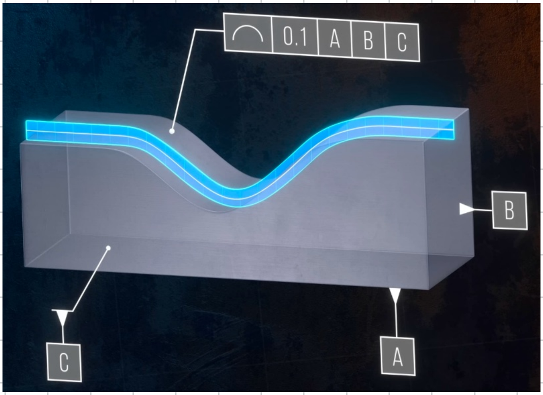
must be ⊥ to A

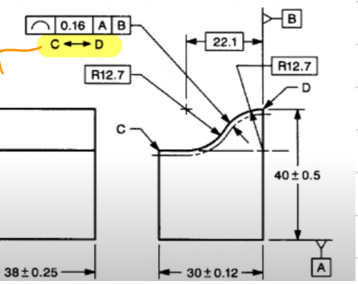


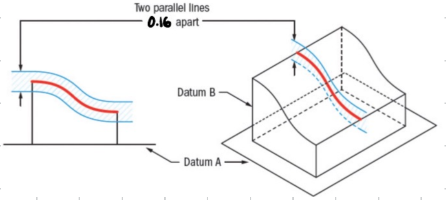


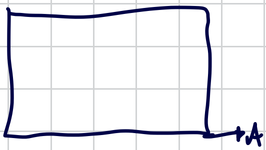
Profile of a Line

the b/w symbol





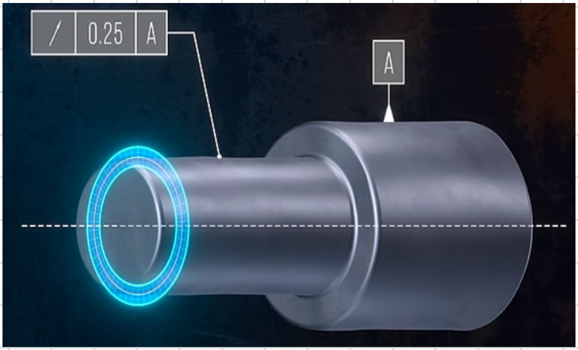




Runout

Runout: Used to describe the eccentricity of a surface relative to a particular axis

Circular Runout: controls the roundness of individual cross sections of a feature relative to a datum axis



Similar to circularity except ○ runout uses datums so tolerance zones must be centerd on the datum axis.

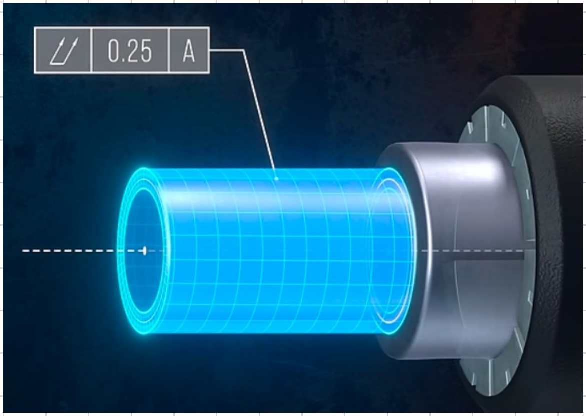
Circularity vs Runout?

○ slice cucumber ½ check if round

↗ skewer cucumber and check if it wobble

○ ↗ → guarantee feature is round + aligned to datum axis

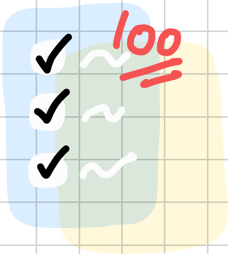
Total Runout: Used to control runout in axial direction as well so tolerance zone is defined by two concentric cylinders



Circular Runout: hold marker on outside of tire and rotate. low wobble means runout good. Lot of wobble is bad

Total Runout: Move marker along width of tire as you rotate line should be smooth for low runout

DFM
&
DFA

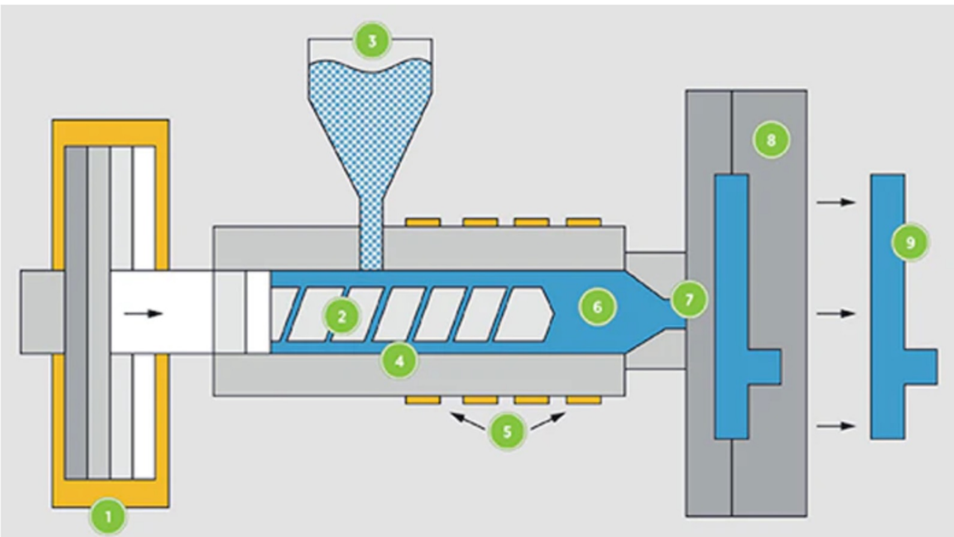


Design for Manufacturing

Injection Molding

Process

1. Plastic Pellets are fed into the injection unit through a hopper
2. Screw rotates to transfer pelles forward, melting them in the process
3. Once at the front, pellets are entirely molten
4. Screw plunges forward, injecting molten plastic into the cavity image
5. Plastic solidifies → Mold Opens → Part is Ejected
6. Mold Closes → Repeat



From left to right, the components are: ram (1), screw (2), hopper (3), barrel (4), heaters (5), materials (6), nozzle (7), mold (8), and part (9).

Design Techniques:

1. Use constant wall thickness (1 – 3 mm) → prevents warping and sinking
2. Hollow out thick sections, then add ribs to increase stiffness
3. Add smooth transitions (i.e. fillets, chamfers) for parts with multiple wall thicknesses
4. Round all edges to avoid stress concentrations
5. Add draft angles (min 2 degrees)
6. Move part line to intersect with undercut
7. Add ribs to increase stiffness, rather than increasing thickness

tolerances of 0.1 (general) to ± 0.025

Materials:

Plastics including:

a. ABS
   - Variety of modifications can be made to ABS to enhance impact resistance, toughness and heat resistance
   - Molding at high temp. improves impact resistance, toughness & heat resistance
   - Molding at low temp. improves strength and impact resistance
   - Examples: pipes, automotive parts, kitchen appliances, Lego bricks, etc.

b. Polyethylene
   - high levels of ductility, tensile strength, impact resistance, resistance to moisture absorption, and recyclability
   - Examples: Plastic bags, bottles, etc.

c. Polycarbonate
   - Can undergo large plastic deformations without cracking or breaking
   - Main properties: impact resistant and transparency
   - Examples: greenhouses, DVD, eyewear lenses, automotive components and phones

d. Nylon (Polyamide)
   - Tough, wear/abrasion resistant and chemical resistant
   - Apparel, footwear, sports equipment, automotive products, etc.

e. High Impact Polystyrene
   - brittle

f. Polypropylene
   - Flexible, high melting point, high resistance to stress, great impact strength and doesn’t break down when reacting with chemicals (ex. Utensils, batteries, etc.)

Casting

Process:

- Minimum thickness: 5mm
- Low-cost process that can produce parts in large quantities with no limit in size, shape or complexity, here's the process:
  1. A pattern made out of metal/wood is used to form the cavity, where the molten metal is poured
  2. Holes are created by sand cores into the mold
  3. Pour molten metal into mold, then cool down

Design Techniques:

1. All sections designed with a uniform thickness
2. Design should include gradual change from section to section, where necessary
3. Adjoining sections should be designed with generous fillets
4. A complicated part should be designed as two or more simple castings to be assembled by fasteners or by welding

Materials:

a. Steel
   - Most difficult to produce due to steel's high melting temperature
   - This can aggravate casting problems

b. Gray Iron

c. Brass

d. Bronze

e. Aluminum

Process	Advantages	Disadvantages	Examples
Sand	Wide range of metals, sizes, shapes, low cost	poor finish, wide tolerance	engine blocks, cylinder heads
Shell mold	better accuracy, finish, higher production rate	limited part size	connecting rods, gear housings
Expendable pattern	Wide range of metals, sizes, shapes	patterns have low strength	cylinder heads, brake components
Plaster mold	complex shapes, good surface finish	non-ferrous metals, low production rate	prototypes of mechanical parts
Ceramic mold	complex shapes, high accuracy, good finish	small sizes	impellers, injection mold tooling
Investment	complex shapes, excellent finish	small parts, expensive	jewellery
Permanent mold	good finish, low porosity, high production rate	Costly mold, simpler shapes only	gears, gear housings
Die	Excellent dimensional accuracy, high production rate	costly dies, small parts, non-ferrous metals	precision gears, camera bodies, car wheels
Centrifugal	Large cylindrical parts, good quality	Expensive, limited shapes	pipes, boilers, flywheels

Sheet Metal Forming Design Techniques

<u>Holes</u>

1. Distance between holes and edge > 1.5x – 2x thickness
2. Bending radius at least 1.5T
3. Hole diameter should be at least equal to part thickness
4. Distance between holes should at least be 2T or greater

<u>General</u>

5. Uniform wall thickness
6. Consistent bend radius (saves time and money)
7. Bend sheet metal in the same plane (to avoid need for reorientation, saving time and money)
8. To prevent parts from fracturing or distorting, make sure to keep the inside bend radius at least equal to the sheet's thickness
9. Outside radius of curls must be at least twice the sheet's thickness
10. Max. depth of a countersink is 3.5x material thickness
11. Add collars to increase stiffness around piercings

<u>Bends</u>

12. Add bend relief to strengthen sheet metal parts
13. Bends at edges reduce likelihood of metal tearing

<u>Spring-Back Effect</u>

14. Add chamfers to corners and beads to bends to reduce spring-back effect

spring-back occurs when metals try to go back to original shape after being bent

Designing for Machining Rules of Thumb

- Design parts that can be machined with the tool of the largest possible diameter.
- Add the large fillets (at least ⅓ x cavity depth) to all internal vertical corners.
- Limit the depth of cavities to 4 times their width.
- Align design main features along one of six principal directions
- Avoid really thin parts (~0.5mm or 0.02in) to avoid warping or bending of part after machining

DFM Summary

- We want minimal part counts that are easy to produce and assemble
  - To achieve this, answer the following questions:
    1. Do parts move relative to each other?
    2. Do parts need insulation?
    3. Do parts need to be made out of different materials?
    4. Will combining parts complicated maintenance?
    5. Will combining parts interfere with assembly of other parts?
  - If answer is No to all questions, then combine parts
  - Reducing part count, reduces assembly time, reducing cost
- Avoid sharp corners, deep holes and thin walls, so parts don't get distorted

Injection Molding vs Die Casting

Benefits of Injection Molding:

- Production is quicker due to more flexibility in the molding process
- Plastic Injection molds can accommodate different plastic or polymer materials
- Fillers can be used in plastic molds to increase strength
- Efficient process with very accurate finishes

Benefits of Die Casting:

- Efficient process with a high degree of accuracy
- No need for secondary operations
- Complicated designs can be more easily cast
- Produces higher-quality products with better tolerance that will last longer

Drawbacks of Die Casting:

- Not applicable for metals with high melting points
- Large lead times
- Can't cast large parts

<u>IM:</u> If you are looking to produce lots of inexpensive parts since labor and material costs are relatively low.

<u>DC:</u> If accuracy in design is a priority or you need many complex parts in a short time frame. More durable and higher quality feel when you go with metals over plastics.

Benefits of Injection Molding over Die Casting, Machining and Sheet Metal Forming:

1. Cost Savings
2. Lighter weight
3. Can form complex shapes, relative to sheet metal forming
4. Noise reduction if parts consistently come in contact
5. Skip the paint when using plastics
6. Plastic less prone to scratches and dents
7. Plastics don't corrode

Design for Assembly (DFA)

Guidelines

1. Reduce number of parts
2. Use common and standardized parts
3. Design for ease of fabrication by:
    a. Use near net shapes to minimize the required machining and processing
    b. Avoid designs with sharp corners (induce stress concentrations)
    c. Avoid undercuts as they require additional costly tools
    d. Design work pieces to used standardized cutters and drill bit sizes
4. Mistake proof the assembly process
    a. Notches, asymmetrical holes and stops can be used to ensure the assembly process is unambiguous
5. Use efficient joining and fasteners
    a. Use self-threading screws or adhesives (nuts and bolts are time consuming)
6. Self-fastening components
7. Self-locating components

Mechanical Engineering Basic Questions

Stiffness vs Strength?

Strength is a ability of a material to withstand an applied load without getting plastically deformed or breaking.

Stiffness is the degree to which an object resists its deformation in applied load.

Hardness vs Toughness?

Hardness: A material's ability to withstand friction or resist abrasion.

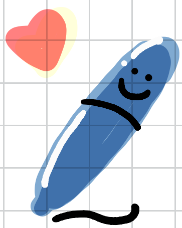
Toughness: How well the material can resist fracturing when force is applied (or how much energy it can absorb before breaking → more energy = tougher)

- **Ex**: Crumple zones on cars
- **Ex**: silly putty is technically tough

Steel vs Aluminum?

- Aluminum is more malleable and flexible than steel
- Aluminum can be pushed to dimensional limits without breaking, unlike steel
- Steel is tougher and more resilient
- Aluminum is corrosion resistant
- Steel is harder than aluminum
- Steel is less likely to deform or bend under weight
- Steel is 2.5x denser than aluminum
- Aluminum is 1/3 the weight of steel
- Aluminum is cheaper than stainless steel
- Aluminum is difficult to weld
- Steel is stronger (assuming weight isn't an issue)

Formulas



Force Equation

$F = ma$

F = force
m = mass
a = acceleration

Torque Equations

$\tau = FL$

$\tau = I\alpha$

τ = torque
F = force
L = distance to pivot point
I = moment of inertia about pivot
α = angular acceleration

Energy Equations

$E_{kinetic} = \frac{1}{2}mv^2$

$E_{rotational} = \frac{1}{2}I\omega^2$

$E_{gravitational\ potential} = mgh$

$E_{spring\ potential} = \frac{1}{2}kx^2$

E = energy
m = mass
v = velocity
I = moment of inertia
ω = angular velocity
g = gravitational acceleration
h = height
k = spring constant
x = spring displacement

Stress Equations

$\sigma = \frac{F}{A}$

$\sigma_{hoop} = \frac{Pr}{t}$

$\sigma_{axial} = \frac{Pr}{2t}$

$\sigma_{beam\ bending} = -\frac{My}{I}$

$\tau = \frac{Tr}{J}$

σ = stress
P = pressure
r = radius
t = thickness of pressure vessel
M = internal moment
y = distance from neutral axis
I = moment of inertia
τ = shear stress from torsion
T = torsional torque
J = polar moment of inertia

Moment of Inertia Equations

$I_{rectangle} = \frac{1}{12}bh^3$

$I_{hoop} = mr^2$

$I_{solid\ cylinder} = \frac{1}{2}mr^2$

$I_{total} = I_c + mh^2$

I = moment of inertia
b = side parallel to bending axis
h = side perpendicular to bending axis
m = mass
r = radius
I_c = moment of inertia about center
h = distance from axis of rotation

Kinematics equations

$v = v_0 + at$

$x = x_0 + v_0t + \frac{1}{2}at^2$

$v^2 = v_0^2 + 2a(\Delta x)$

$a_{centripetal} = \frac{v^2}{r}$

$\omega = \frac{v}{r}$

x = position
v = linear velocity
a = acceleration
t = time
r = radius
ω = angular velocity

Pressure Equations

$P = \frac{F}{A}$

$P_{hydrostatic} = \rho gh$

P = pressure
ρ = density
g = gravity
h = height of fluid
v = velocity

Bernoulli's Equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$$

P = pressure
ρ = density
g = gravity
h = height of fluid
v = velocity

Natural Frequency Equation

$w_n = \sqrt{\frac{k}{m}}$

w_n = natural frequency
k = stiffness
m = mass

Buckling Equation

$F_{cr} = \frac{\pi^2 EI}{L_e^2}$

F_{cr} = critical buckling load
E = Young's Modulus
I = moment of inertia
L_e = effective length (differs based on how end points of beam are attached)

Bending Equation

$\delta_{max} = \frac{FL^3}{3EI}$

δ_{max} = max deflection of beam in bending
F = force applied
L = length of beam
E = Young's Modulus
I = moment of inertia

Momentum Equations

$\rho = mv$

$L = mvr$

ρ = linear momentum
L = angular momentum

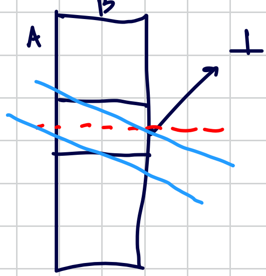
Heat Conduction Equation

$\frac{Q}{t} = \frac{kA(\Delta T)}{\Delta x}$

Q = heat (Joules)
t = time
k = coefficient of thermal conductivity
A = surface contact area
T = temperature in Kelvin
x = length / distance between the two points

Bolted dsgn textbook

bolted joint
↑
not as stiff as members
so bolt near loose
grib on cyl dc



Max applied load 36 kN So good

Proof strength ✓

bolted joint M12 × 10.9 Std

9NM

torque test on crimp

die cast
↑
alum

high pressure die castings

mix of iron/sand casting

gasket design

6-7 castings