2023 Digital Manufacturing Challenge powered by SME's DDM Advisory Team

The webinar titled

Fundamentals of Geometric Dimensioning and Tolerancing, Part I

will begin shortly

Georgia Tech

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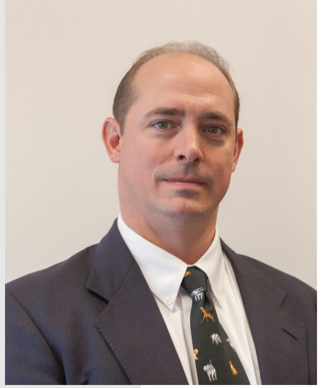
A
B
C

Fundamentals of Geometric Dimensioning and Tolerancing (GD&T)

-Part I-

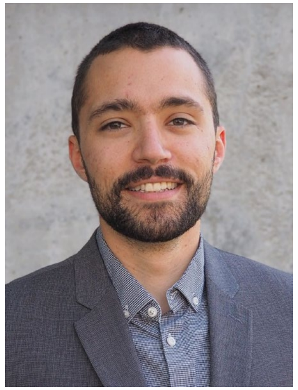


Host: Carl Dekker

President
Met-L-Flo and Chair of the Direct Digital Manufacturing Advisory Team

Moderator: Jason Fox

Mechanical Engineer
National Institute of Standards and Technology (NIST)



Speaker: Jaime Berez

Ph.D. Candidate, Instructor
Georgia Institute of Technology

Speaker: Maxwell Praniewicz

Mechanical Engineer
National Institute of Standards and Technology (NIST)

2023 Digital Manufacturing Challenge powered by SME's DDM Advisory Team

Theme: AM to the Rescue: Digital Manufacturing Agility to Address Crises

Deadline: February 27, 2023 (11:59 PM)

NEW THIS YEAR: High school and undergraduate students are highly encouraged to prepare a submission! Tiers have been added to separate High School, Undergraduate, and Graduate student submissions and a winner from each tier will be identified. Updated Submission Requirements - Geometric Dimensioning and Tolerancing included in Requirements (university students)

https://www.sme.org/aboutsme/awards/digital-manufacturing-challenge/

Fundamentals of GD&T Seminar series overview

Georgia Tech

Part 1

February 3rd, 2023

Speakers

Jaime Berez
Georgia Institute of Technology

Topics

- Introduction to imprecision in manufacturing
- Tolerancing systems (ASME Y14.5, etc.)
- Datums, form, orientation, location, and size
- The ‘symbolic language’ of GD&T– feature control frames & more

Part 2

February 17th, 2023

Speakers

Jaime Berez
Georgia Institute of Technology

Maxwell Praniewicz
National Institute of Standards and Technology

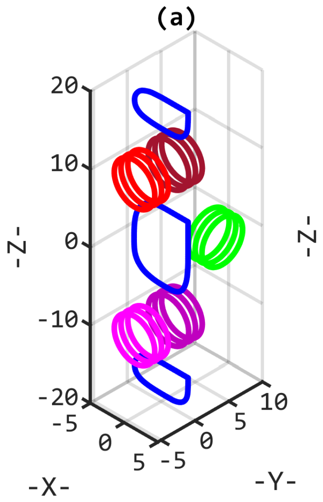
Topics

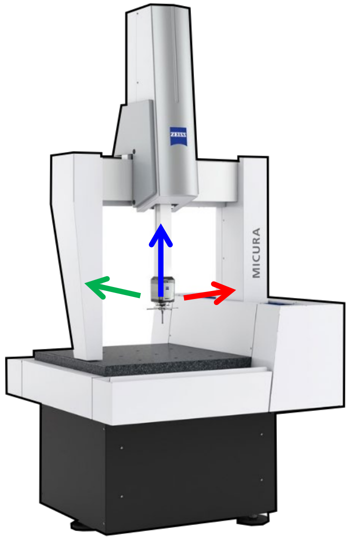
- Designer checklist for implementing GD&T
- Example implementation
- Case studies! (Focus on digital manufacturing)

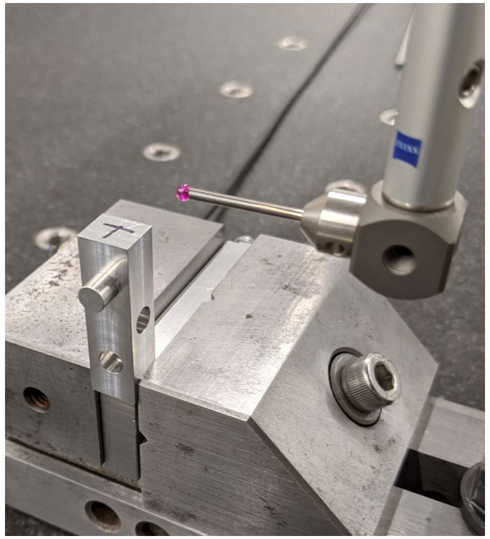
Introductions

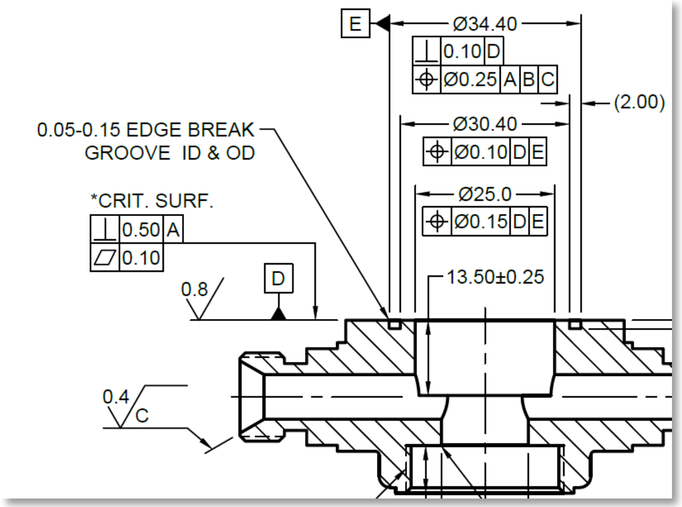
Jaime Berez
j.berez@gatech.edu

- Ph.D. Candidate, Georgia Institute of Technology
  - **Instructor**, ME 3210, Design Materials, and Manufacture
  - Research: Fatigue, manufacturing process monitoring, metal AM, **dimensional metrology**, NDE
- B.S. Mechanical Eng., University of Maryland, College Park
- Prior experience: Aerospace, automotive









Why GD&T?

Problems:

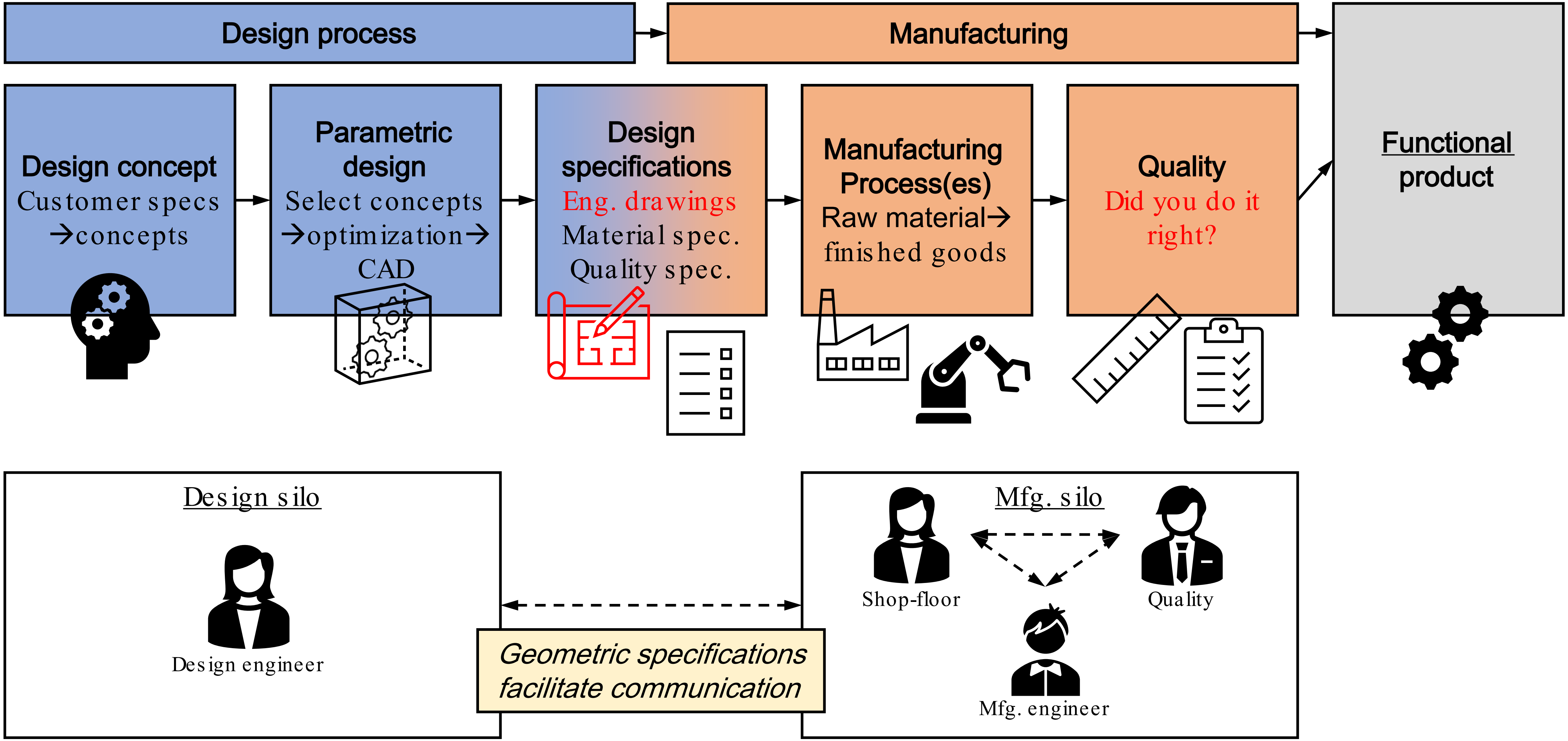
(1) Communication between stakeholders

(2) Manufacturing imprecision

(3) *Meaningful* geometric specification

Solution: Geometric dimensioning and tolerancing (GD&T)

Problem 1: Communication between stakeholders



Problem 2: Imprecision in manufacturing

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No manufacturing method is perfectly precise

- Nothing is ever exactly 1in, 10 mm… etc. in size
- Nothing is 'perfectly' flat, round, square… etc.

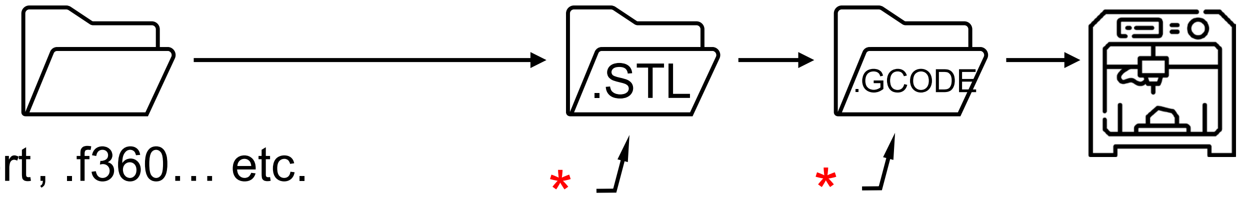
Therefore, how do engineers specify what size they want something to be, and how do manufacturers achieve that?

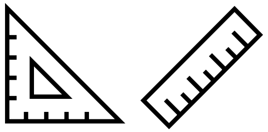
Problem 2: Imprecision in manufacturing (example)

Georgia Tech

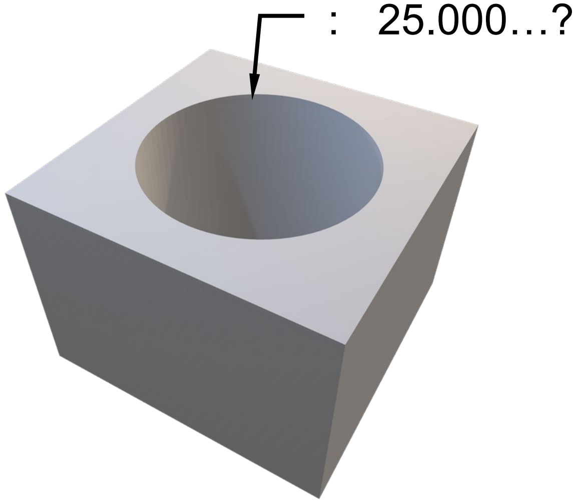
Just because it's <u>digital</u> doesn't mean the manufacturing process is perfect

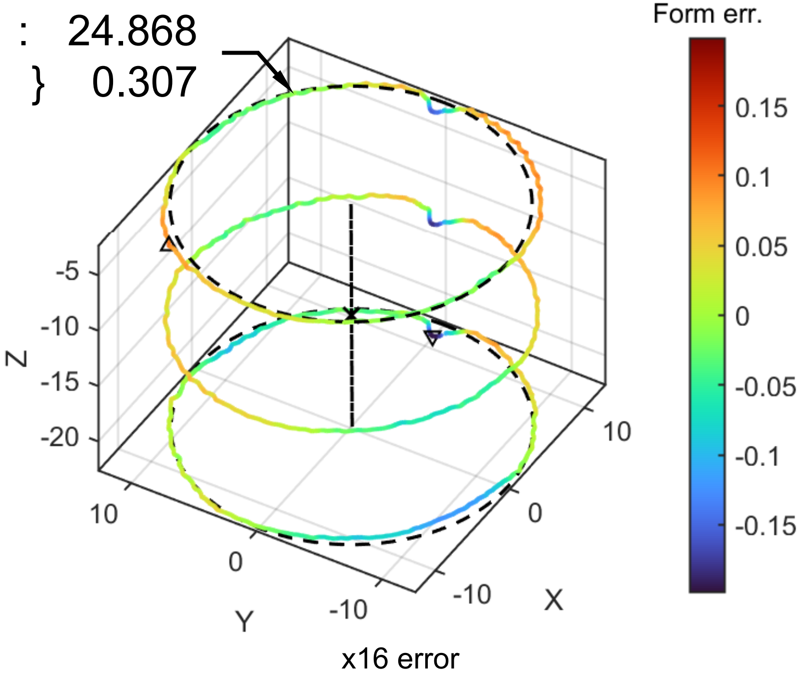
CAD → FFF additive manufacturing → Dimensional inspection





.sldprt, .f360… etc.





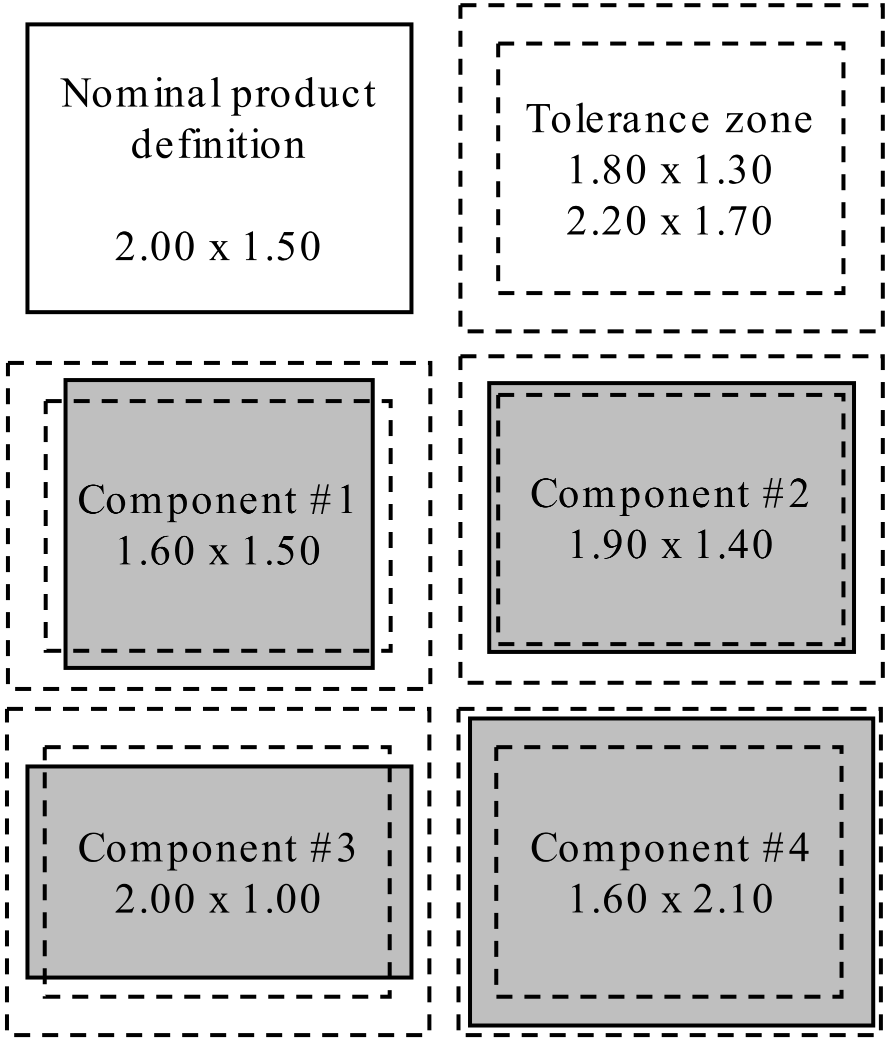
Problem 3: *Meaningful* geometric specification

Problem:

- Exact dimensions don't acknowledge imprecision… so let's use **tolerances**
- Tolerances must be unambiguous and easily interpreted

Solution:

- Designers define **tolerance zones** which the workpiece must fall in to be 'in-spec'



Solution: GD&T

Problems:

(1) Communication between stakeholders

(2) Manufacturing imprecision

(3) *Meaningful* geometric specification

Solution: Geometric dimensioning and tolerancing (GD&T)

Today's seminar will cover fundamentals like…

- Dimensioning & tolerancing systems (e.g., ASME Y14.5)
- GD&T essentials
  - Datums & datum reference frames
  - Geometric characteristics & features of size
  - Feature control frames & engineering drawing practices

Applications covered in Part II

Dimensioning and tolerancing systems

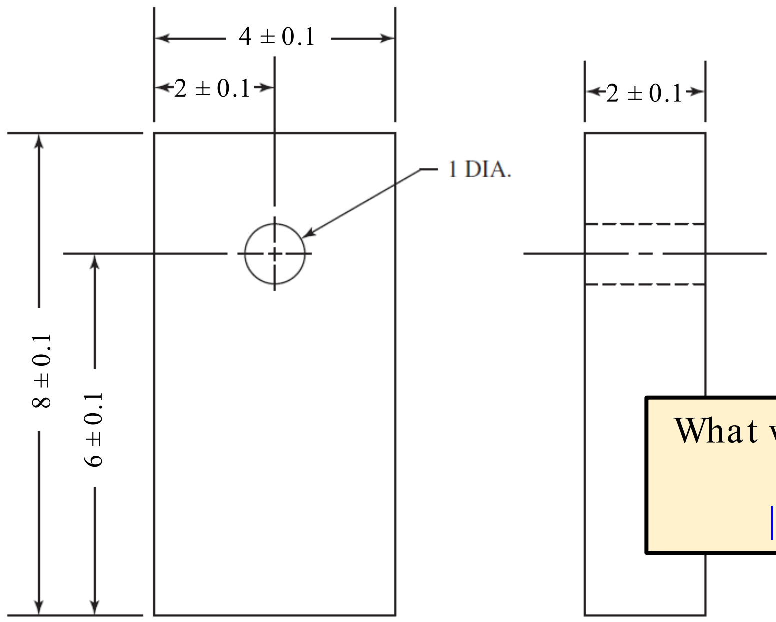
Dimensioning & tolerancing systems

Georgia Tech

Direct dimensioning, aka plus/minus tolerancing

- Only appropriate to use with features of size
- Difficult to interpret designer intention without the larger context of GD&T

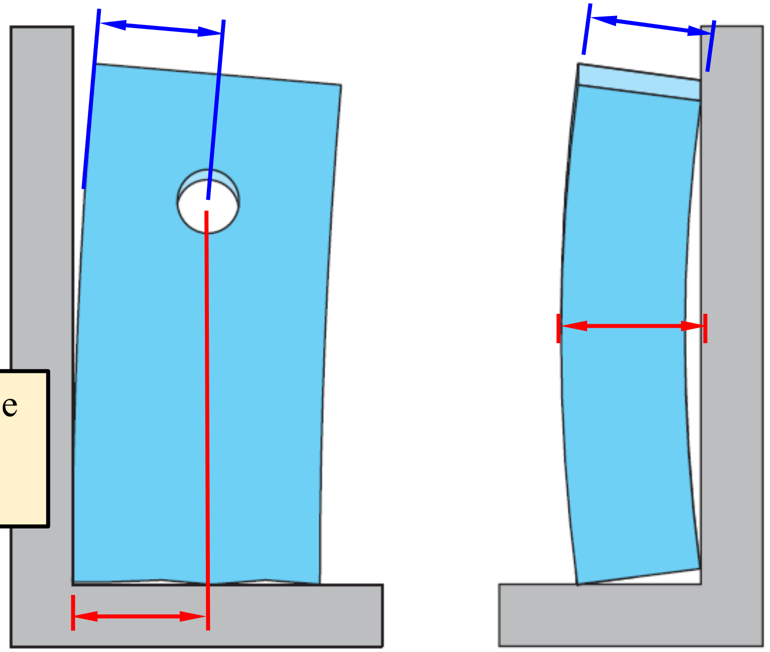
The drawing
Derived from perfect CAD



Shigley, adapted

What was intended by the designer?
|←→| or |←→|

The actual component
Manufactured with imprecision



Dimensioning & tolerancing systems

Georgia Tech

Geometric dimensioning and tolerancing, as per **ASME Y14.5-2018**

- ASME Y14.5 is the bulk of all GD&T concepts
- ASME Y14 committee publishes supporting standards such Y14.5.1M (GD&T math), Y14.1 (drawing sheet size), Y14.1 (digital product defn.)

Geometric product specification, as per **ISO TC 213** series, e.g., **ISO 1101:2017**

- ISO technical committee (TC) 213 publishes over 20 standards which are like chapters in the overall concept of GPS

ASME-ISO comparison

- Highly similar symbolic language & associated definitions
  – if you learn one you will know 90% of the other
- Disagree on:
  Exact implementation of datums, the envelope principle as a default, third- and first-angle projections, drawing style, some symbols, etc.

ASME Y14 landing page
https://www.asme.org/codes-standards/y14-standards

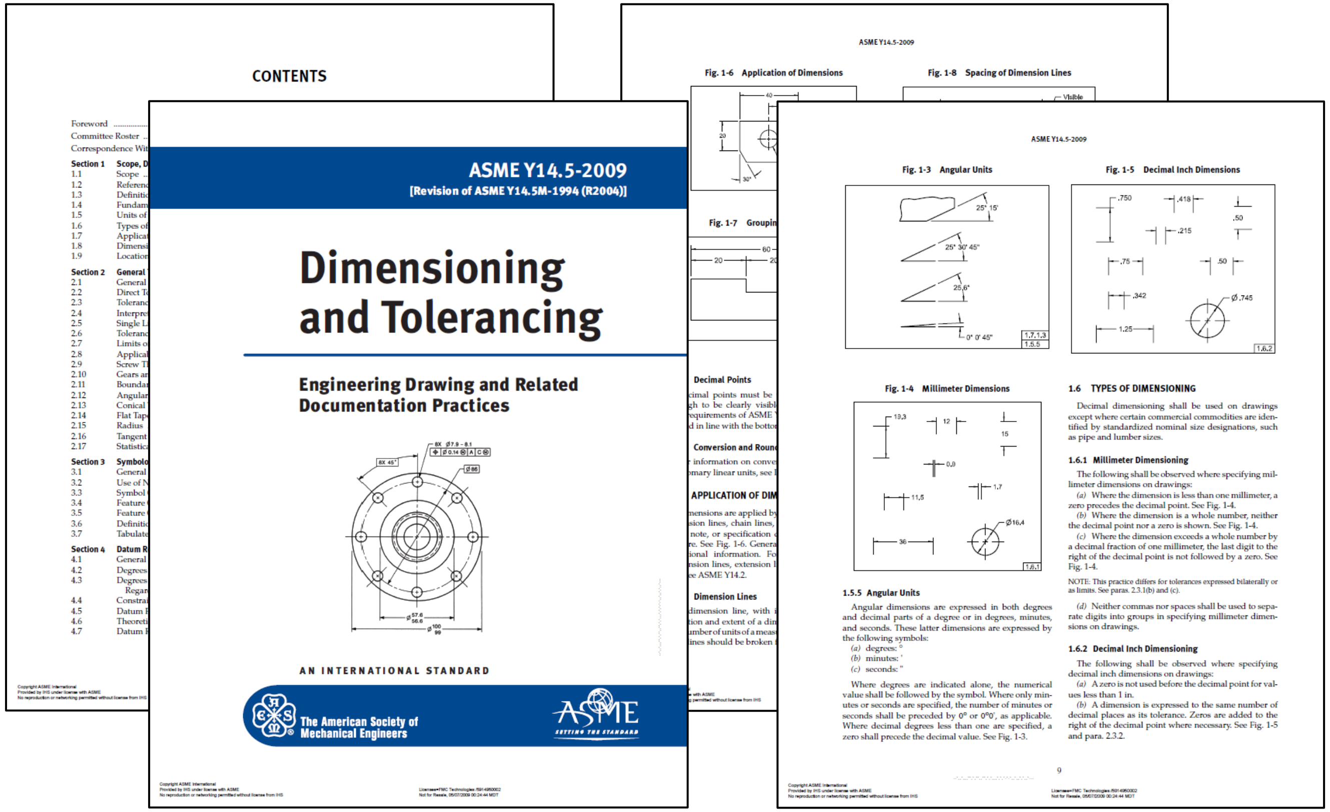
ISO TC 213 landing page
https://www.iso.org/committee/54924.html

Dimensioning & tolerancing systems

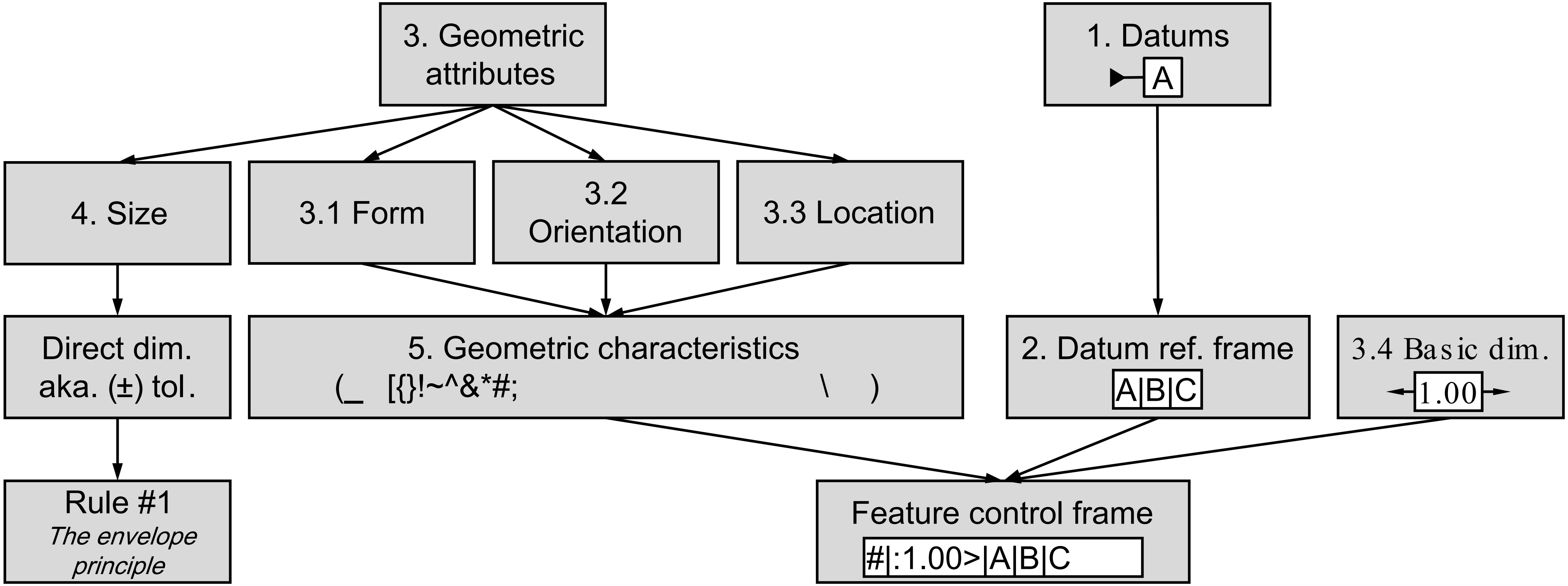
Why use GD&T/GPS?

- **Functional** – related to component functionality
- **Unambiguous** – clearly defined and standardized
- **Inspectable** – specifications relate to inspection methods

Don't be afraid to go and read it for yourself!
It's long (300+ pg.), but well illustrated and designed for comprehension.



Map of GD&T


3. Geometric attributes
1. Datums
A
4. Size
3.1 Form
3.2 Orientation
3.3 Location
Direct dim. aka. (±) tol.
5. Geometric characteristics
(_ [{}!~^&*#; \ )
2. Datum ref. frame
A|B|C
3.4 Basic dim.
1.00
Rule #1
The envelope principle
Feature control frame
#|:1.00>|A|B|C

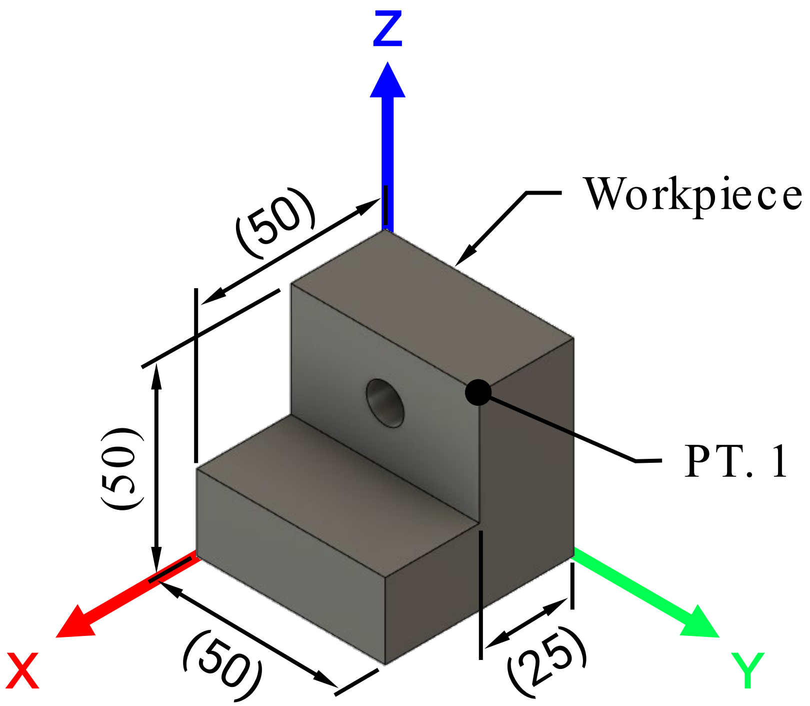
Datums & datum reference frames

Why do we need datums?

Q: Where is point 1?

Insights on the problem:

- Location is relative!
- By picking a **location** and **orientation** for the block within a coordinate system we can answer the question. *Nominally*: (25, 50, 50)
- By placing a workpiece in a coordinate system, we effectively constrain its **degrees of freedom**

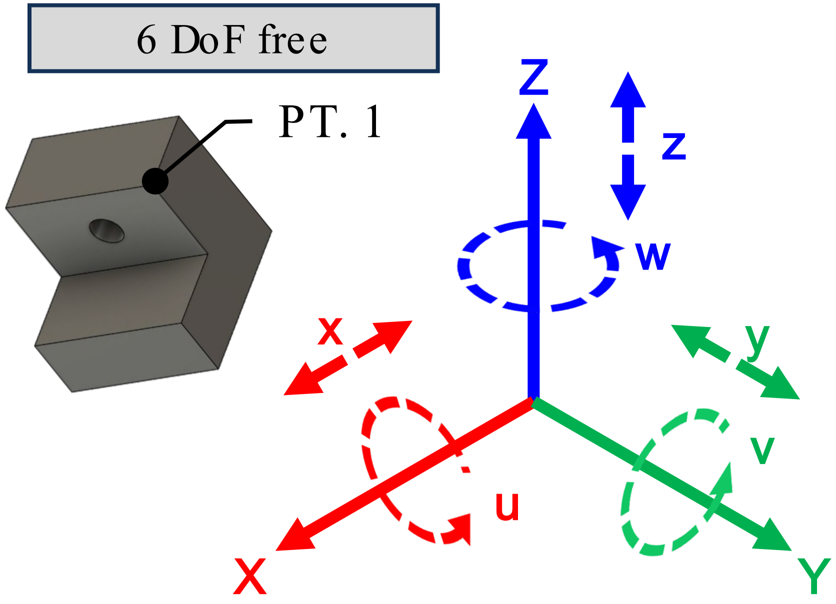


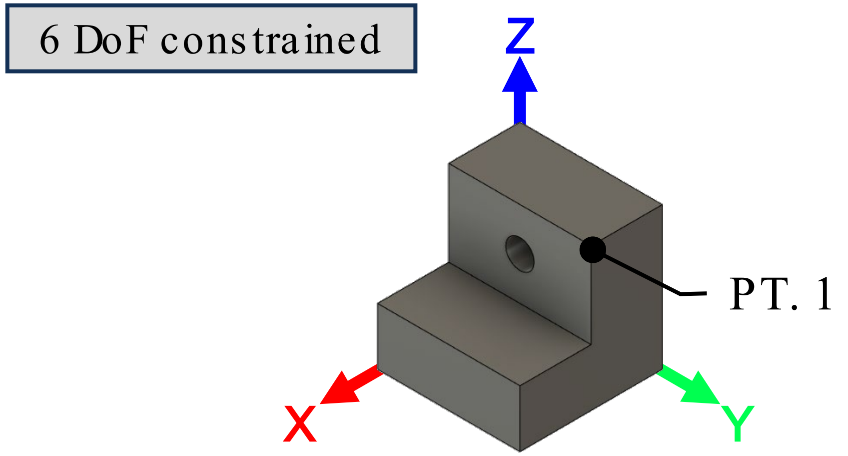
A: Place the workpiece in a coordinate system.

Degrees of freedom

- There are **six degrees of freedom** (**DoF**) in the motion of a *rigid body*
- By placing the workpiece in a coordinate system, we effectively constrain all 6 DoF

DoF	Motion
1.	**Translation** in X (x)
2.	**Translation** in Y (y)
3.	**Translation** in Z (z)
4.	**Rotation** about X (u)
5.	**Rotation** about Y (v)
6.	**Rotation** about Z (w)



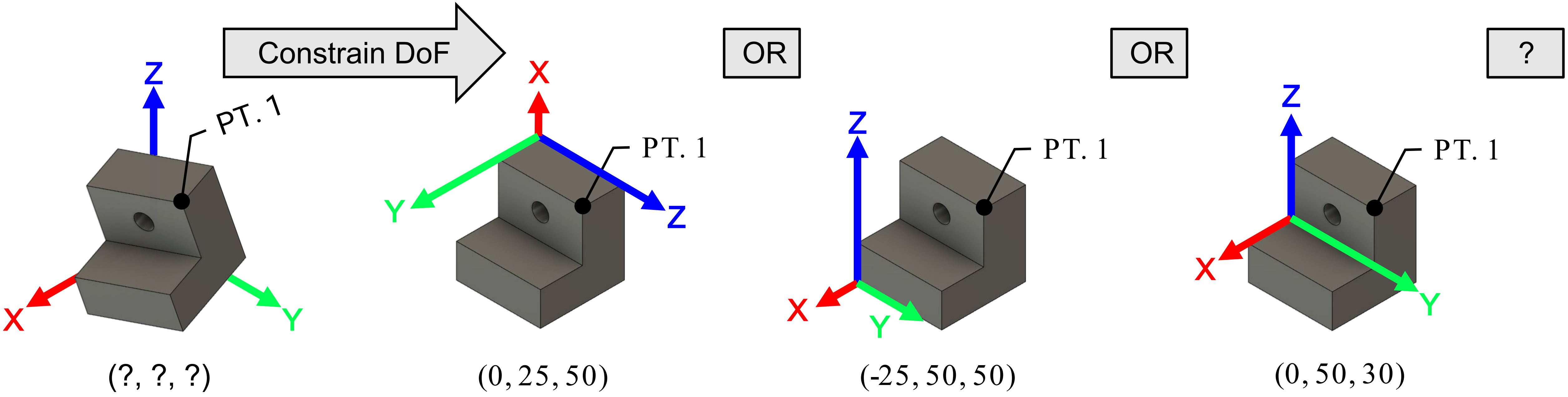


Why do we need datums?

Q: Where is point 1?

A: Place the workpiece in a coordinate system.

..But which one?...



Solution: Define a *specific* coordinate system relative to features on the workpiece! We call this the **datum reference frame.**

Datums

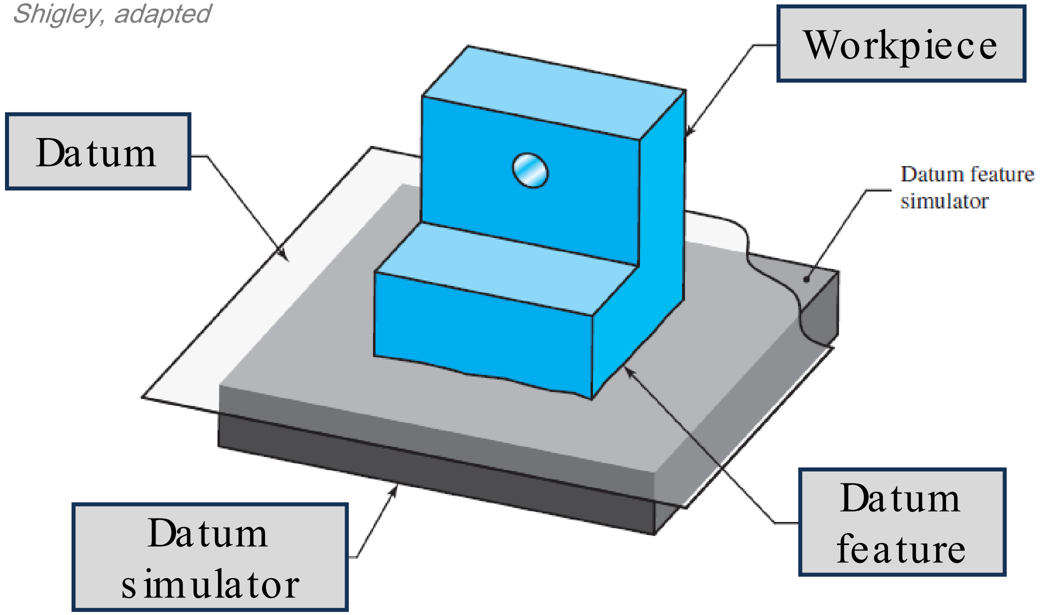
Datum feature: A nonideal physical reference from which a theoretically exact datum is derived

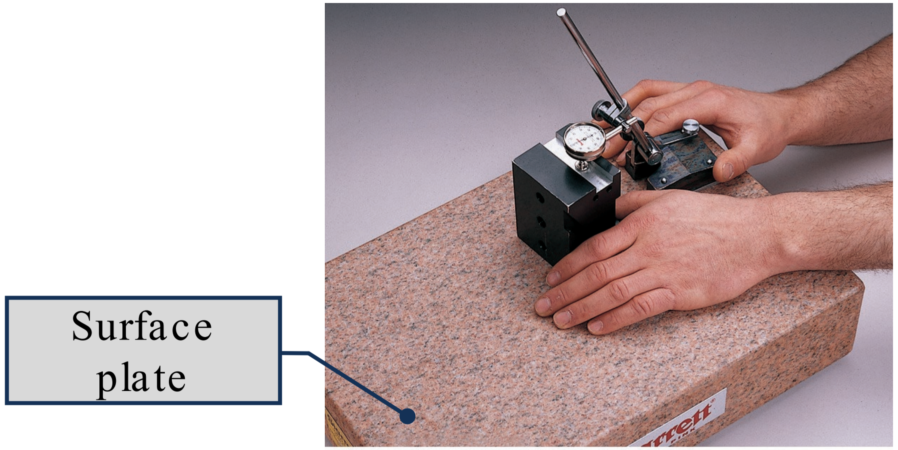
Datum: A perfect theoretical feature which forms a reference from which a location or orientation is established

Datum simulator: A precision embodiment of the datum feature.

Datum reference frame: A set of datum features which establish a coordinate system

Shigley, adapted





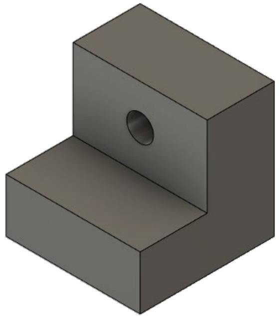
Starrett

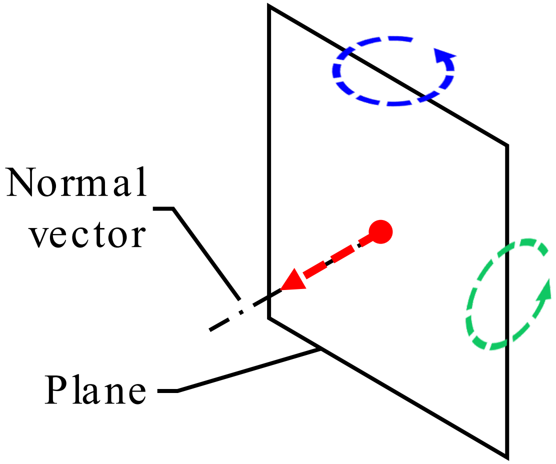
Datum features Planes and cylinders

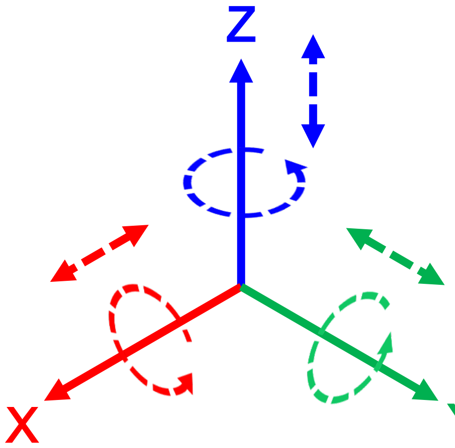
Many features can serve as datums – planes and cylinders are common.

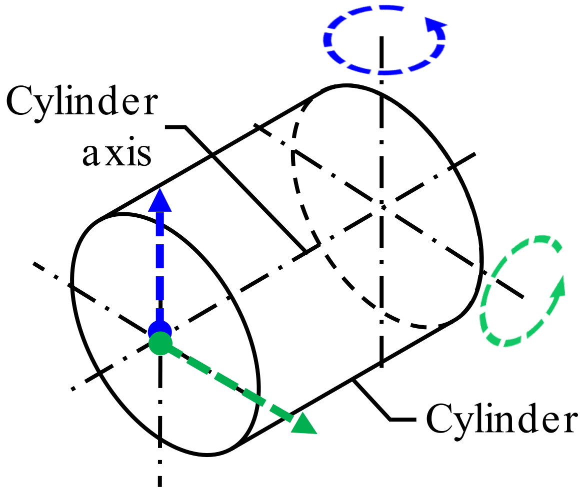
At maximum, a planar datum controls **2 rot.** and **1 trans.** DoF.

At maximum, a cylindrical datum controls **2 rot.** and **2 trans.** DoF.





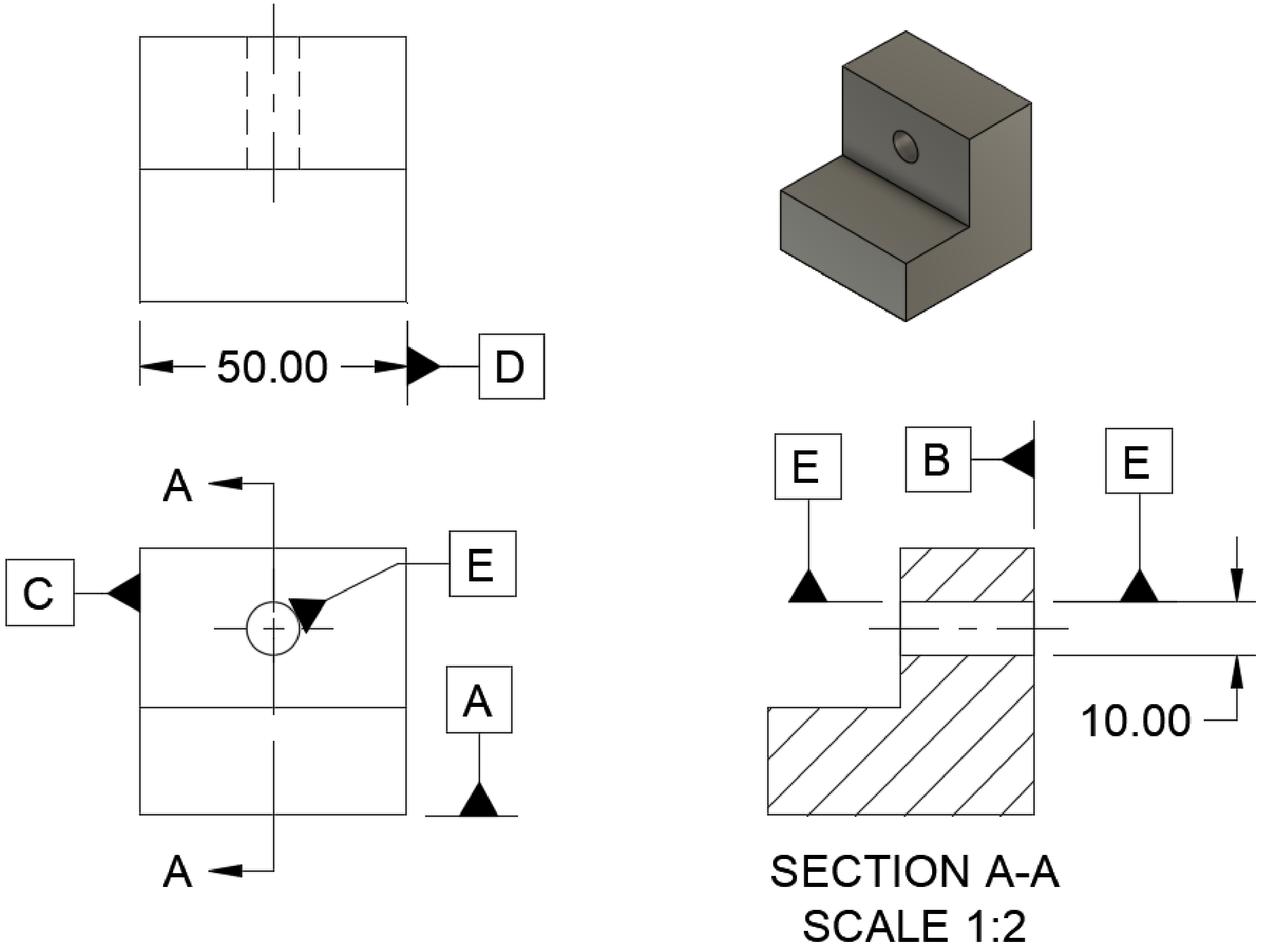




Datums – Drawing conventions

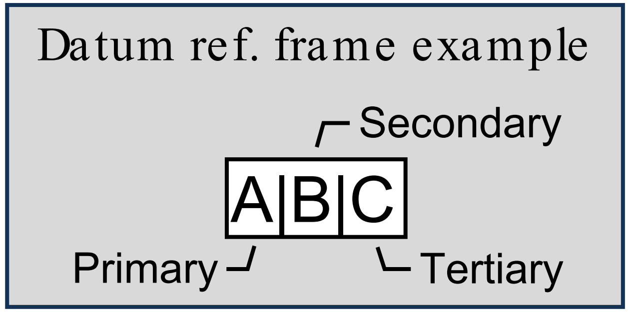
Many acceptable ways to apply datums to the drawing!

- -A-, -B-, and -C- refer to planar surfaces
- -D- refers to a median plane between two surfaces
- -E- refers to a cylinder

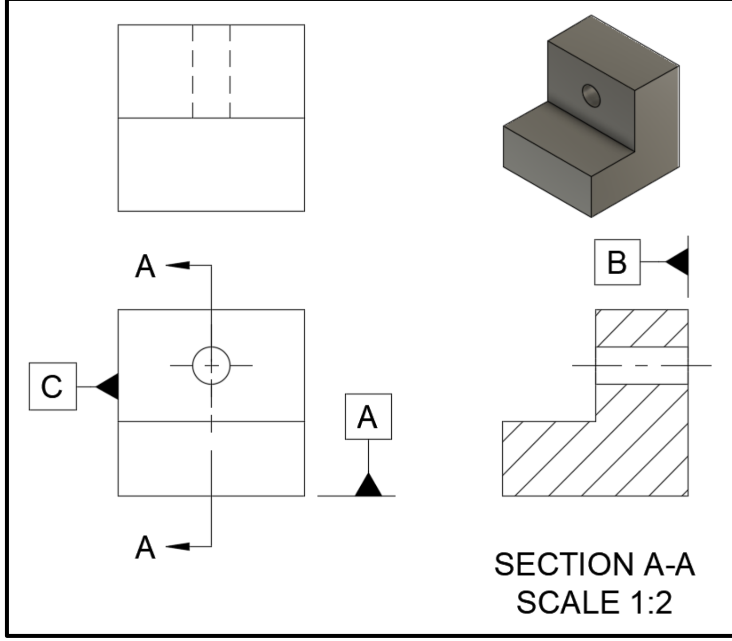


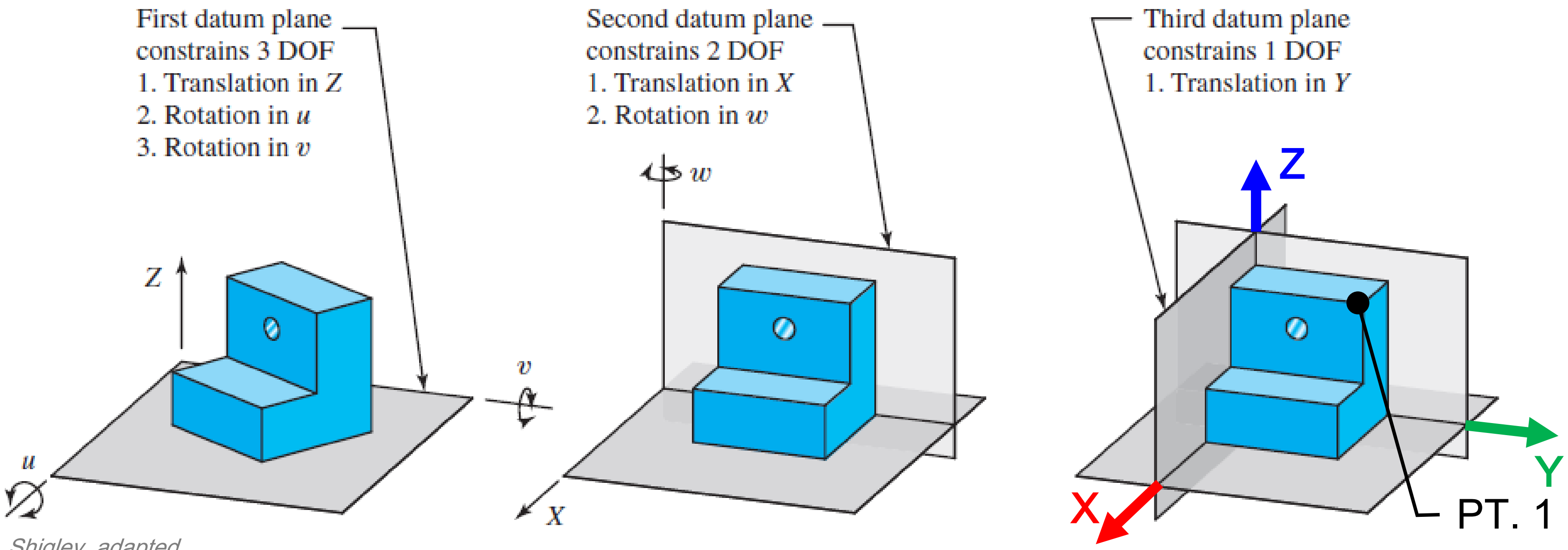
Datum reference frames

Datum reference frames (DRF) constrain degrees of freedom (DoF) based on this **precedence**.



This DRF…
…means this:



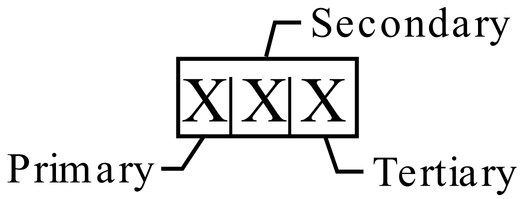


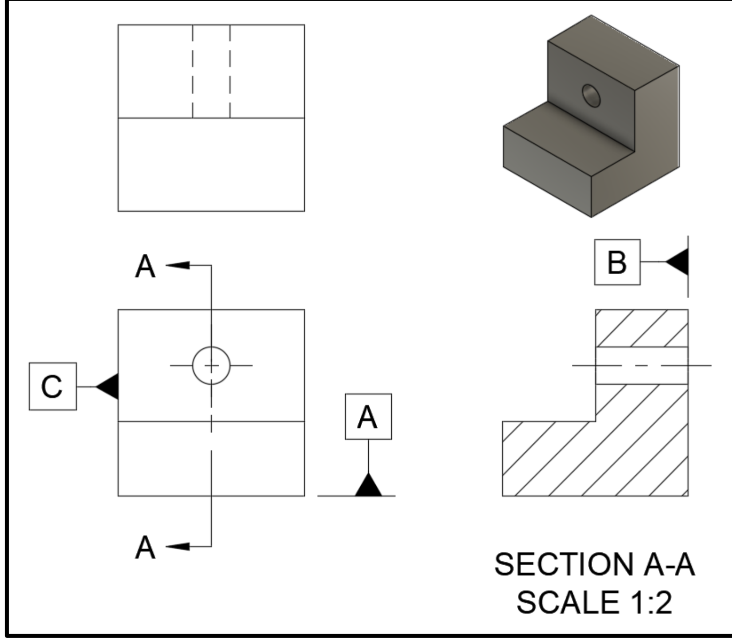
Shigley, adapted

Note:
Lower precedence datums do not influence DoF already controlled by higher precedence datums.

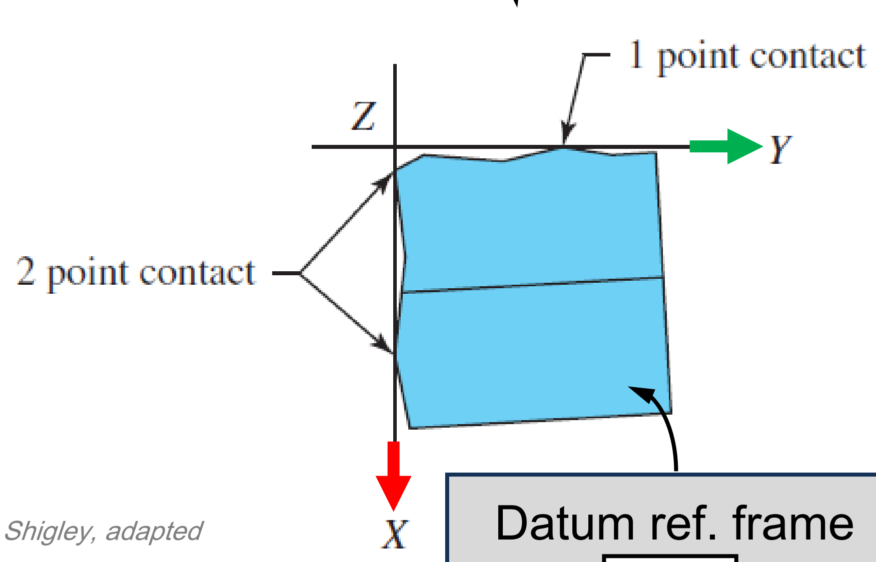
Datum reference frames

Datum precedence matters! This is especially clear considering imperfect datum feature geometry.





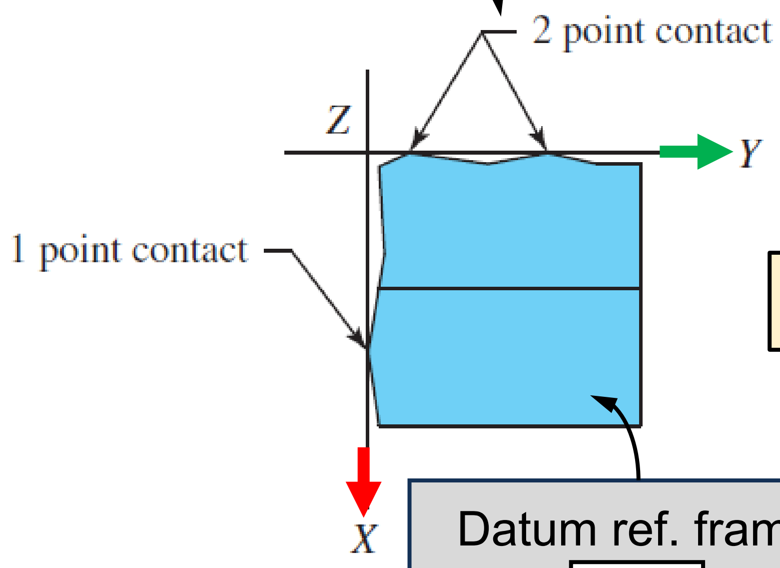
*1. -A- constrains **2 rot.** & **1 trans.***
*2. -C- constrains **1 rot.** & **1 trans.***
*3. -B- constrains **1 trans.***



Datum ref. frame
A|C|B

Shigley, adapted

*1. -A- constrains **2 rot.** & **1 trans.***
*2. -B- constrains **1 rot.** & **1 trans.***
*3. -C- constrains **1 trans.***



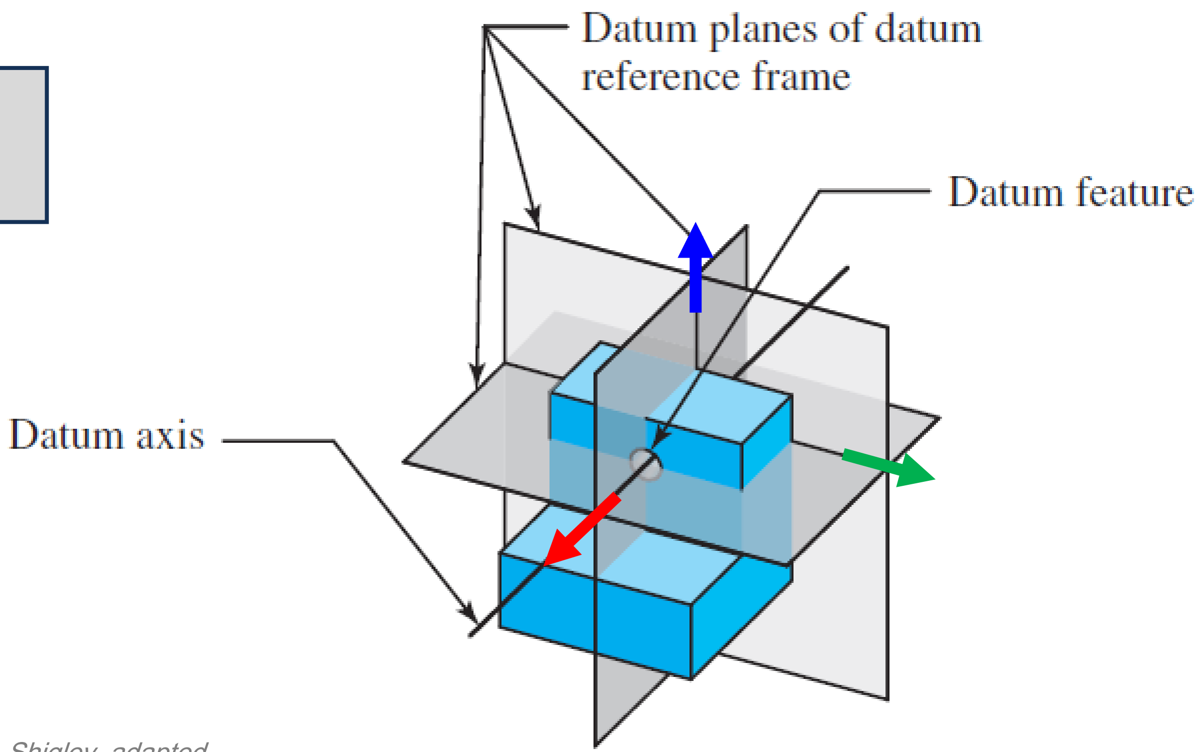
Datum ref. frame
A|B|C

Selecting functional datums will be covered in Part II.

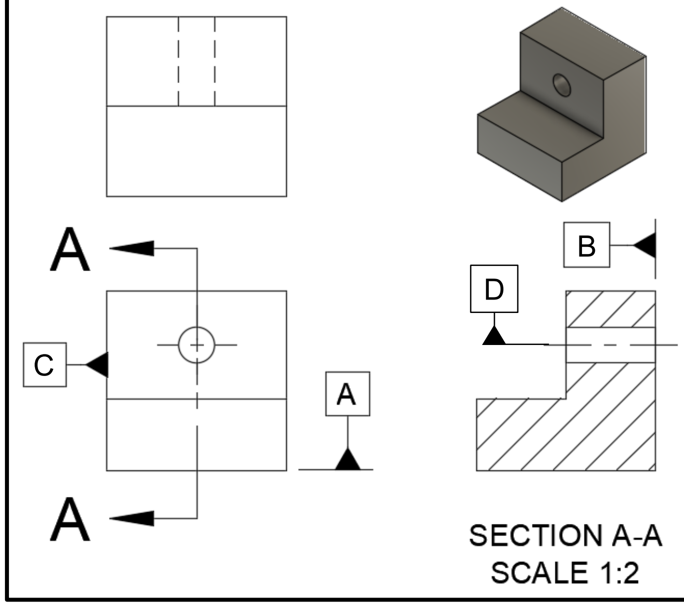
Datum reference frames

Consider a plane–cylinder DRF.

Datum ref. frame
B|D



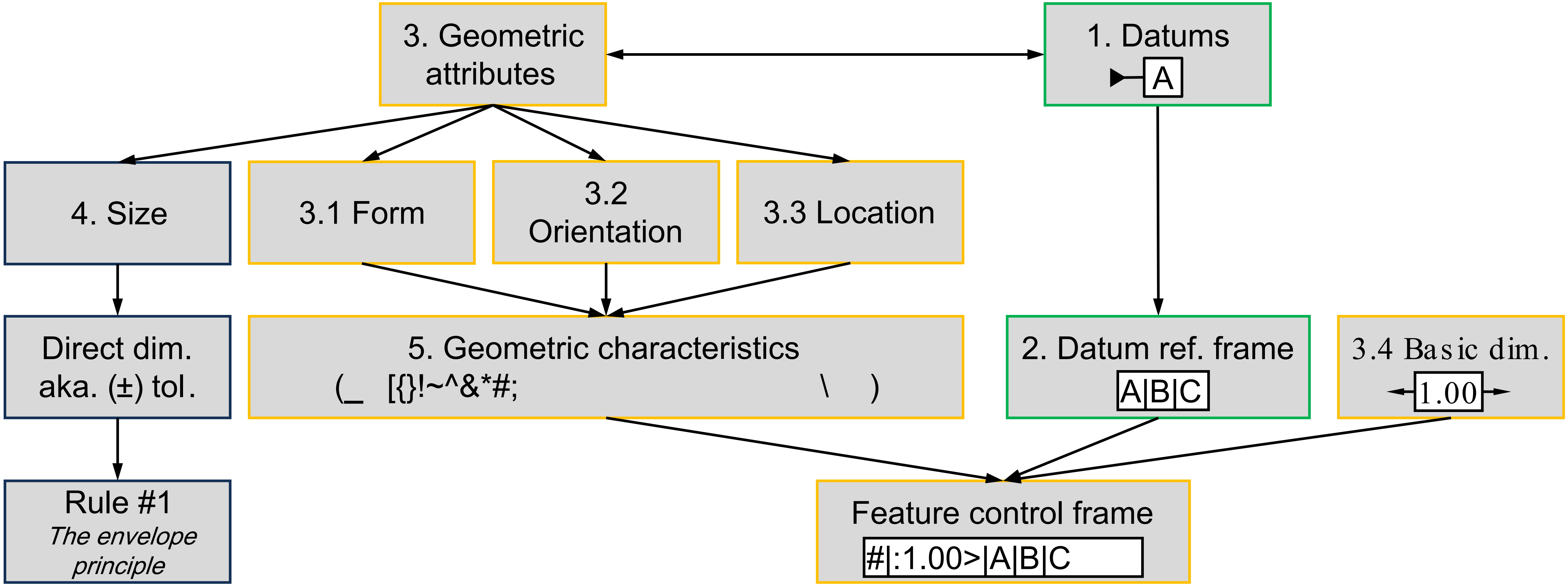
Shigley, adapted



Selecting functional datums will be covered in Part II.

Geometric attributes & geometric characteristics

Map of GD&T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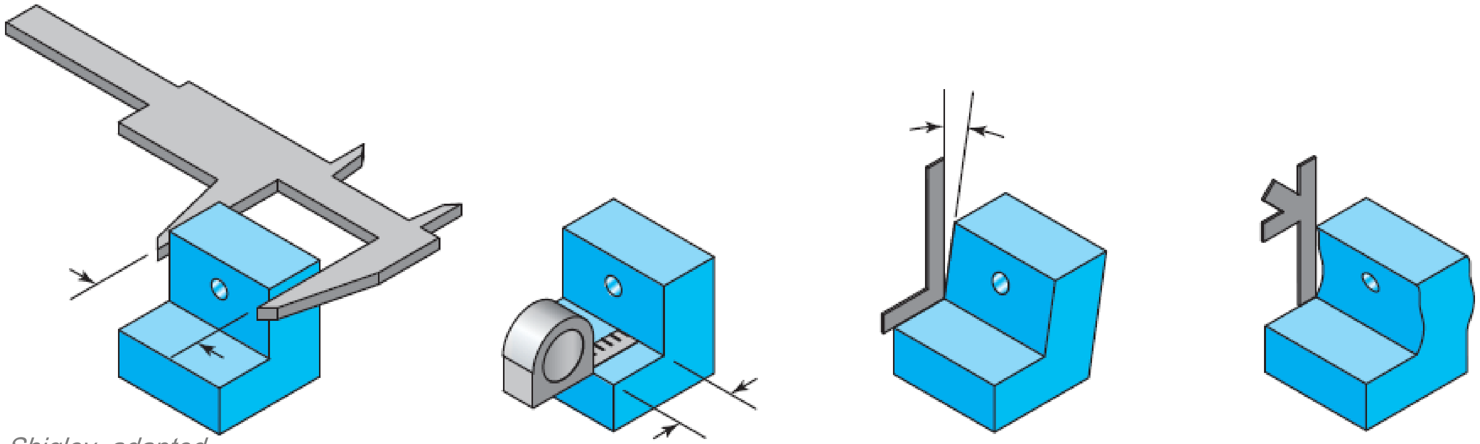
1.00
Rule #1
The envelope principle
Feature control frame
#|:1.00>|A|B|C

Geometric attributes

GD&T concepts categorize geometry to have 4 possible attributes



Shigley, adapted

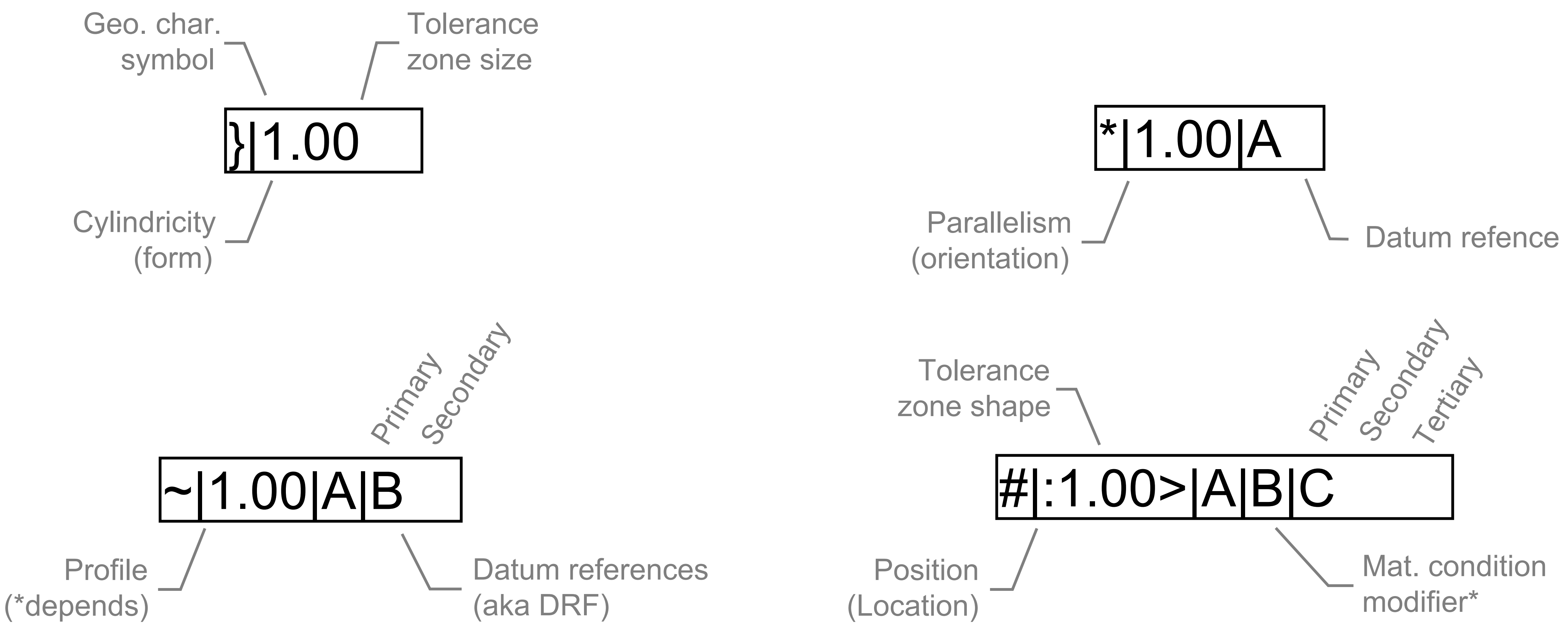
Size aka 'feature-of-size' *(Directly dim.)*	Location	Orientation	Form

*Your job as the drafter is to control **geometry**, not just size. GD&T is the tool.*

Geometric characteristics

Geometric characteristic	Symbol	Geometric attribute	Datum referencing?
Straightness	_	Form	No.
Flatness	[		
Circularity	{		
Cylindricity	}		
Profile of a line	!	Profile (*location, orientation, size, & form*)	Sometimes datum referencing
Profile of a surface	~		
Angularity	^	Orientation	Datum referencing
Perpendicularity	&		
Parallelism	*		
Position	#	Location	Datum referencing
Circular runout	;	Runout (*location of a cylinder*)	Datum referencing
Total runout	\		
~~Concentricity~~	$	*Elim. in ASME Y14.5 2018*	Datum referencing
~~Symmetry~~	%		

The feature control frame—Review



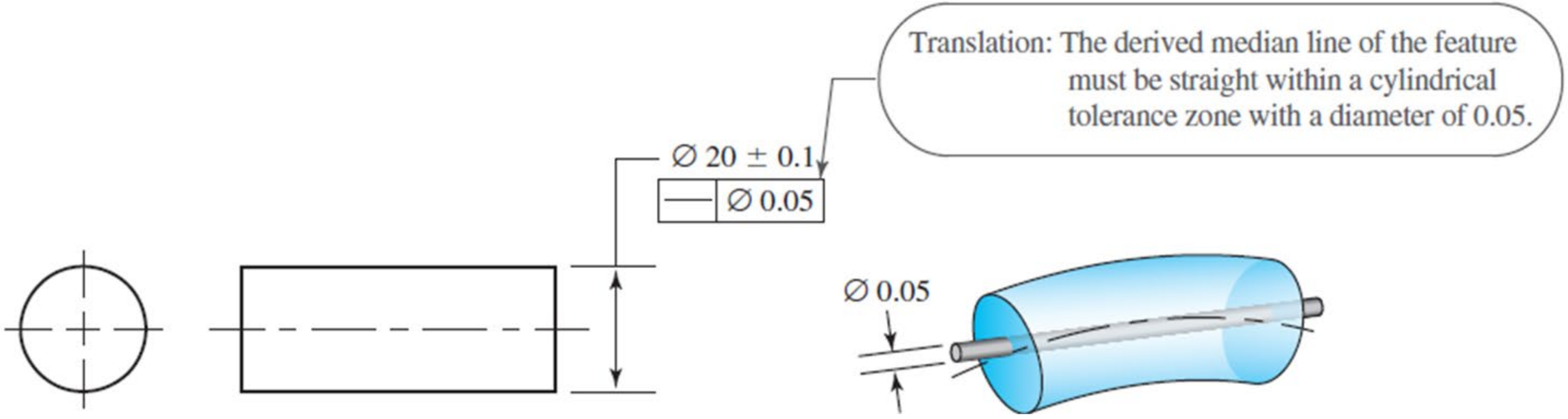
**Material condition modifiers not covered in this seminar*

Form – Straightness —

Straightness controls deviation of a surface line element or a feature axis from a perfect linear geometry

[ ] Datum referencing [√] Floating

- Good for: Long, high-aspect features which may need separate size and form control levels



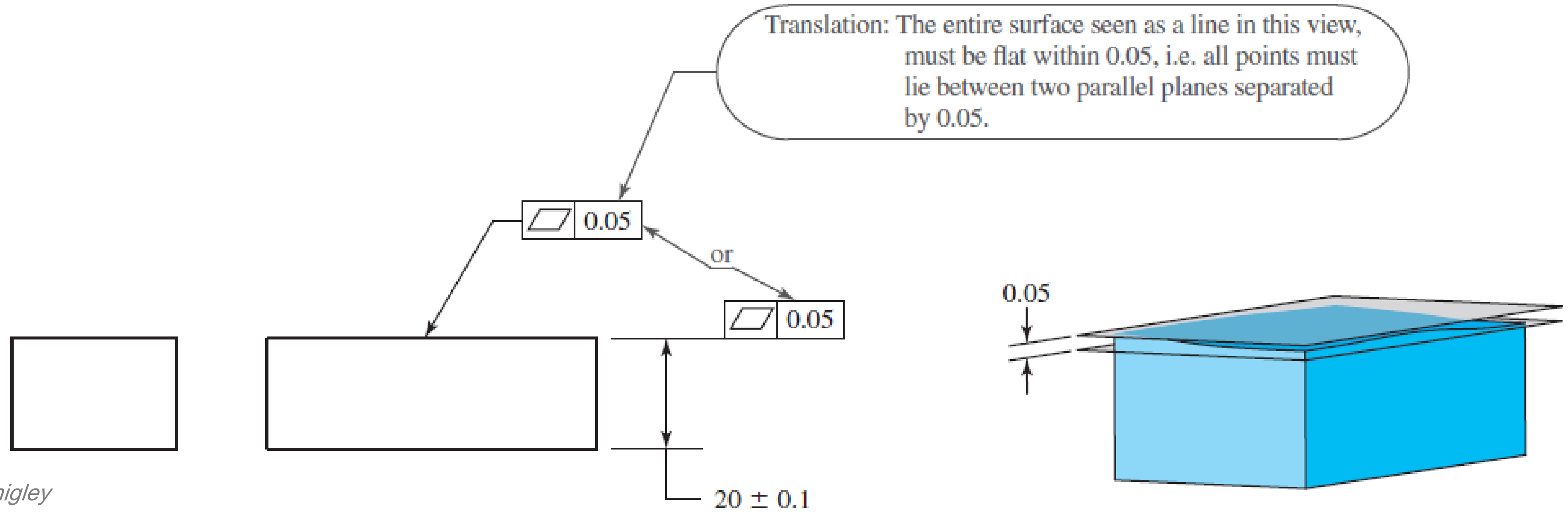
Shigley

Form– Flatness [

Flatness controls deviation of surface from a perfect planar geometry

[ ] Datum referencing [√] Floating

- Good for: mating surfaces, faces that must bear lots of load and wear, faces must seal against others, and controlling datum features



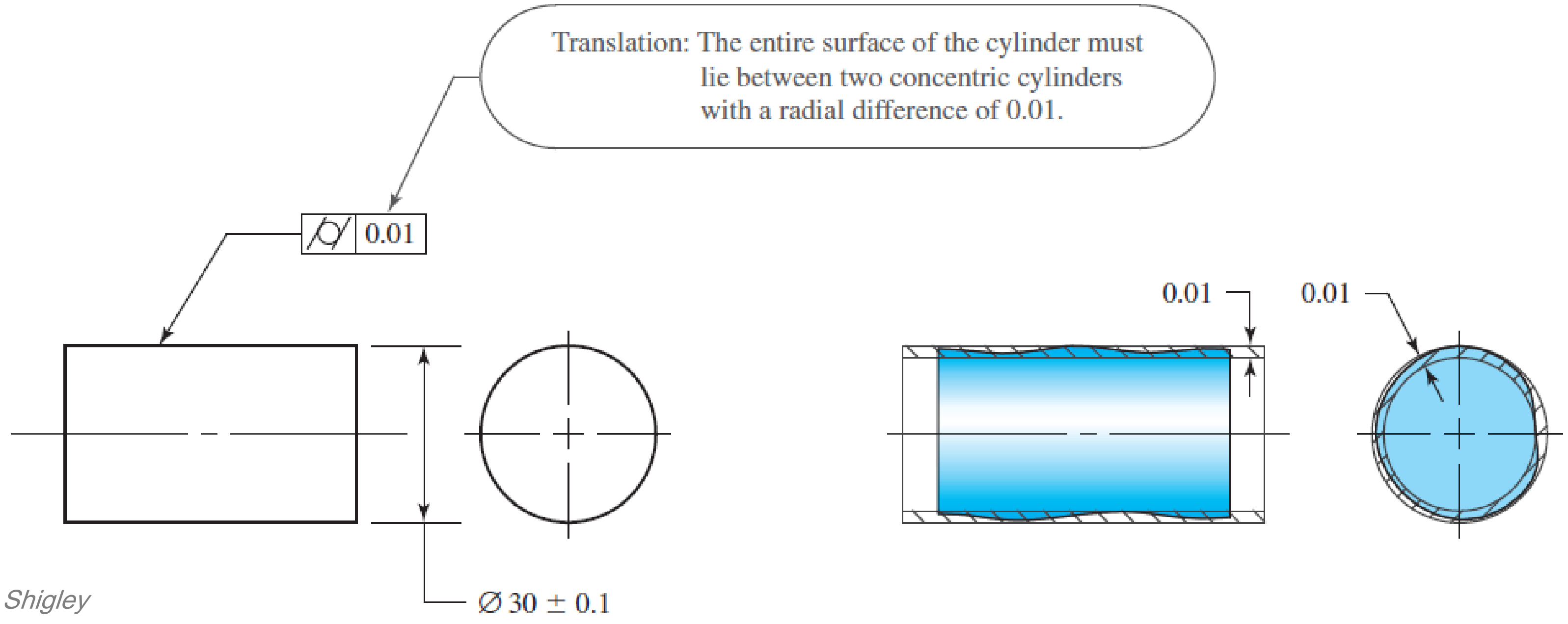
Shigley

Form – Roundness { & Cylindricity }

Roundness controls deviation of a 2D cross section from perfect circular form.
Cylindricity controls deviation of a surface from perfect cylindrical form

[ ] Datum referencing [√] Floating (shrinks & expands to feature size, too!)

- Good for: Boss-on-bore contact (e.g., bushings), bores/bosses that mate with other features (prevents 'out-of-round'), sliding shaft/bore assembles (prevents binding)



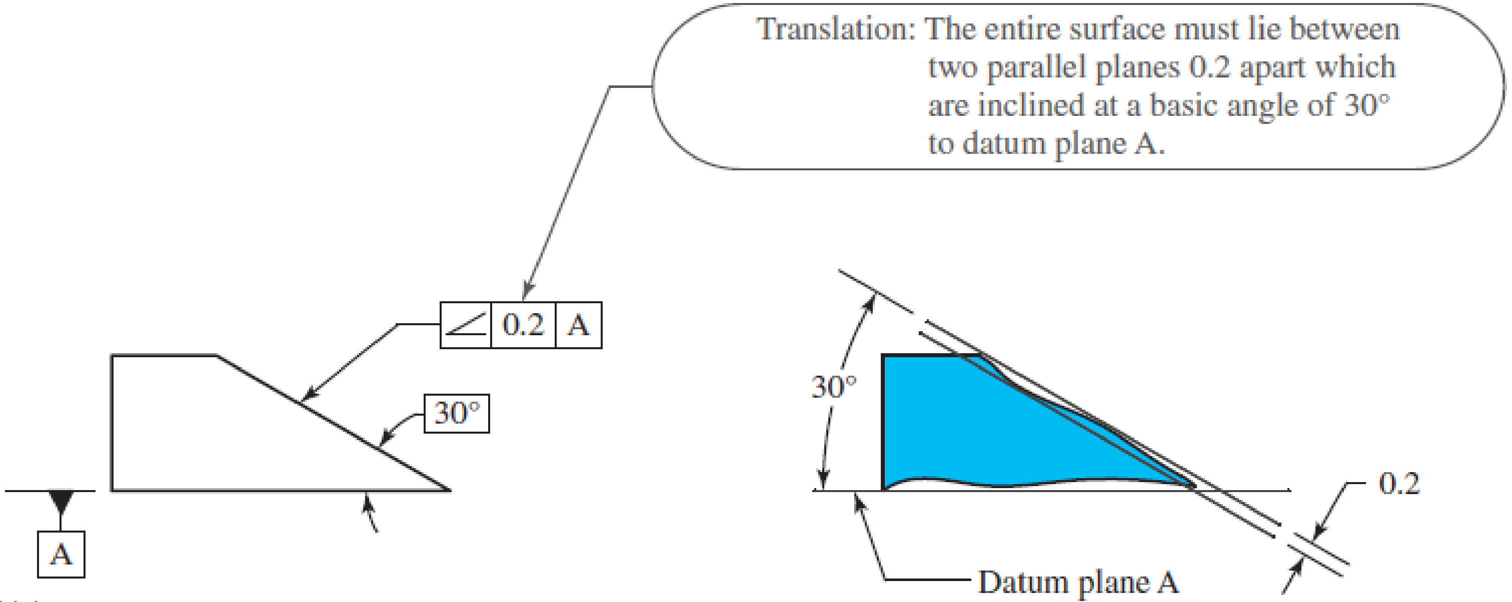
Shigley

Orientation – Angularity ^

Parallelism, **perpendicularity**, and **angularity** control the deviation a surface, axis, or center plane from 0°, 180°, 90°, or X° relative to a datum reference

[√] Datum referencing [ ] Floating

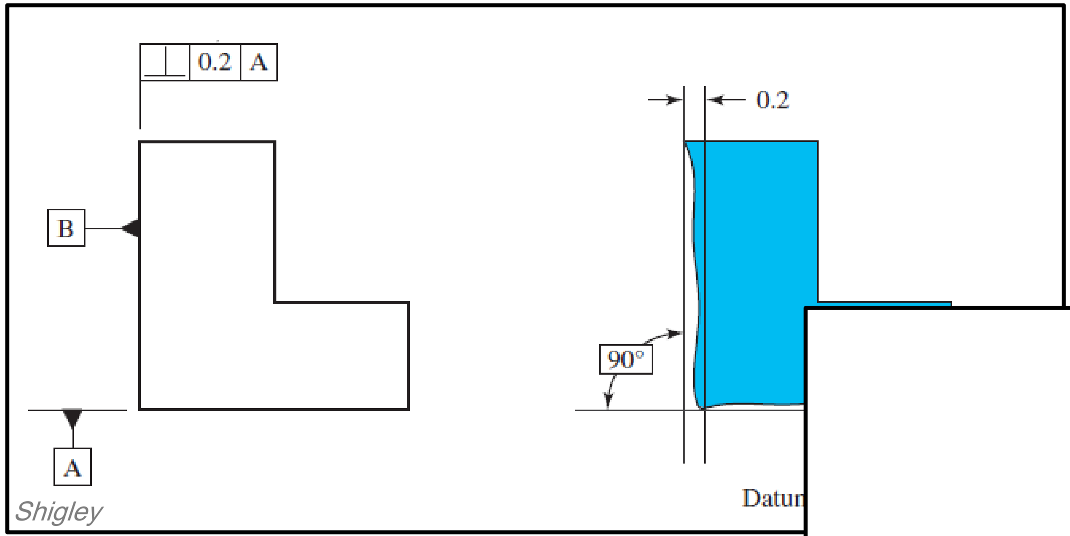
- Good for: controlling how well assemblies mate when put together
- Good for: controlling orientation of a bore/boss to a face, relation of faces, non-primary datums

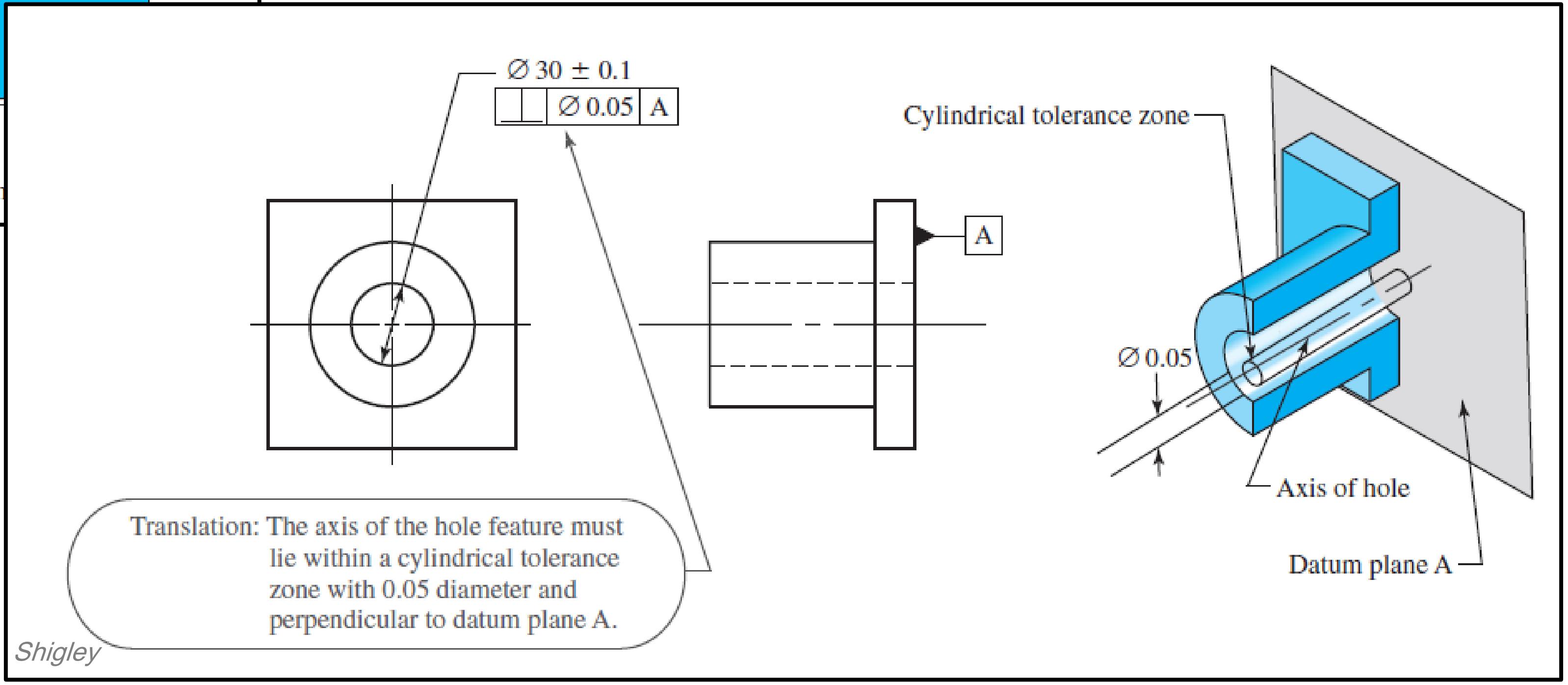


Shigley

Orientation – Perpendicularity &

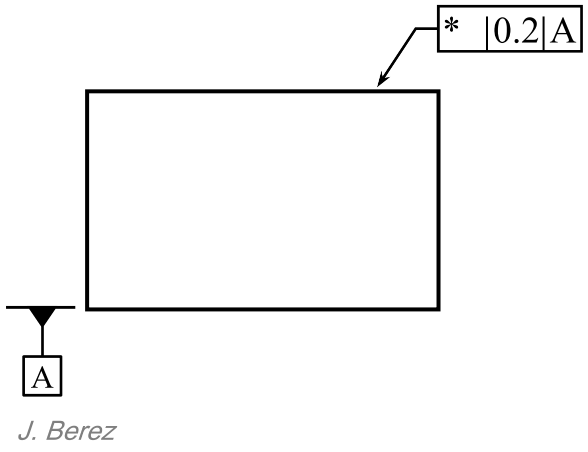
Applications to feature surfaces & axes

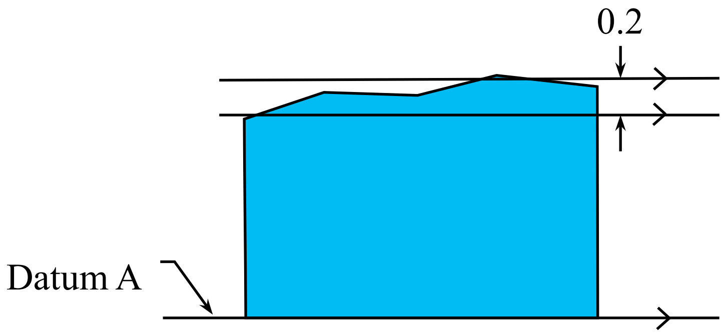


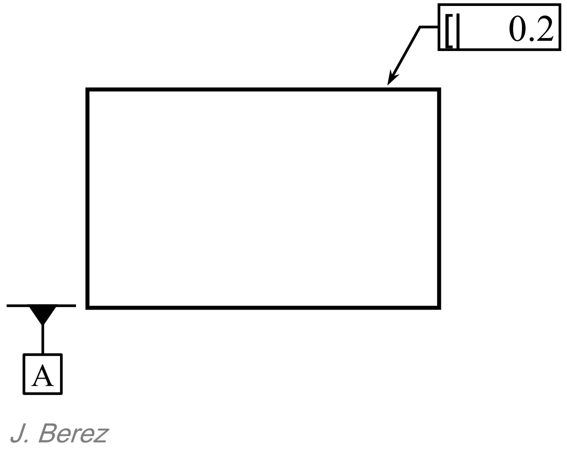


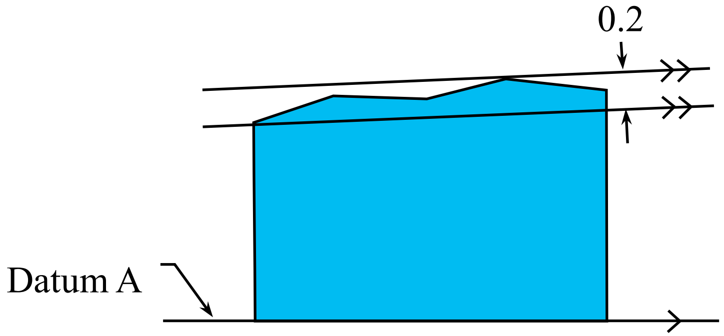
Orientation – Parallelism *

Note: Parallelism is NOT flatness – it has a datum reference





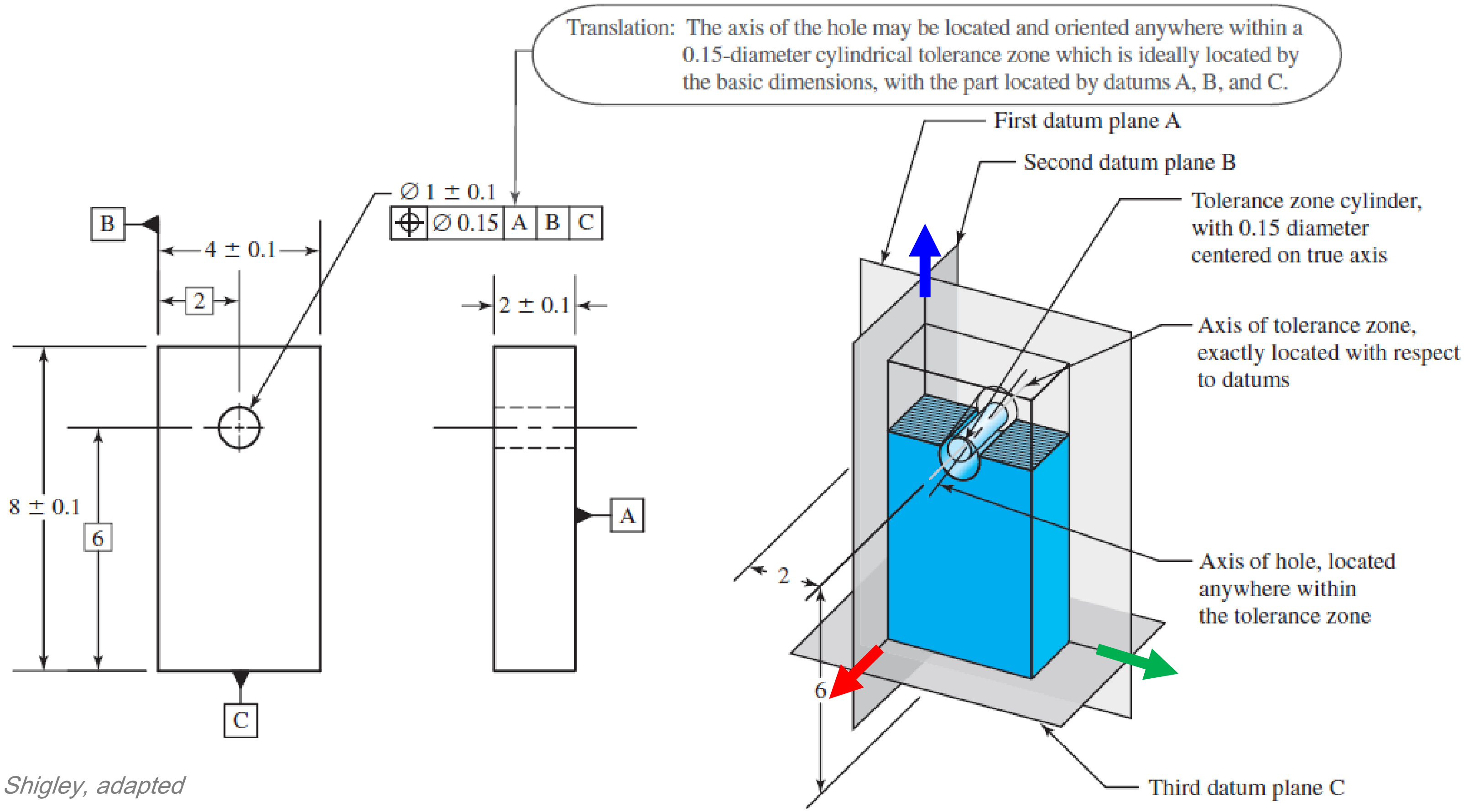




Position⌖

Position controls the location of a center point, axis, median plane or boundary of a feature of size relative to a datum or DRF

[√] Datum referencing [ ] Floating



Shigley, adapted

Basic dim.

1.00

Basic dimensions are theoretically exact.

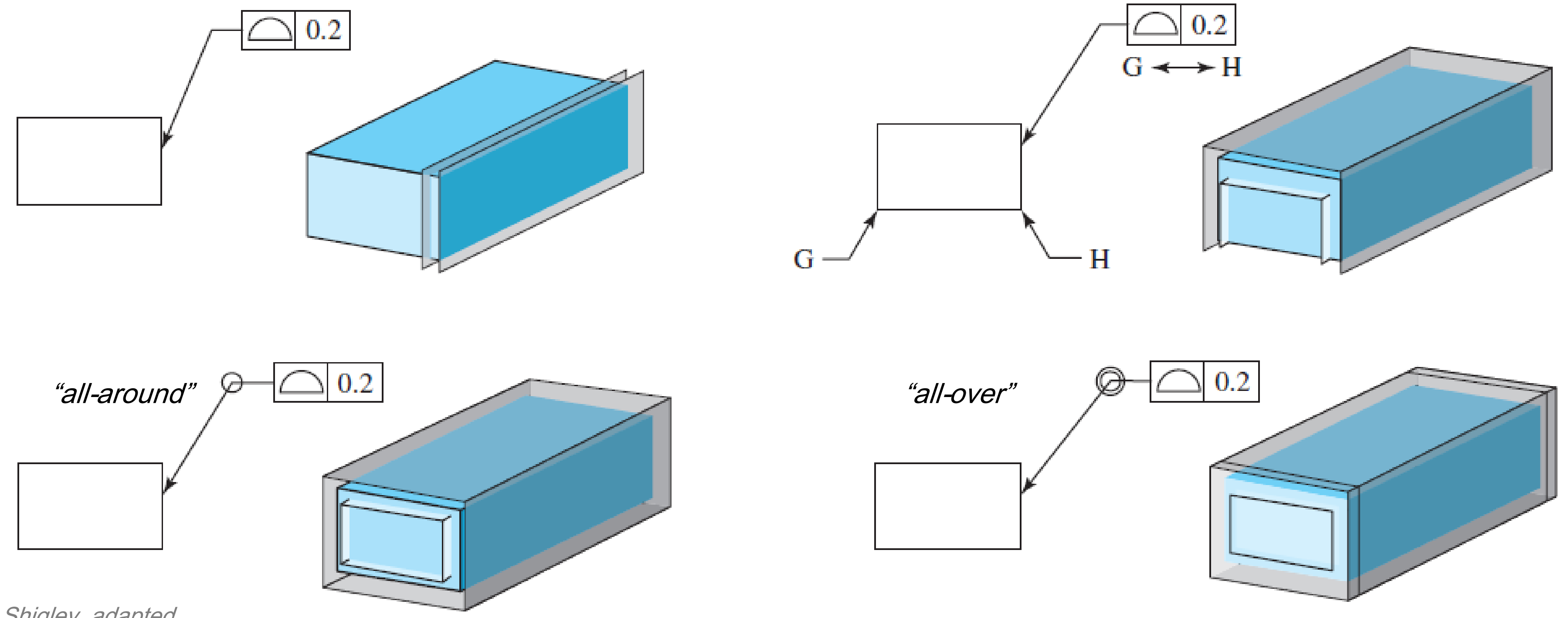
They do not have to originate from a datum on the drawing, but it is best practice

Profile! & profile of a surface

Profile and **profile of a surface** control the location and/or orientation and/or size of a feature

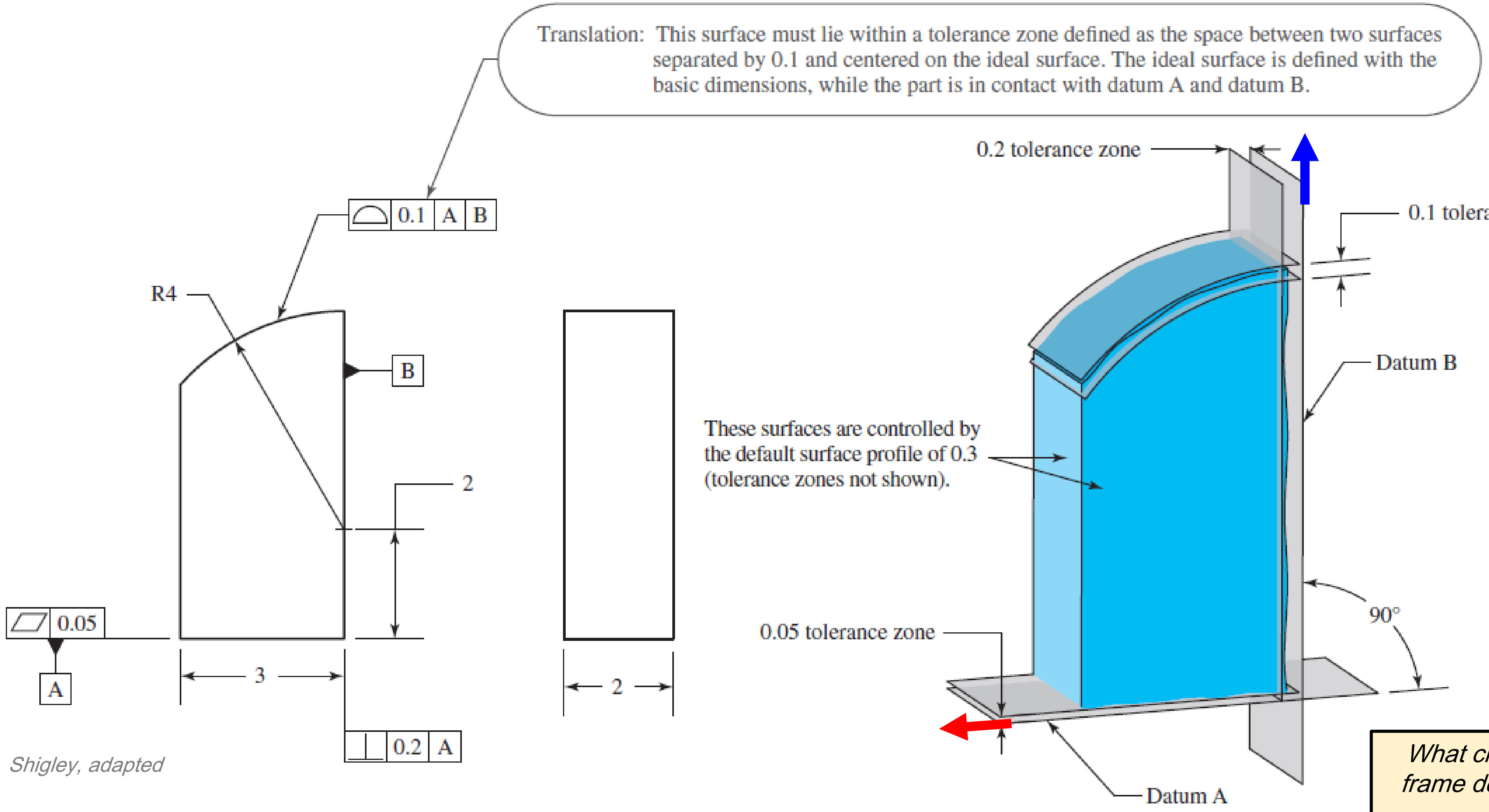
[√] Datum referencing [√] Floating (It depends!)

- Control a 2D cross section's or 3D surface's deviation from their nominal form (no datum reference), orientation and location (with datum references)
- Powerful, but easily abused



Shigley, adapted

Profile! & profile of a surface



Shigley, adapted

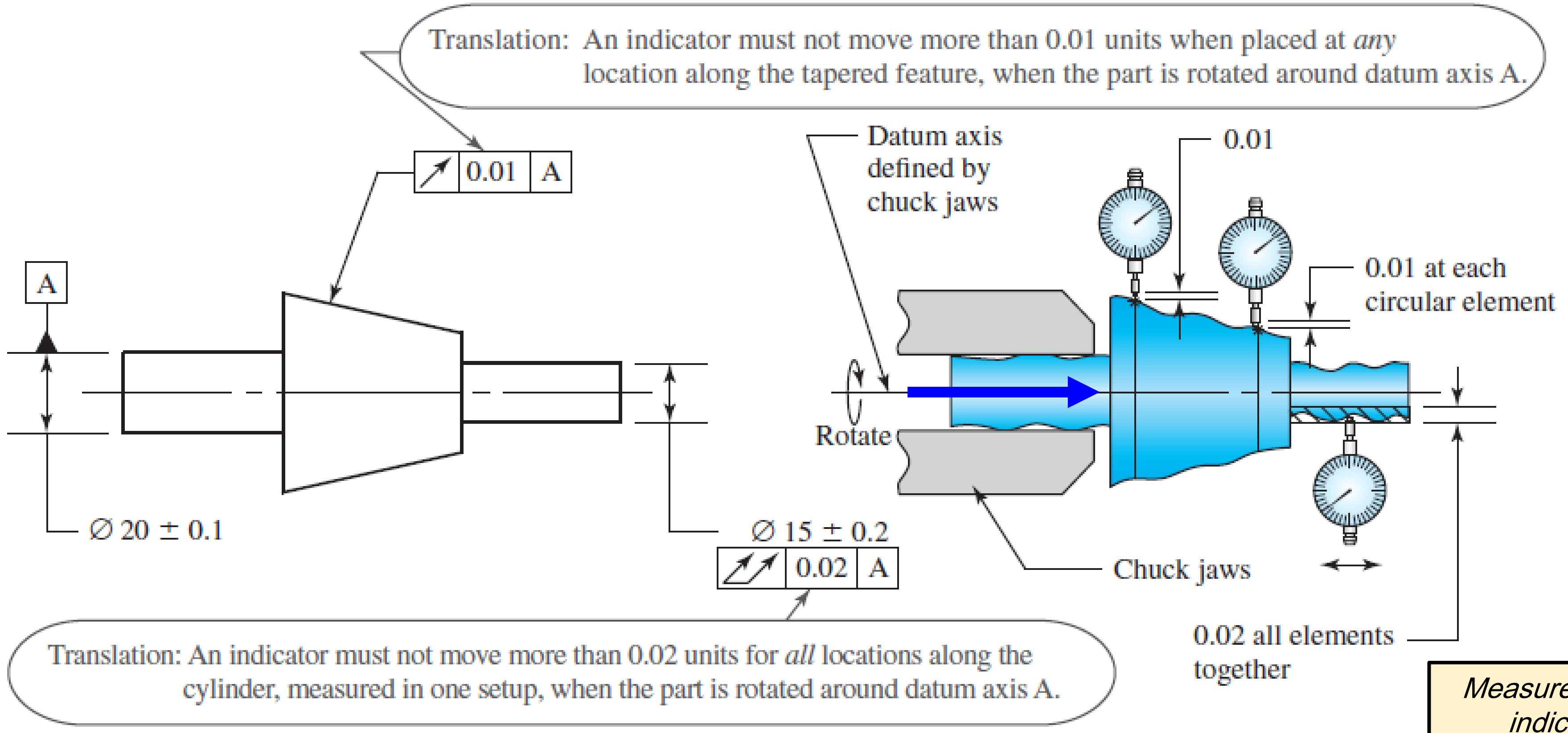
What changes if this control frame does not reference the -AB- DRF?

Runout, & total runout

Runout and total runout control the form, orientation, and location of surfaces relative to a datum axis

[√] Datum referencing [ ] Floating

- Use to control radially symmetric features on rotating assemblies
- Controls 'wobble' of rotating assemblies, controls balance, prevents binding



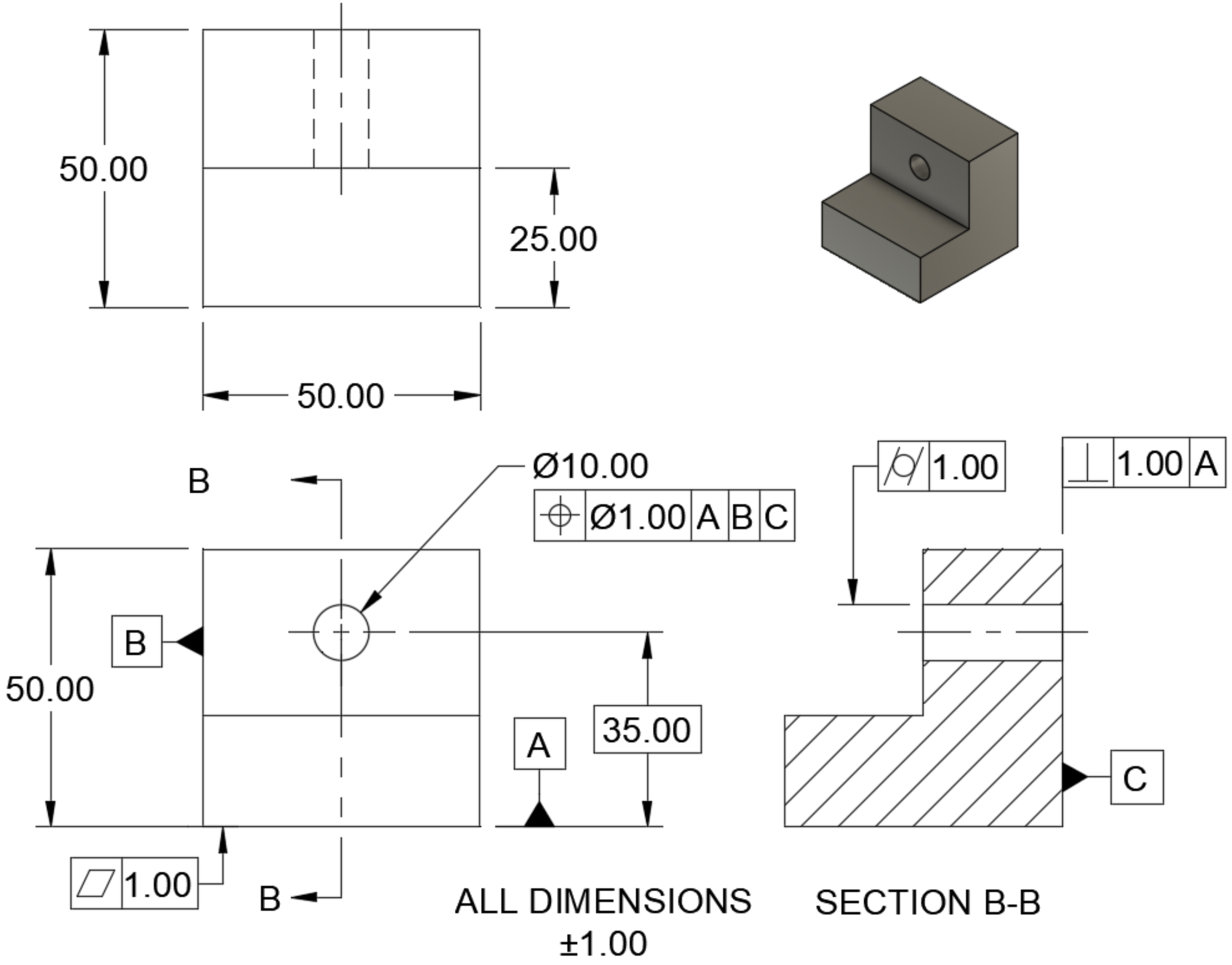
Shigley, adpated

*Measured with a as the "total indicator reading" **TIR***

Feature control frames Drawing conventions

Many acceptable ways to apply control frames to the drawing!

1. Use a leader pointing to the feature
2. Use an extension line from the feature
3. Associate with a feature of size



Geometric characteristics

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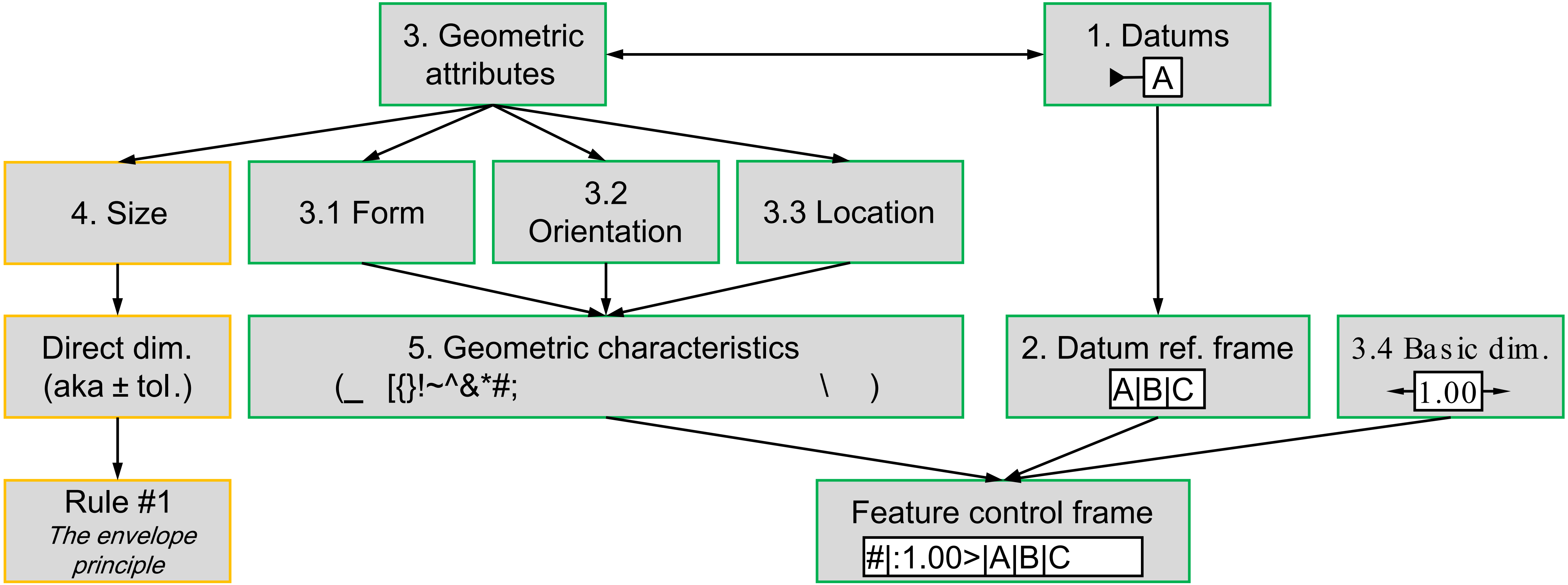
Geometric characteristic	Symbol	Geometric attribute	Datum referencing?
Straightness	_	Form	No
Flatness	[		
Circularity	{		
Cylindricity	}		
Profile of a line	!	Profile (*location, orientation, size, & form*)	Sometimes datum referencing
Profile of a surface	~		
Angularity	^	Orientation	Datum referencing
Perpendicularity	&		
Parallelism	*		
Position	#	Location	Datum referencing
Circular runout	;	Runout (*location of a cylinder*)	Datum referencing
Total runout	\		

Not too bad, right?

Features of size

Map of GD&T

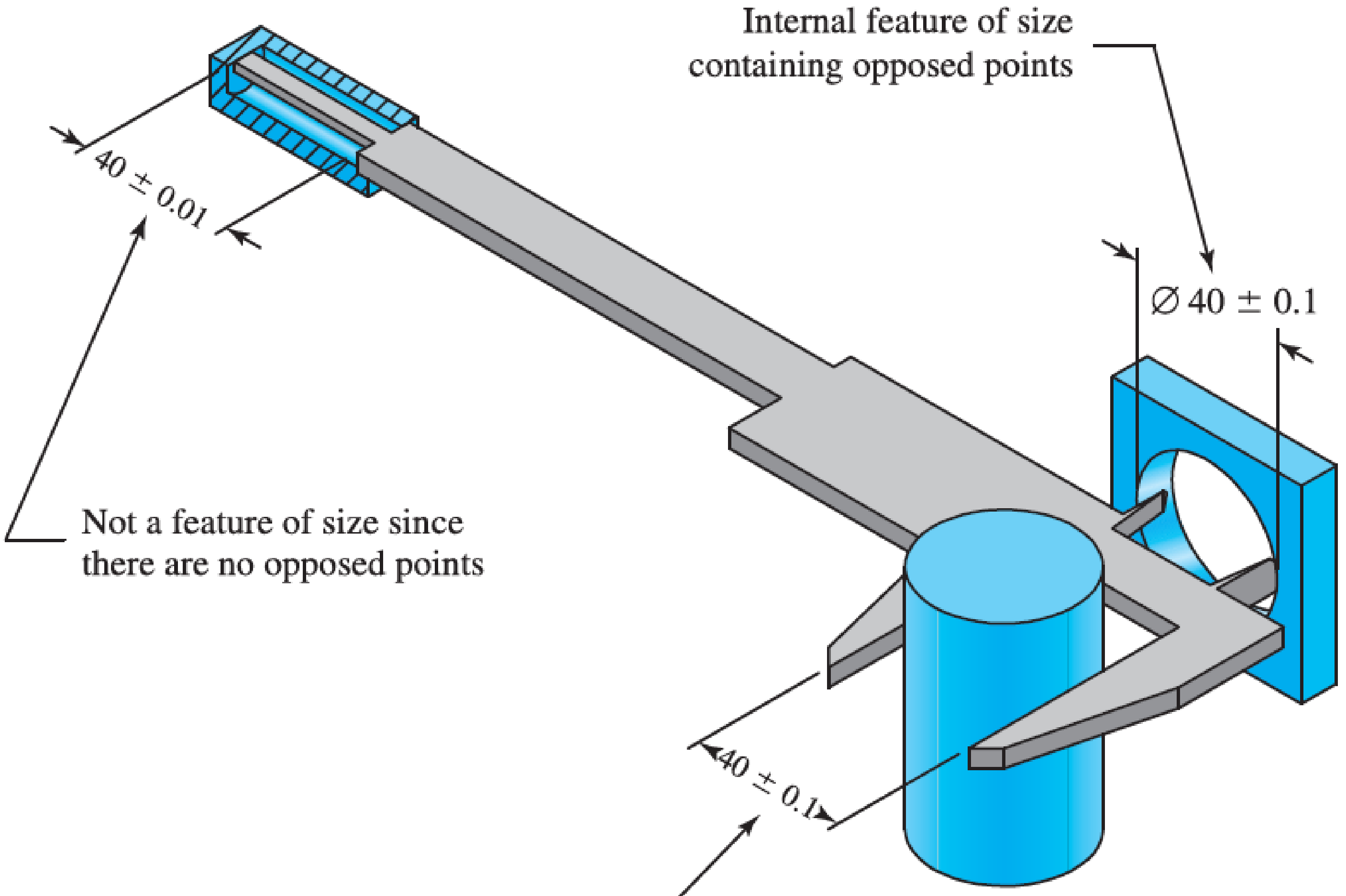


3. Geometric attributes
1. Datums
A
4. Size
3.1 Form
3.2 Orientation
3.3 Location
Direct dim. (aka ± tol.)
5. Geometric characteristics
(_ [{}!~^&*#; \ )
2. Datum ref. frame
A|B|C
3.4 Basic dim.
1.00
Rule #1
The envelope principle
Feature control frame
#|:1.00>|A|B|C

Features of size

Features of size have <u>opposing surfaces</u>

- The opposing surfaces may be externally or internally facing
- Features of size may use plus/minus tolerancing
- Not a feature of size…
  - Depth
  - Position



Shigley

Rule of thumb: If you can put caliper jaws around or inside it, it is a feature-of-size

Direct dimensioning styles

Georgia Tech

Fig. 2-1 Limit Dimensioning

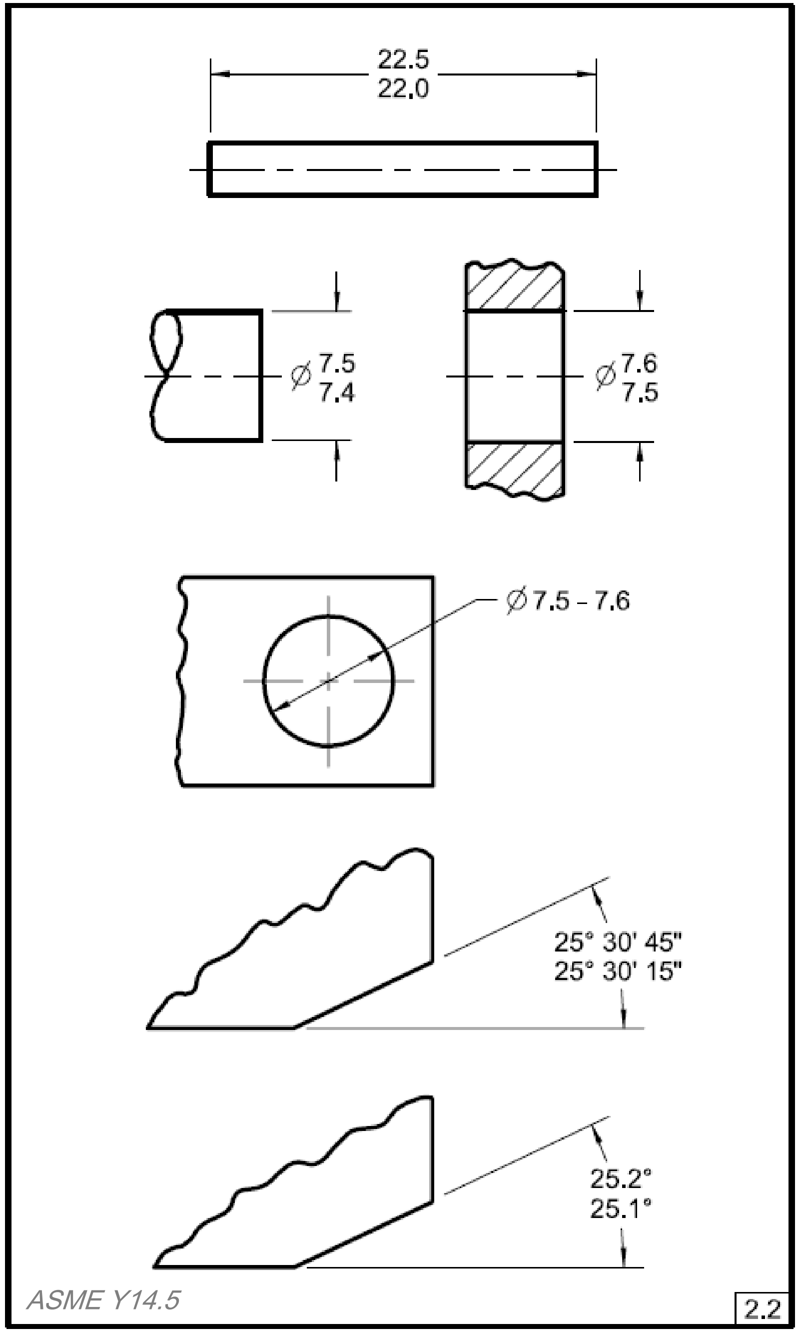


Fig. 2-2 Plus and Minus Tolerancing

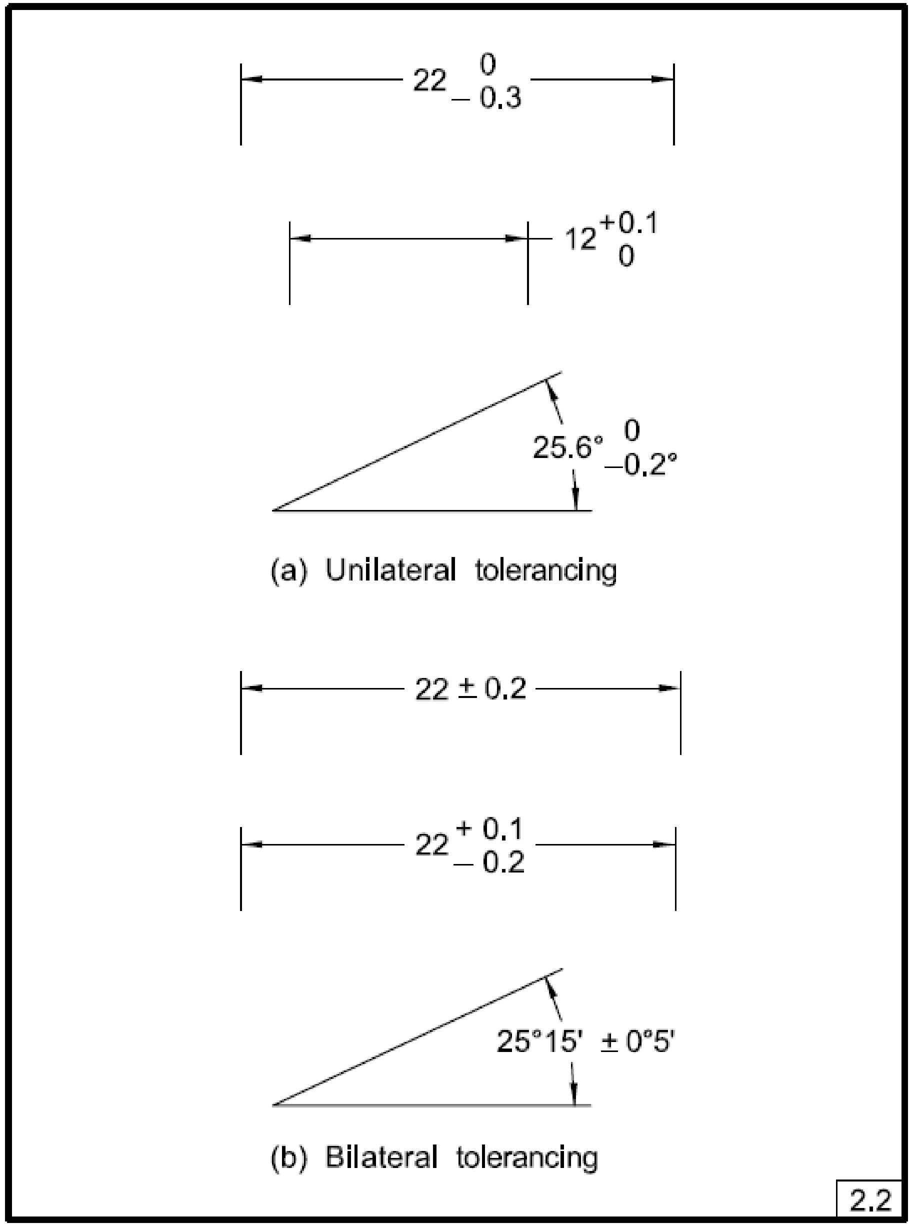
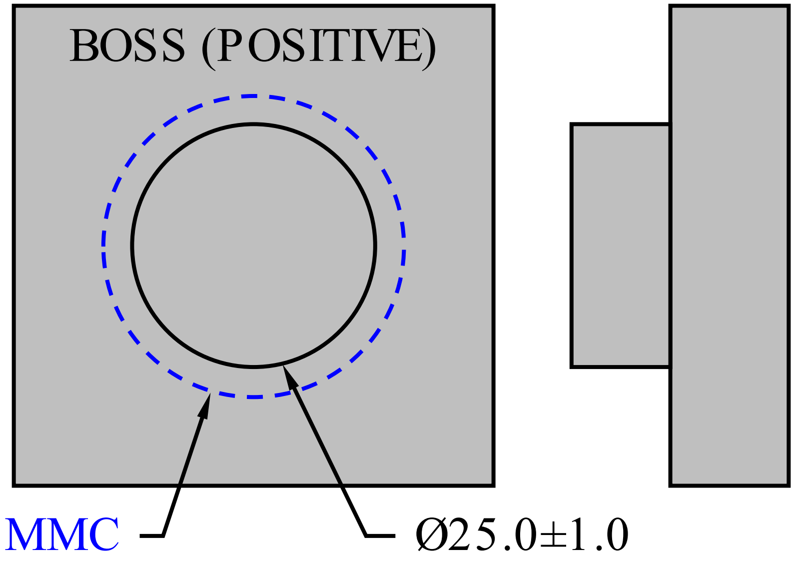


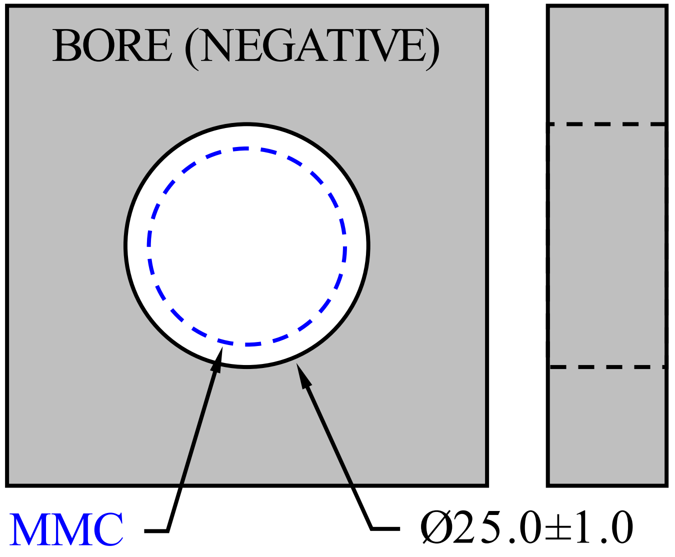
Fig. 2-3 Indicating Symbols for Metric Limits and Fits

Maximum & minimum material conditions

- **Maximum material condition** – The feature condition which creates the maximum amount of material.
- **Least material condition** – The feature condition which creates the minimum amount of material



*MMC:*Ø26.0
*LMC:*Ø24.0

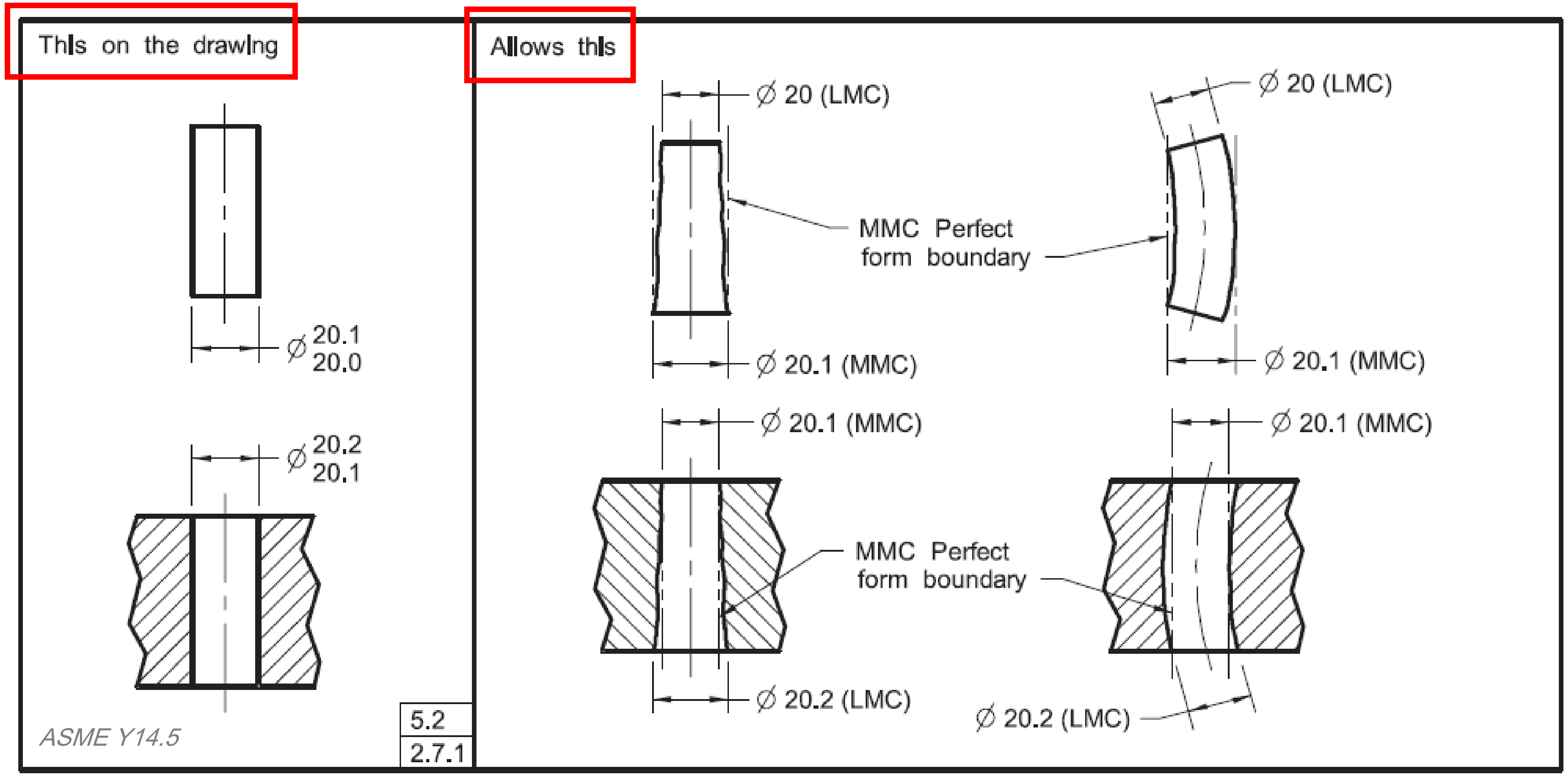


*MMC:*Ø24.0
*LMC:*Ø26.0

Rule #1– The envelope principle

"The form of an individual regular feature of size is controlled by its limits of size"

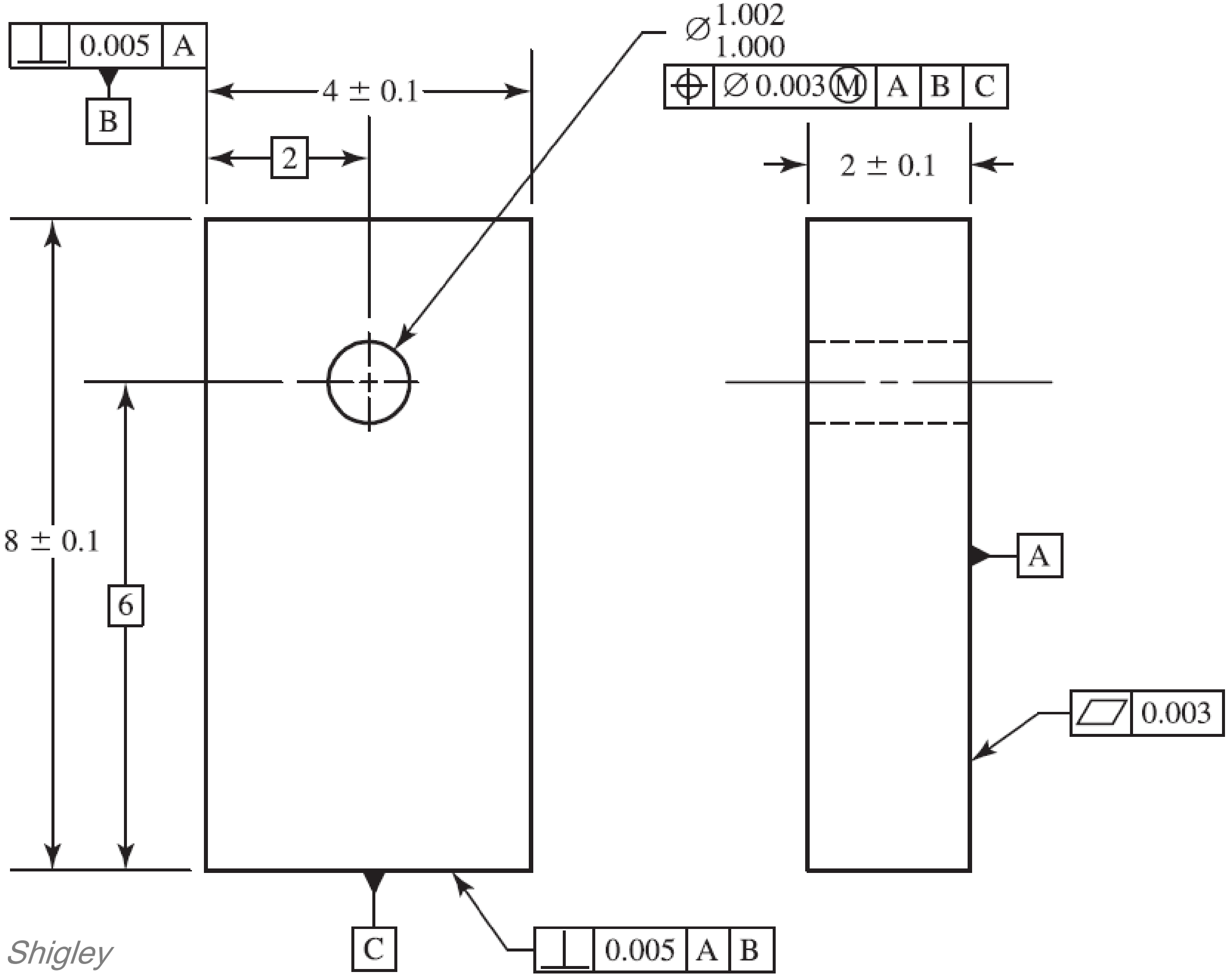
- *The MMC acts like an envelope, therefore a feature of size inherently has form control.*
- *Form control can be additionally refined via*_, [, {, }, !, ~



GD&T Summary

Why use GD&T/GPS?

- **Functional** – related to component functionality
- **Unambiguous** – clearly defined and standardized
- **Inspectable** – specifications relate to inspection methods



Shigley

Resources

Source standards

- ASME Y14.5-2018
- ISO TC 213 (E.g., ISO 1101:2017)

Texts & reference books

- "Shigley's Mechanical Engineering Design", 10th Ed. or newer, Chp. 20
- Machinery's Handbook, 26 Ed. or newer
  - Note that some resource may be slightly out of date
- Professional development through societies or for-profit consulting

ASME Y14 landing page
https://www.asme.org/codes-standards/y14-standards

ISO TC 213 landing page
https://www.iso.org/committee/54924.html

SME Tooling U Intro to GD&T
https://learn.toolingu.com/class/140210

2023 Digital Manufacturing Challenge powered by SME's DDM Advisory Team

Thank you for your time!

Questions?

Seminar 2 teaser

Part1: Established the core fundamental concepts of GD&T

Part 2: Apply them! **Be sure to attend, Feb. 17th 12pm Eastern!**

GD&T check list for designers & walk-through	Digital/AM examples of product specification	DRFs & CAD-Actual measurements