A Self-Reflective Design Study of Three Visio and Visio-Haptic Artifacts For Use in Mechanical Engineering Design Education

MSc Thesis Defense

James Dillon Sykes, P.Eng.

March 24th, 2023

Faculty of Graduate Studies

University of Manitoba

Welcome

Chair

- Dr Jason Morrison (Price Faculty of Engineering)

Committee

- Dr Jillian Seniuk Cicek, Advisor (Price Faculty of Engineering)
- Dr Marcia Friesen, Co-Advisor (Price Faculty of Engineering)
- Dr Zana Lutfiyya (Faculty of Education)
- Dr Philip Ferguson (Price Faculty of Engineering)

Guests

Overview

Introduction

Jim (James) Dillon Sykes, P.Eng

- B.Eng ‘93 Carleton University
- P.Eng (ON 1997-current, MB 2015-2022, BC 2013-2015)
- 12 years industry employment
- 17 years instructing & consulting GD&T in industry
- 6 years EiR – Price Faculty of Engineering (2016-2021)

Motivations

A Self-Reflective Design Study of Three Visio and Visio-Haptic Artifacts for Use in Mechanical Engineering Design Education

Carleton University, Undergraduate Studies

- Heavy emphasis on theory
- **Absence of practical design skills / knowledge**
    - **Tolerancing**
    - **Materials selection**
    - **Design esoterica**
    - **Practical thermodynamics & heat transfer**
- Strong systems thinking
- Rudimentary drafting skills
- Strong programming skills

Felt unprepared for design practice

Industry Employment

- **Recognized that Engineering Degree did little to prepare for design application**
- Informal apprenticeship
- SME (DFM, tooling, container threads, documentation, GD&T, …)
- Devil's Advocacy
- Design Coach
- Unconventionality
- Fixer

Confirmed undergrad degrees don't prepare for design practice

Recognized design esoterica not taught in school

Understanding of magnitude can be taught

Instructional Experience

- GD&T in industry (2006 – present)
- EiR with Price Faculty of Engineering (2016-2021)
    - Advanced Graphical Communications (AGC) (2016-2021)
    - Mechanical Design Skills Workshop (MDSW) (2020)
    - Advise Mechanical Capstone teams
    - Advise UMSAE & Coach design, DFM, DFA
    - Coach EngComm teams (2018-2021)
- Coach EngComm teams (2022-2023)
- Coach Engineering Competition teams (2023)

Industry feels new grads unprepared for design practice

Faculty largely indifferent to industry voice

Absence of artifacts to teach tolerancing

Industry no longer has skillsets to teach design practice to new hires

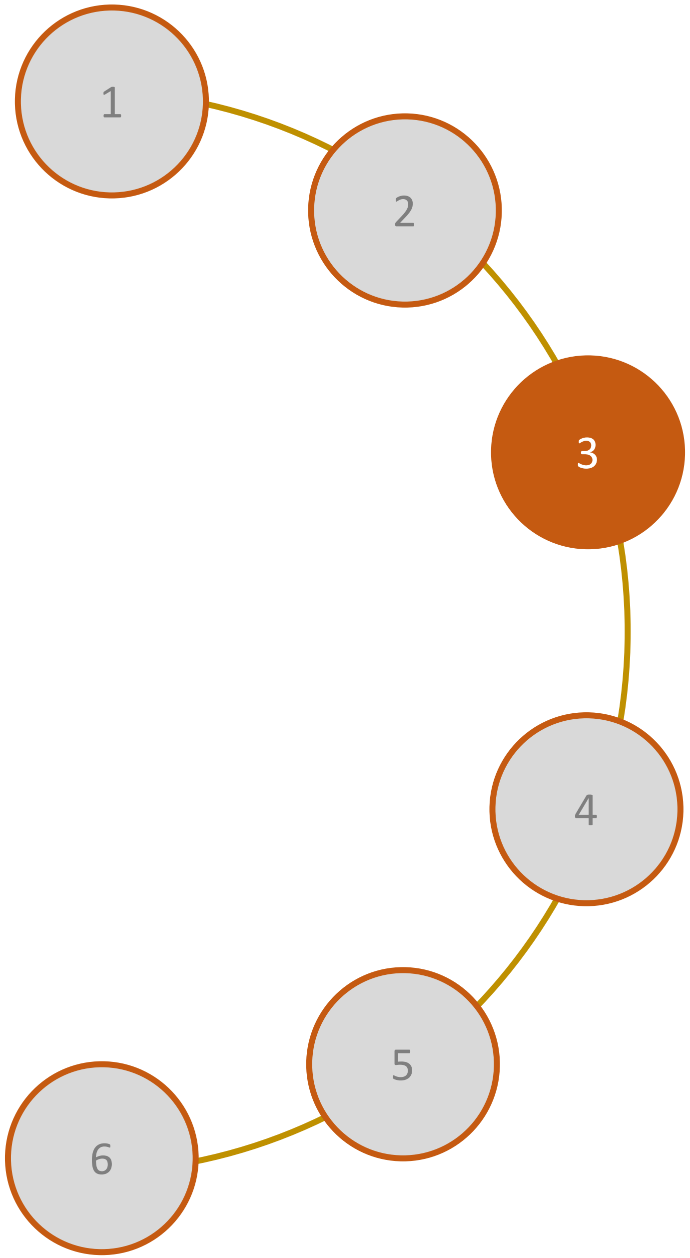
Research faculty no longer has skillsets to teach design practice

University of Manitoba, Graduate Studies

Focused Studies On Teaching and Learning Engineering Design

Need ***academic credentials*** for acceptance as a voice of change

Need to change how mechanical engineering design is taught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2
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6

Design Esoterica is a broad field describing ***specialized design knowledge*** that is not included in core mechanical engineering design courses.

Examples of Mechanical Engineering Design Esoterica:

- The use of chamfers, fillets, rounds
- Tolerance selection
- Standardized undercuts and tooling reliefs
- Material grade selection
- Terminologies
- Surface finish selection
- Metallurgical processes
- Design for manufacturing / assembly
- **…**

Design Esoterica is essential to a complete product specification.

Gap Identification

My Journey of Learning Mechanical Engineering Design Esoterica

University Education

- Drafting
- ◆ **Tolerance specification**

Practical **Manufacturing** Education by **Mold Shop**

- ◆ **Tolerancing (first artifact)**
- Common machine processes
  - Milling
  - Turning
  - Grinding
  - EDMing
  - Surface finishing
  - Gundrilling
  - CNC profile milling
- Uncommon manufacturing processes
  - 3D pantography
  - Thread milling
  - Peening
- Terminologies
- Inspection / Metrology

Practical **Design** Education by **Mold Shop**

- ◆ **Tolerancing (first artifact)**
- Design Features
  - Fillets
  - Rounds
  - Chamfers
  - O-ring grooves
  - Venting
  - Threads (containers)
  - Surface finishes
  - Cooling
  - Electrodes

Practical **Design** Education by **Senior Designers**

- Mold Design
  - Injection-blow
  - Two-stage stretch blow
  - Extrusion-blow
  - Injection
  - Blow
  - Metal Powder Injection
- Hot Runner Design
- Post-mold robotics
- Mold refurbishment

Practical **Design** Education by **Self**

- Advanced electrodes
- Form tools
- Mold cooling
- ◆ **Fits-basis tolerancing**
- Surface finish specification
- CAD (modeling, drafting)
- Standardization
- Threads (advanced)

Specialized **Design** Education by **Specialists**

- ◆ **GD&T**
- Advanced freeform modelling
- Design of experiments

3 Gap Identification

Tolerancing is at
the heart of
what I instruct

TOLERANCING

ASME Y14.5 GD&T

FITS-BASIS ANSI / ASME B4.2

Standards establish theory

Fits-basis tolerancing applies theory in a given context, but remains theoretical due to micron-scale tolerance magnitudes

Cognizance of tolerance magnitudes necessitates experiential artifacts

An ***Artifact*** is *an item made by skill and used as a teaching example*.

Gap Identification

Visual comparisons of ***identifiable*** and ***relatable*** items can help establish cognizance of magnitude

1 sheet = 10µm (0.01mm)

CC

Issue 1: Human vision threshold is 30-40µm

Issue 2: Clearance Fit gaps are as small as 2µm

CC

3

Gap Identification

Tolerancing is at
the heart of
what I instruct

TOLERANCING

ASME Y14.5 GD&T FITS-BASIS ANSI / ASME B4.2

Standards establish theory

Fits-basis tolerancing applies theory in a given context, but remains theoretical due to micron-scale tolerance magnitudes

Cognizance of tolerance magnitudes necessitates experiential artifacts

Commercially-made micron-scale artifacts are not available

Designs for micron-scale artifacts are not available

Gap Identification

Gap Identification

Absence of artifacts for developing cognizance of the magnitude of micron-scale tolerances as experienced in ASME B4.2 Fit-classifications.

Absence of recognition of the contributions of a design engineer's lived experiences in the design process.

Research Process

Study Type

A Self-Reflective Design Study

A hybrid of engineering design study and self-reflective study examining the role of lived experience behind the design thinking of three instructional artifacts.

Research Process

A Self-Reflective Design Study

Study Purpose

To design three visio and visio-haptic artifacts for use in teaching dimensional tolerancing with the intent of developing cognizance of Fit-basis tolerances and their micron-scale magnitudes.

To convey through a combination of self-reflective study and conventional academic description, the humanity and collected experience behind the design evolution of the three instructional artifacts.

Study Methodologies

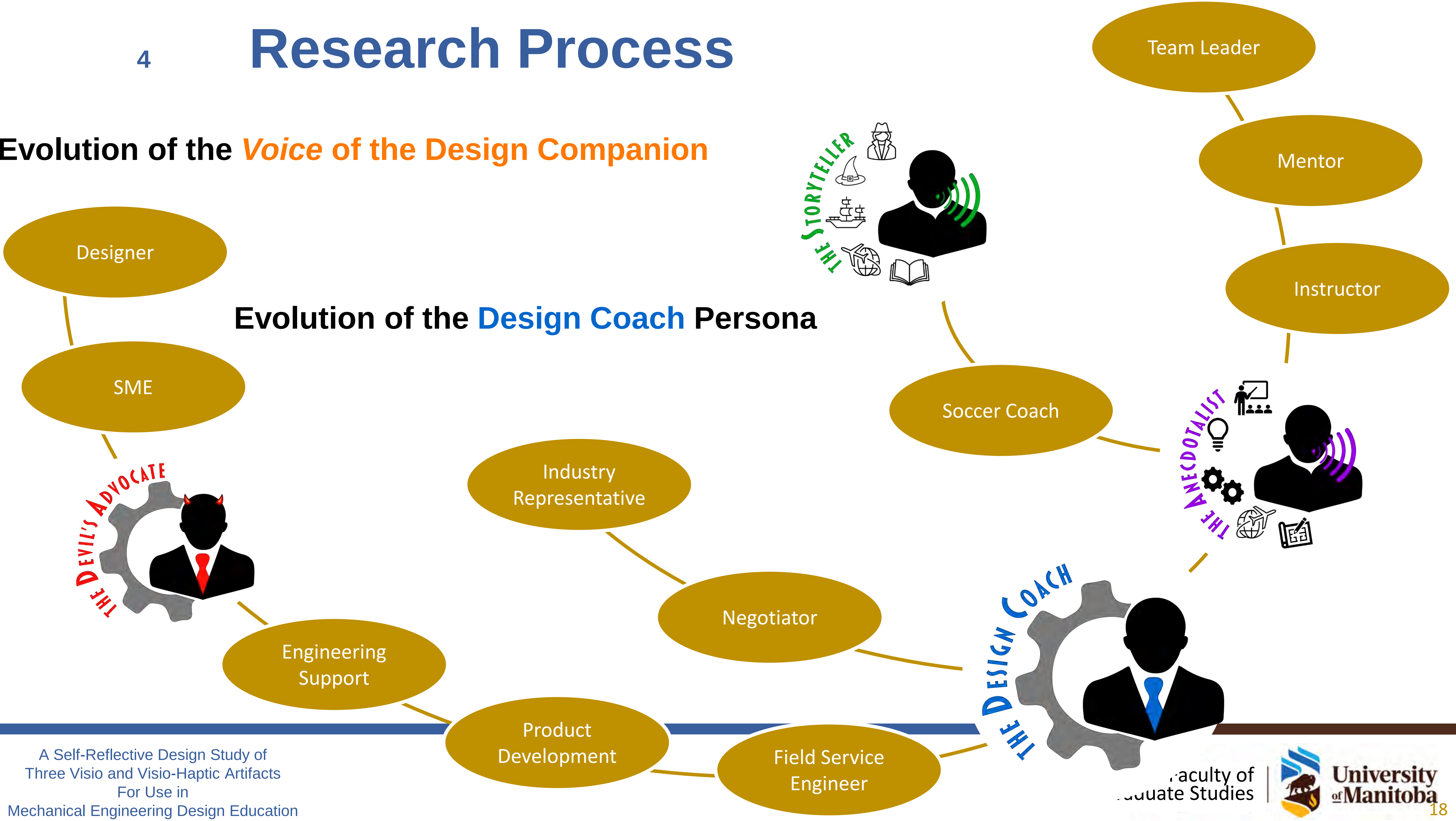
Six-element methodology including design intent, research in human visio- and visio-haptic capabilities, design considerations, iterative ideation, final design, and discussion of artifacts.

A self-reflective study invoking the rhetorical *Voice of the Design Companion* to convey the evolution of design thinking, and to describe the evolution of artifacts.

Research Process

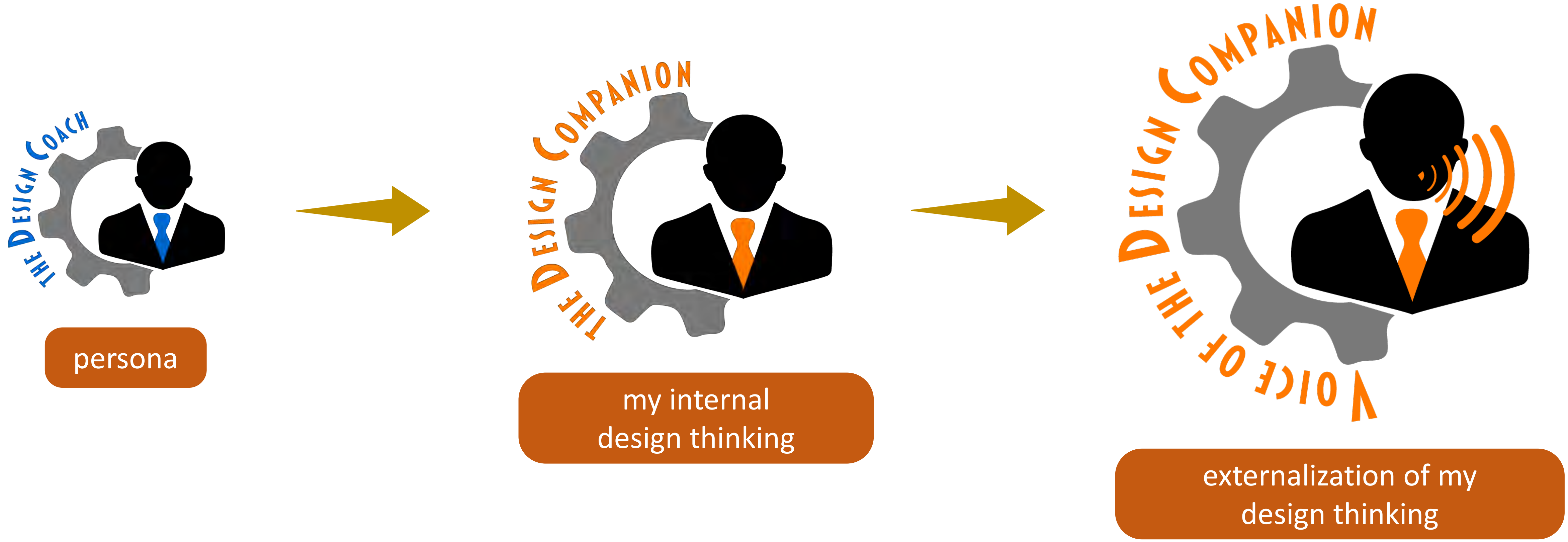
Evolution of the *Voice* of the Design Companion

Evolution of the Design Coach Persona



Research Process

Evolution of the rhetorical *Voice of the Design Companion*



4 Research Process

Mechanical engineering design is a personal experience

Lived experience is involved in my mechanical engineering design.

- Engineering education
- Professional engineering experience
- Personal experiences (positive & negative) shape & shadow how I see, interact with, and experience ***everything***
- ***How can lived experience, as it affects mechanical design engineering, be communicated in an academic work?***

Communication style is personal

My natural writing style is as I teach, casual and using anecdotes.

- Anecdotes are a very personal communication. I am very much a part of the anecdotes that I share
- With anecdotes, I don't just tell you a story, I try to engage you in the story, making it a personal experience for you
- Anecdotes can effectively convey lived experience, which adds credibility for the listener

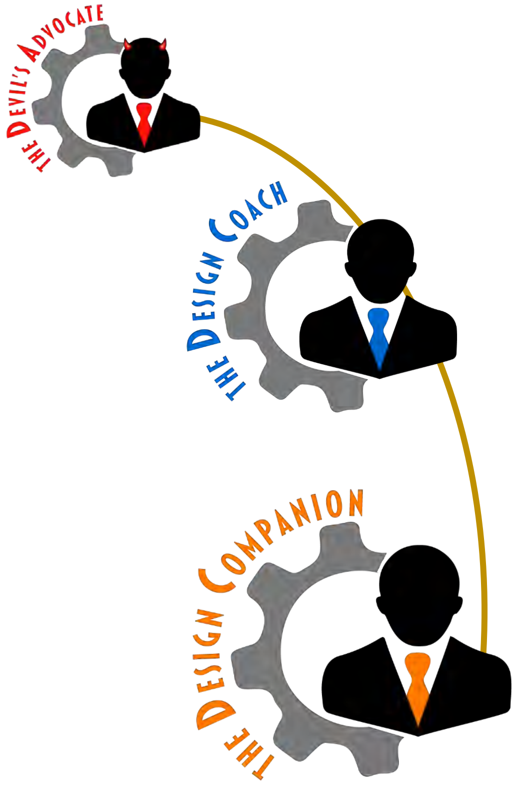
Conventional engineering academic writing is **not** personal

Qualitative research methodologies recognize the value of alternative forms of communication.

4

Research Process

How can lived experience, as it affects mechanical design engineering, be communicated in an academic work?



Precedence for including the voice of the researcher

Self-study research recognizes that the researcher is inherently a part the subject being studied, and allows the use of the voice of the researcher in the reporting.

Shawn Wilson, an Indigenous Scholar, complemented conventional academic writing with his personal voice as a way of reflecting Indigenous Peoples' traditions of storytelling. He conveyed his voice in written form by addressing his words to his sons.

My Use of a rhetorical voice

- Allows a non-academic voice
- Allows use of anecdotes to explore how lived experiences contribute to design thinking

*The **Voice of the Design Companion** communicates with **Aubrey**, an aggregate of AGC students*

Research Process

Tolerance as Design Esoterica in Mechanical Engineering Education

- Design Esoterica in Mechanical Engineering Curricula
- Tolerancing as Esoterica in Mechanical Engineering Design
- Engineering Education – A Brief History for Context
- Teaching and Learning of Dimensional Tolerancing
- Experiential Learning of Tolerancing
- Approaches to Teaching GD&T
- The Focus of Research in Tolerancing
- Visual and Somatosensory Perceptions of Small-Scale Magnitudes
- The Engineering Research Focusing on Haptic and Visio-Haptic Inputs

Use of Artifacts in Mechanical Engineering Design Education

- Use of Visual Artifacts in GD&T Instruction
- Design and Use of Artifacts in Mechanical Engineering Education
- Artifacts as Instructional Aids in Mechanical Engineering Education
- Considerations for the Design of Artifacts for Mechanical Engineering Education
- Considerations for Use of Physical Artifacts in Instructing Mechanical Design Esoterica

Visio refers to vision-based input.

Haptic refers to touch-based input.

Visio-haptic refers to a combination of visual and touch input.

Three Visio & Visio-Haptic Instructional Aids

1. A **visual comparison graphic** of items that are both identifiable and relatable in the size range of 0.5µm to 1000µm

2. A primarily **haptic demonstrator** of the five clearance-Fit-Classes based on ASME B4.2 Preferred Fits
   - loose running
   - free running
   - close running
   - sliding

   Transition and interference fits in ASME B4.2 are static engagements of components, providing no sensory distinction.

1. A visio-haptic demonstrator of micron-scale magnitudes from 0.5µm to 1000µm

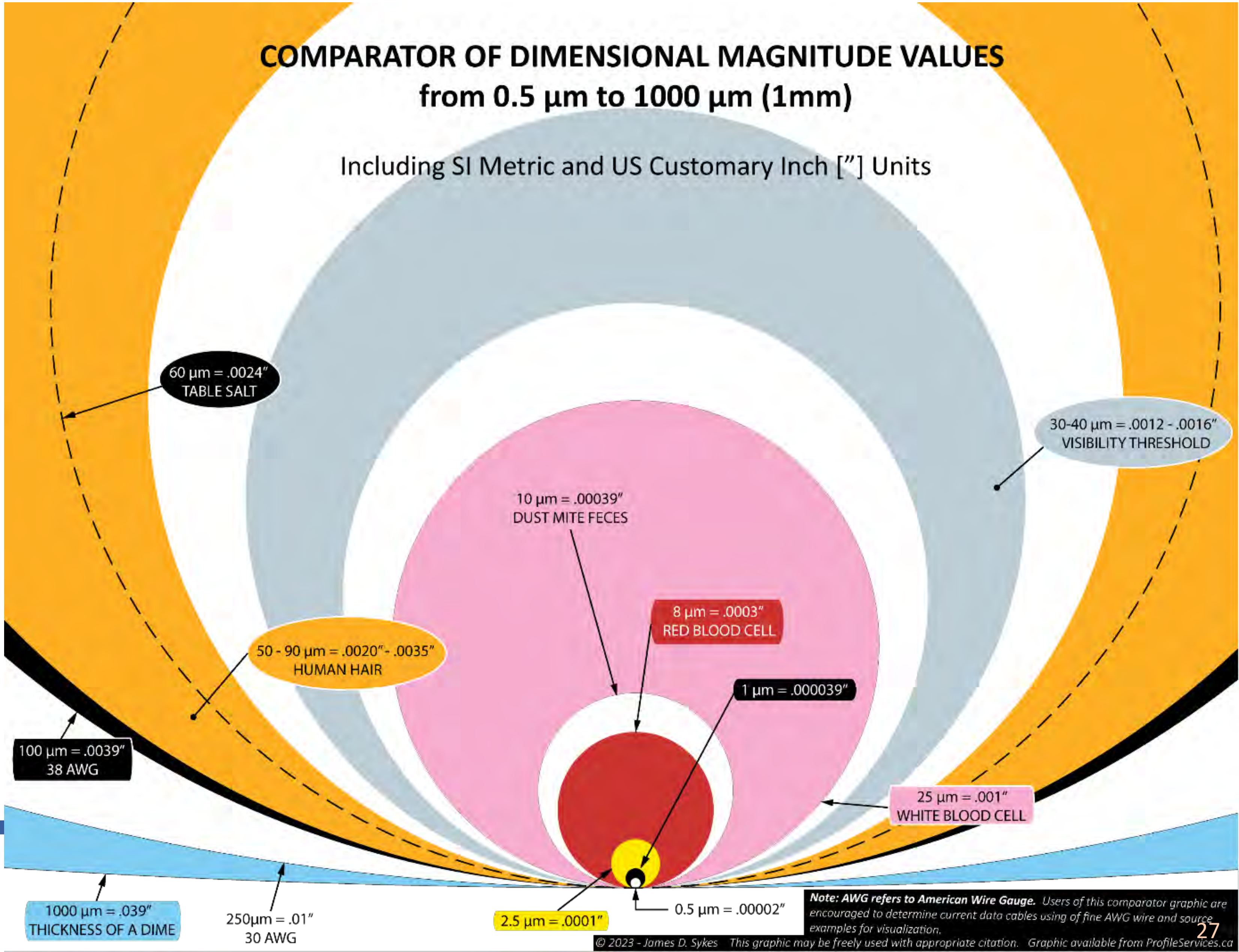
Outcomes Artifact Design

Artifact #1 A Visual Comparison Graphic

Outcomes Artifact Design

Artifact #1 A Visual Comparison Graphic

A **visual comparison graphic** of items that are both ***identifiable*** and ***relatable*** in the size range of 0.5-1000µm (0.001-1mm)



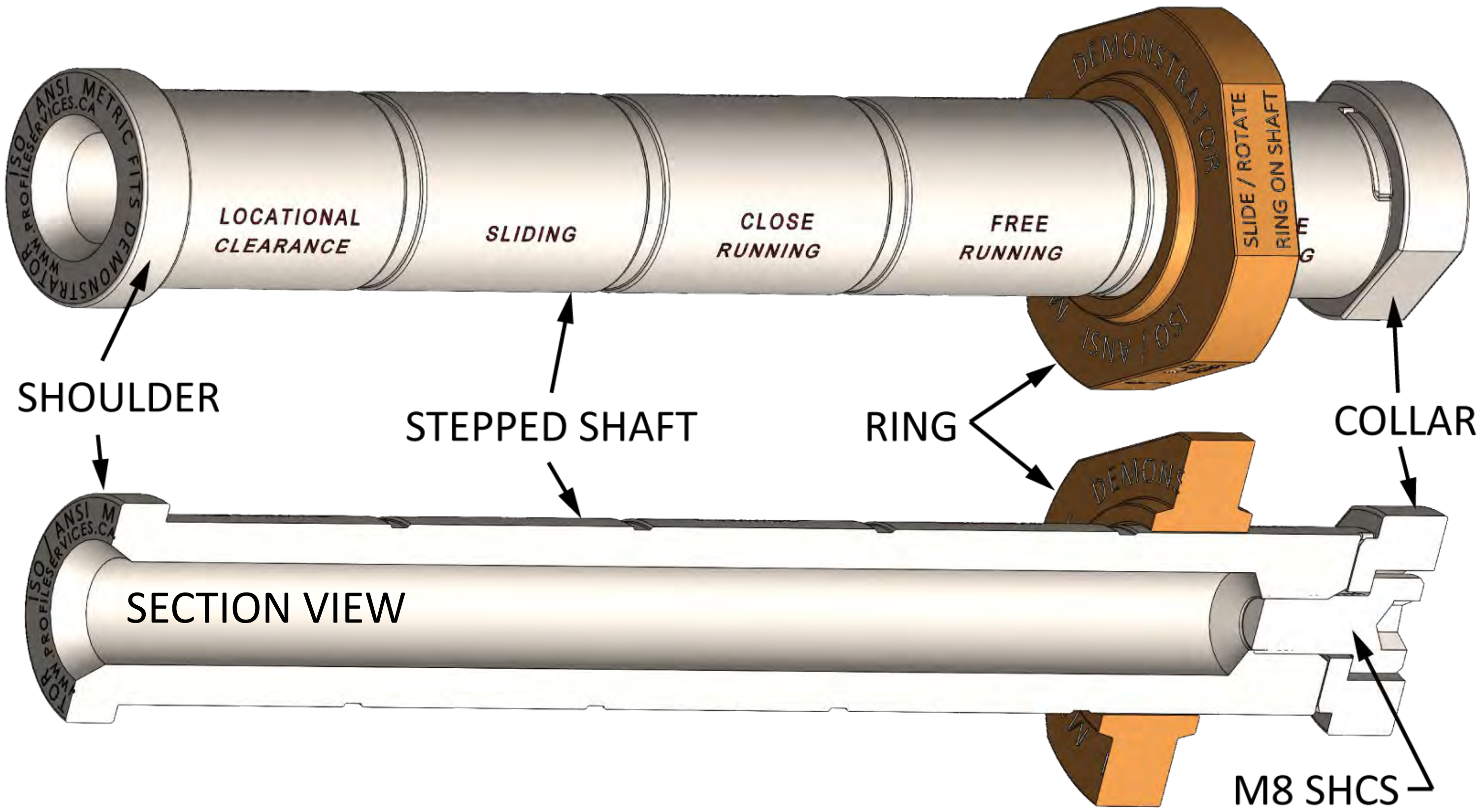
Outcomes Artifact Design

Artifact #2 A Primarily Haptic Demonstrator of Clearance Fit-Classifications (per ASME B4.2)

Outcomes Artifact Design

Artifact #2 A Primarily Haptic Demonstrator of Clearance Fit-Classifications (per ASME B4.2)

Overall Length:	205mm
Overall Ø:	50mm
Overall Mass:	680 gram [1.5 lb]
Nominal Shaft Ø:	25mm
Segment Length:	34mm
Collar/Shoulder Ø:	30mm
Ring Outer Ø:	50mm
Ring A/F:	□45mm
Ring Thickness:	15mm
Ring Mass:	107 gram [0.25 lb]

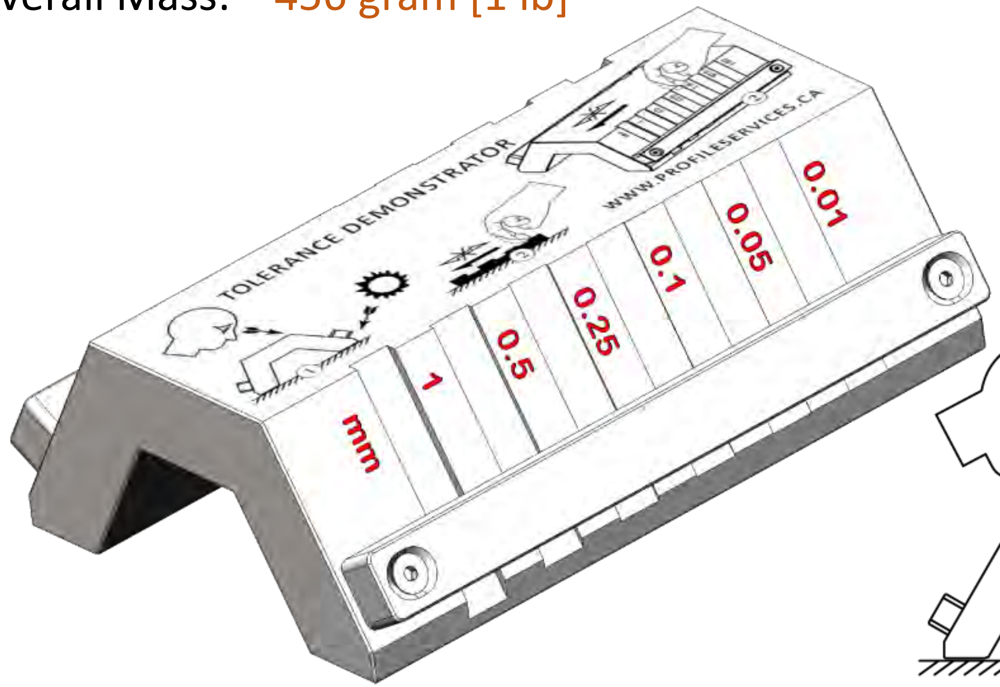


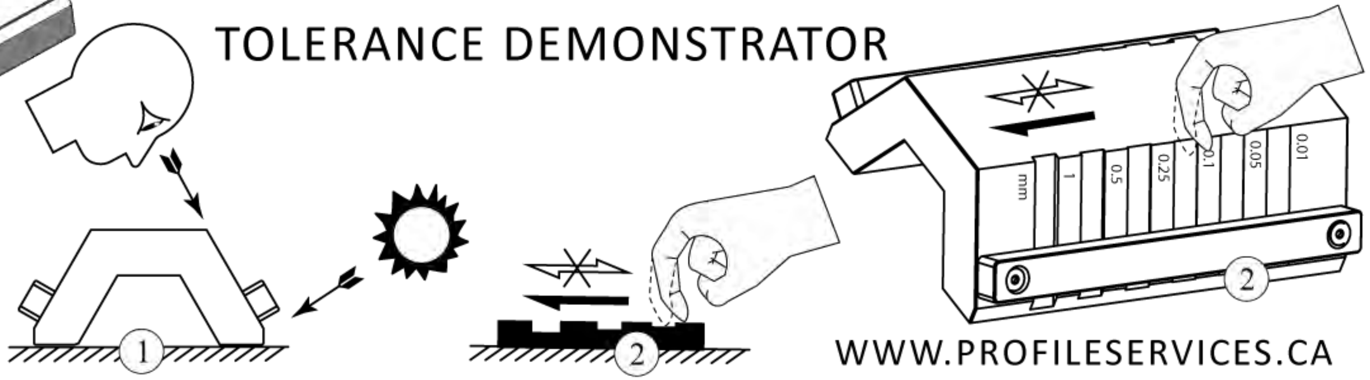
Artifact #3 A Visio-Haptic Demonstrator of Micron-Scale Magnitudes

5 # **Outcomes** Artifact Design

Artifact #3 A Visio-Haptic Demonstrator of Micron-Scale Magnitudes

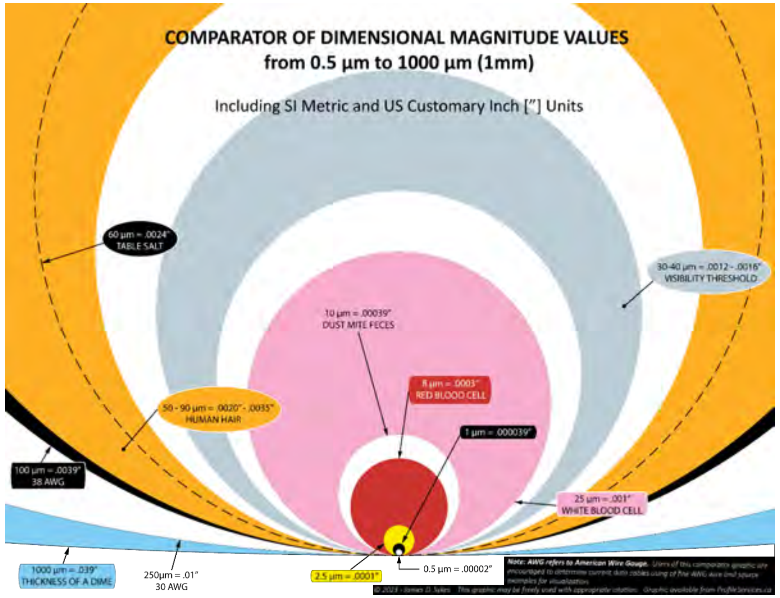
Length: 80mm
Width: 57mm
Height: 25mm
Overall Mass: 456 gram [1 lb]





Outcomes Artifact Design

Three Visio & Visio-Haptic Instructional Aids

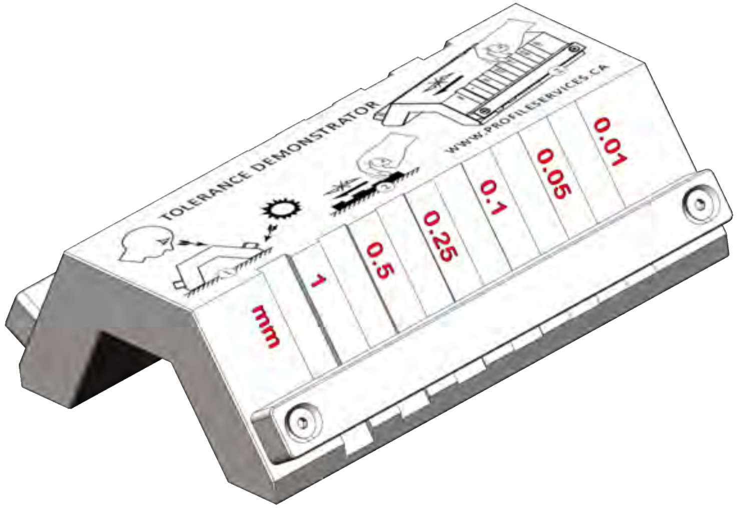


Artifact #1

A Visual Comparison Graphic

Artifact #2

A Primarily Haptic Demonstrator of Clearance Fit-Classifications
(per ASME B4.2)



Artifact #3

A Visio-Haptic Demonstrator of Micron-Scale Magnitudes

Outcomes Self-Reflective Design Study

I explored why I am the way that I am. That understanding will adjust my expectations of others.

Through the Voice of the Design Companion, I have expressed my own thoughts and feelings.
In many ways, these echo what other design engineers have shared with me, particularly in their early careers.
I hope that others who read this may feel they are not alone.

Self-reflective writing is awkward and to me, unnatural. I rewrote most of the *Voice* dialog to Aubrey several times. Eventually, I found my writing reflecting my natural voice, the one that my actual students heard in our frequent, lengthy, out-of-class conversations that I found so enjoyable.

1 2 3 4 5 6

Future Work

Design Esoterica in general

- Explore what should be considered as mechanical engineering design esoterica.
- Inventory mechanical engineering design esoterica knowledge and skillsets in faculties and industry.

Tolerance artifacts from this study

- Physical production
- Study usability and effectiveness

Self-reflective study

- Explore various engineering design roles / personae: Devil's Advocate, Design Coach, etc.

A Self-Reflective Design Study of
Three Visio and Visio-Haptic Artifacts
For Use in
Mechanical Engineering Design Education

University of Manitoba

Thank you for attending today.

MSc Thesis Defense

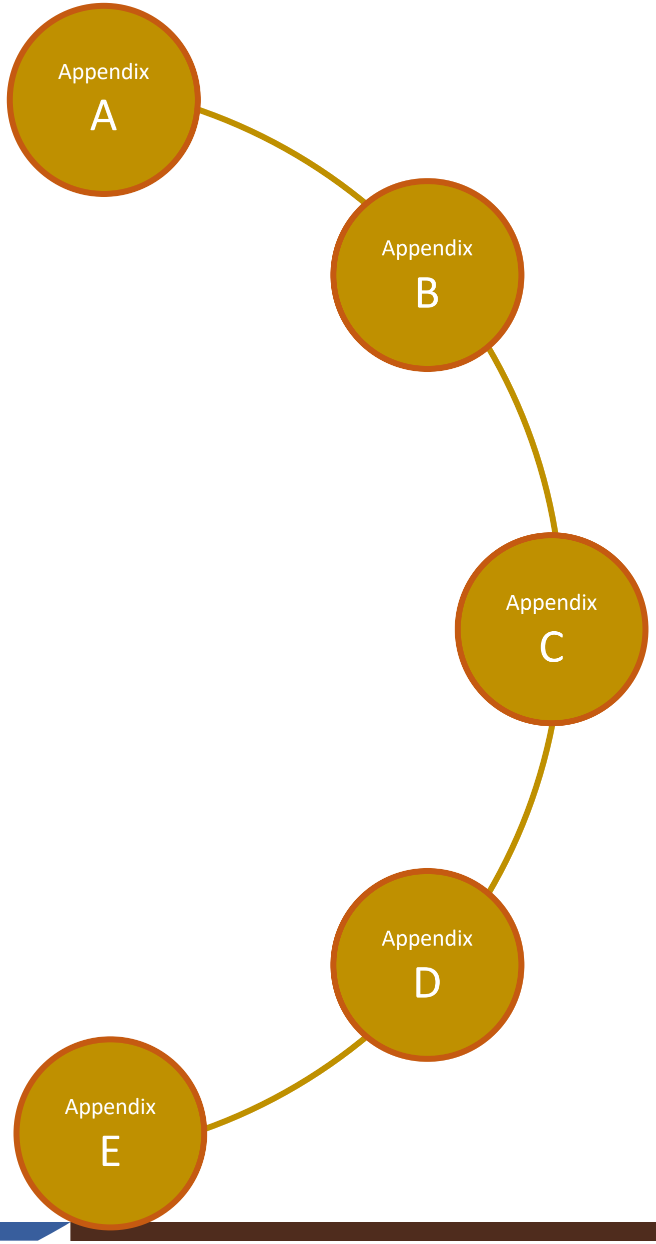
James Dillon Sykes, P.Eng.

March 24th, 2023

University of Manitoba

Copyright

Appendix A	Design Considerations
Appendix B	Artifact #1 Graphic
Appendix C	Artifact #2 Specifications
Appendix D	Artifact #3 Specifications
Appendix E	ANSI / ASME B4.2



Appendix A

Artifact Design Considerations

General Artifact Design Considerations

C#	Consideration Query
C1	What are the instructional goals for the artifact? What are the learning goals for the artifact?
C2	Are all features incorporated into the artifact meaningful in their use? If not, can they be excluded from the artifact?
C3	Are there other existing artifacts, individually or collectively, representing the same concepts? If so, explain why this new artifact design is needed.
C4	Is the artifact design rooted in a predecessor? If so, identify predecessor and describe insights (strengths and deficiencies) carried over to the new artifact.
C5	How is the artifact broadly useful? If not, identify specific limitations (sizes, conditions, etc.).
C6	How has the artifact been designed to be extended in use from the particular context to additional practical uses?
C7	How is the underlying technical concept clear and distinguishable from the physical details of the artifact?
C8	What are the specific design elements and functionalities represented by the artifact?
C9	What elements of the artifact design are intertwined in ways that are not immediately apparent? Explain any changes to the artifact that are necessary.
C10	How are critical and non-critical physical characteristics of the artifact differentiated?

C#	Consideration Query
C11	What is the anticipated usage environment (lighting, temperature, hygiene, other)?
C12	What sensory inputs are anticipated in the artifact's use? Visual / Olfactory / Haptic / Auditory / Taste / Other
C13	How are intended functionalities of artifact made explicit?
C14	What other artifacts should / must be chained with this artifact to convey the core concept?
C15	What other chain of artifacts may this artifact be added into or substituted to convey a core concept?
C16	Will the artifact be produced physically? How will the artifact be incorporated into teaching?
C17	What are the limitations of useability based on location, disability, capability, or capacity?
C18	How does the artifact design encourage a critical evaluation of merits and concerns about the elements demonstrated? How may the artifact be used in group discussion?
C19	How do you anticipate the user's perspective and understanding of the various elements to evolve as they engage with the artifact?
C20	Is the technical nature of the artifact effectively documented and communicated such that instructors can readily understand and use the artifact?

Artifact Design Considerations

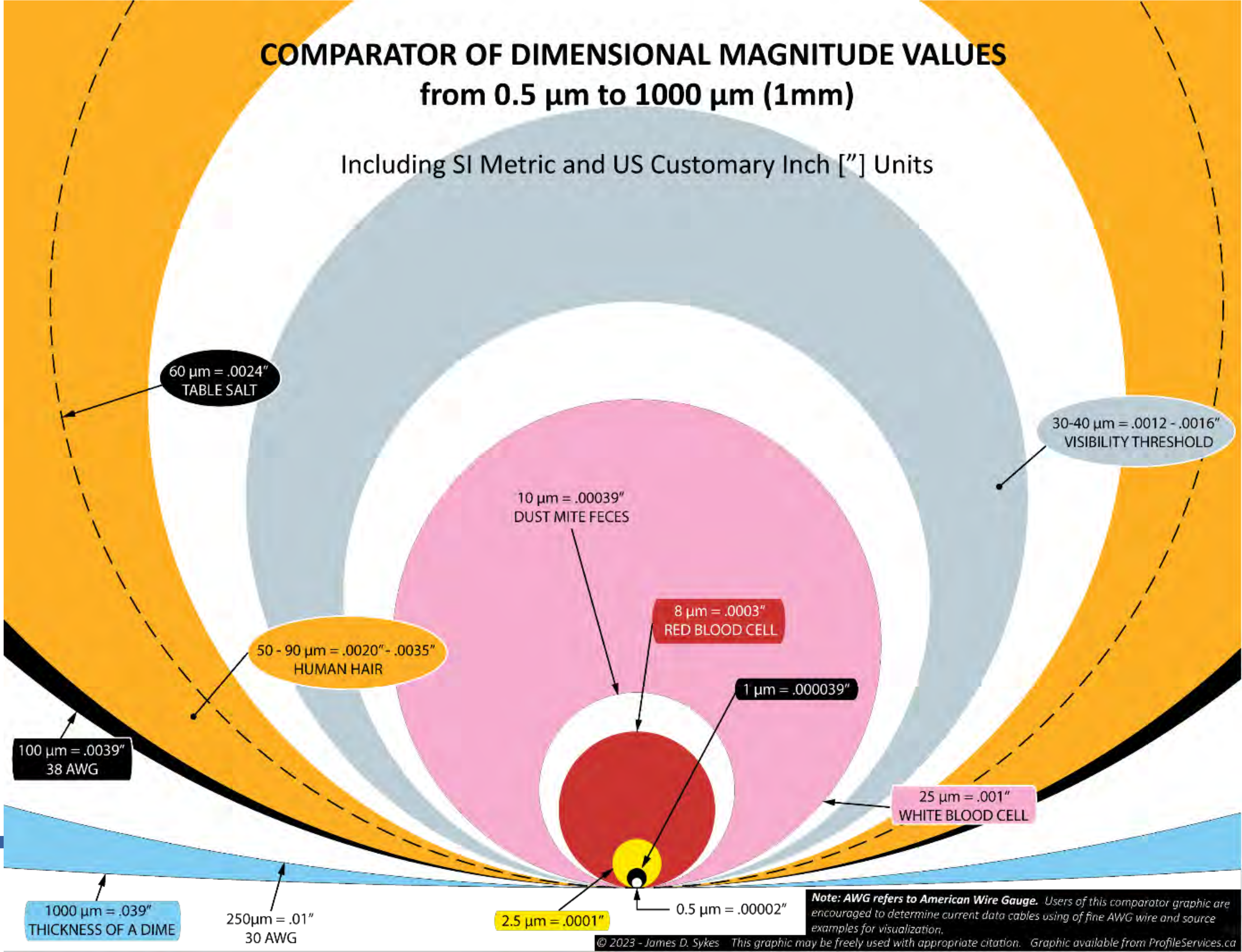
Tolerance Artifact Design Considerations

C#	Consideration
C21	**Safety**
	Injuries - Significant Potential
	Injuries - Moderate Potential
	Injuries - Low Potential
C22	**Ergonomics**
	Vision
	Finger size
	Weight Limit
	Size Limits
C23	**Operating / Usage**
	Lubrication
	Hygiene
	Static / Dynamic
C24	**Assembly**
	Complexity
	Features
	Techniques
C25	**Design Complexity**
C26	**Aesthetics and Handling**
	Colours
	Chamfer / Radius / Sharp Edges
	Surface Reflectivity
	Text Format

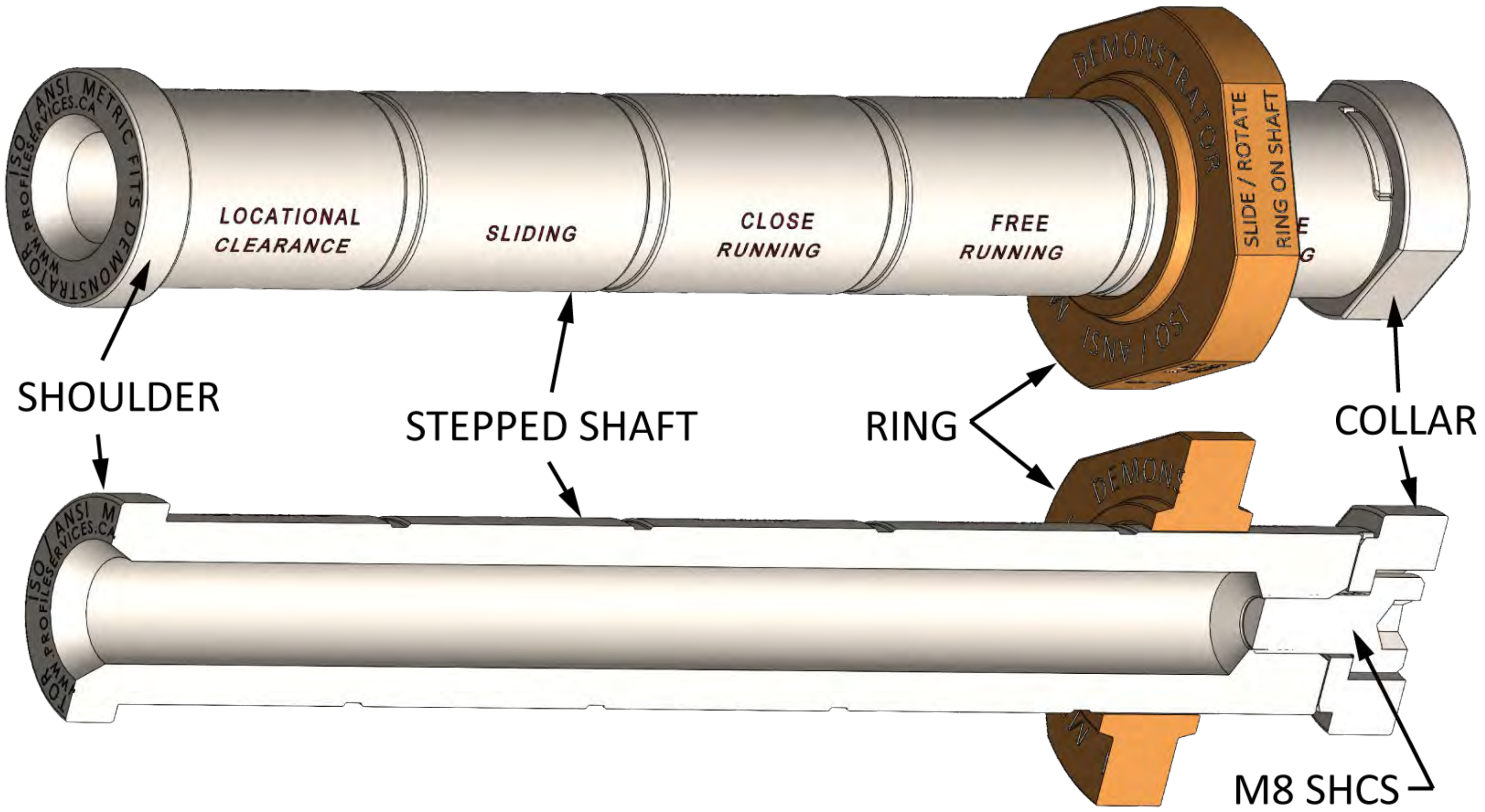
C#	Consideration
C27	**Communications - instructions**
	Pack/ Unpack
	Handling
	Use / Operation
	Learning Goals
	Maintenance
C28	**Material**
	Durability
	Corrosion
	Lubrication
C29	**Manufacturing**
	Design Complexity
	Processes
	Tolerance Requirement
	Surface Finish
	Markings
C30	**Shipping**
	Method
	Packaging Type
	Size
C31	**Design Rules of Thumb**
C32	**Reference Artifacts**

Appendix B

Artifact #1 Graphic

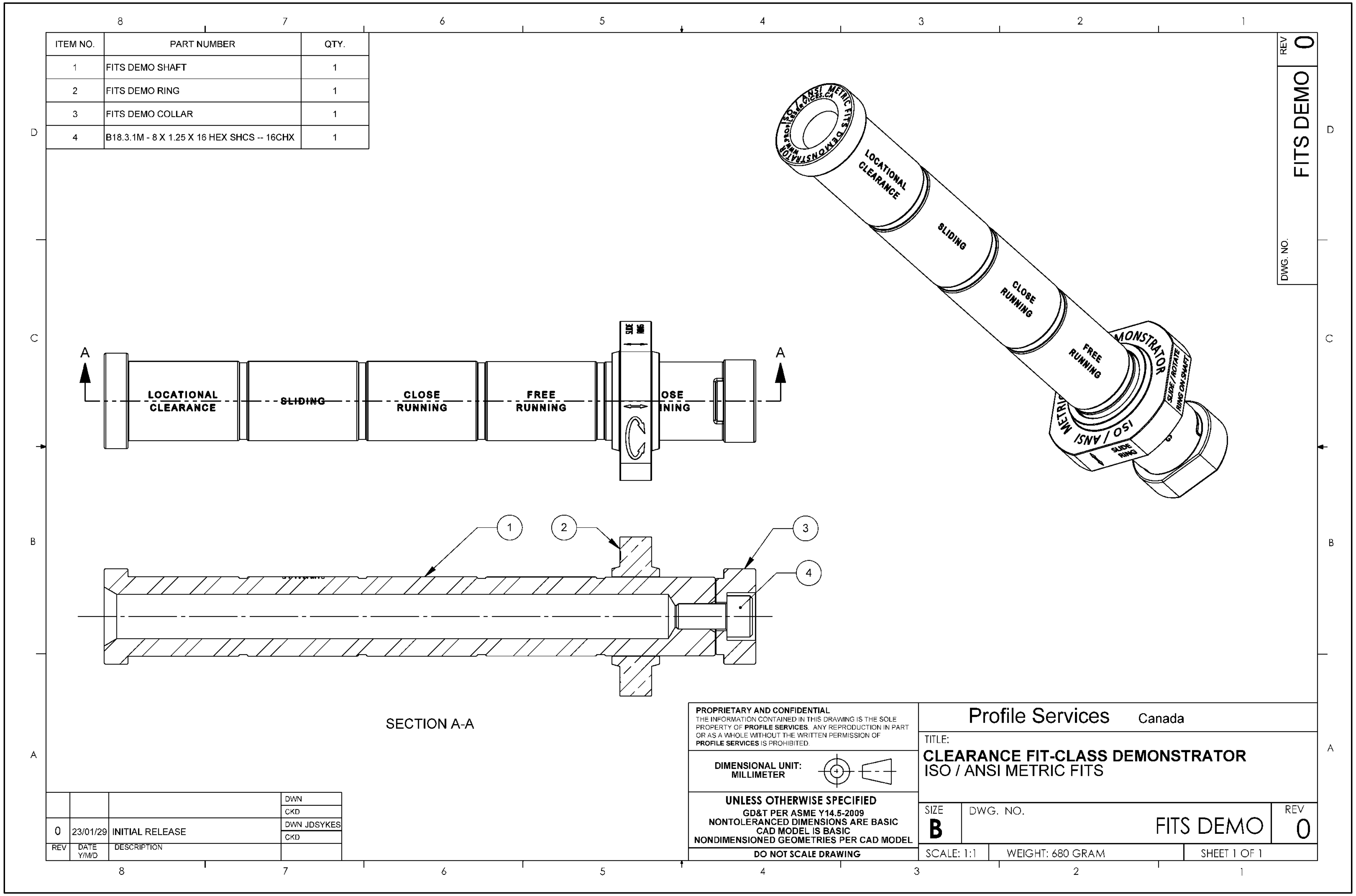


Artifact #2 Specifications



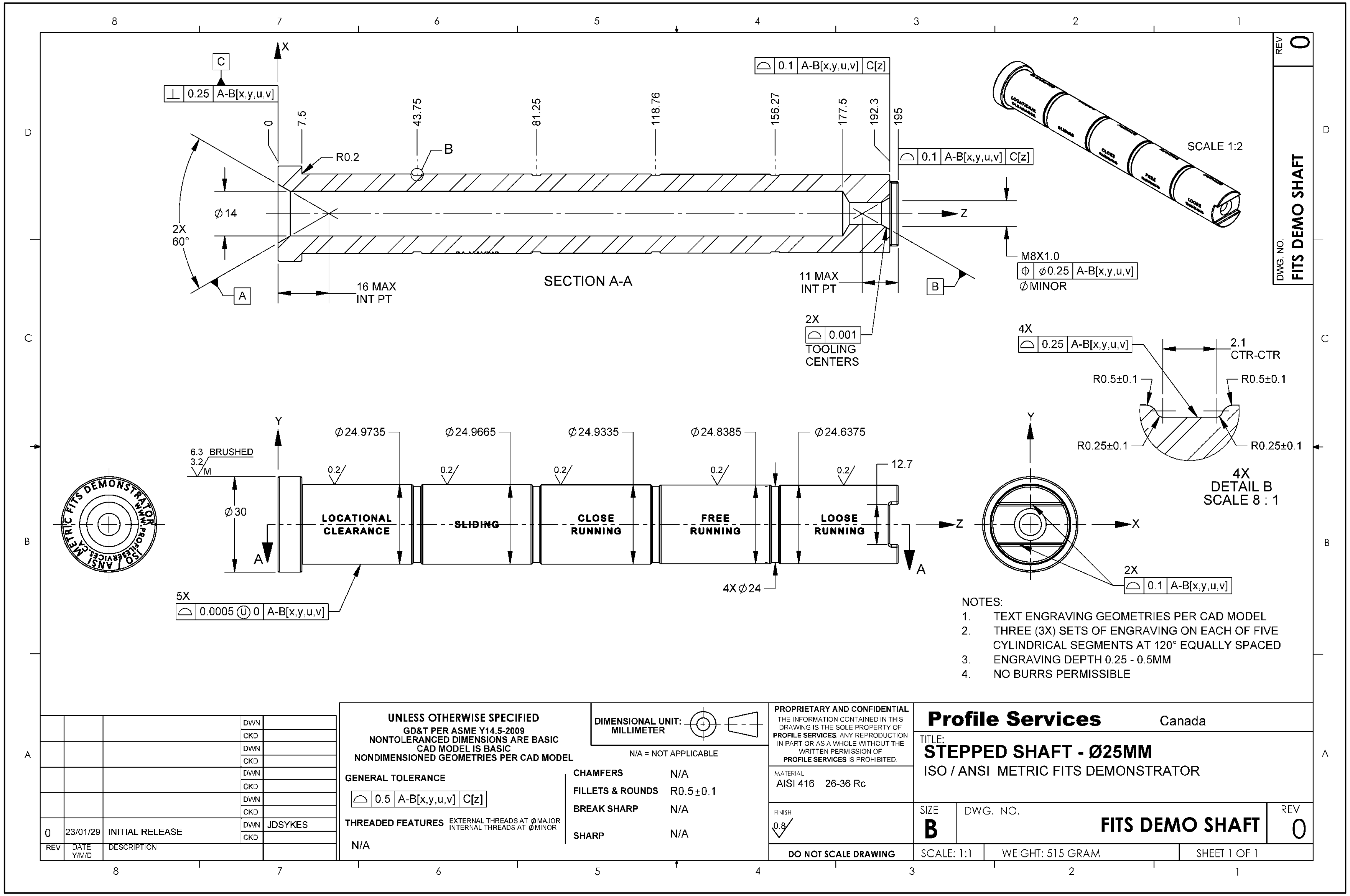
Appendix C

Artifact #2 Specifications



Appendix C

Artifact #2 Specifications



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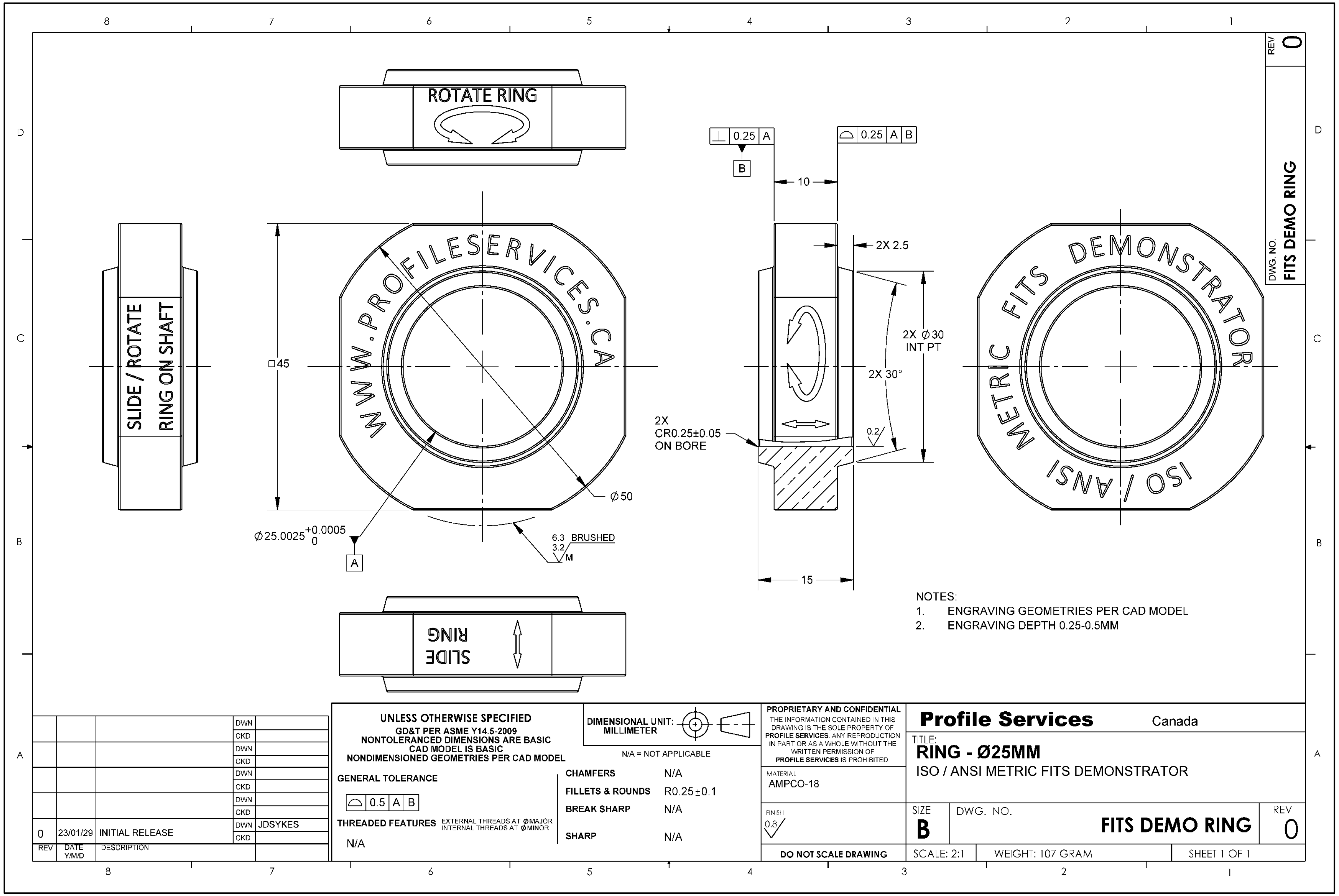

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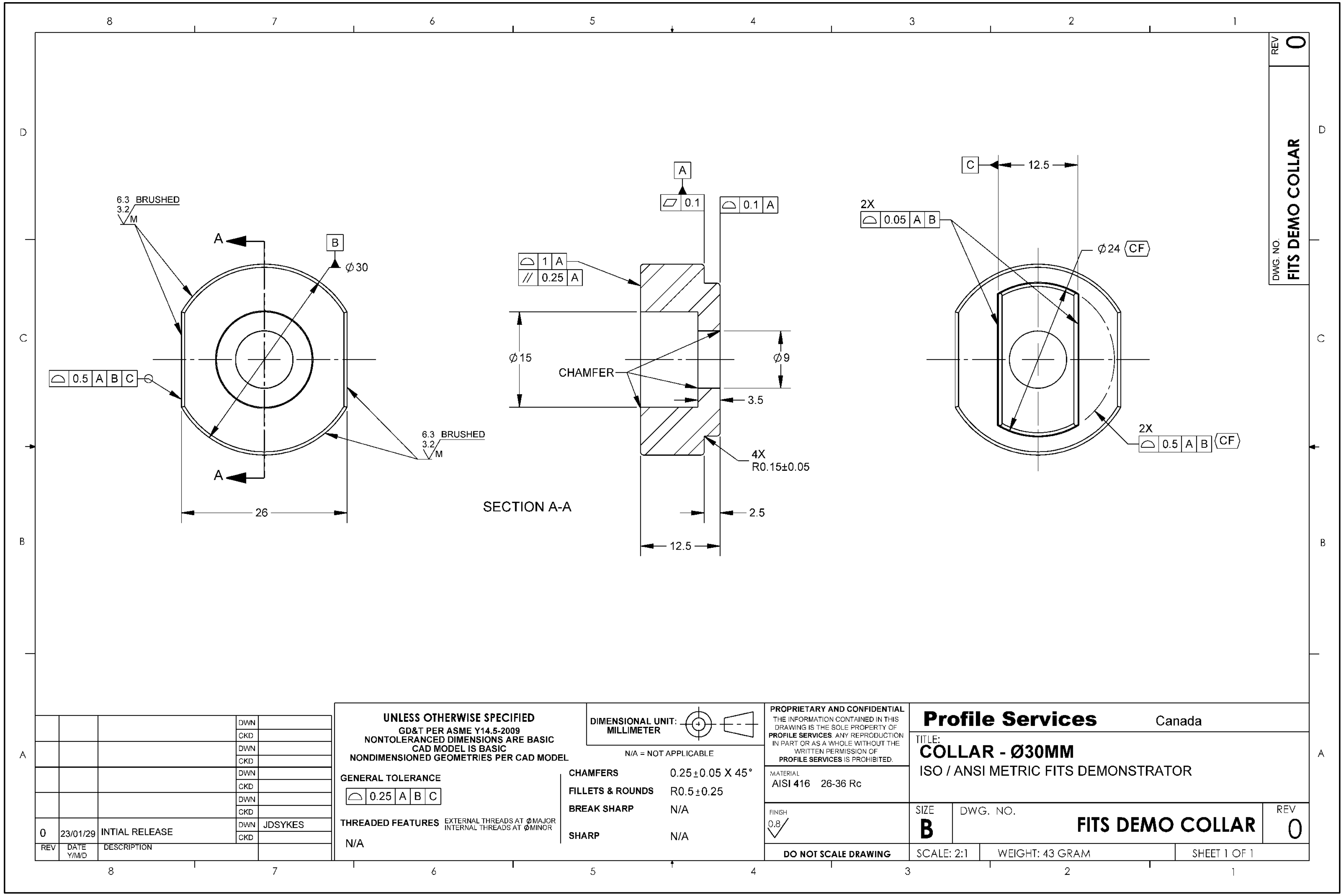

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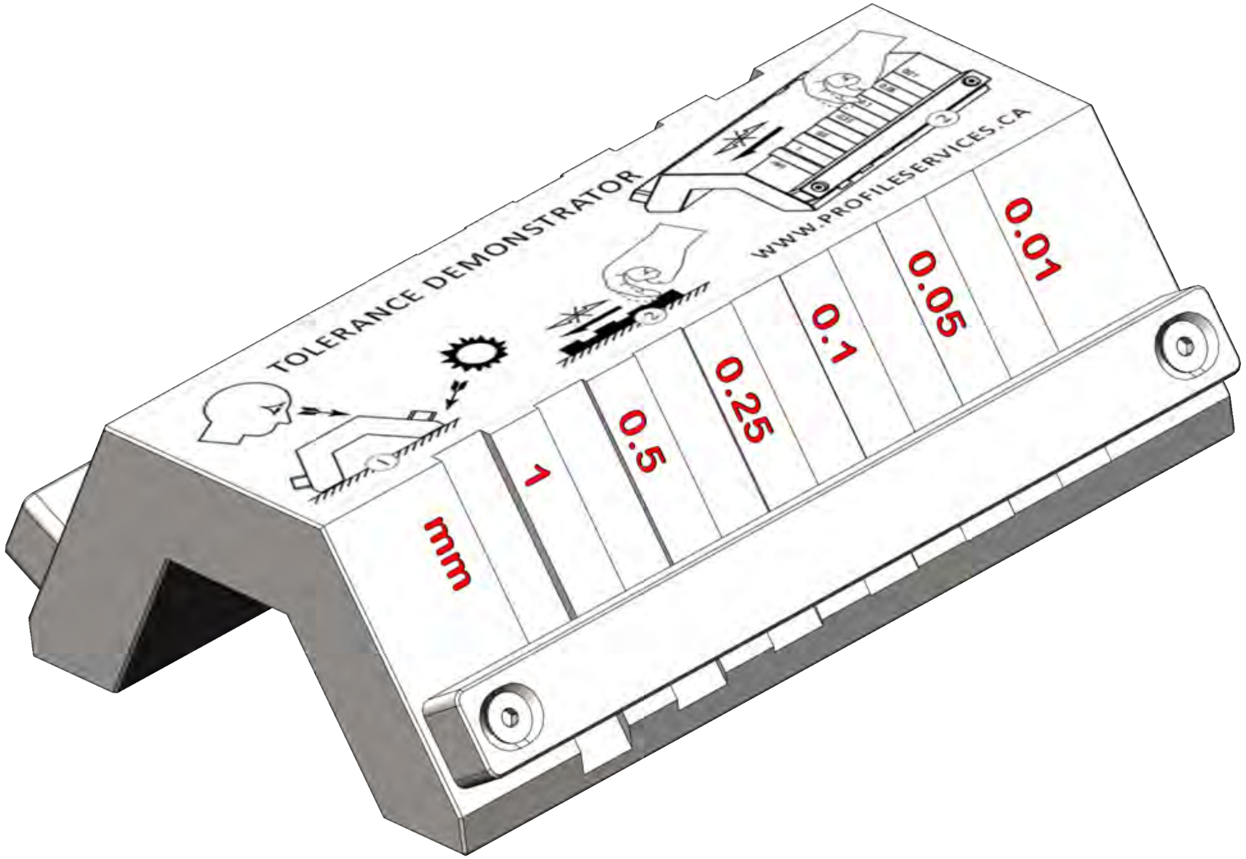
Faculty of Graduate Studies
University of Manitoba

Appendix D

Artifact #3 Specifications



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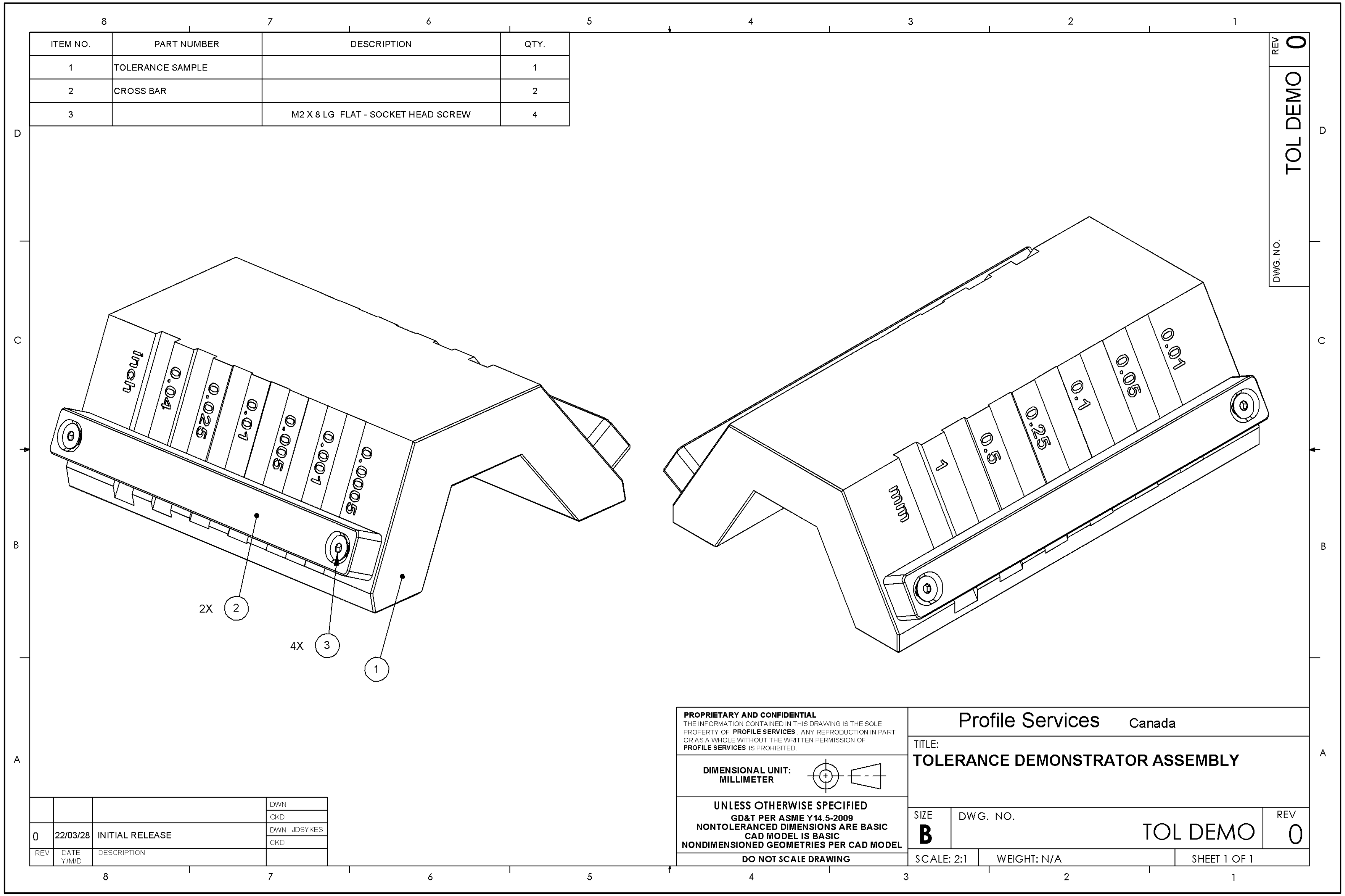
Artifact #3 Specifications



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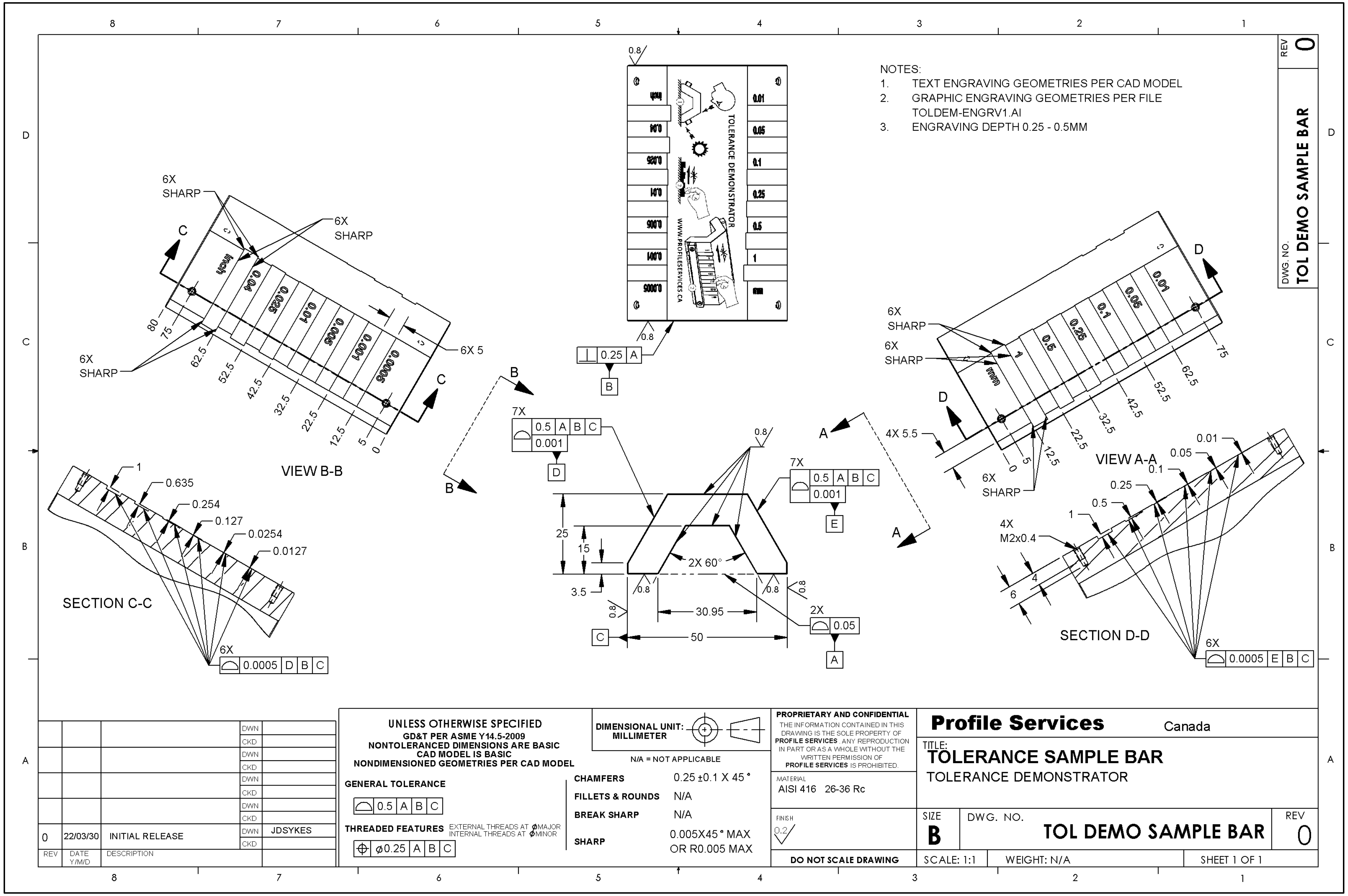

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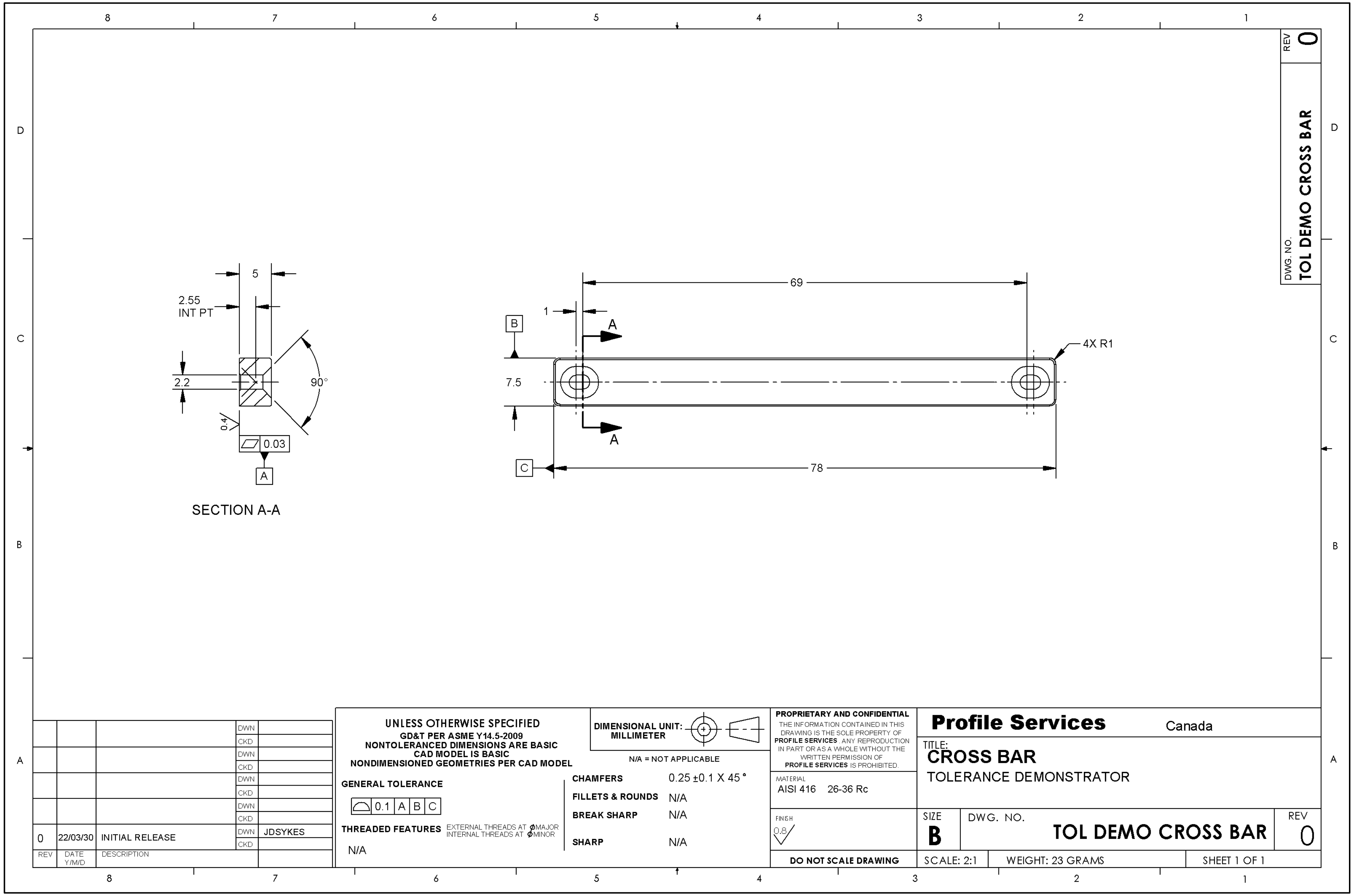

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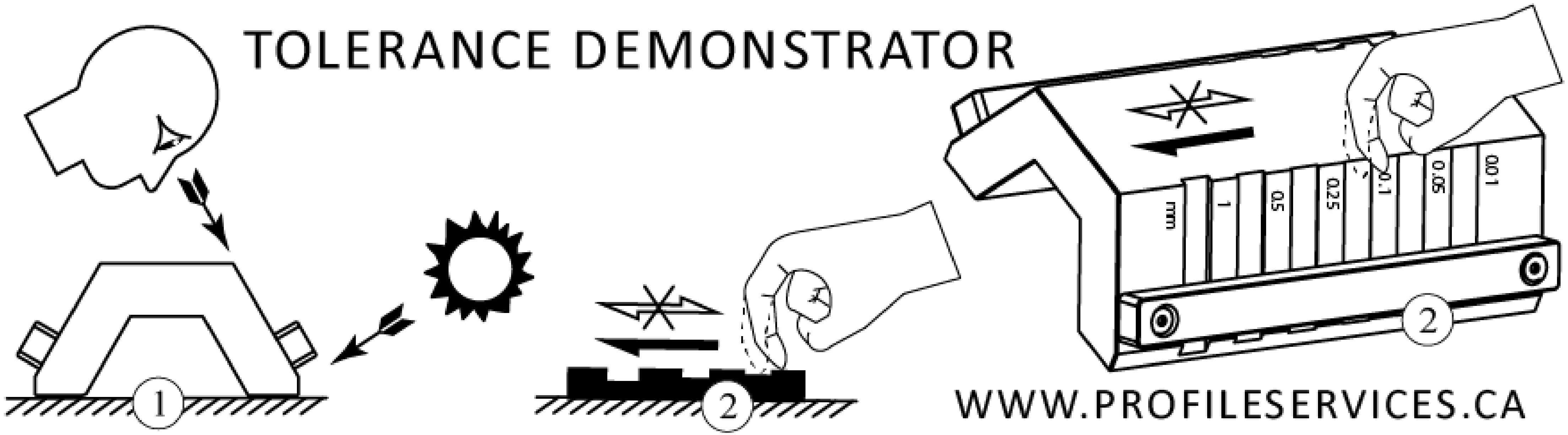
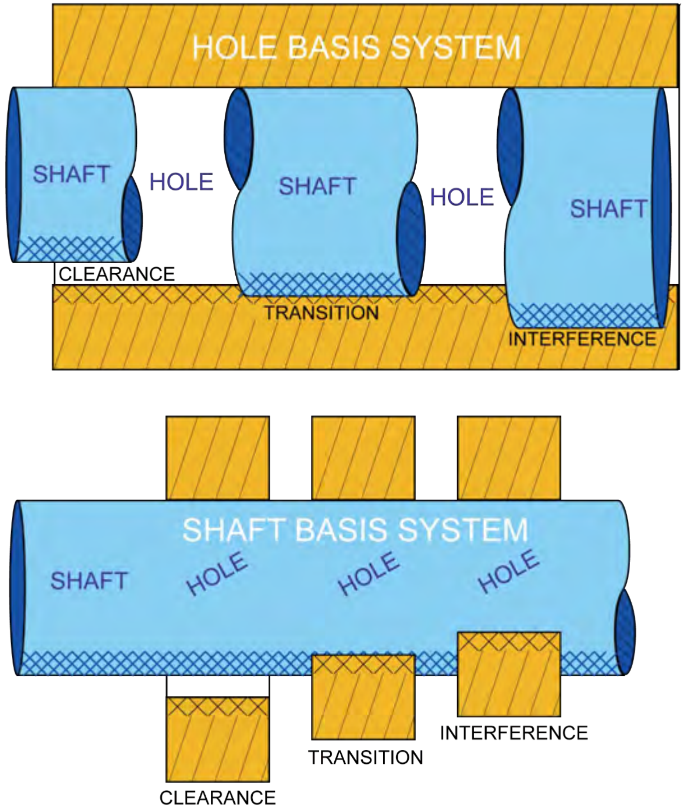


ANSI / ASME B4.2

Appendix E

ANSI / ASME B4.2

ASME B4.2 Preferred Fit Classifications



Category	ISO SYMBOL Hole Basis	ISO SYMBOL Shaft Basis	Description
CLEARANCE	H11/c11	C11/h11	**Loose Running**: wide commercial tolerances or allowances on external members
CLEARANCE	H9/d9	D9/h9	**Free Running**: not for use where accuracy is essential; good for large temperature variations, high running speeds, heavy journal pressures
CLEARANCE	H8/f7	F8/h7	**Close Running**: for running on accurate machines and for accurate location at moderate speeds and moderate journal pressures
CLEARANCE	H7/g6	G7/h6	**Sliding**: not intended to run freely, but to move and turn freely and locate accurately
CLEARANCE	H7/h6	H7/h6	**Locational Clearance**: snug fit for locating stationary parts; freely assembled and disassembled
TRANSITION	H7/k6	K7/h6	**Locational Transition**: for accurate location; a compromise between clearance and interference
TRANSITION	H7/n6	N7/h6	**Locational Transition**: for more accurate location where greater interference is permissible
INTERFERENCE	H7/p6*	P7/h6	**Locational Interference**: for parts requiring rigidity and alignment with prime accuracy of location but without special bore pressure requirements
INTERFERENCE	H7/s6	S7/h6	**Medium Drive**: for ordinary steel parts or shrink fits on light sections; the tightest fit usable with cast iron
INTERFERENCE	H7/u6	U7/h6	**Force**: for parts that can be highly stressed or for shrink fits where the heavy pressure forces required are impractical

More Clearance

More Interference

* Transition fit for nominal sizes from 0 thru 3mm.

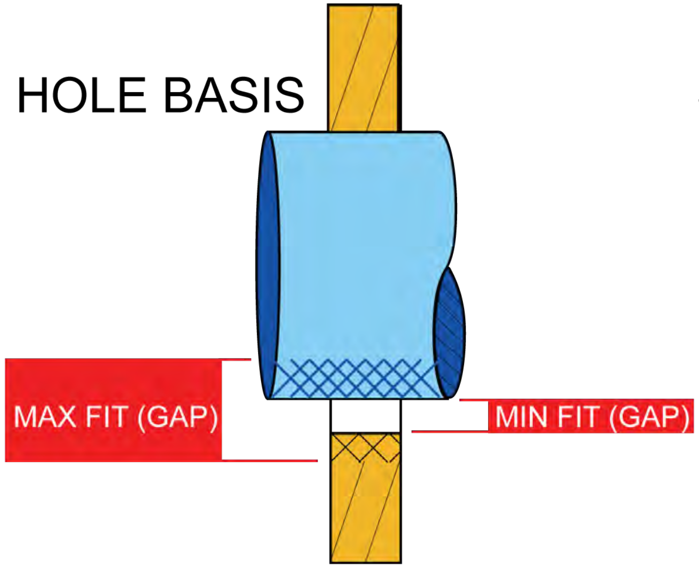
Resolution Artifact Design

Artifact #2 A Primarily Haptic Demonstrator of Clearance Fit-Classifications (per ASME B4.2)

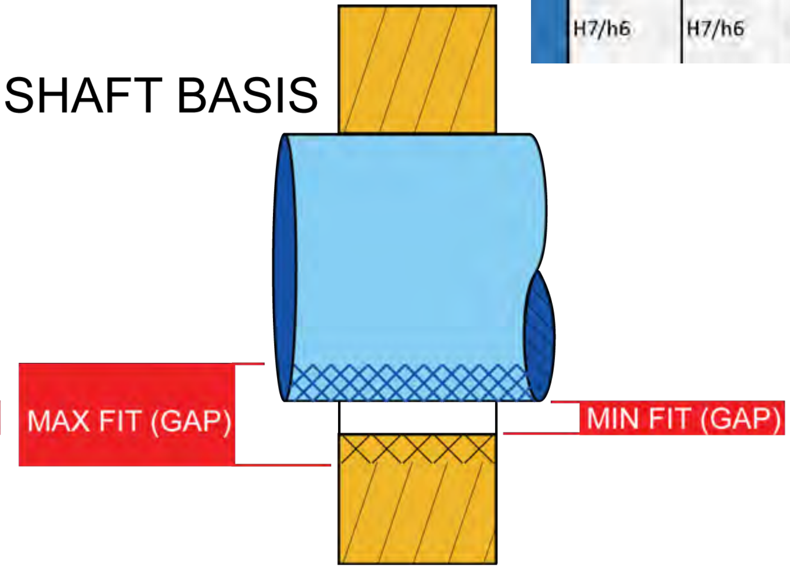
ASME B4.2 Preferred Fit Classifications

	ISO SYMBOL			
	Hole Basis	Shaft Basis	Description	
CLEARANCE	H11/c11	C11/h11	**Loose Running**: wide commercial tolerances or allowances on external members	More Clearance ↑
	H9/d9	D9/h9	**Free Running**: not for use where accuracy is essential; good for large temperature variations, high running speeds, heavy journal pressures	
	H8/f7	F8/h7	**Close Running**: for running on accurate machines and for accurate location at moderate speeds and moderate journal pressures	
	H7/g6	G7/h6	**Sliding**: not intended to run freely, but to move and turn freely and locate accurately	
	H7/h6	H7/h6	**Locational Clearance**: snug fit for locating stationary parts; freely assembled and disassembled	

HOLE BASIS



SHAFT BASIS



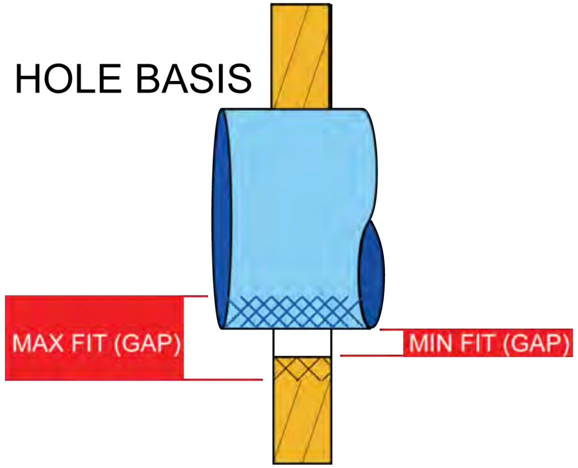
Appendix E

ANSI / ASME B4.2

ASME B4.2 Preferred Fit Classifications

Hole Basis 20H8/f7

HOLE BASIS



Reproduced from: Machinery's Handbook 25, [illegible] DS on 18 March 2020)

Table 2. American National Standard Preferred Hole Basis Metric Clearance Fits *ANSI B4.2-1978 (R1984)*

Basic Size *		Loose Running Hole H11	Loose Running Shaft c11	Loose Running Fit†	Free Running Hole H9	Free Running Shaft d9	Free Running Fit†	Close Running Hole H8	Close Running Shaft f7	Close Running Fit†	Sliding Hole H7	Sliding Shaft g6	Sliding Fit†	Locational Clearance Hole H7	Locational Clearance Shaft h6	Locational Clearance Fit†
1	Max	1.060	0.940	+ 0.180	1.025	0.980	+ 0.070	1.014	0.994	+ 0.030	1.010	0.998	+ 0.018	1.010	1.000	+ 0.016
	Min	1.000	0.880	+ 0.060	1.000	0.955	+ 0.020	1.000	0.984	+ 0.006	1.000	0.992	+ 0.002	1.000	0.994	+ 0.000
1.2	Max	1.260	1.140	+ 0.180	1.225	1.180	+ 0.070	1.214	1.194	+ 0.030	1.210	1.198	+ 0.018	1.210	1.200	+ 0.016
	Min	1.200	1.080	+ 0.060	1.200	1.155	+ 0.020	1.200	1.184	+ 0.006	1.200	1.192	+ 0.002	1.200	1.194	+ 0.000
1.6	Max	1.660	1.540	+ 0.180	1.625	1.580	+ 0.070	1.614	1.594	+ 0.030	1.610	1.598	+ 0.018	1.610	1.600	+ 0.016
	Min	1.600	1.480	+ 0.060	1.600	1.555	+ 0.020	1.600	1.584	+ 0.006	1.600	1.592	+ 0.002	1.600	1.594	+ 0.000
2	Max	2.060	1.940	+ 0.180	2.025	1.980	+ 0.070	2.014	1.994	+ 0.030	2.010	1.998	+ 0.018	2.010	2.000	+ 0.016
	Min	2.000	1.880	+ 0.060	2.000	1.955	+ 0.020	2.000	1.984	+ 0.006	2.000	1.992	+ 0.002	2.000	1.994	+ 0.000
2.5	Max	2.560	2.440	+ 0.180	2.525	2.480	+ 0.070	2.514	2.494	+ 0.030	2.510	2.498	+ 0.018	2.510	2.500	+ 0.016
	Min	2.500	2.380	+ 0.060	2.500	2.455	+ 0.020	2.500	2.484	+ 0.006	2.500	2.492	+ 0.002	2.500	2.494	+ 0.000
3	Max	3.060	2.940	+ 0.180	3.025	2.980	+ 0.070	3.014	2.994	+ 0.030	3.010	2.998	+ 0.018	3.010	3.000	+ 0.016
	Min	3.000	2.880	+ 0.060	3.000	2.955	+ 0.020	3.000	2.984	+ 0.006	3.000	2.992	+ 0.002	3.000	2.994	+ 0.000
						3.970	+ 0.090	4.018	3.990	+ 0.040	4.012	3.996	+ 0.024	4.012	4.000	+ 0.020
						3.940	+ 0.030	4.000	3.978	+ 0.010	4.000	3.988	+ 0.004	4.000	3.992	+ 0.000
						4.970	+ 0.090	5.018	4.990	+ 0.040	5.012	4.996	+ 0.024	5.012	5.000	+ 0.020
						4.940	+ 0.030	5.000	4.978	+ 0.010	5.000	4.988	+ 0.004	5.000	4.992	+ 0.000
						5.970	+ 0.090	6.018	5.990	+ 0.040	6.012	5.996	+ 0.024	6.012	6.000	+ 0.020
						5.940	+ 0.030	6.000	5.978	+ 0.010	6.000	5.988	+ 0.004	6.000	5.992	+ 0.000
						7.960	+ 0.112	8.022	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+ 0.024
						7.924	+ 0.040	8.000	[illegible]							+ 0.000
						9.960	+ 0.112	10.022	[illegible]							+ 0.024
						9.924	+ 0.040	10.000	[illegible]							+ 0.000
						1.950	+ 0.136	12.027	[illegible]							+ 0.029
						1.907	+ 0.050	12.000	[illegible]							+ 0.000
						5.950	+ 0.136	16.027	[illegible]							+ 0.029
						5.907	+ 0.050	16.000	15.966	+ 0.016	16.000	15.983	+ 0.006	16.000	15.989	+ 0.000
20	Max	20.130	19.890	+ 0.370	20.052	19.935	+ 0.169	20.033	19.980	+ 0.074	20.021	19.993	+ 0.041	20.021	20.000	+ 0.034
	Min	20.000	19.760	+ 0.110	20.000	19.883	+ 0.065	20.000	19.959	+ 0.020	20.000	19.980	+ 0.007	20.000	19.987	+ 0.000

All dimensions are in millimetres.

* The sizes shown are the first choice basic sizes. Preferred fits for other sizes can be calculated from data given in ANSI B4.2-1978 (R1984).

† Fits: + indicates CLEARANCE / – indicates INTERFERENCE

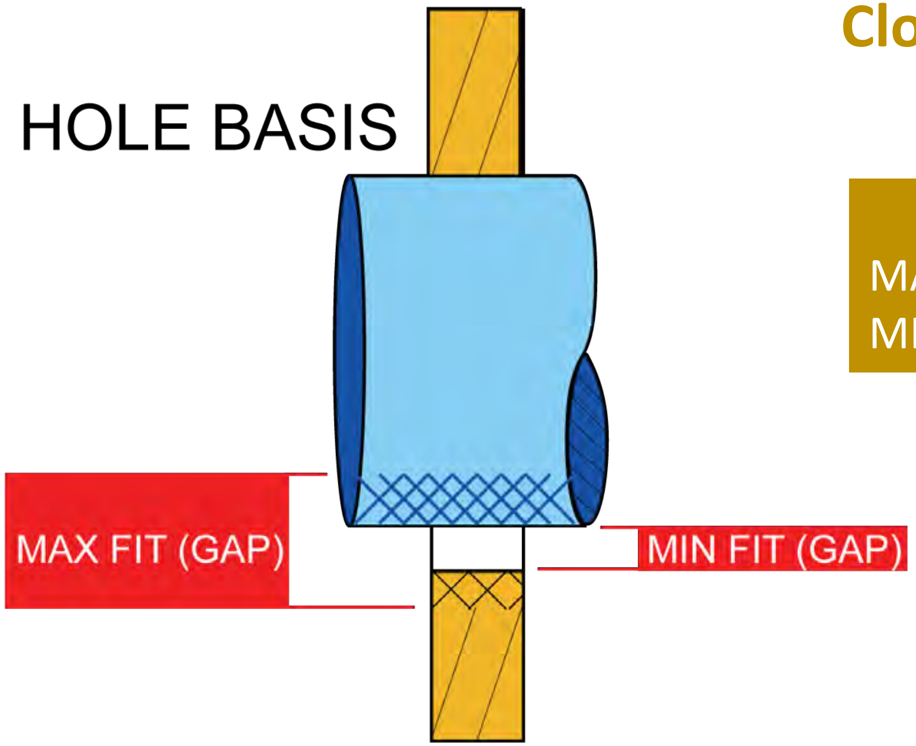
NOTE: The information in this table has not been verified for accuracy. This information is provided for educational purposes only, and must be verified before use in practice.

	ISO SYMBOL Hole Basis	ISO SYMBOL Shaft Basis	Description	
CLEARANCE	H11/c11	C11/h11	**Loose Running**: wide commercial tolerances or allowances on external members	↑ More Clearance
	H9/d9	D9/h9	**Free Running**: not for use where accuracy is essential; good for large temperature variations, high running speeds, heavy journal pressures	
	H8/f7	F8/h7	**Close Running**: for running on accurate machines and for accurate location at moderate speeds and moderate journal pressures	
	H7/g6	G7/h6	**Sliding**: not intended to run freely, but to move and turn freely and locate accurately	
	H7/h6	H7/h6	**Locational Clearance**: snug fit for locating stationary parts; freely assembled and disassembled	

	Hole	Shaft	Fit
MAX	20.033	19.980	+0.074
MIN	20.000	19.959	+0.020

ANSI / ASME B4.2

ASME B4.2 Preferred Fit Classifications



20H8/f7
Close Running Fit

	Hole	Shaft	Fit
MAX	20.033	19.980	+0.074
MIN	20.000	19.959	+0.020

Maximum gap = 74µm
Minimum gap = 20µm

A Self-Reflective Design Study of Three Visio and Visio-Haptic Artifacts For Use in Mechanical Engineering Design Education

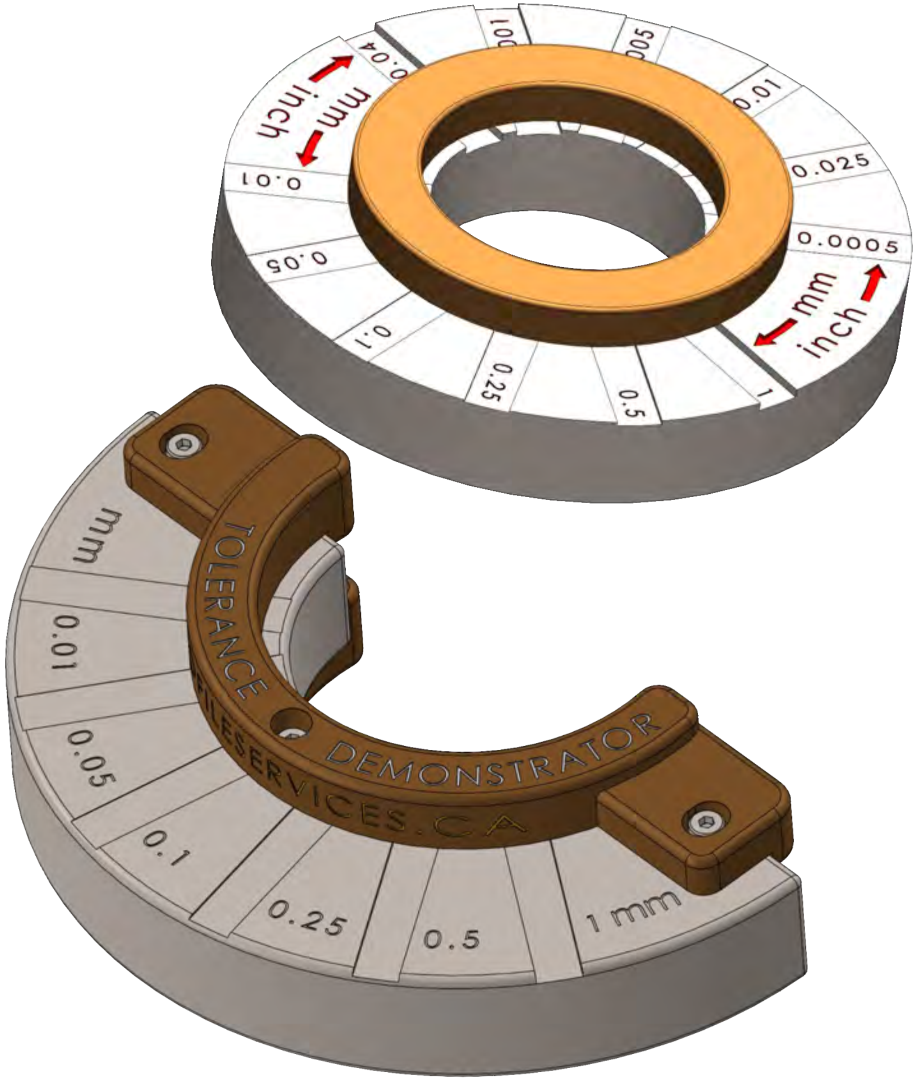
University of Manitoba

MSc Thesis Defense

James Dillon Sykes, P.Eng.

March 24th, 2023

Resolution



Design Elegance

Design Elegance generally suggests an evident clarity or cleanliness of the design beyond what a typical practitioner would derive.

It often reflects a simplified solution that addresses the core requirements with an element of flair that elevates the design stylistically or aesthetically above mere functionality.

Design elegance is a coveted status in mechanical design engineering.