The Force of Decision Rules: Metrology Meets Star Wars

The Force of Decision Rules: Metrology Meets Star Wars

Henry Zumbrun II, President Morehouse Instrument Company

1742 Sixth Ave

York, PA 17403

PH: 717-843-0081

web: www.mhforce.com

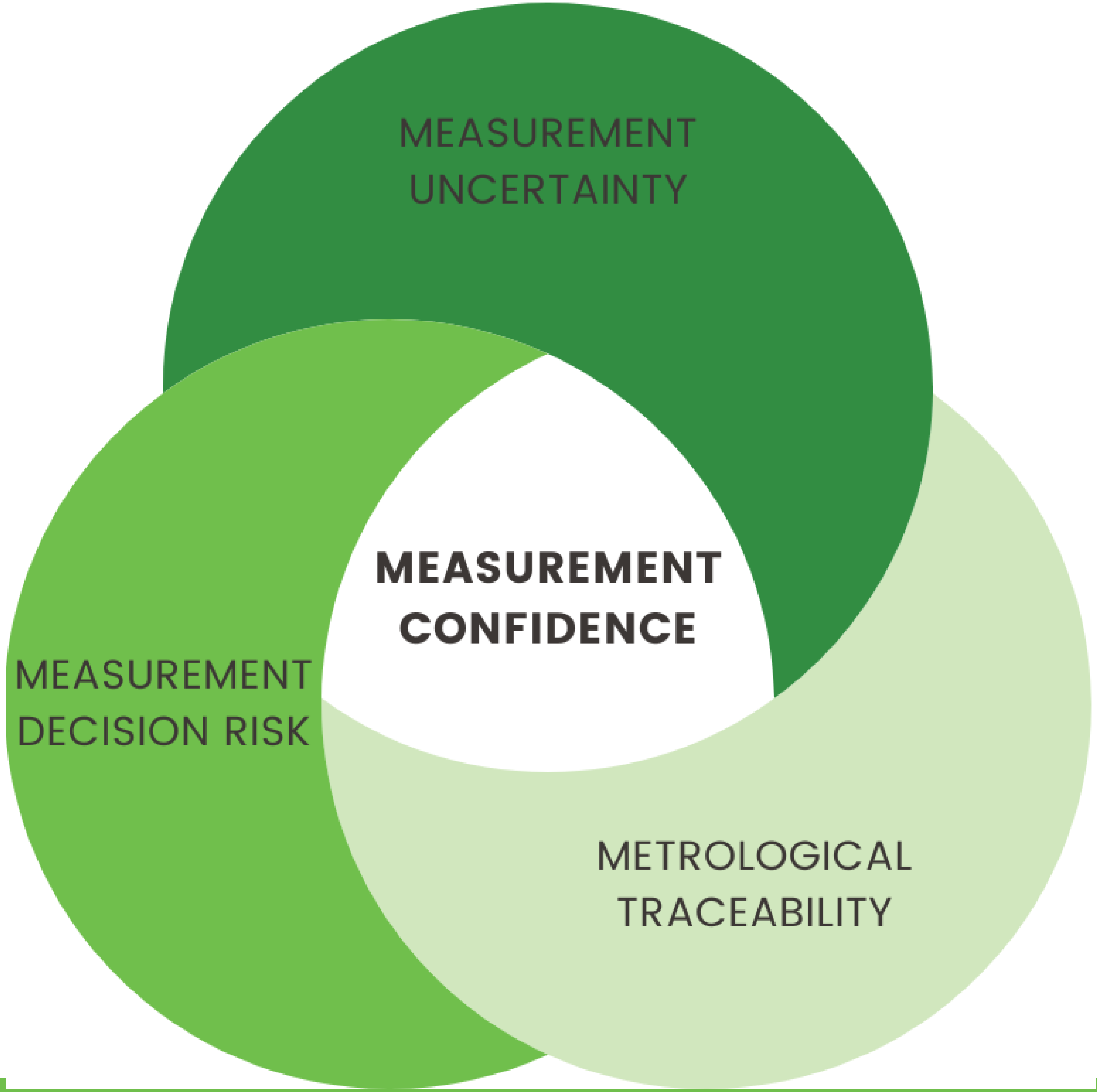
info: hzumbrun@mhforce.com

Measurement Confidence

We are going to focus on Measurement Decision Risk.

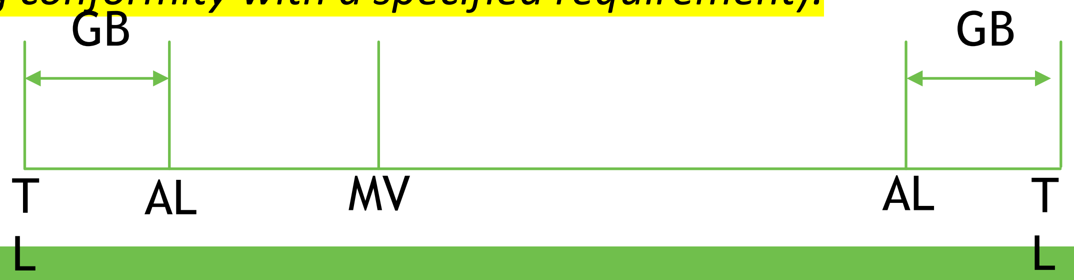
Specific Risk Using Star Wars

Global Risk Using Star Wars

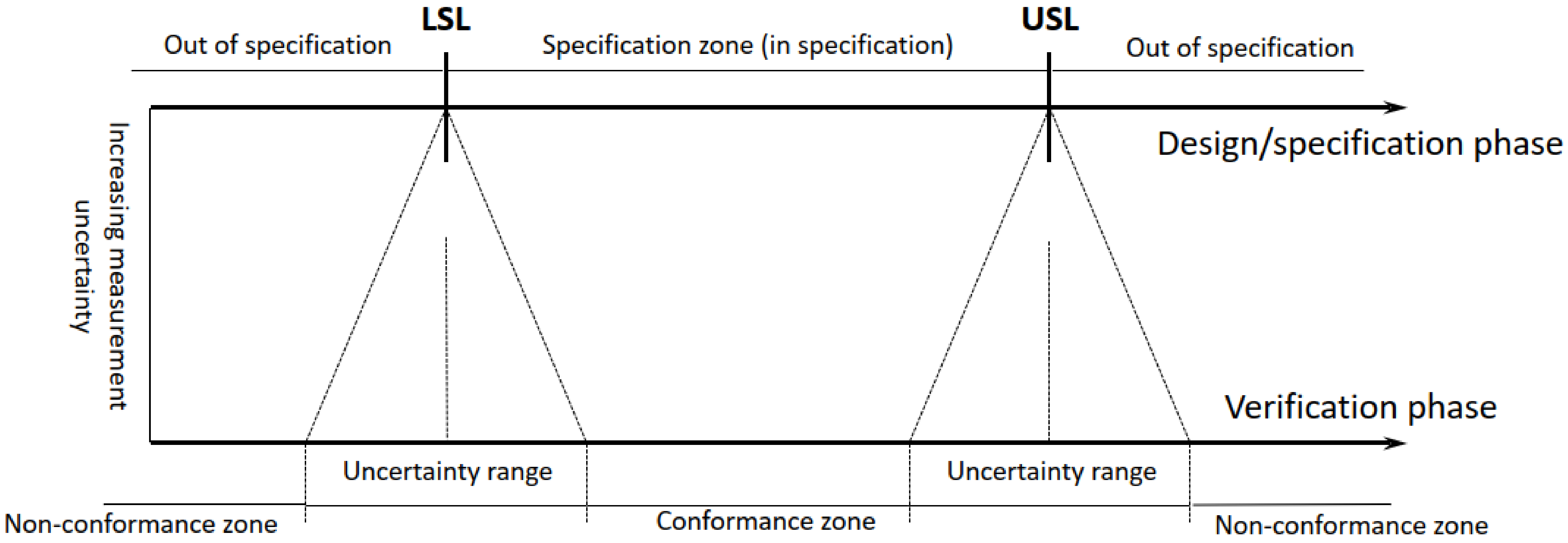


Common Definitions ILAC G8

- **Tolerance Limit (*TL*) (Specification Limit)** specified upper or lower bound of permissible values of a property.
- **Acceptance Limit (*AL*)** specified upper or lower bound of permissible measured quantity values.
  - LSL – Lower Specification Limit
  - USL – Upper Specification Limit
- **Measured Quantity Value** quantity value represents a measured result.
- **Guard Band (*w*)** interval between a tolerance limit and a corresponding acceptance limit where length $w = |TL - AL|$.
- **Decision Rule** describes how measurement uncertainty is accounted for when stating conformity with a specified requirement. *(ISO/IEC 17025:2017 3.7 a rule that describes how measurement uncertainty will be accounted for when stating conformity with a specified requirement).*



The Size of Acceptance limits is Determined by the Measurement Uncertainty and Desired Risk Level.

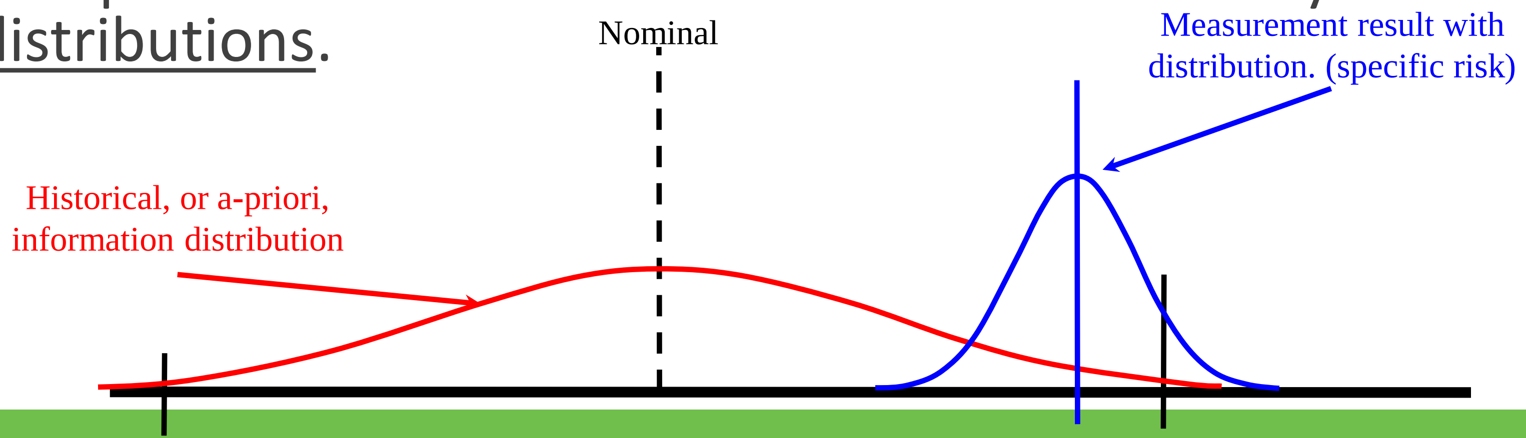


ISO 14253-1:2017

Consumer and Producer Risk

- **<u>Specific Risk</u>** (also called bench-level risk) is based on a specific measurement result.
  - It triggers a response based on measurement data gathered at time of test.
  - It may be characterized by one or two probability distributions, depending on the method.
  - Any representation with only <u>one probability distribution</u> is always a specific risk method.

- **<u>Global Risk</u>** (also called process-level risk) is based on a future measurement result.
  - It is used to ensure the acceptability of a documented measurement process.
  - It is based on expected or historical information and is usually characterized by <u>two probability distributions</u>.



Types of Risk Scenarios

- ASME B89.7.4.1-2005 describes both risk levels well

- **Specific Risk** mitigation can be thought of as "controlling the quality of the workpieces," while **Program Level Risk** strategies are described as "controlling the average quality of workpieces."

- Specific Risk being instantaneous liability at the time of the measurement and program level is more about the average probability that incorrect acceptance decisions will be made based on historical data

Specific Risk

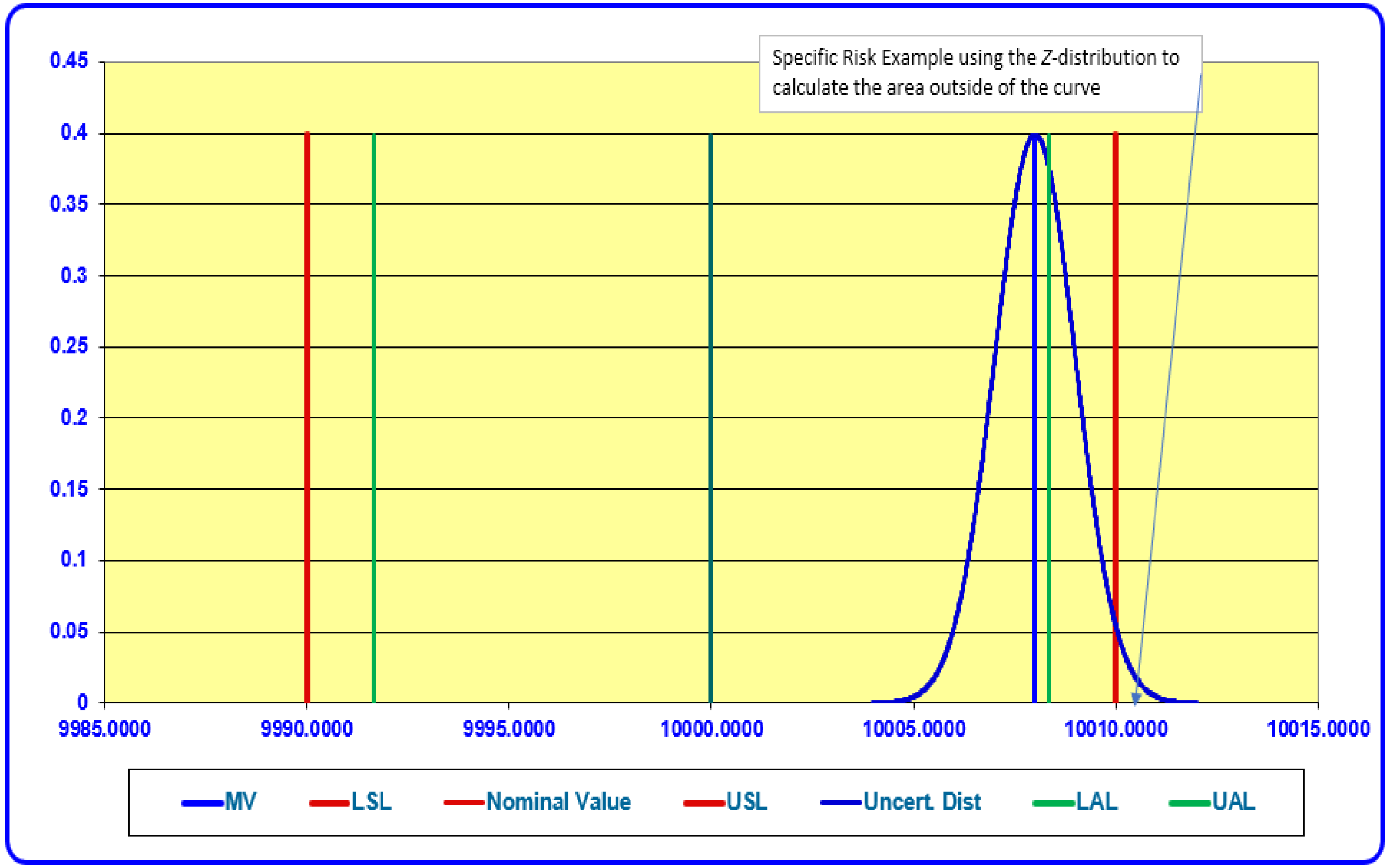
Specific Risk (also called bench-level risk) is based on a specific measurement result.

- It triggers a response based on measurement data gathered at the time of the test.
- It may be characterized by one or two probability distributions, depending on the method.
- Any representation with only one probability distribution is always a specific risk method.

Measurement Decision Risk

Risk Calculator		
Upper Tolerance T_U	10010.0000	
Lower Tolerance T_L	9990.0000	
Nominal Value	10000.0000	
Measurement Unc um	1.0000	
Measured Value xm	10008.0000	
Tolerance T	20.00	Area Outside of USL
Z Upper	2.00	2.275%
		Area Outside of LSL
Z Lower	-18.00	0.000%

Setting the Guard Band Upper and Lower p_c	
Select Desired Conformance Probability	95.00%
Maximum Risk if within G_U & G_L	5.00%
h U (GB Multiplier)	0.8224
Guard Band Upper G_u	10008.3551
Guard Band Lower G_L	9991.6449



A customer writes a PO that states: Please calibrate "As Found" Manufacturer 10,000 N Load cell S/N XXXX with indicator Manufacturer Readout XXXX to 10,000 N in Compression only and issue a "Pass" when the PFA using Specific Risk is ≤ 2.5 %, Otherwise Fail. ☺

Classic 50 % risk scenario with "Simple Acceptance" at the bench level (w = 0), No Guard Band.

Risk Calculator	
Upper Tolerance T_U	1500.2000
Lower Tolerance T_L	1499.8000
Nominal Value	1500.0000
Measurement Unc um	0.0400
Measured Value xm	1500.2000
Tolerance T	0.40

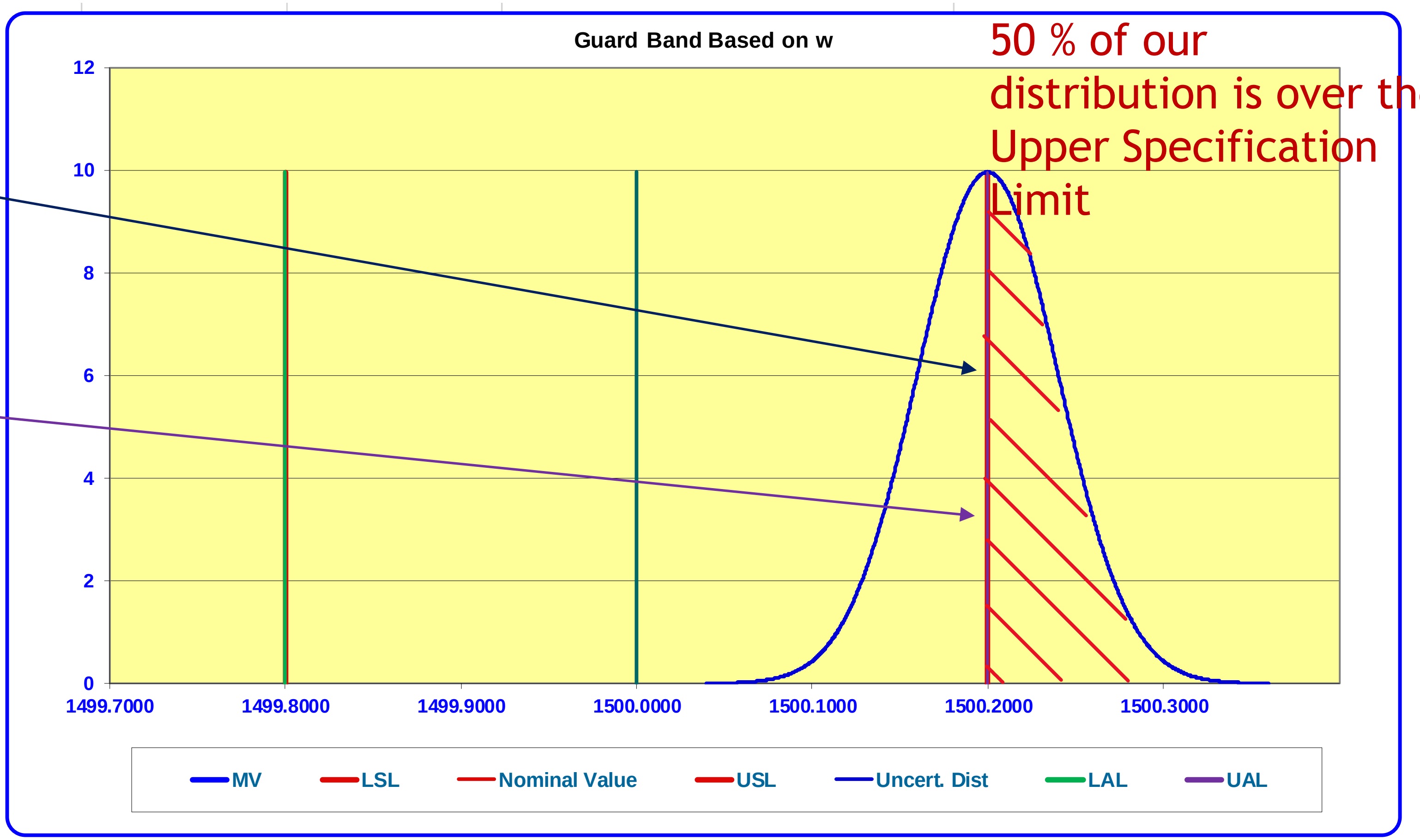
Probability of Conformance (p_c)	50.000%
Probability of NonConformance ($1 - p_c$)	50.000%

Setting the Guard Band Upper and Lower AL	
Guard Band Upper G_u (AL= TL - w)	1500.2000
Guard Band Lower G_L (AL = TL + w)	1499.8000

Setting AL based on Guard Band	
r	0.0000
$w = U_{95} * r$	0.00000
C_m	2.50000

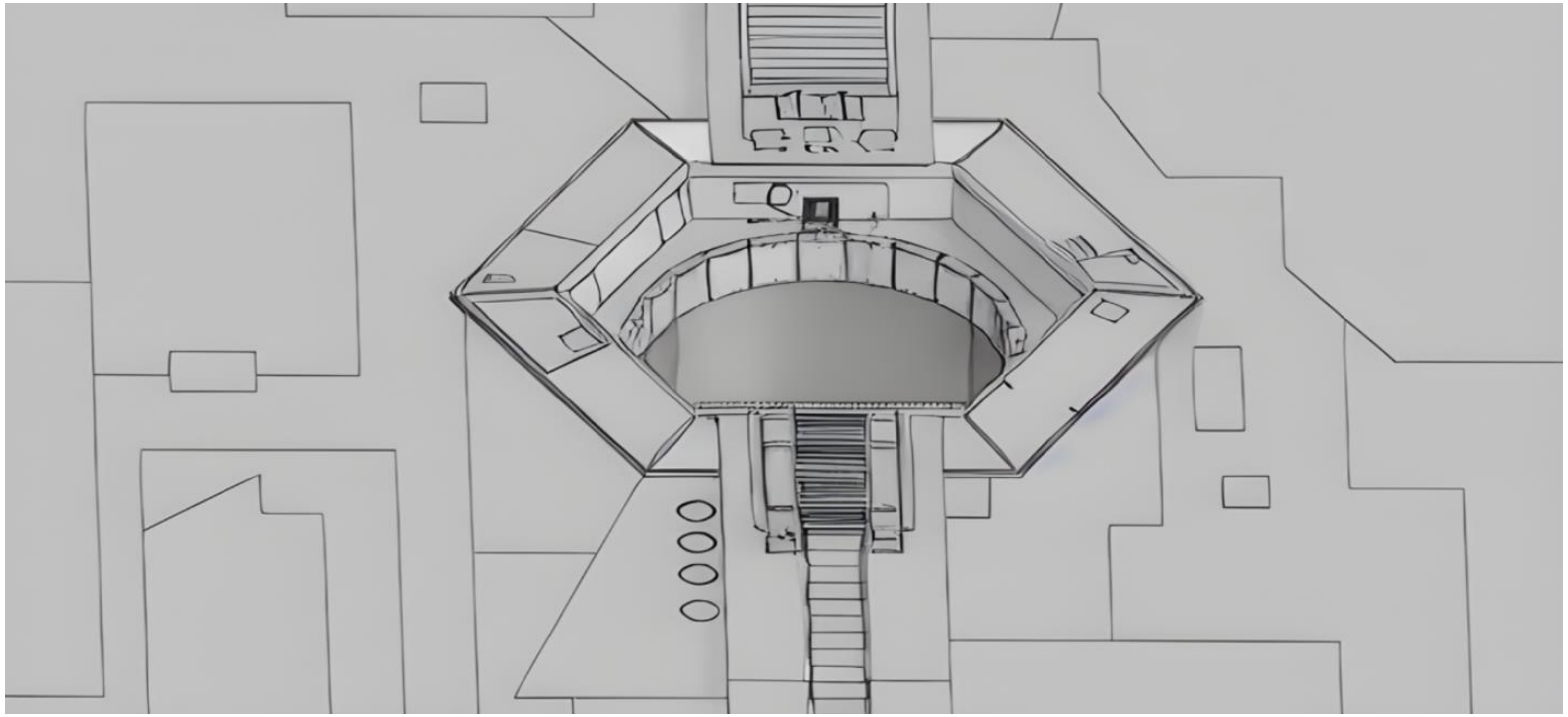
Setting AL based on Guard Band w	
Upper Acceptance Limit	PASS
Lower Acceptance Limit	PASS

Area of Curve Outside of the AL	50.000%



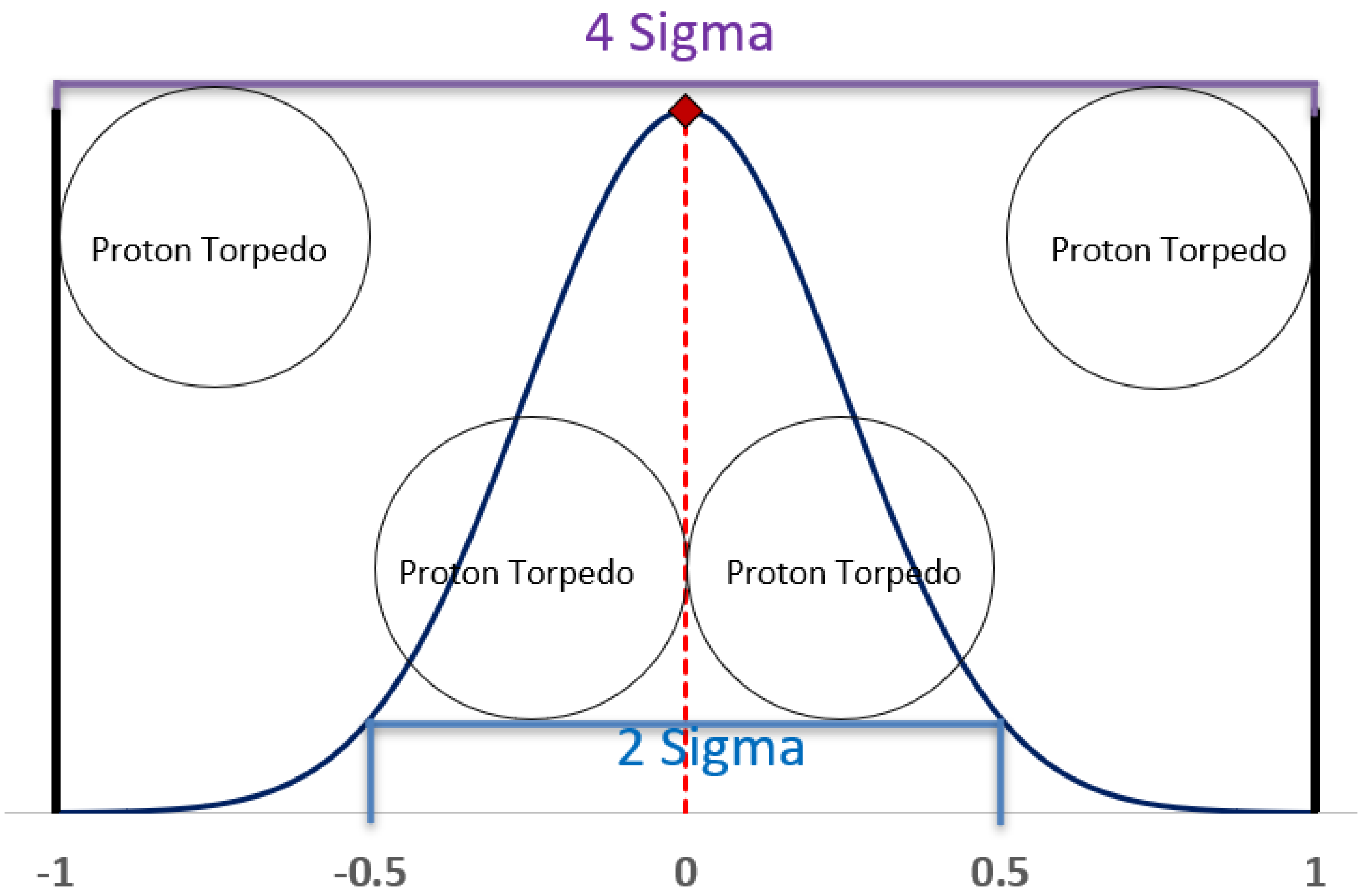
Star Wars Example

The Death Star Exhaust Port with a 2-meter hole and a 0.5-meter Proton Torpedo.



Knowing our torpedo measures 0.5 meters and the empire does not think an X-wing can get close enough to take the shot, we need to devise a plan that will ensure if we can take the shot, we will make it.

A TUR of 4:1 Means 4 Proton Torpedo's Can Fit Between the Tolerance/Specification Limits



Guard Band Multiplier

Conformance Probability Table	
Conformance Probability , P_c	Guard Band Multiplier, *r* Two Sided
0.0668	-0.750
0.1590	-0.499
0.3085	-0.250
0.5000	0.000
0.6914	0.250
0.8000	0.421
0.8500	0.518
0.9000	0.641
0.9500	0.822
0.9545	0.845
0.9750	0.980
0.9800	1.027
0.9900	1.163
0.9990	1.545

What we are calculating is our Conformance probability for 97.50 % Confidence. We calculate the Guardband Multiplier by using the formula in Excel of Norm.S.Inv(0.975)/2.

We then use this number of 0.845 as our GB Multiplier as follows.

*For the Guardband upper limit, we have 1 – (GB Multiplier * Coverage Factor * Standard Measurement Uncertainty)*

*1 – (0.980 * (2 * 0.125)) = 0.7550*

*For the Guardband lower limit, we have -1 + (GB Multiplier * Coverage Factor *Standard Measurement Uncertainty)*

*-1 + (0.980 * (2 * 0.125)) = -0.7550*

The formula can be simplified to Acceptance Limit = Tolerance Limit ± Guardband multiplier * Expanded Measurement Uncertainty.

Star Wars Example – AL for 2.5 % Maximum risk

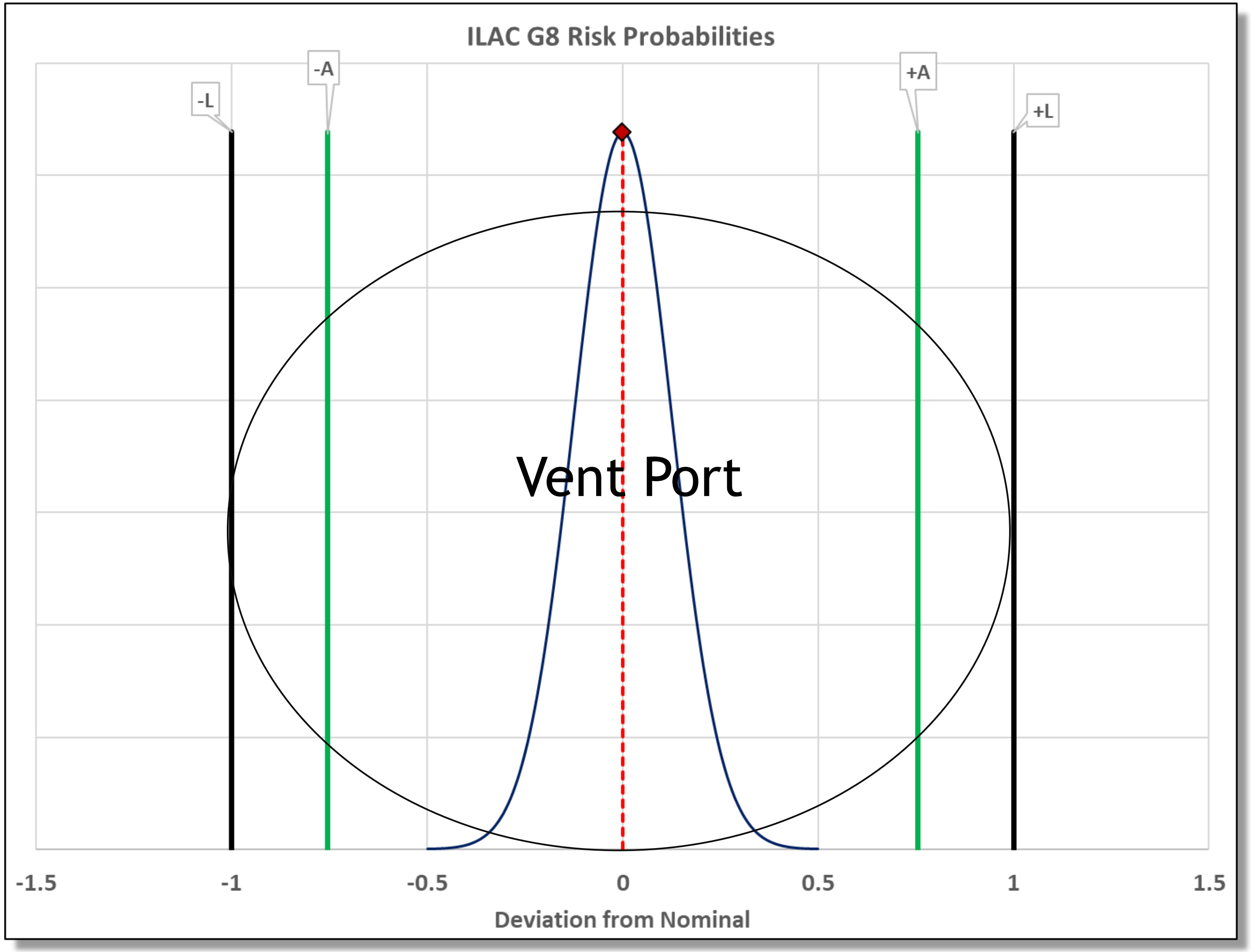
Risk Calculator	
Upper Tolerance T_U	1
Lower Tolerance T_L	-1
Nominal Value (default = blank, otherwise 0)	
Measured Value xm	0.0000
Measurement Unc um	0.1250
Maximum Allowable Risk	2.50%
Tolerance T	2.00

Probability of Conformance (p_c)	100.000%
Probability of NonConformance ($1 - p_c$)	0.000%

Setting the Guard Band Upper and Lower AL	
Guard Band Upper G_u (AL= TL - w)	0.7550
Guard Band Lower G_L (AL = TL + w)	-0.7550

Setting AL based on Probability of Conformance	
Probability of Conformance (pc)	97.50%
r	0.9800
$w = U_{95} * r$	0.24500
C_m (TUR)	4.00000

Setting AL based on Guard Band w	
Upper Acceptance Limit	PASS
Lower Acceptance Limit	PASS



Star Wars Example – Measured Value not Centered

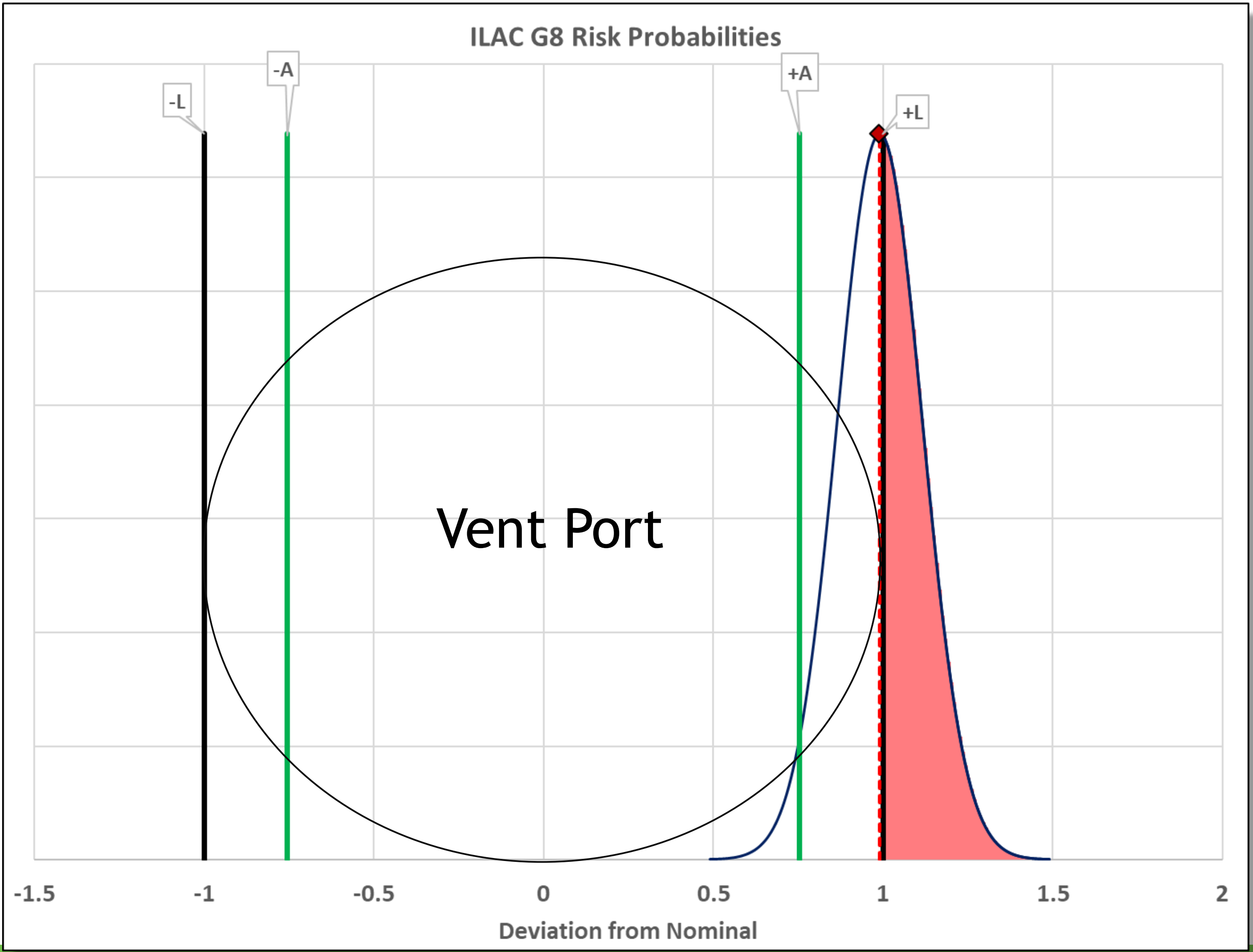
Risk Calculator	
Upper Tolerance T_U	1
Lower Tolerance T_L	-1
Nominal Value (default = blank, otherwise 0)	
Measured Value xm	0.9900
Measurement Unc um	0.1250
Maximum Allowable Risk	2.50%
Tolerance T	2.00

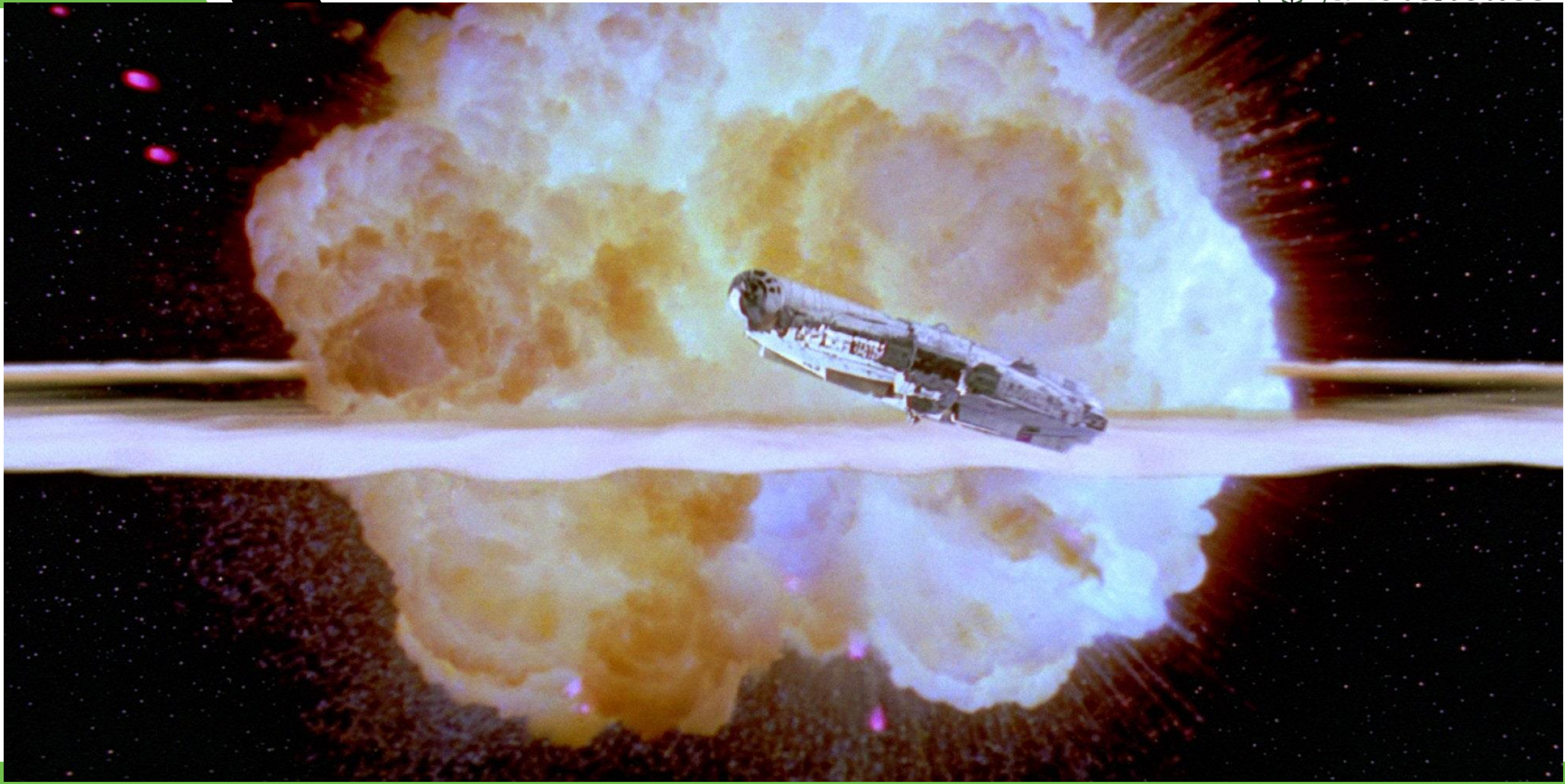
Probability of Conformance (p_c)	53.188%
Probability of NonConformance (1 - p_c)	46.812%

Setting the Guard Band Upper and Lower AL	
Guard Band Upper G_u (AL= TL - w)	0.7550
Guard Band Lower G_L (AL = TL + w)	-0.7550

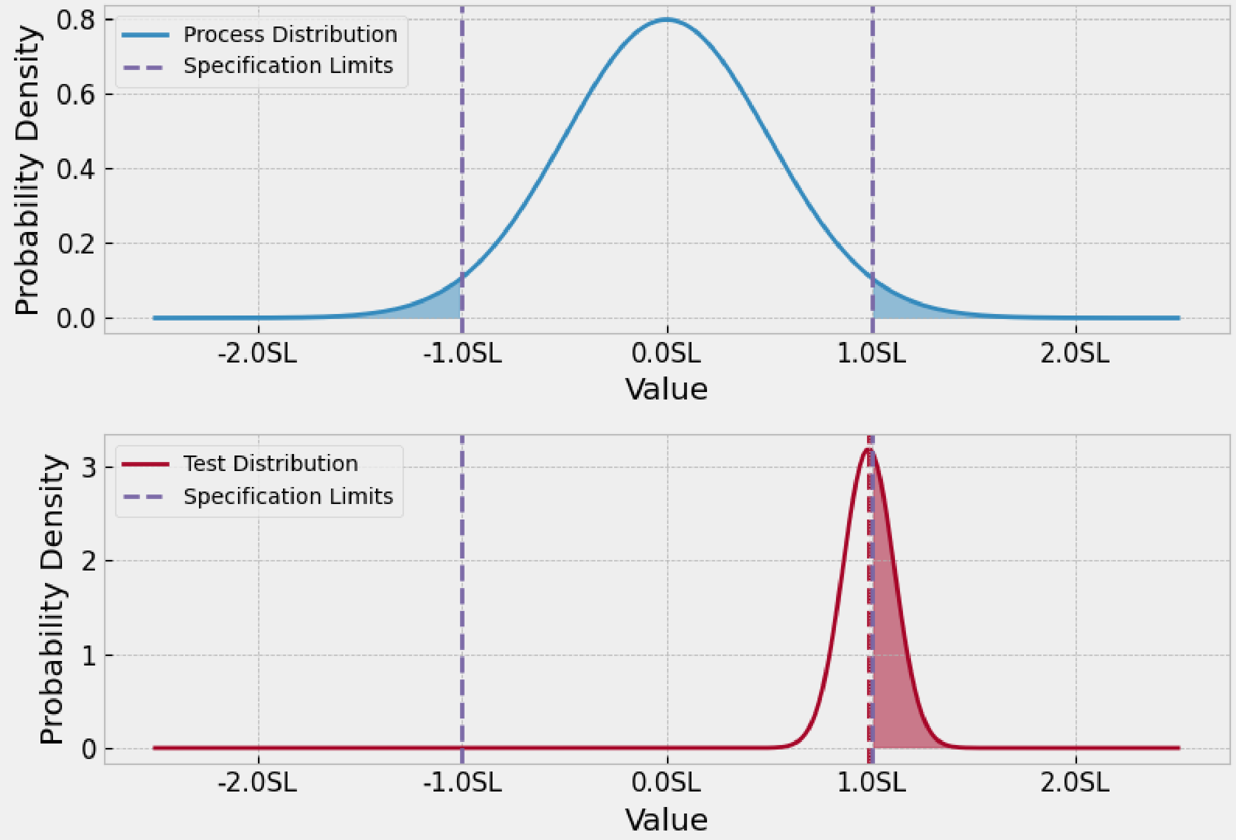
Setting AL based on Probability of Conformance	
Probability of Conformance (pc)	97.50%
r	0.9800
w = U_{95} * *r*	0.24500
C_m (TUR)	4.00000

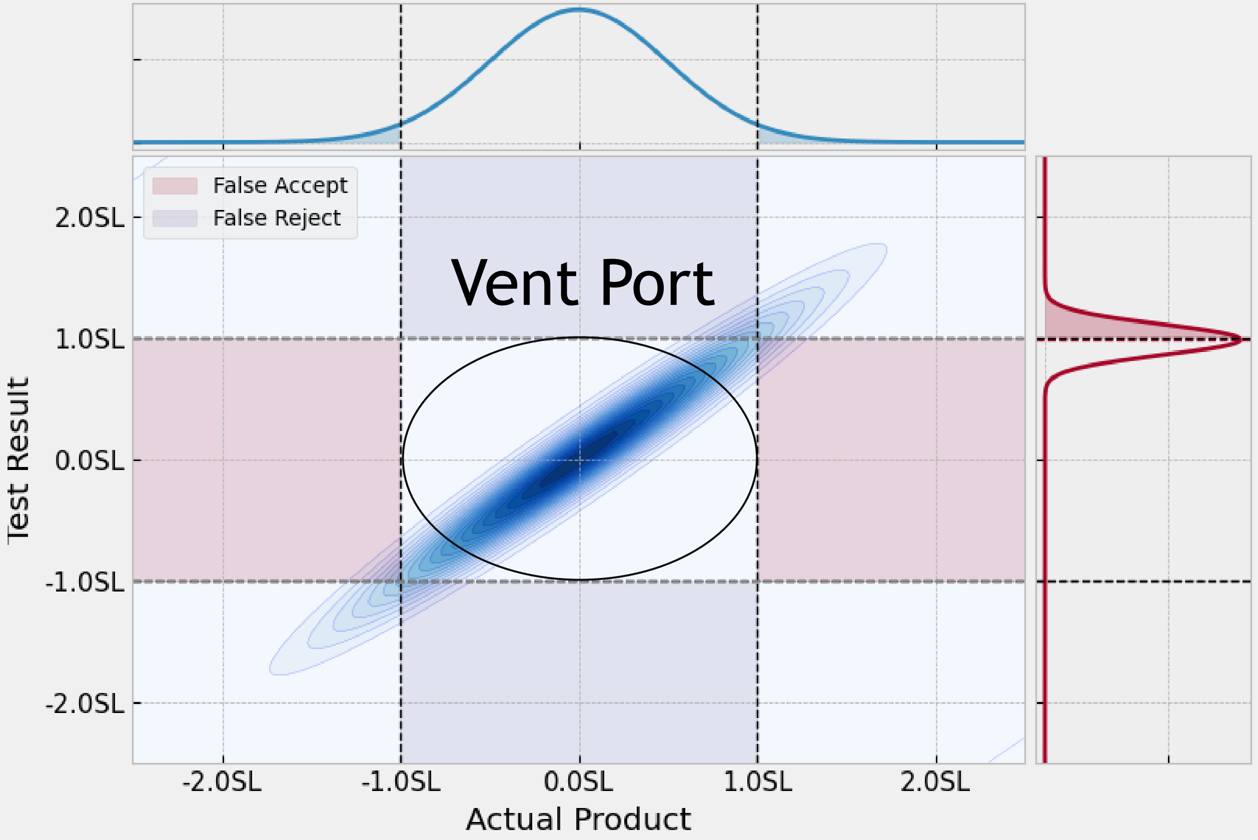
Setting AL based on Guard Band w	
Upper Acceptance Limit	FAIL
Lower Acceptance Limit	PASS





Star Wars Example

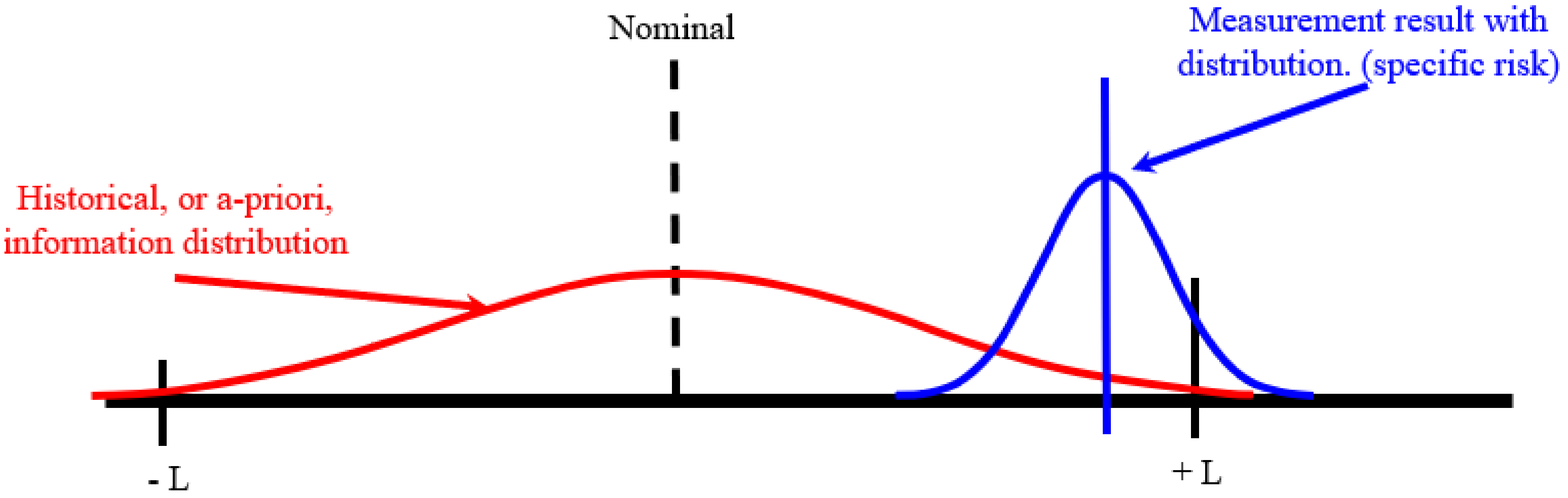




Process Risk	Specific Measurement Risk	Global Risk
Process Risk: 4.6%	TUR: 4.0	Total PFA: 0.79%
Upper limit risk: 2.3%	Measured value: 0.99	Total PFR: 1.5%
Lower limit risk: 2.3%	Result: ACCEPT	-
Process capability index (Cpk): 0.67	Specific FA Risk: 46%	-

Process Risk	Specific Measurement Risk	Global Risk
Process Risk: 4.6%	TUR: 4.0	Total PFA: 0.79%
Upper limit risk: 2.3%	Measured value: 0.99	Total PFR: 1.5%
Lower limit risk: 2.3%	Result: ACCEPT	-
Process capability index (Cpk): 0.67	Specific FA Risk: 46%	-

Destroying the Death Star – Global Risk Example



Global risk (also called process-level risk) is often based on a future measurement result.

It is used to ensure the acceptability of a documented measurement process.

It is based on expected or historical information and is usually characterized by two probability distributions.

If we look at the same example, the X-wing is not that much different from the T-16 skyhopper that he used to blast womp rats.

Global Risk – EOPR Basic Overview

$$EOPR = \frac{\text{Number of in-tolerance results}}{\text{Total number of calibrations}}$$

In simplistic terms, End of Period Reliability is defined as the number of calibrations that meet acceptance criteria divided by the total number of calibrations.

Reliability Considerations may include:

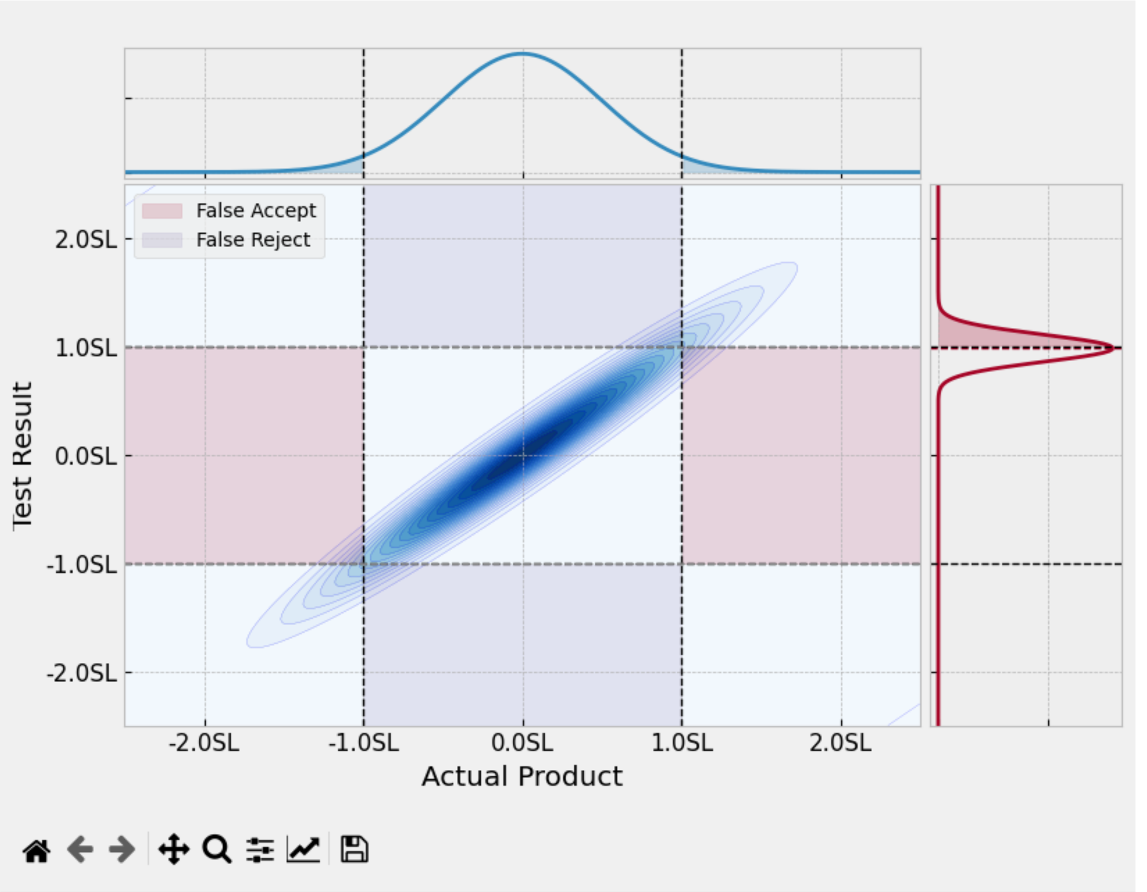
- Reliability decreases with time after calibration
- How much testing is required to demonstrate Reliability with confidence?
- *A priori* knowledge of the M&TE

Global Risk – EOPR Basic Overview

This formula to determine "In-Tolerance" Reliability from historical data is easy to replicate in Excel. The formula is **Sample Size = ln(1-Confidence)/ln(Target Reliability).**

When we use this formula for 95 % EOPR at a 95 % Confidence Interval, we need 59 samples with 0 failures or rejects as this will give us an estimation of our process.

Thus, if Luke successfully targeted 59 womp rats out of 59 shots, we would now have our reliability data and could start to use global risk models.



Process Risk	Specific Measurement Risk	Global Risk
Process Risk: 4.6%	TUR: 4.0	Total PFA: 0.79%
Upper limit risk: 2.3%	Measured value: 0.99	Total PFR: 1.5%
Lower limit risk: 2.3%	Result: ACCEPT	-
Process capability index (Cpk): 0.67	Specific FA Risk: 46%	-

Global Risk

We want to build an army of clones to defeat the Rebellion.

The optimum height is 70 inches ± 2 inches to fit our clones with the same gear and maximize cloning efficiencies.

Our measurement system has a TUR of 8:1 meaning our Calibration Process Uncertainty is 0.25 inches.

The question becomes what is the probability of saying a clone conforms to the specification when it does not?

Global Risk

Parameters | Notes

Mode: Full

Calculation: Integral

Lower Specification Limit: 68

Upper Specification Limit: 72

☑ Process Distribution:

	Parameter	Value
1	Distribution	normal
2	median	70
3	std	0.53148265198...

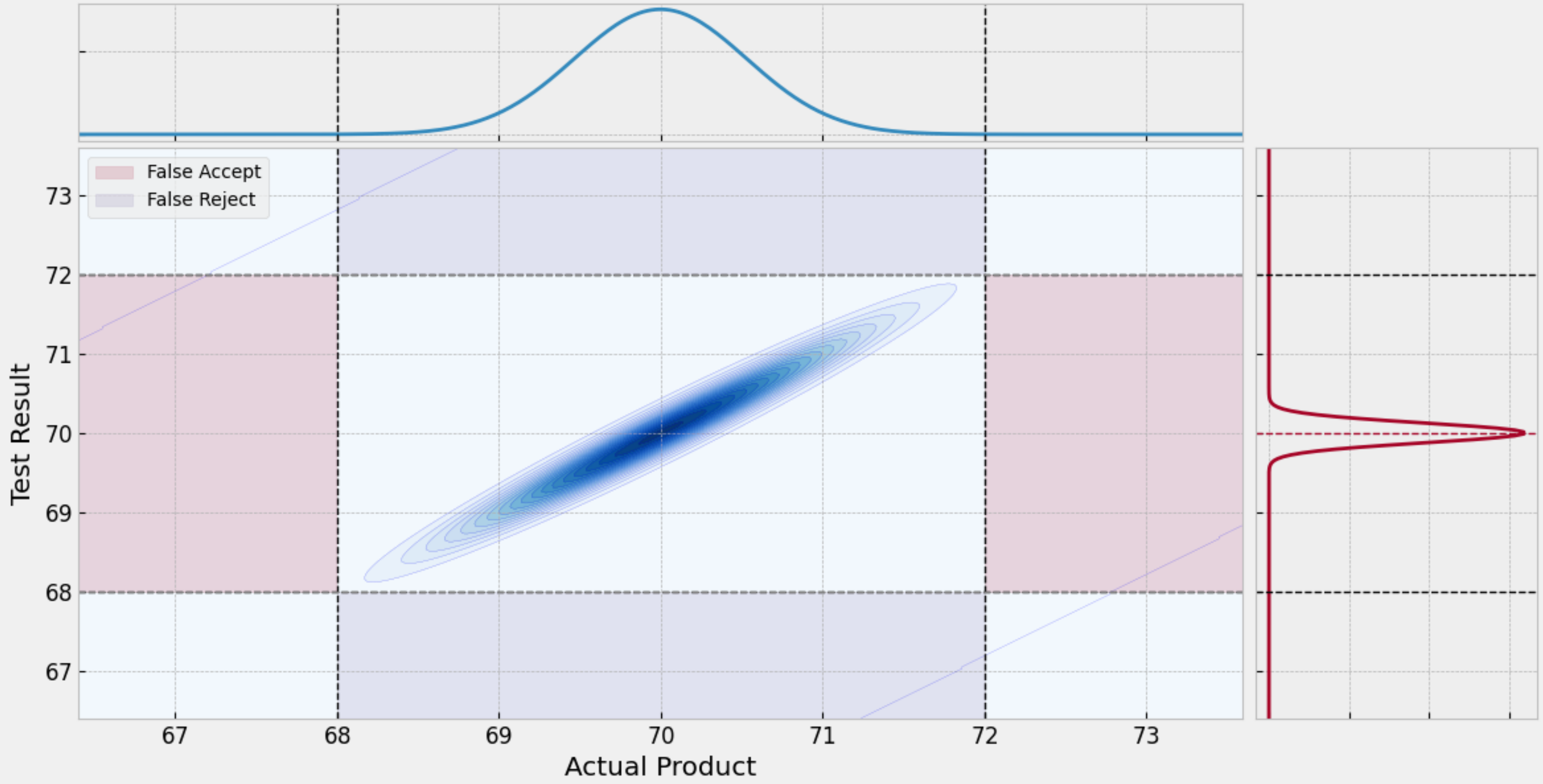
☑ Test Measurement:

	Parameter	Value
1	Distribution	normal
2	measurement	70
3	std	0.125
4	bias	0

☐ Guardband

Lower Guardband (relative): 0

Upper Guardband (relative): 0



Process Risk	Specific Measurement Risk	Global Risk
Process Risk: 0.017%	TUR: 8.0	Total PFA: 0.0039%
Upper limit risk: 0.0084%	Measured value: 70	Total PFR: 0.012%
Lower limit risk: 0.0084%	Result: ACCEPT	-
Process capability index (Cpk): 1.3	Specific FA Risk: 6.4e-56%	-

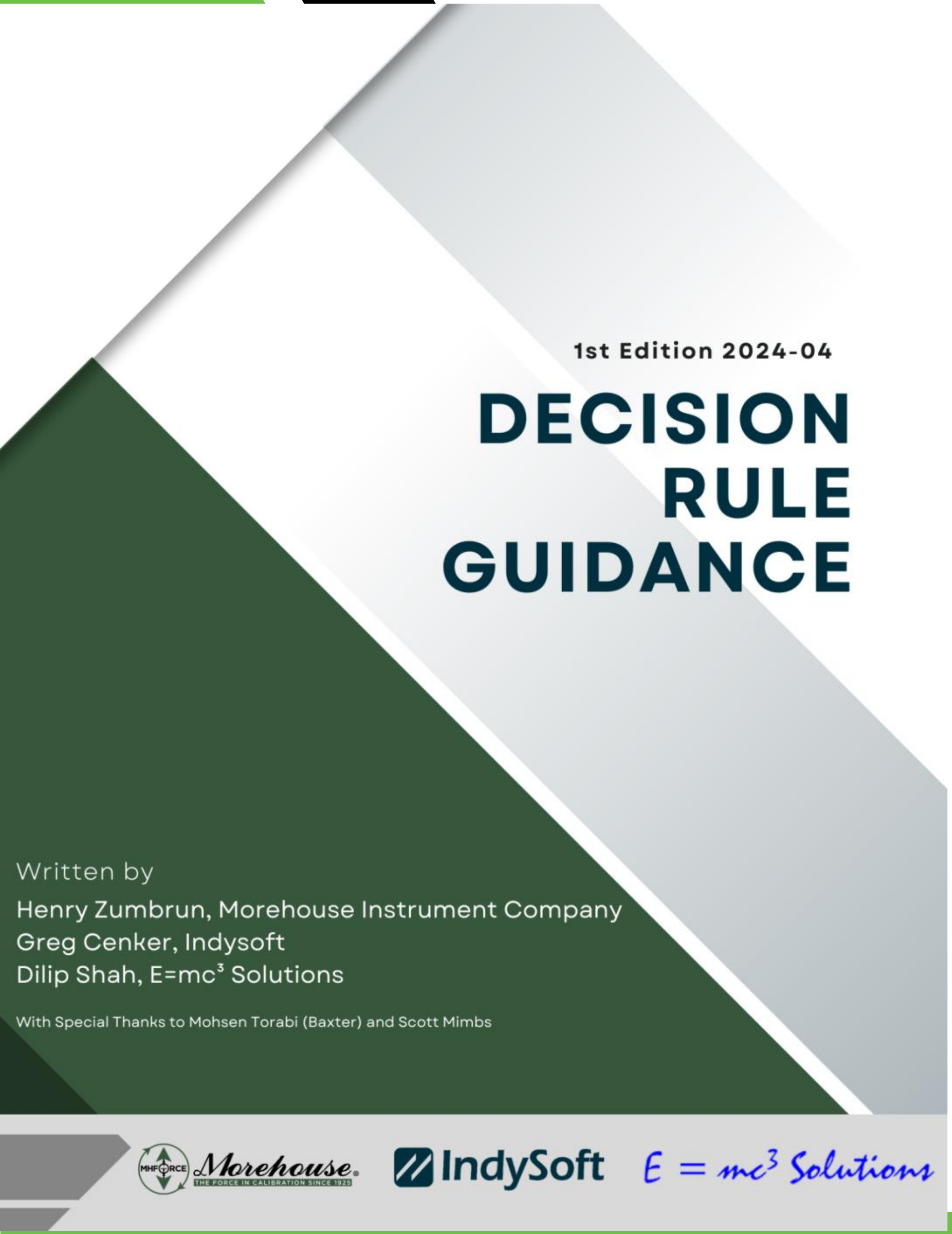
Global Risk

Global vs Specific Risk Summary

- Specific Risk is usually dependent on a single probability function and can be referred to as Probability of Conformance from the customer's point of view.
- Global Risk is dependent on two probabilities, the second being the a priori knowledge, which could be taken as the process or instrument reliability.
- Typically, when we talk about TUR, we are talking about Global Risk.
- TUR is also a ratio useful at the bench level as higher TURs increase our acceptance zone.

What are Some of the Things We Can Control to Mitigate Our Risk?

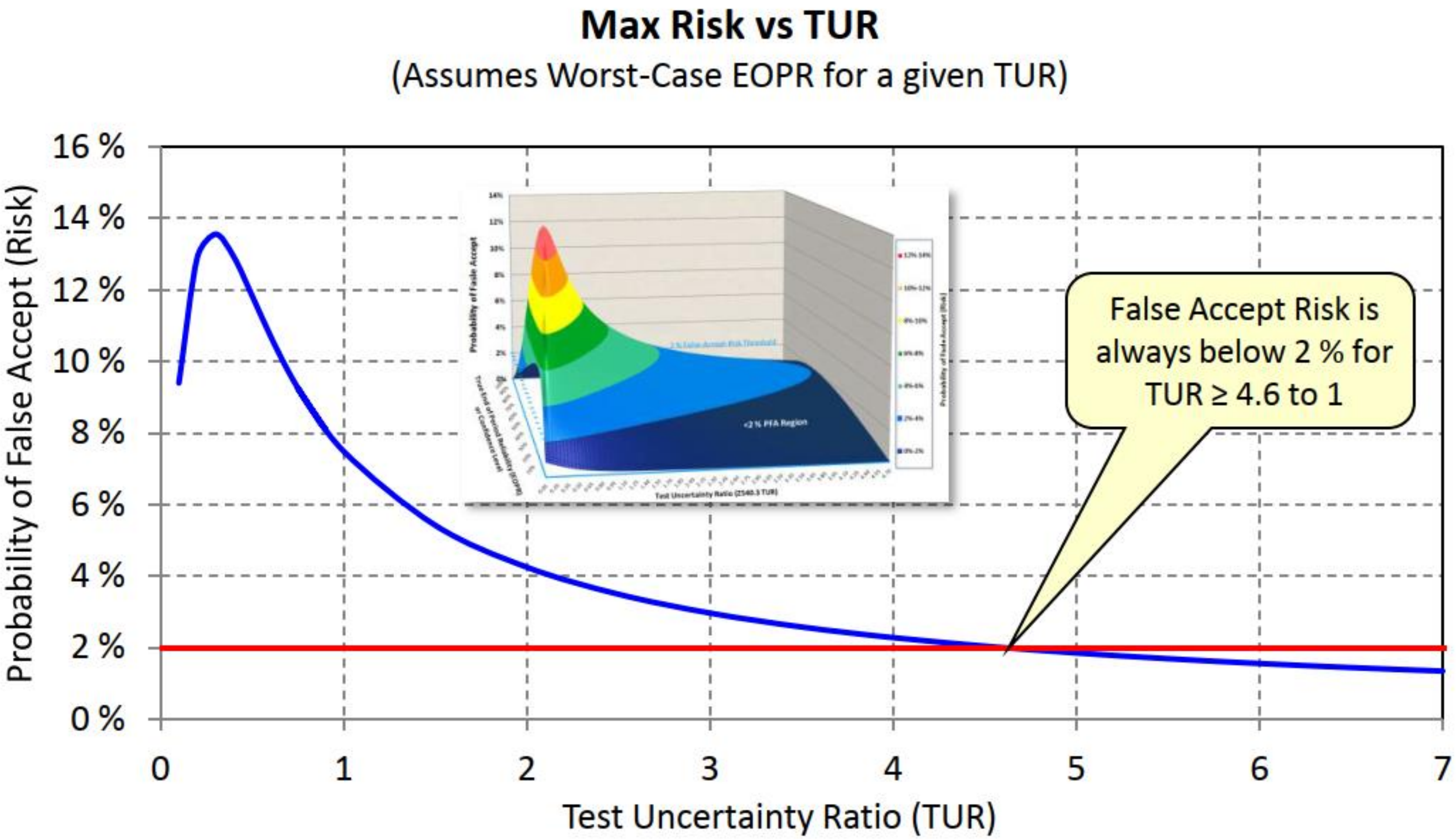
- We can buy better standards or send our equipment to labs with lower measurement uncertainties.
- We can raise our tolerance if we do not need what the manufacturer states.
- We can decrease the time between calibrations.
- Maybe it is a matter of a too-coarse resolution where a different indicator would help.



More information on Decision Rules is covered at length in our Decision Rule Guidance Document

https://mhforce.com/wp-content/uploads/2024/04/Decision-Rule-Guidance-1st-Edition-V1.1.pdf

Global Risk

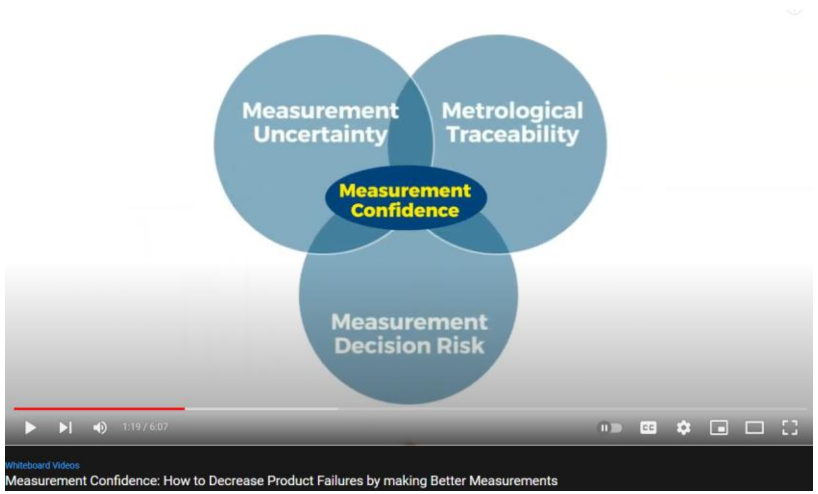


The image is taken from Implementing Strategies for Risk Mitigation In the Modern Calibration Laboratory

Recommended Reading - Guidance

- ILAC G8:09/2019 *Guidelines on Decision Rules and Statements of Conformity*
- JCGM 106:2012 *Evaluation of measurement data – The role of measurement uncertainty in conformity assessment*
- UKAS LAB 48: *Decision Rules and Statements of Conformity*
- ISO/IEC 17025 2017 *General requirements for the competence of testing and calibration laboratories*
- Handbook for the Application of ANSI Z540.3-2006: *Requirements for the Calibration of Measuring and Test Equipment*
- The Metrology Handbook 3rd Edition Chapter 30
- NCSLI-RP18 Estimation and Evaluation of Measurement Decision Risk
- ASME B89.7.3.1-2001 Guidelines for Decision Rules: Considering Measurement Uncertainty in Determining Conformance to Specifications
- ASME B89.7.4.1-2005 Measurement Uncertainty and Conformance Testing: Risk Analysis *
- ISO 14253-5 Part 1: Decision rules for proving conformity or nonconformity with specifications
- WADA Technical Document – TD2017DK
- Decision Rules Guidance Document by Henry Z, Dilip S, Greg C and more

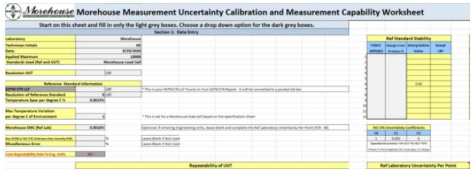
Want More Information?



[Morehouse YouTube Videos]

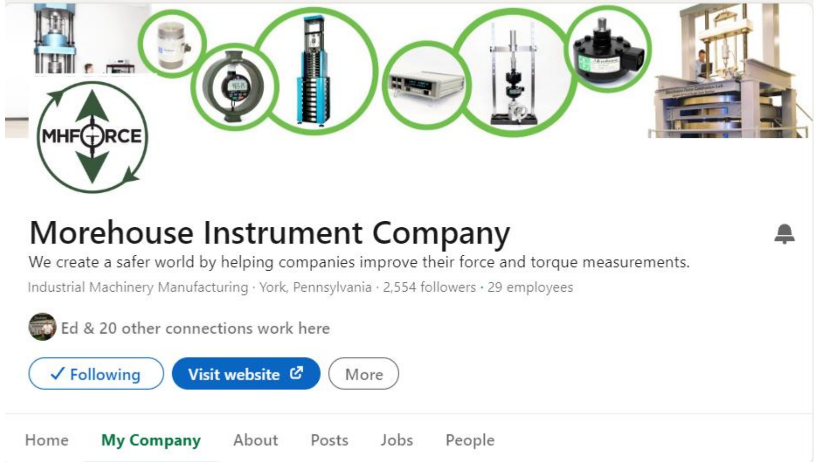
#1 CMC Calculation Made Easy Tool for Force Uncertainty

Are you having problems figuring out all of the requirements to calculate a CMC for force uncertainty or torque uncertainty? This excel sheet provides a template to calculate CMCs (force uncertainty) with explanations of everything required to pass an ISO/IEC 17025 audit.



Morehouse Free Force Uncertainty Spreadsheet to Calculate Calibration and Measurement Capability Uncertainty

[Morehouse Free Downloads]



[Follow Morehouse on LinkedIn]

Contact us at [info@mhforce.com]