Assembly as a Process

Dan Whitney

Why Study Assembly?

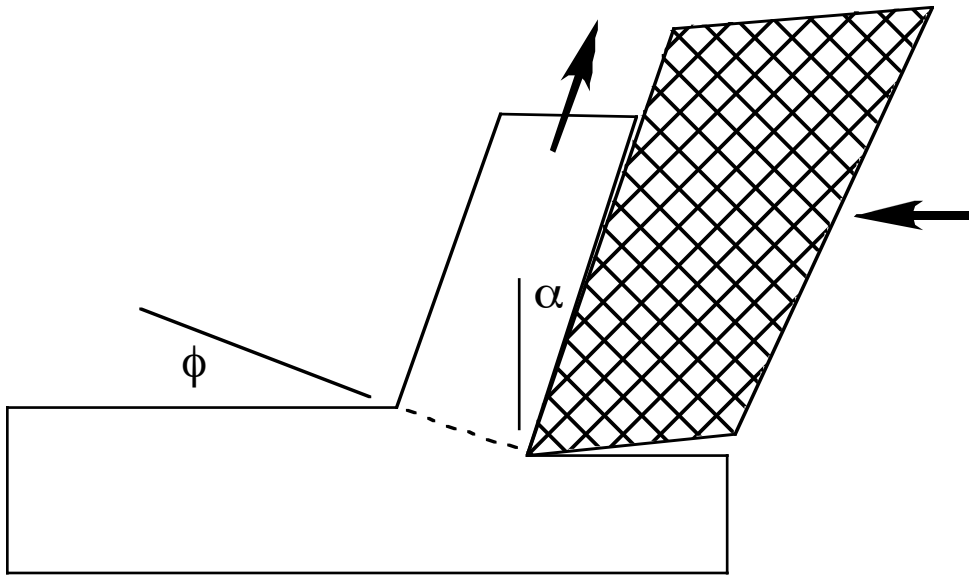
- Processes make parts
- Parts make assemblies
- Assemblies actually do things customers want
  - There aren't many one-part products

There Are Three Aspects to Assembly

- Design of assemblies so that they will do something useful
  - A topic worth several courses in design
- The process of putting two parts together
  - The “fundamental process” of assembly - today
- The organization of assembly in factories - Next time
  - People
  - Equipment
  - Economics
  - Operations and efficiency
  - Quality control etc etc

What is the Fundamental Process of Metal Cutting?

- Raising a chip
- What physics are involved?
  - Geometry
    - Rake angle
    - Shear plane angle
  - Shear modulus
  - Friction

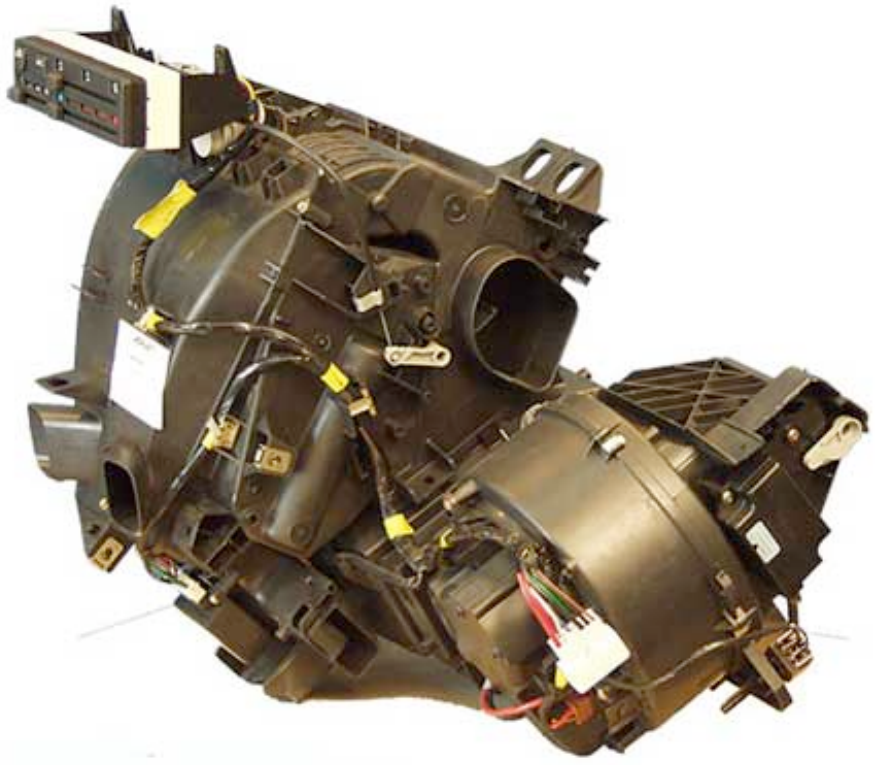


What is the Fundamental Process of Assembly?

- Putting two parts together
- What physics are involved
  - Geometry of the mating shapes
  - Compliance of parts or their holding apparatus
  - Friction between the parts
- You learned about these in 2.001

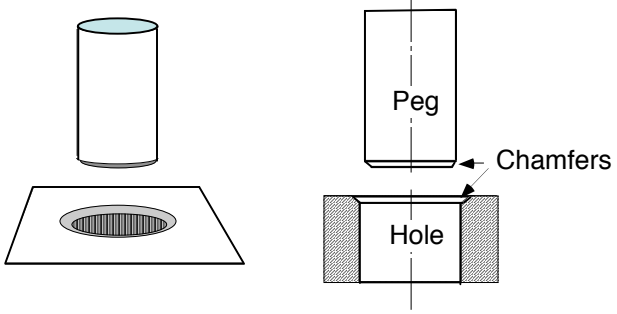
What Shapes of Part Mates Do We See?

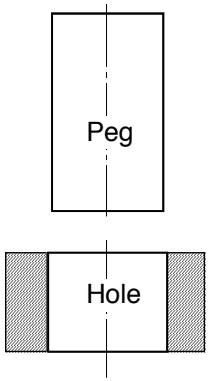
- Circular
- Helical
- Rectangular
- Gears
  - External
  - Internal (spline)
- Motocross rally track

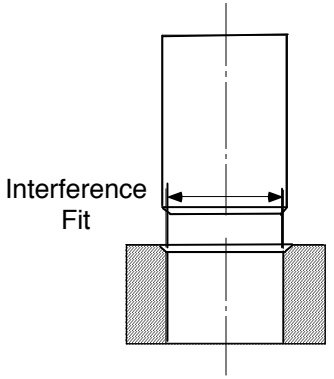


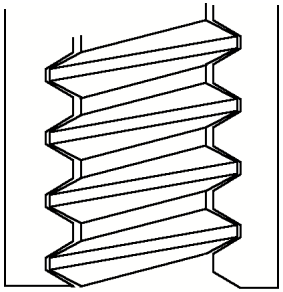
http://www.20un.com/images/feather_product/mehrcampars/13-b.jpg

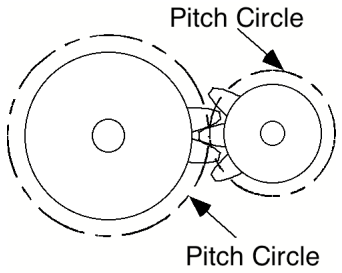
Different Part Mating Geometries





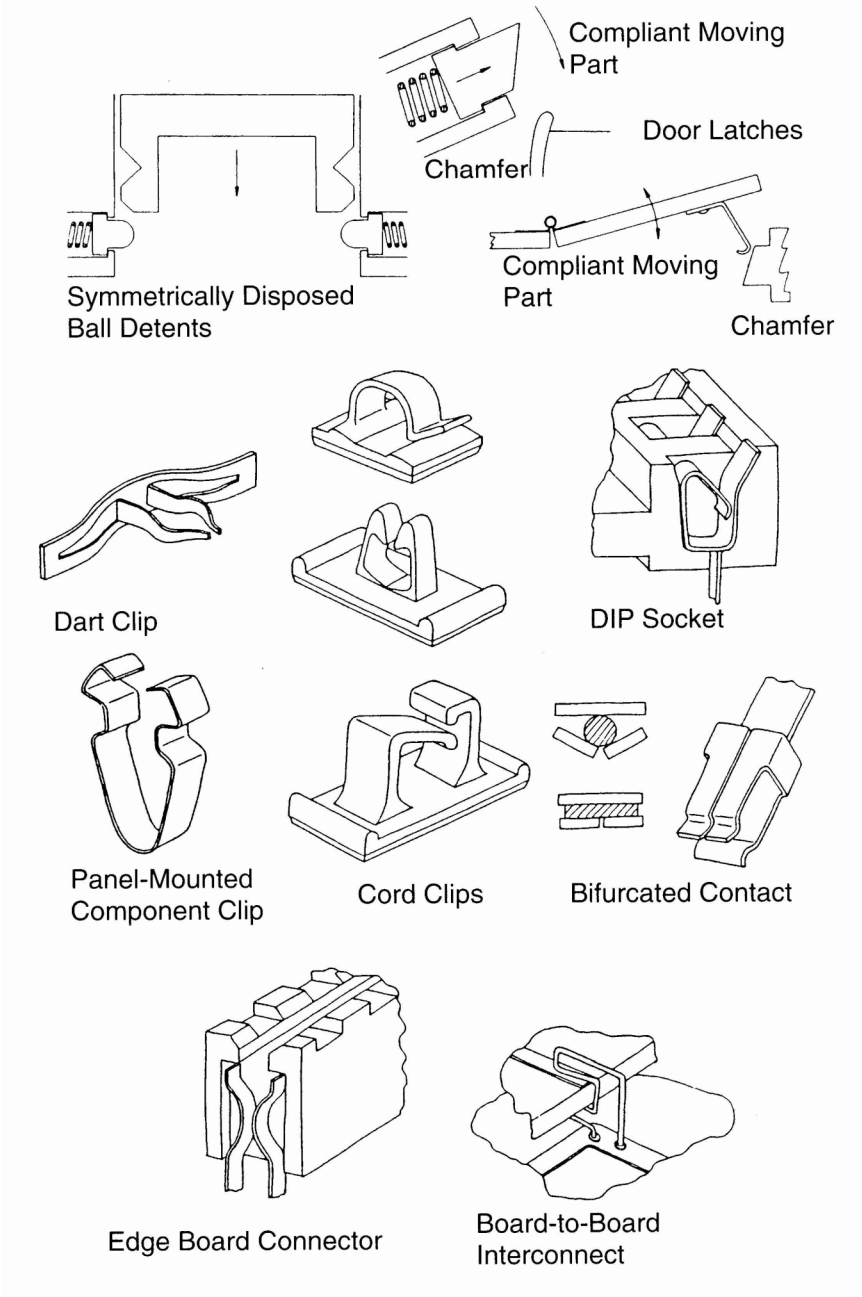




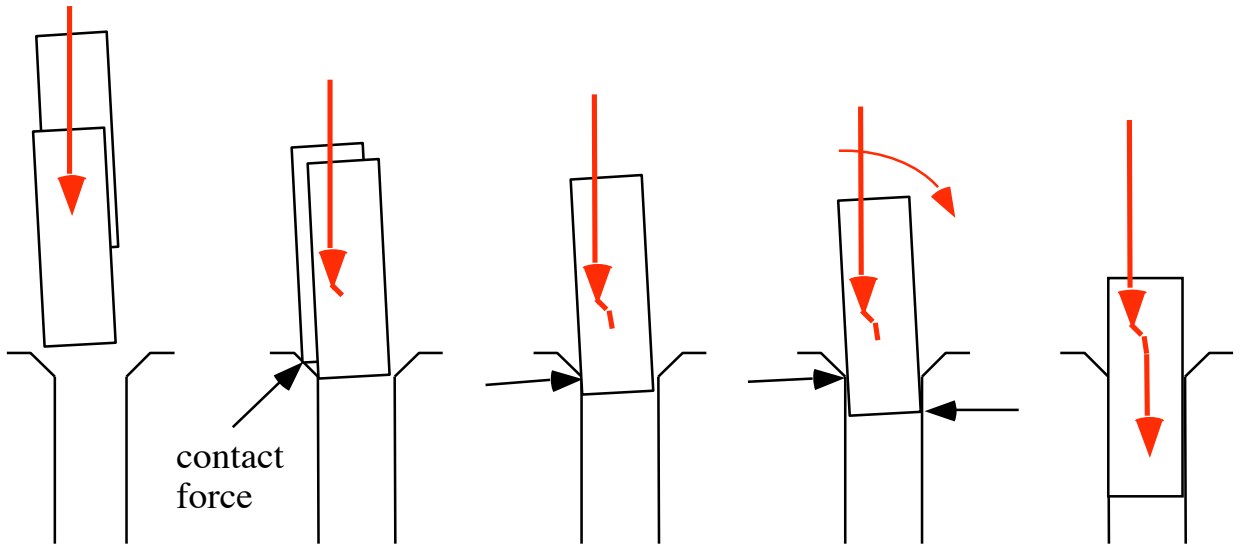


http://www.leftyray.com/images/spline-closeup.jpg

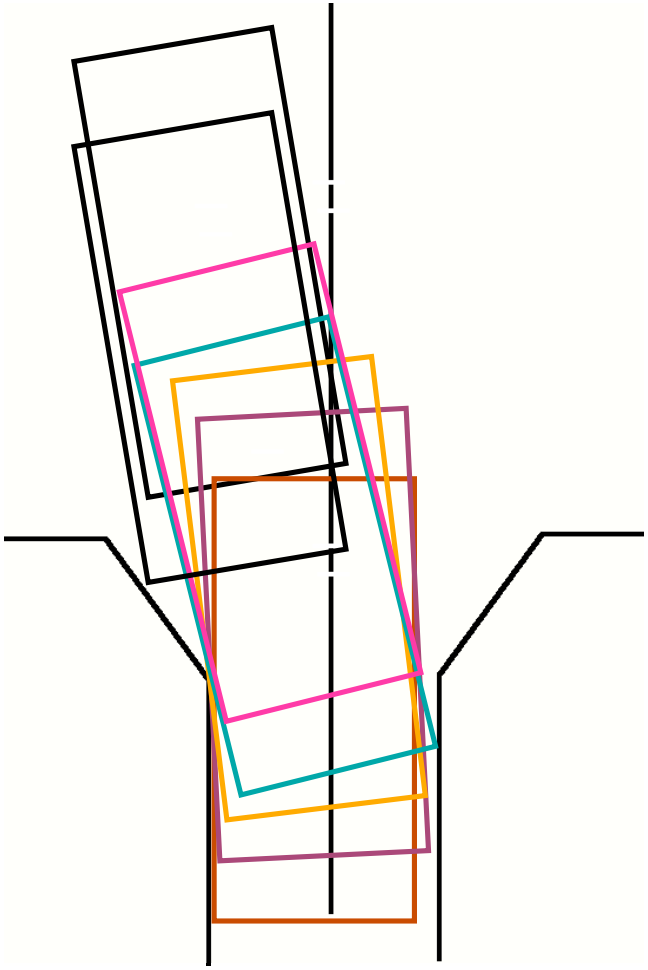
Compliant Part Mates



Main Phases of a Part Mating Event

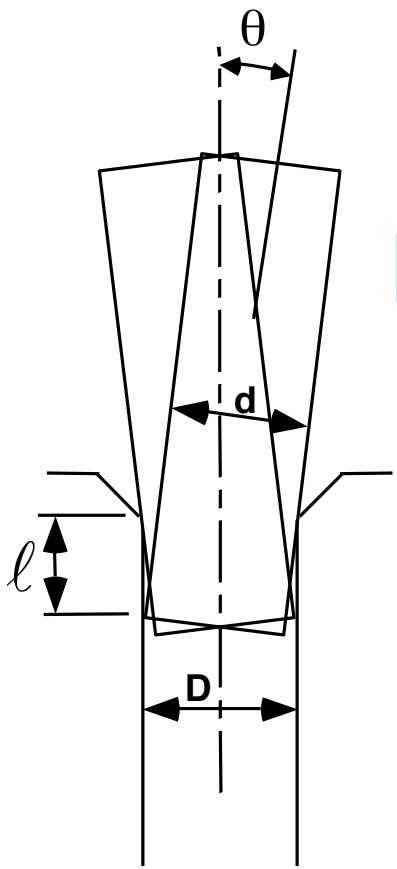


Insertion History



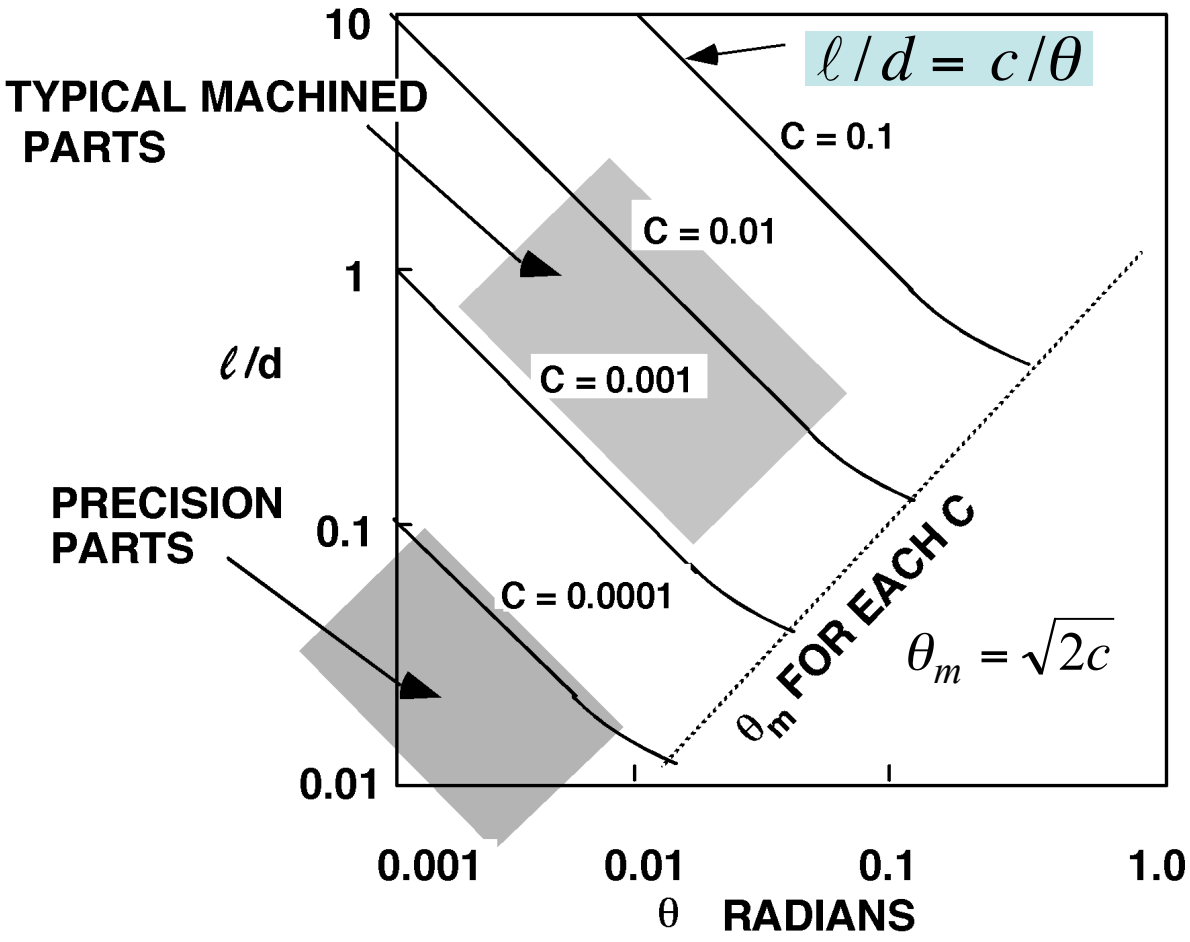
Demo of Part Mating Phases

Geometry of Peg-Hole Mates

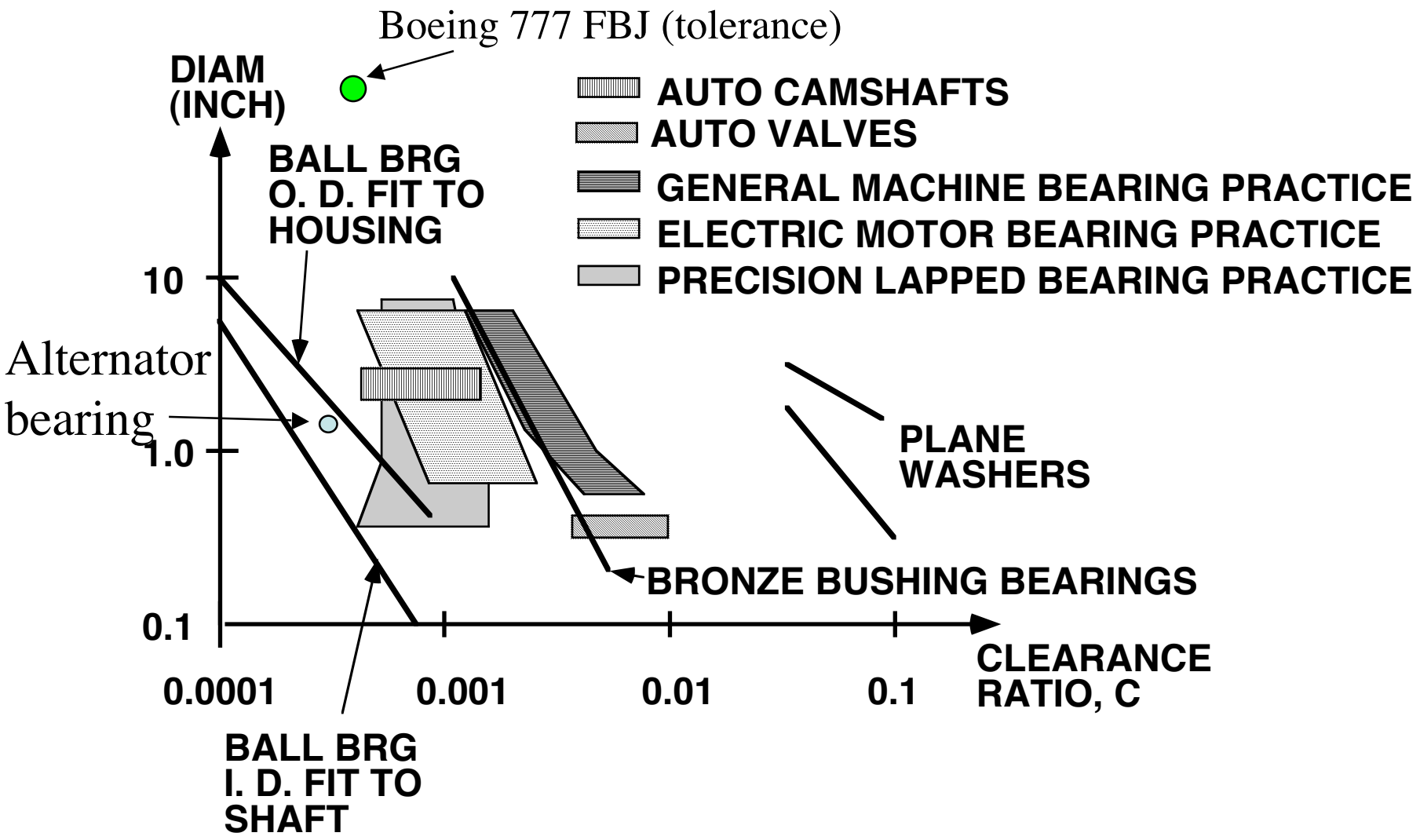


$$\ell / d = c / \theta$$

$$c = \frac{D - d}{D}$$



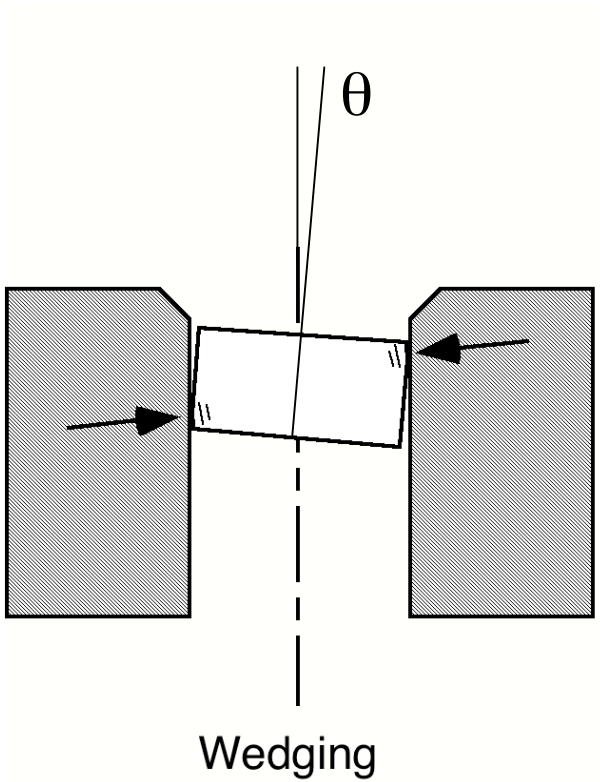
Dimensioning Practice



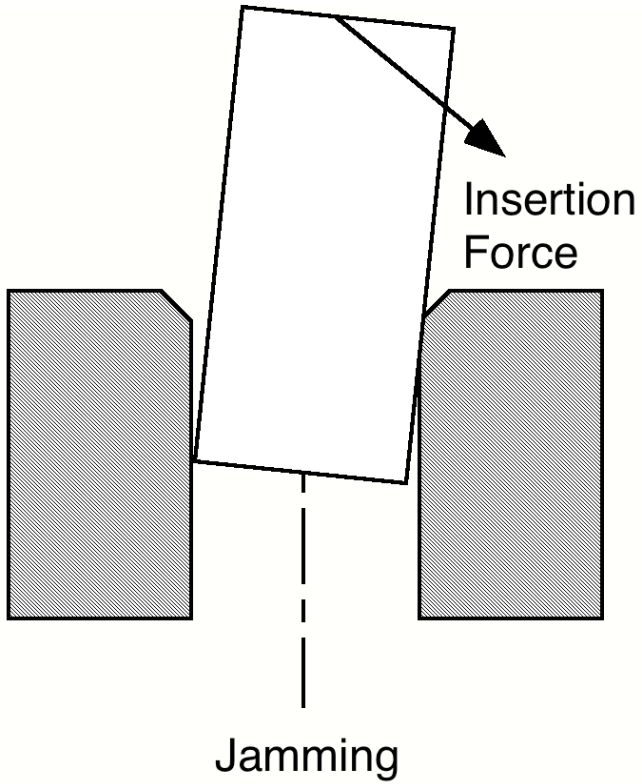
Does Assembly Have Failure Modes?

- Cocked peanut butter jar lids
- Stuck drawers:
  - Furniture
  - Produce drawer in fridge
- Doors that won't latch or won't open
- Airplane luggage bin doors that won't open
- Do you know why?

Wedging and Jamming



Wedging



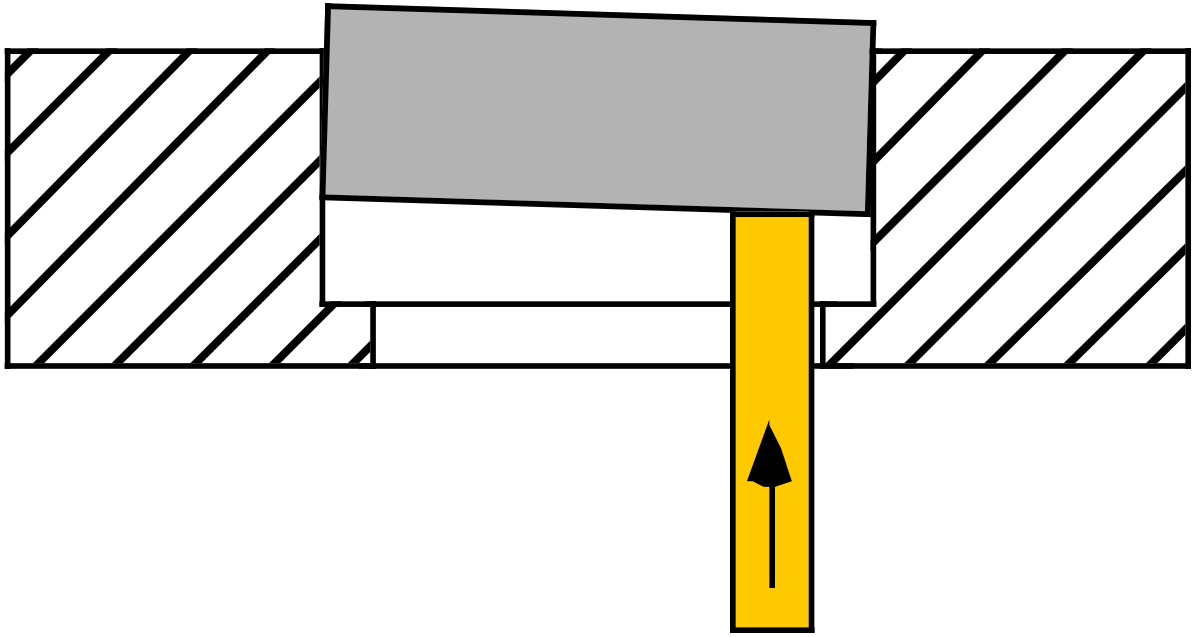
Jamming

Wedging can occur if two-point contact occurs when $\theta > c/\mu$

Jamming can occur if the insertion force does not point close enough to the hole's axis

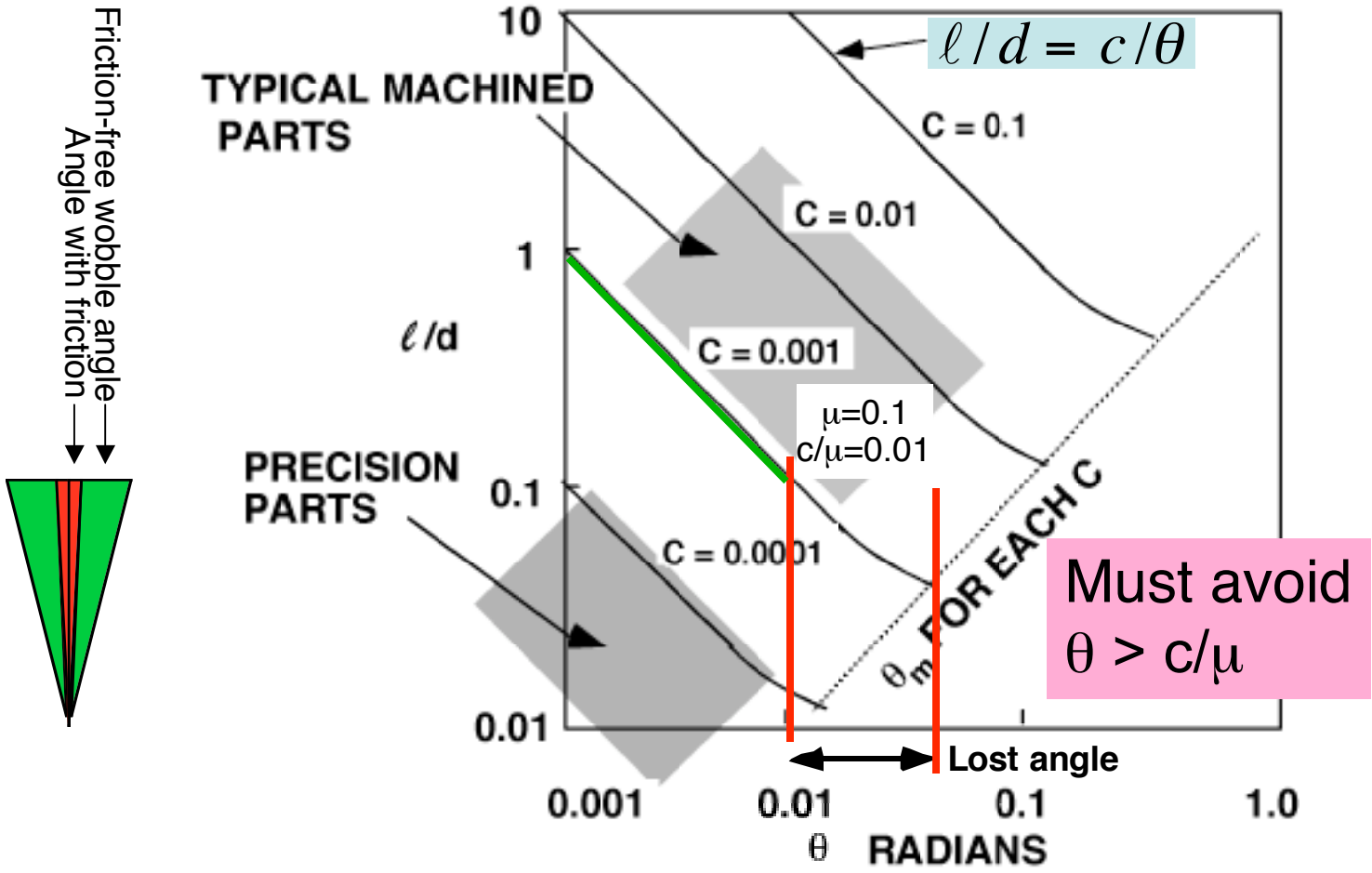
Demo of Wedging

If it gets stuck:



Tap here

Friction Reduces Allowed Entry Angle a Lot

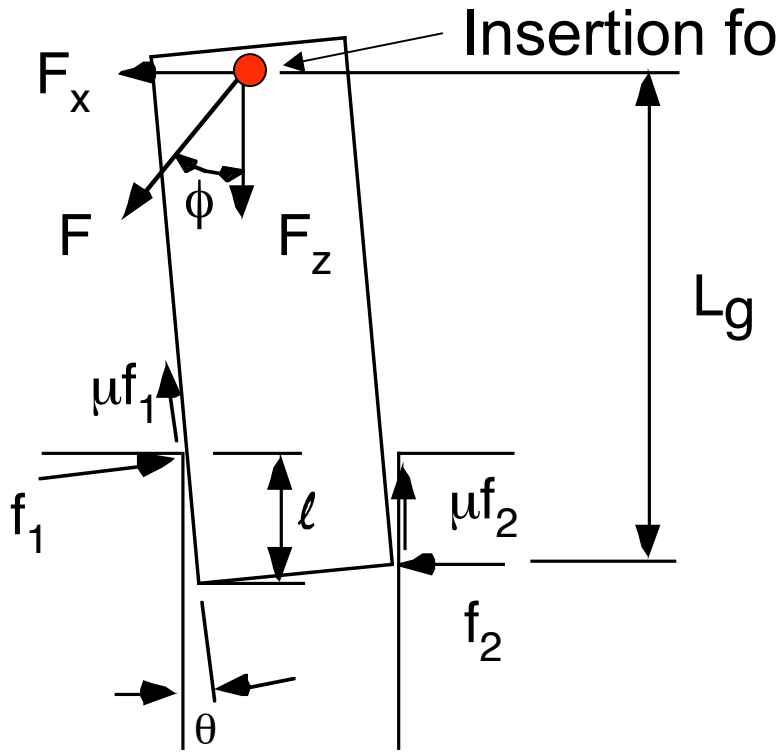


Wedging and Jamming

- Wedging conditions involve geometry and friction
- No insertion force is involved in the conditions and little or no force is needed to create wedging
- Jamming conditions involve force, geometry, and friction
- In particular, two things about insertion force are important
  - The direction it points
  - Where it is applied

Part Mating Mechanics for Jamming

How close to axially aligned must the insertion force F be to avoid jamming?

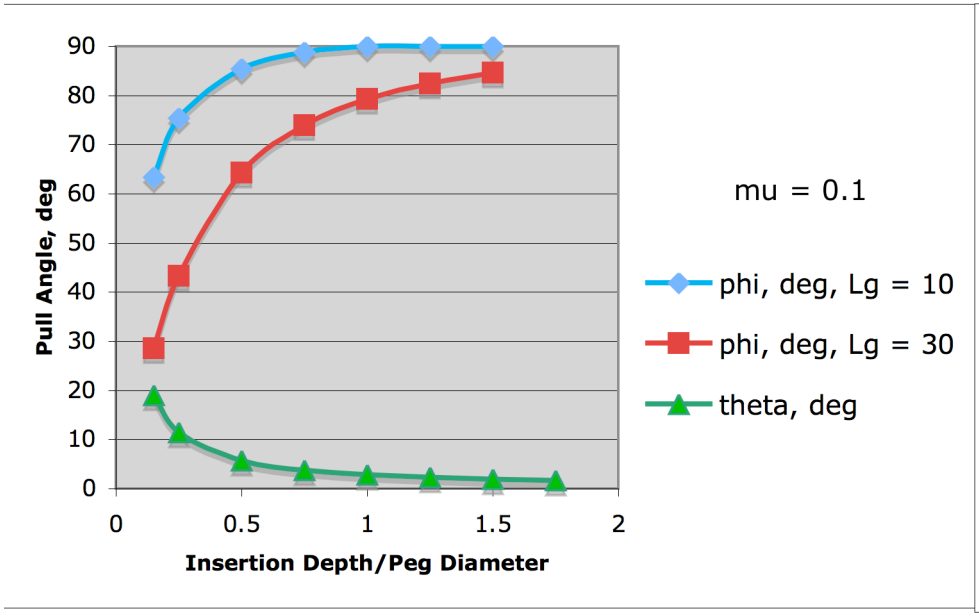


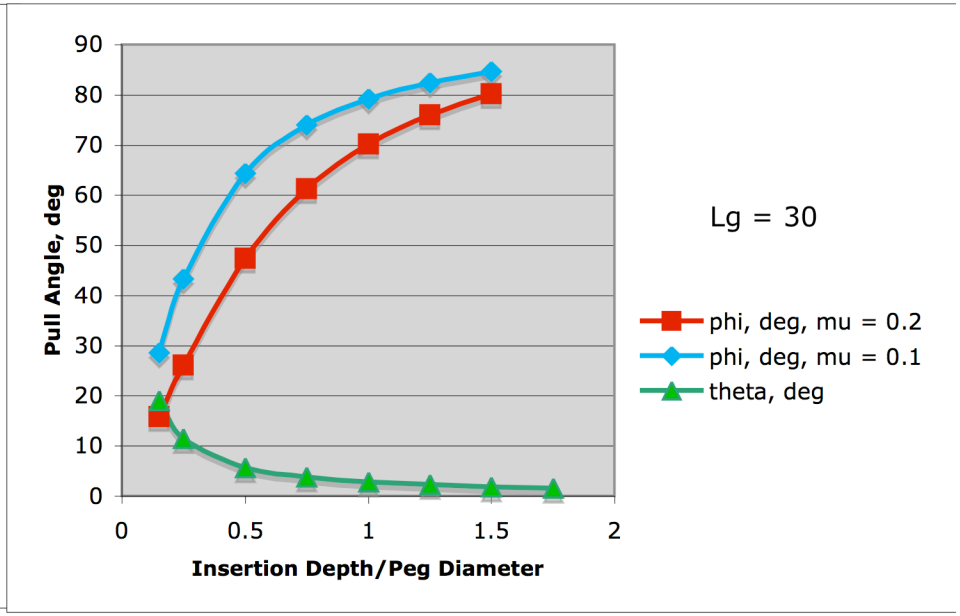
$$\tan\phi = \frac{F_x}{F_z} = \frac{1}{\mu\left[2\frac{L_g}{\ell} - 1 - 2\mu\frac{r}{\ell}\right]}$$

based on assuming $\theta \approx 0$

Demo of Pull Angle

Pull Angle vs Depth/Diameter





For smaller L_g, bigger ϕ is possible

For smaller μ, bigger ϕ is possible

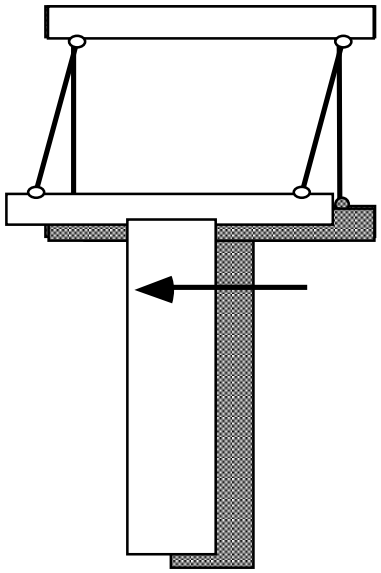
θ measures peg tilt angle

ϕ measures force direction

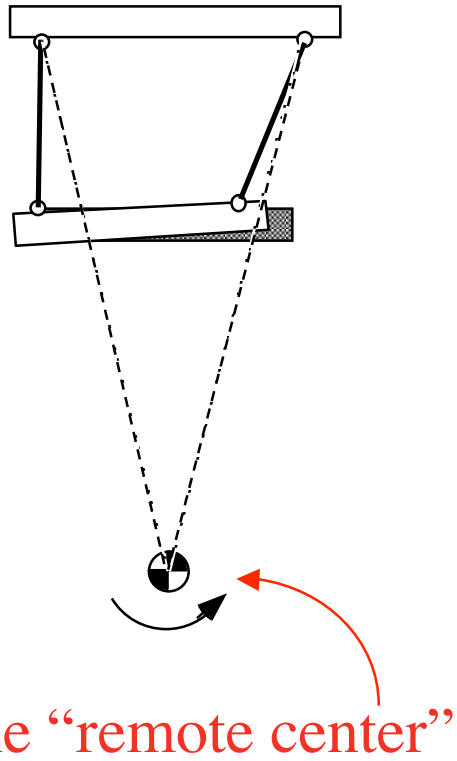
Making L_g Small is Good

- It is equivalent to grabbing the peg by its tip (normally impossible)
- How to do it?
- Active Robot Force Feedback
  - Costly
  - Slow
- Some way that acts by itself would be better
- It was invented almost 30 years ago
- Called Remote Center Compliance
- Reduces assembly force
- Avoids one of two main failure modes: jamming

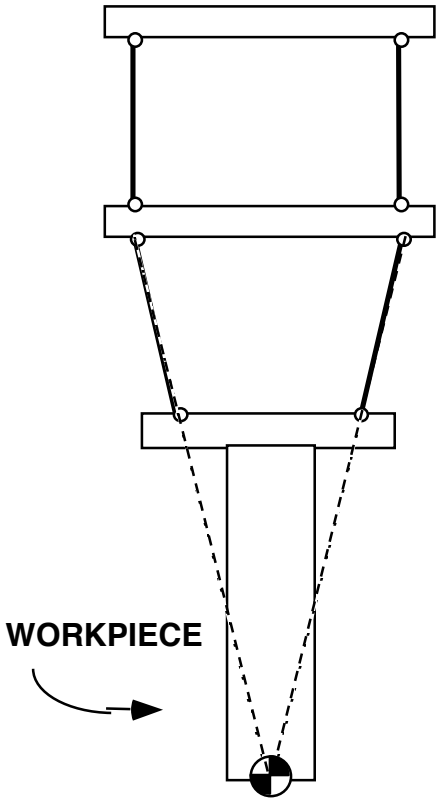
Simplified Explanation of the Remote Center Compliance (RCC)



(a) LATERAL PART OF LINKAGE RCC

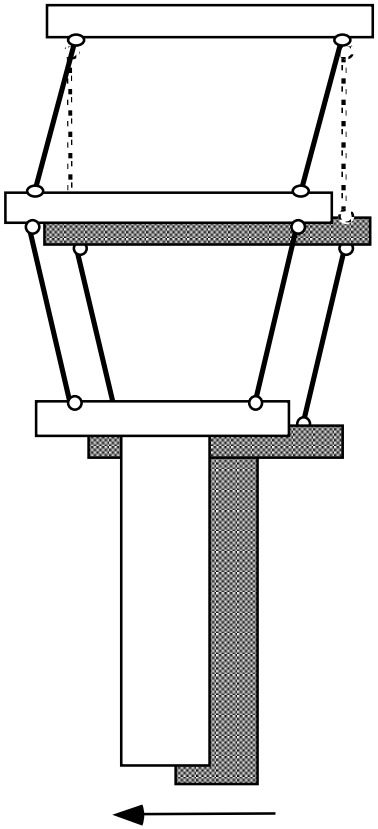


(b) ANGULAR PART OF LINKAGE RCC

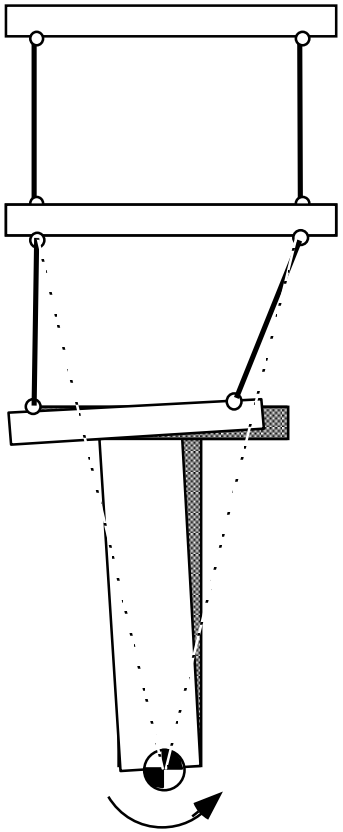


(c) COMPLETE LINKAGE RCC

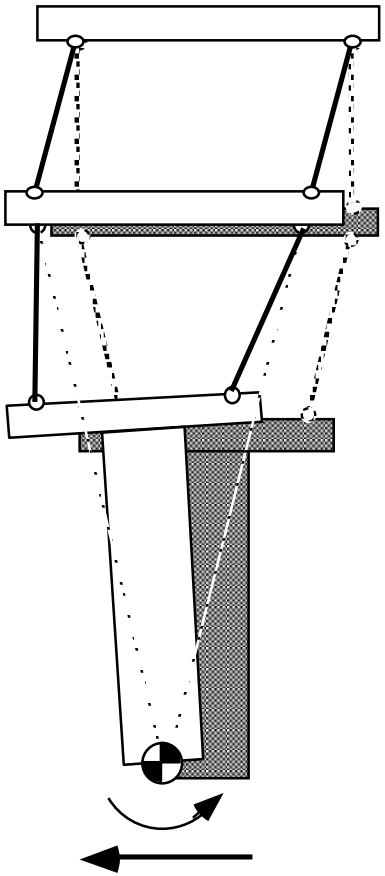
RCC Response to External Loads



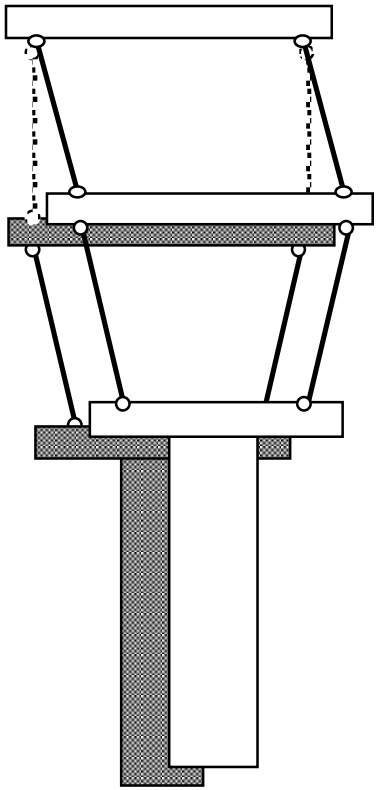
(d) RCC UNDER LATERAL LOAD



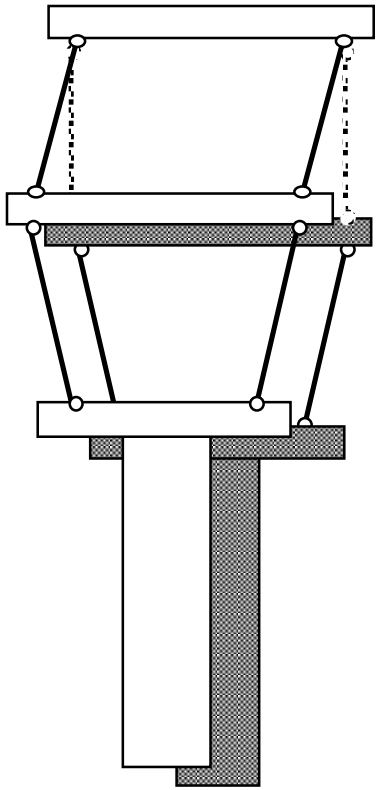
(e) RCC UNDER ANGULAR LOAD



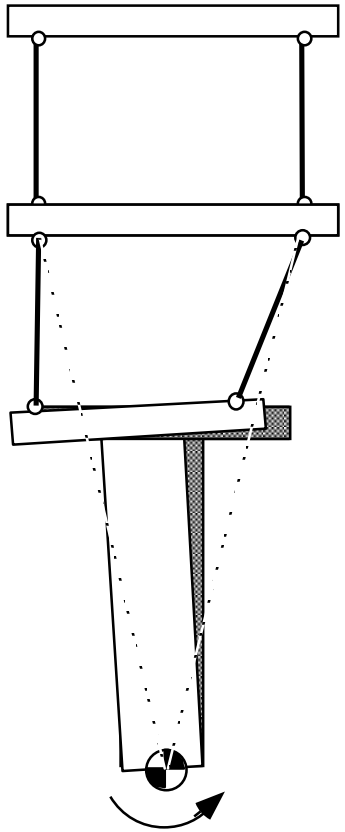
(f) LINKAGE RCC UNDER LATERAL AND ANGULAR DEFORMATION



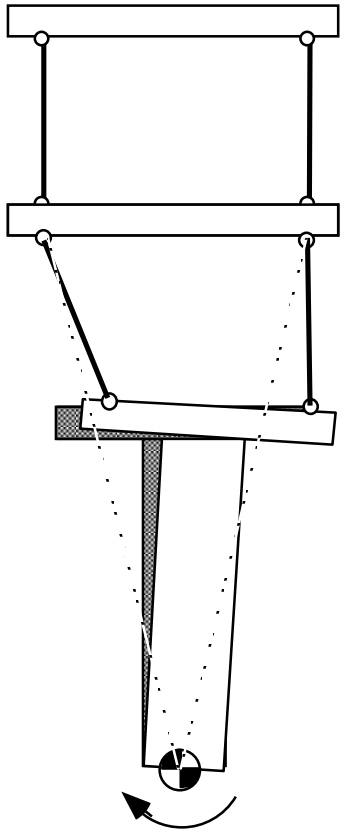
(d) RCC UNDER LATERAL LOAD



(d) RCC UNDER LATERAL LOAD

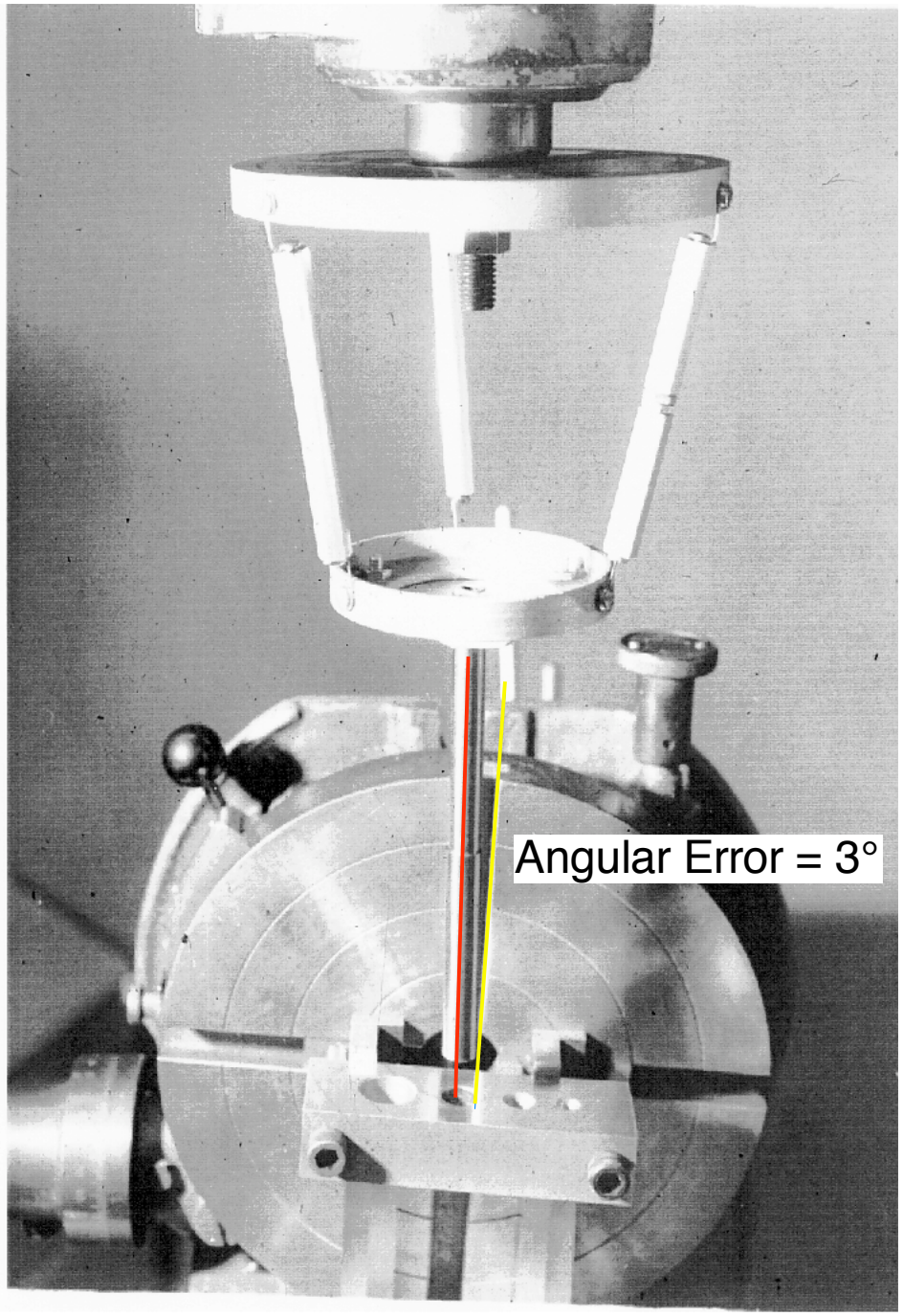


(e) RCC UNDER ANGULAR LOAD

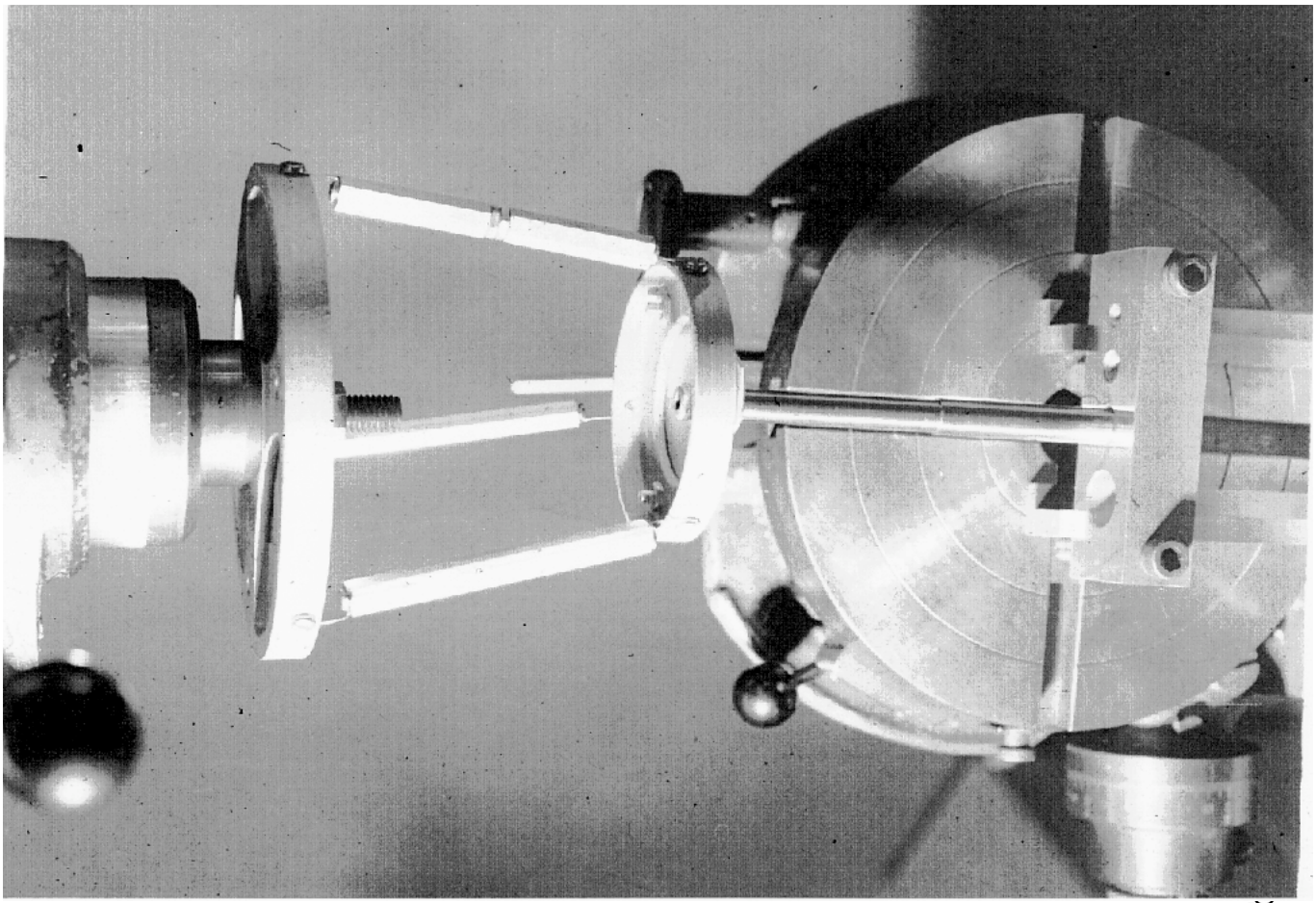


(e) RCC UNDER ANGULAR LOAD

First RCC Experiment - 1



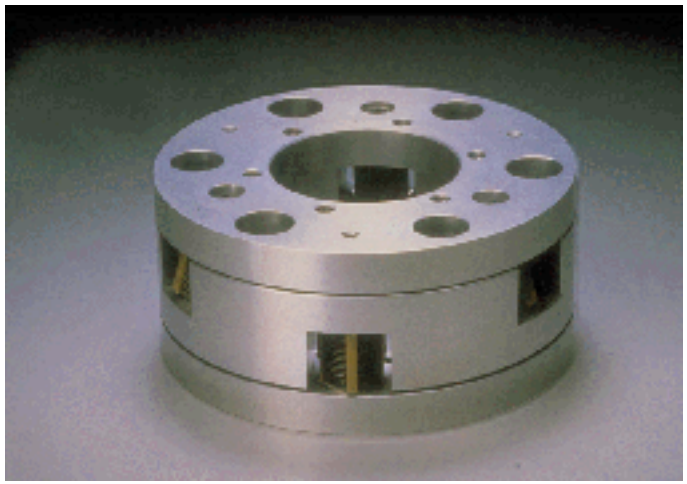
First RCC Experiment - 2



Demo of RCC

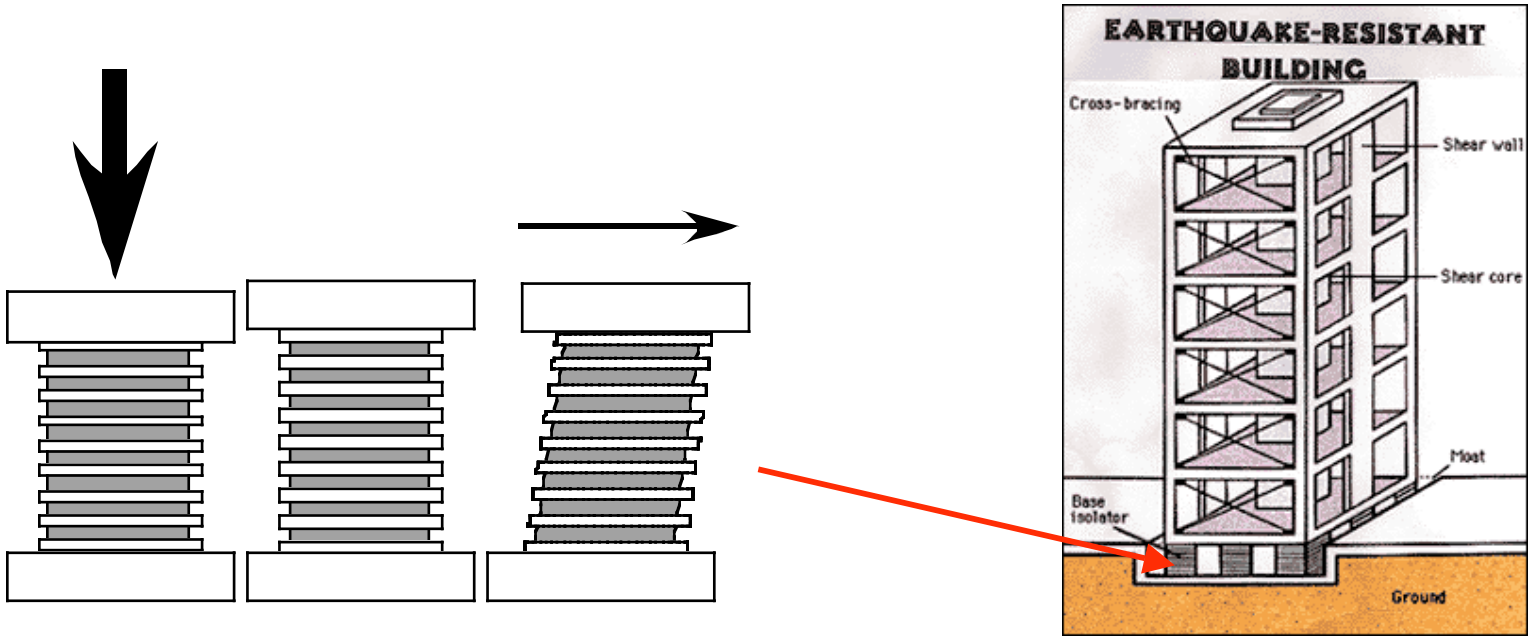
Commercial Remote Center Compliances

ATI Industrial Automation
503-D Highway 70 East Garner
North Carolina 27529 USA



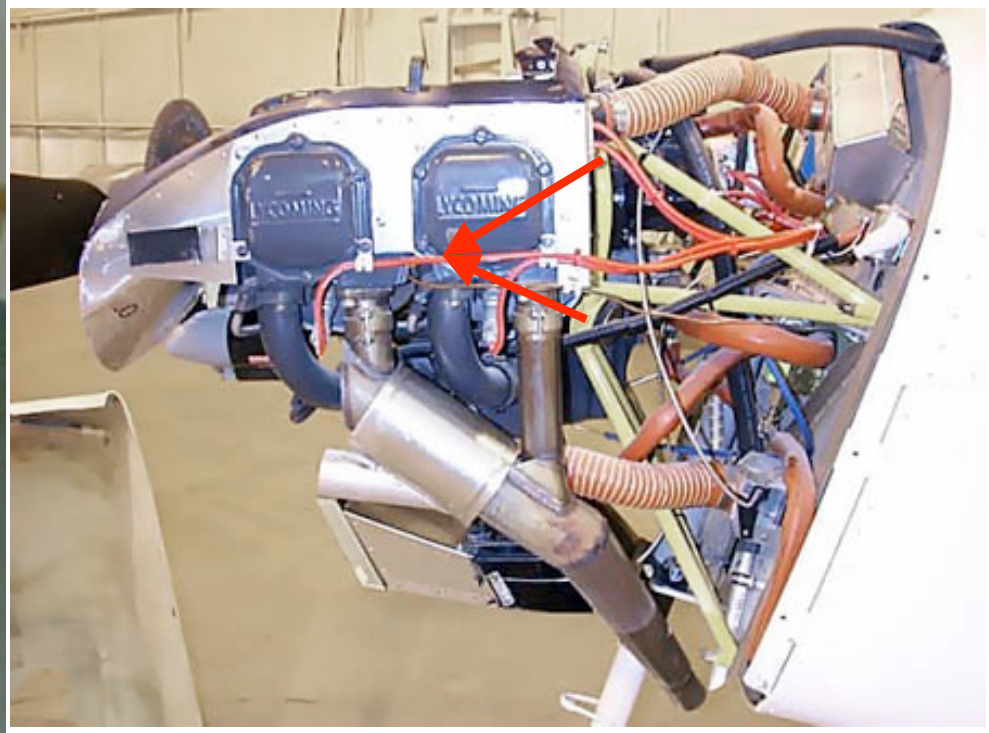
PFA, Inc.
N118 W18251 Bunsen Drive
Germantown, WI 53022
Ph: 414-250-4410
Fax: 414-250-4409

RCCs Have Shear Pads Inside



http://www.amnh.org/nationalcenter/youngnaturalistawards/1999/images/parikh/Resistant.gif

Dynafocal Engine Mount Is An RCC



Invented by MIT Prof Taylor in 1938

http://www.zenair.com/gif/firewall.jpg

Variation Analysis

- Tolerance = what error we can live with
- Variation = what error we actually get
- Process capability = comparison of tolerance and variation
- Tolerance > Variation is good
- Variation > Tolerance is bad
- More on this later in the term

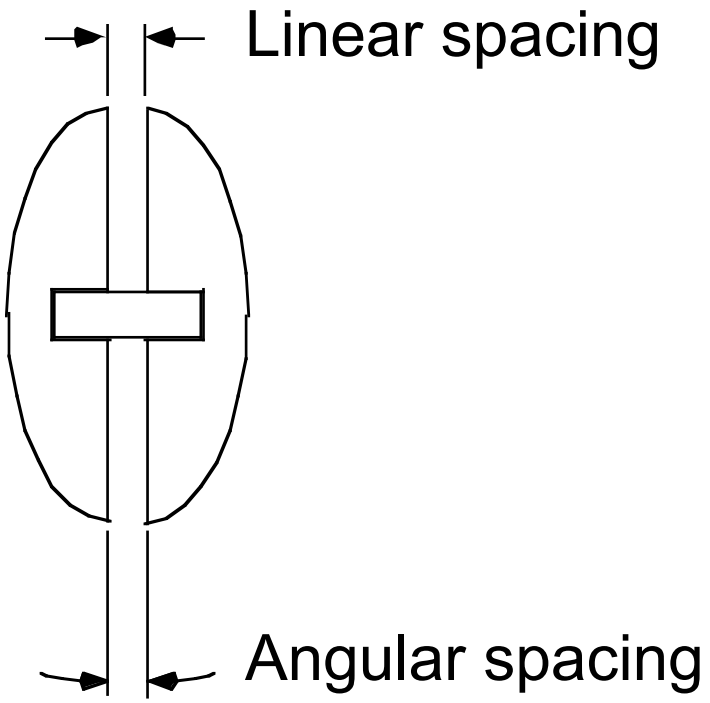
What Variations Matter?

- The ones that affect the performance of the product or its “ilities”
  - Reliability
  - Durability
  - Safety
  - Etc
- These variations exist at the assembly level

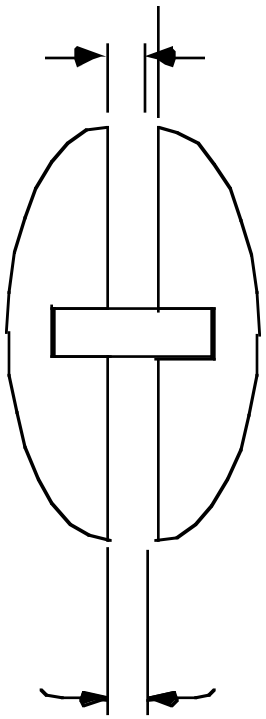
Where Do Assembly-Level Variations Come From?

- They come from variations in the parts
- Especially they come from variations in the places where the parts assemble to each other, although other error sources are also important
- Both position and angle errors matter

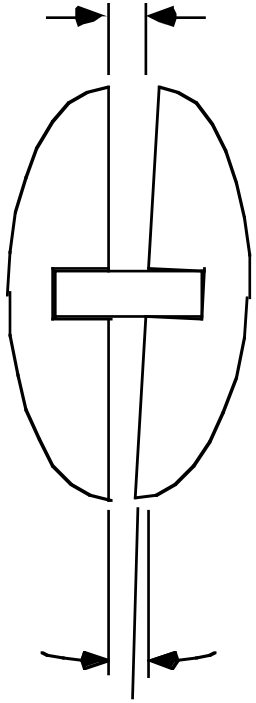
Nominal Yo-yo with Key Dimensions



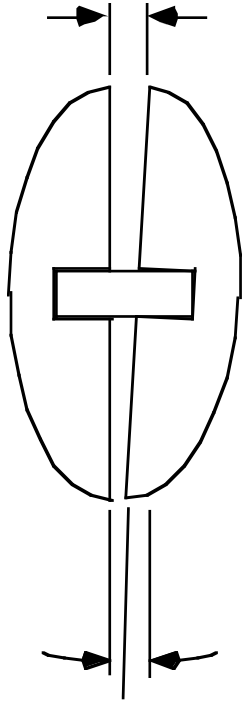
Some Variations



Pin too long



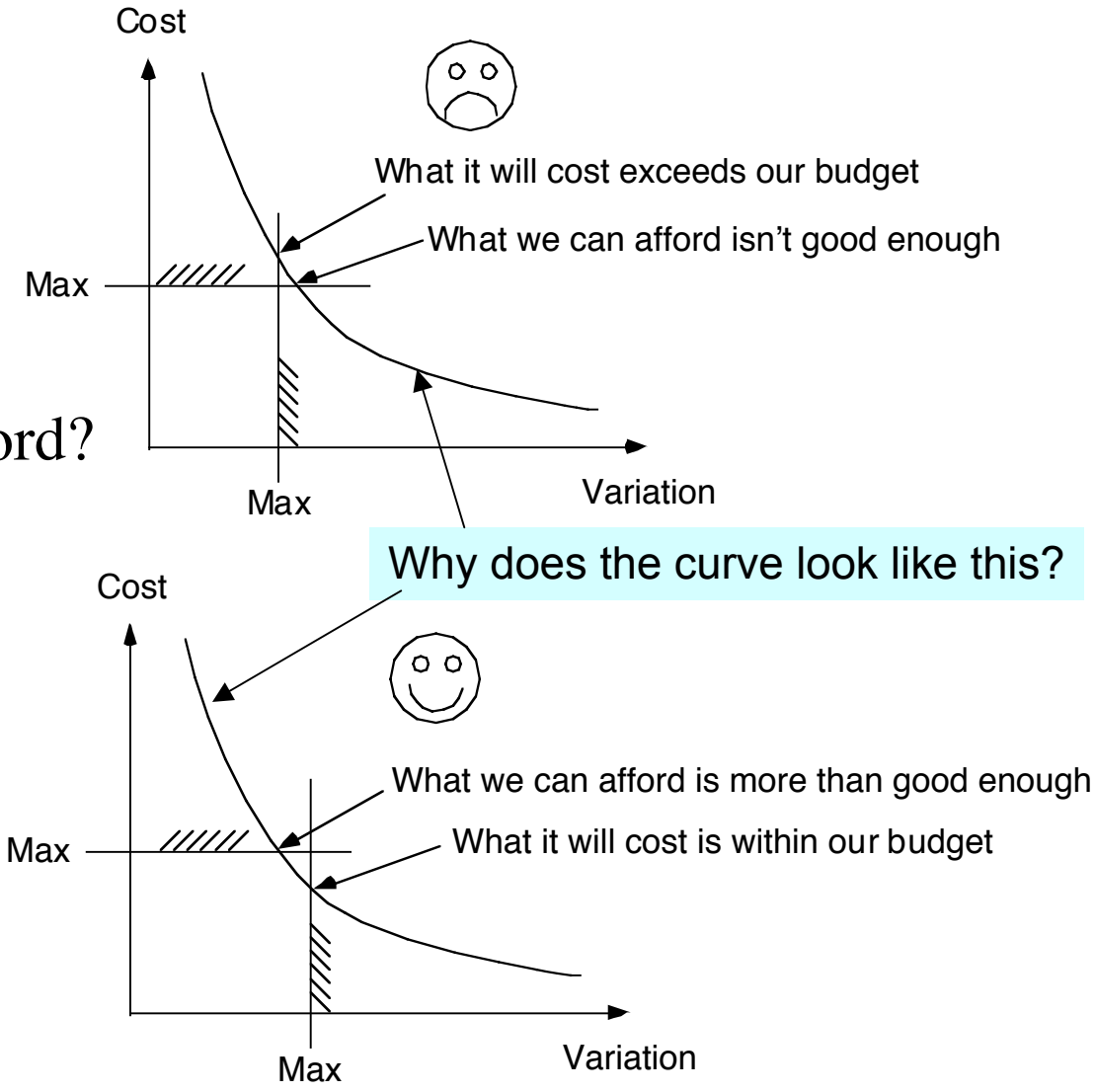
Pin bent or
hole cocked



Pin too short
Plus hole cocked
or pin bent

How Much Variation Should We Seek?

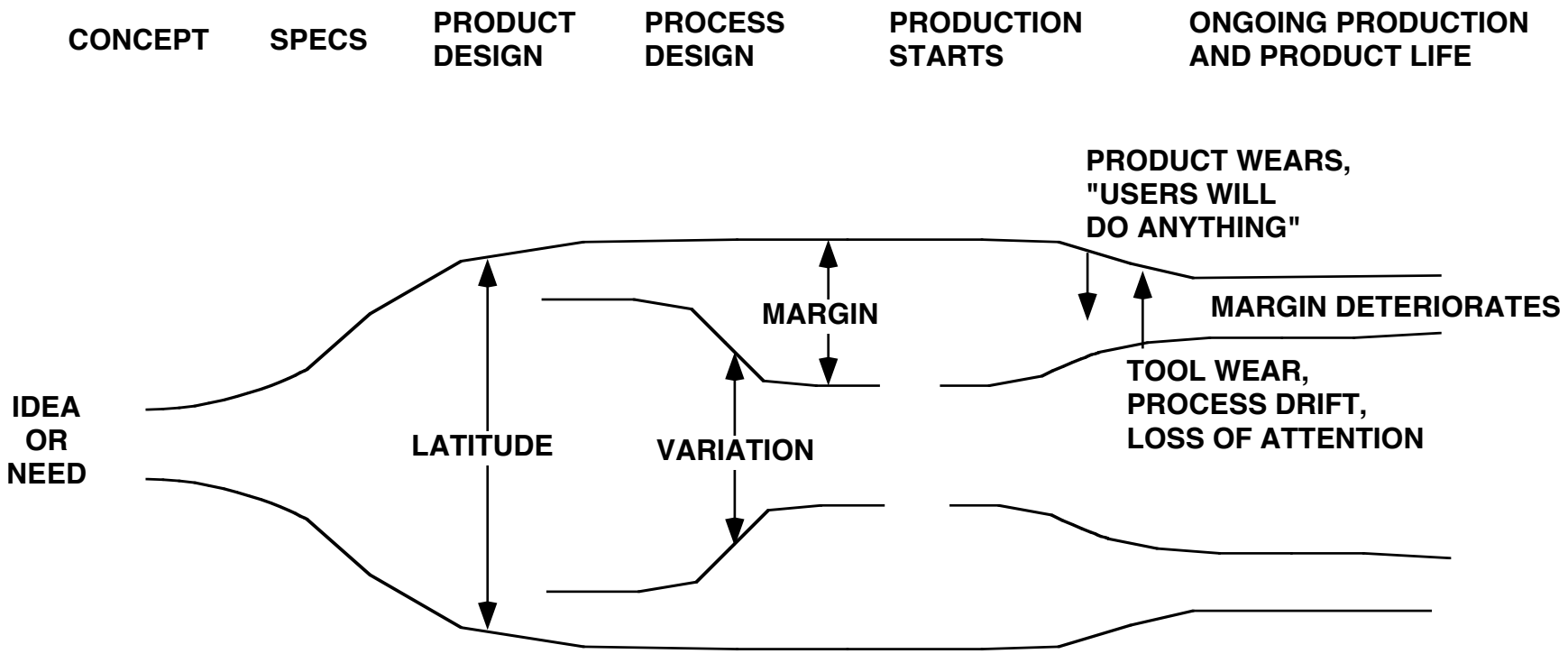
- As little as possible?
- As little as we need?
- As little as we can afford?



Latitude and Variation

- A great unifying view, heavily engineering-oriented
- Directly links production and user domains
- Your job is to create concepts, designs, and production methods that produce high latitude and low variation
- Latitude = domain in which product behaves well
- Variation = unsteadiness or vulnerability of behavior
- Latitude - variation = quality margin
  - "takes a licking and keeps on ticking"
- You can expect this margin to deteriorate throughout the product's life

PRODUCT DEVELOPMENT AS A PROCESS OF INCREASING LATITUDE AND DECREASING VARIATION THROUGHOUT THE PRODUCT DEVELOPMENT PROCESS AND PRODUCT LIFE CYCLE



SOURCE: H. BARRY BEBB, FORMERLY OF XEROX.
HE CREDITS DON CLAUSING AND MAURICE HOLMES,
AND SAYS IT TOOK 10 YEARS TO DRAW THIS CHART.

LATITUDE AND VARIATION

