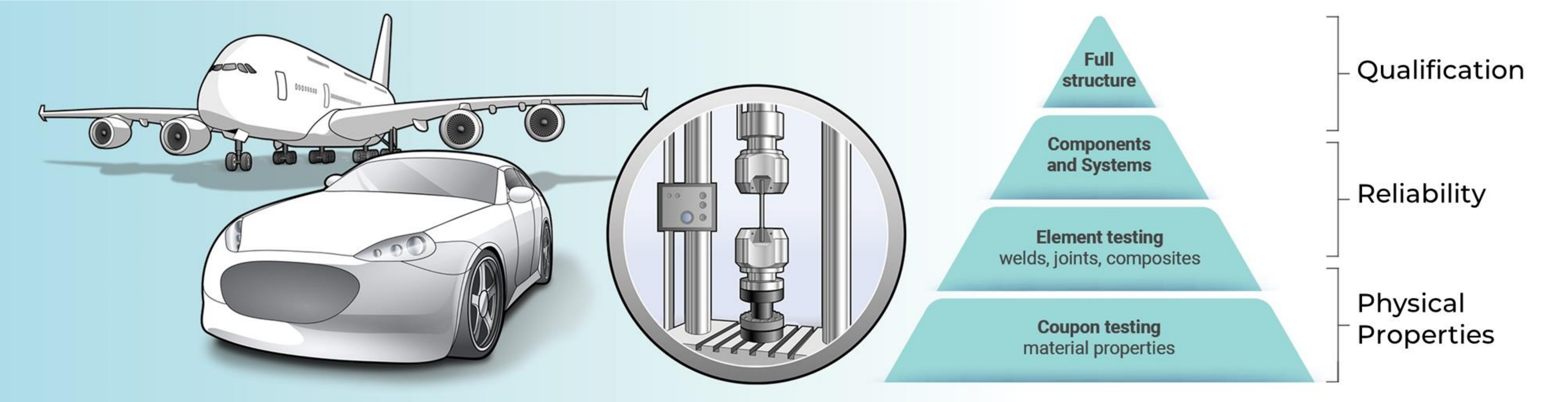


2023 HBK Technology Days

21 November 2023

- **Prioritising tests required to mitigate reliability risk exposure**

Chris Wynn-Jones,
Application Engineer – Reliability, HBK

Prioritising tests required to mitigate reliability risk exposure

Abstract

- Continuous Improvement of asset reliability is made possible with a combination of test data and field data. Using Failure Mode and Effect Analysis (FMEA), we can ask the right questions when attempting to study test and field data to calculate failure distributions over time. Failure modes can then be ranked, and plans proposed for supplementary testing where the data are found to be weak, or the reliability is lowest. Changes to the asset with respect to reliability improvement is actioned and traced through FMEA revision control. In this presentation we demonstrate how FMEA may be used to improve component reliability by combining qualitative engineering judgement with quantitative evidence derived through statistical rigour.

About the presenter, Chris Wynn-Jones, Application Engineer – Reliability, HBK

- Christopher Wynn-Jones has a BEng (Hons) in Mechanical Engineering from University of Wolverhampton coupled with 25 years of engineering experience. After various manufacturing roles Chris went on to become a Safety and Reliability Engineer for civil and military products in the air, at sea and ground vehicles. He is an Application Engineer for ReliaSoft reliability software, supporting customers in industry and in universities with software solutions and best practices in Engineering for Reliability.
- Chris also sits on the WG1 committee of the Institute of Mechanical Engineers [IMechE] Safety and Reliability Group (SRG). The SRG group promotes the development of safety and reliability requirements for products such as equipment, systems or services.

Prioritizing tests required to mitigate reliability risk exposure

SYSTEM RELIABILITY – HBK TECHNOLOGY DAYS 2023

Chris Wynn-Jones

PUBLIC

Internal vs. External Reliability View

Engineering Teams

- View reliability as the domain to address mechanical, electrical and manufacturing issues

Customers

- View reliability as a system-level issue
  - Focus on total product performance

The primary measure of reliability is made by the Customer

- Engineering teams must maintain a balance of views to develop a reliable product
  - Business needs vs. Customer expectations
  - System vs. Domain vs. Component

Factor of 10 Rule

- Fact - cost of discovering issues increases tenfold through the development process

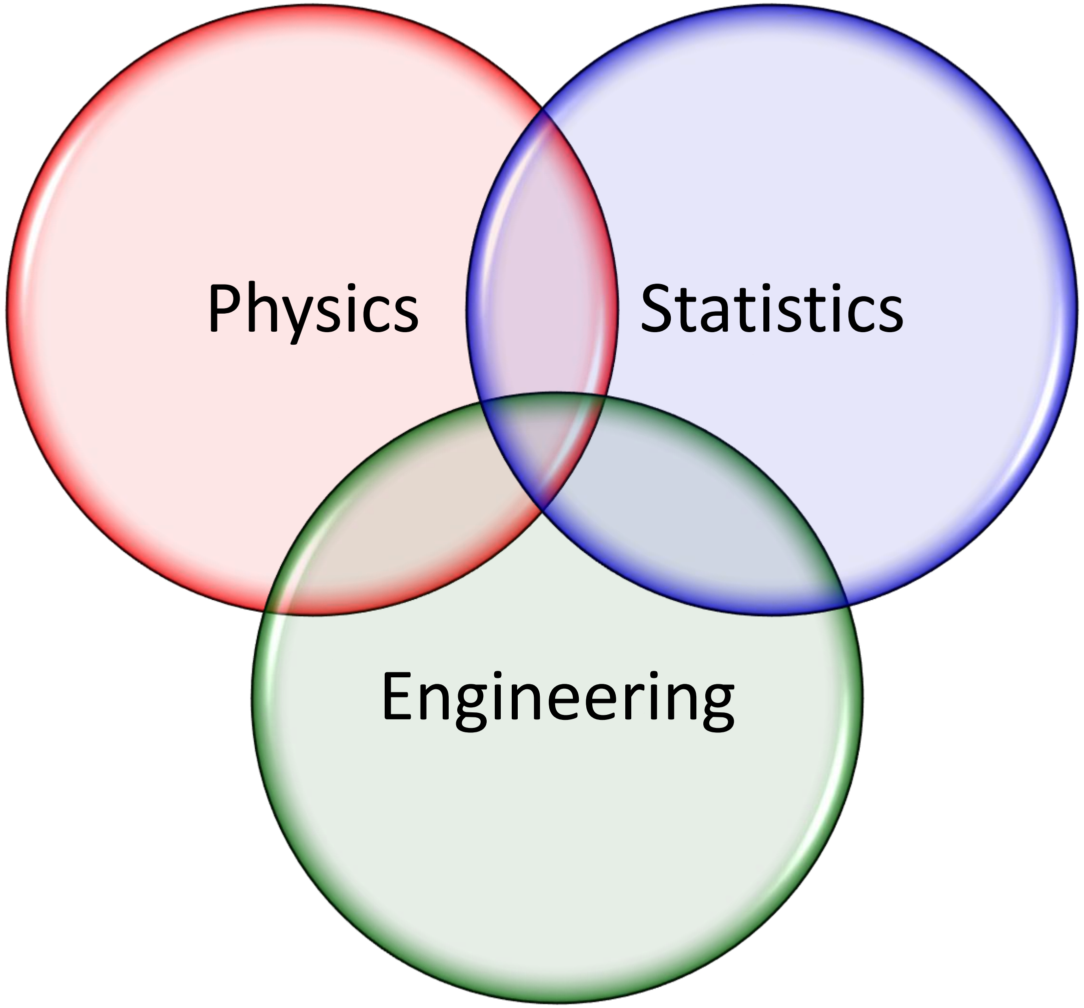
Concept Phase	$
Design Phase	$ x 10
Development Phase	$ x 100
Manufacture Phase	$ x 1000
Support Phase	$ x 10000

- Complex system reality

Concept Phase	$
Support Phase	$ x 10000

Final assembly product release test!

scientific know-how



System Hierarchy

Concept System

List of Sub Systems

- FIRE PROTECTION
- ICE AND RAIN PROTECTION
- PNEUMATIC
- CENTRAL MAINTENANCE SYSTEM (CMS)
- POWERPLANT
- AC77 TURBOFAN ENGINE
- ENGINE FUEL AND CONTROL
- IGNITION (includes ATA 74-10, 74-20 & 74-30)
- AIR
- ENGINE CONTROLS
- ENGINE INDICATING
- EXHAUST
- OIL
- STARTING

- FIRE PROTECTION
  - Detection
    - Engine Fire Detection
      - Zone 1 Sensor.
      - Zone 2 Sensor.
  - Extinguishing
    - Engine Fire Extinguishing
      - Fire Extinguisher bottle assembly.
      - Double Check Tee
      - Discharge Pipe LH
      - Discharge Pipe RH
      - Pipe Assembly L-H with permaswage fittings
      - Pipe Assembly R-H with permaswage fittings
- ICE AND RAIN PROTECTION
  - Nacelle Inlet Anti-Ice
    - Pressure Regulating Shut Off Valve
    - PRSOV to inlet break point pipework
    - Inlet break point to Piccolo tube pipework.
    - Piccolo Tube
    - Dual Ground-Flight Idle Low Pressure Switch
    - V Band Clamps
    - Low Pressure Switch Sensing Pipe
    - W1 Engine Wiring Harness Assembly
    - W2 Engine Wiring Harness Assembly

Complexity grows over time

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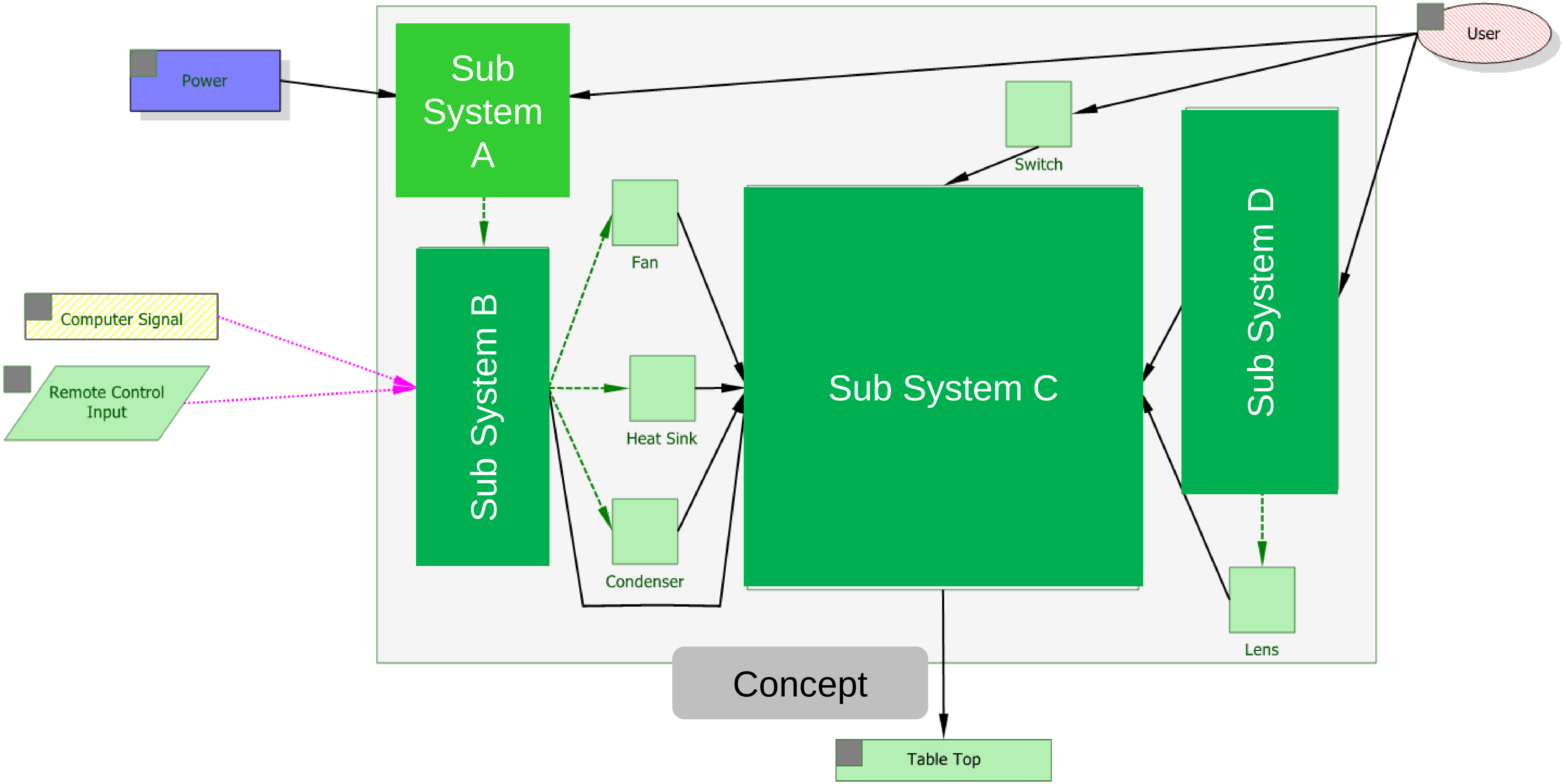
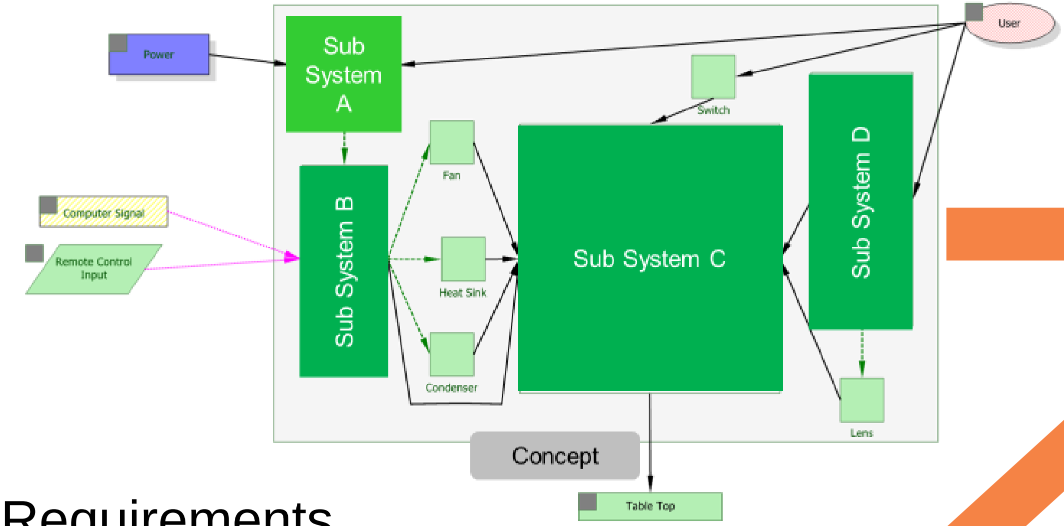
System Interfaces



System Functions

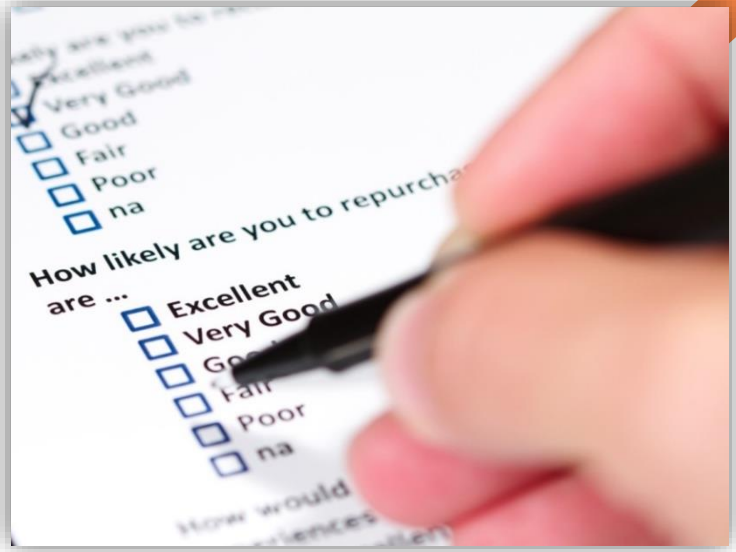
Interfaces



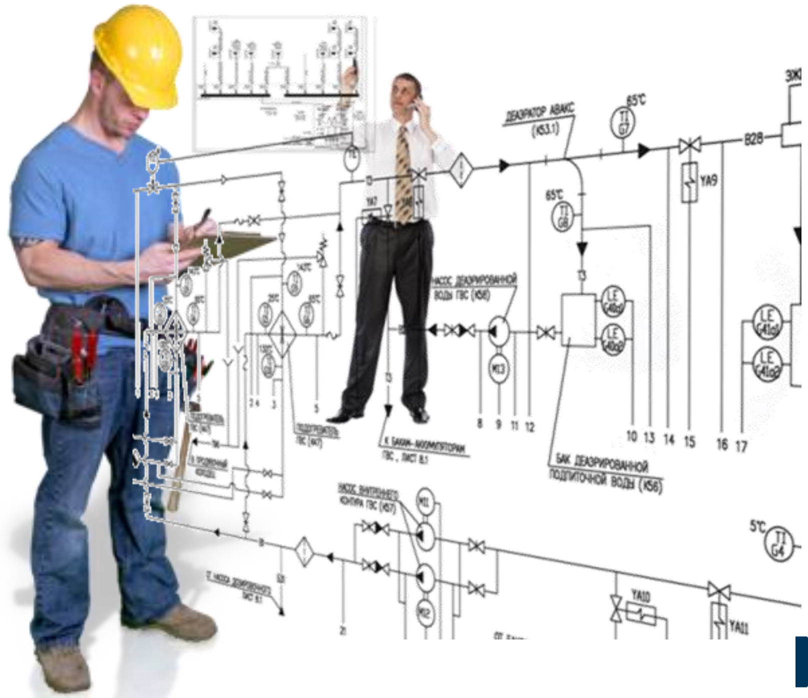
Failure Mode and Effects

	Function	Failure	Failure Probability	Severity Class	Effect	Si
1	Provide light for image transfer	Lamp burns			No light (7)	7

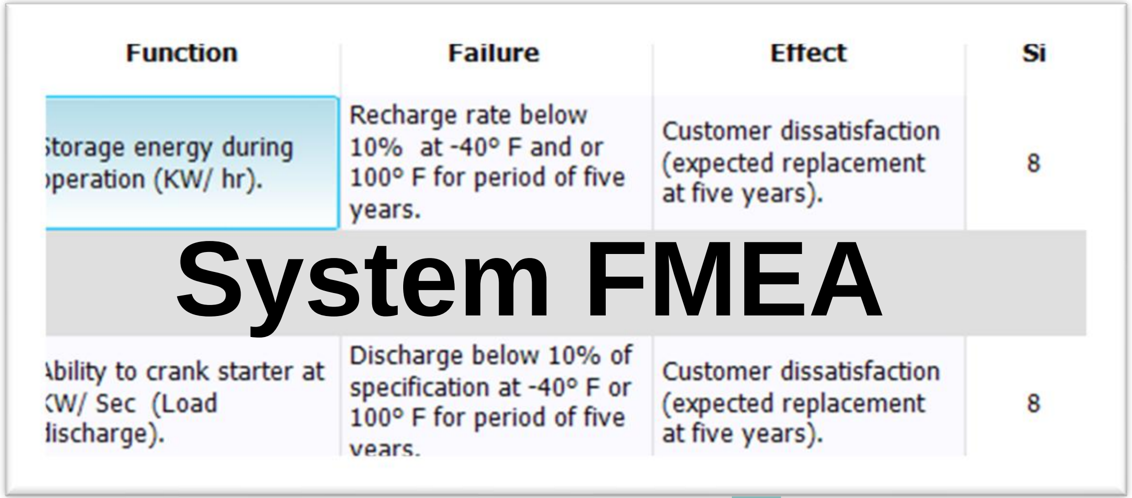
Customer Requirements



Standards & Legislations



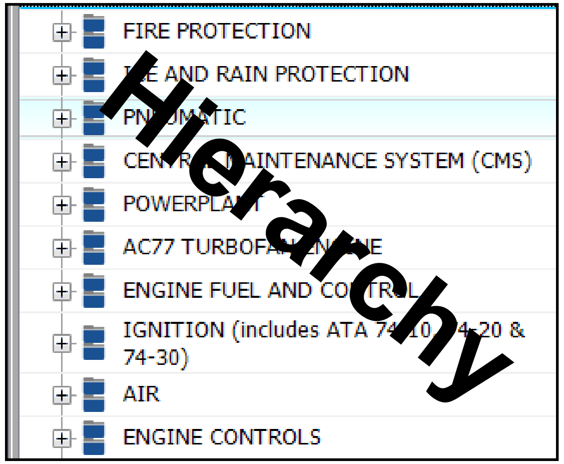
System level Failure Modes and Effects Analysis (FMEA)

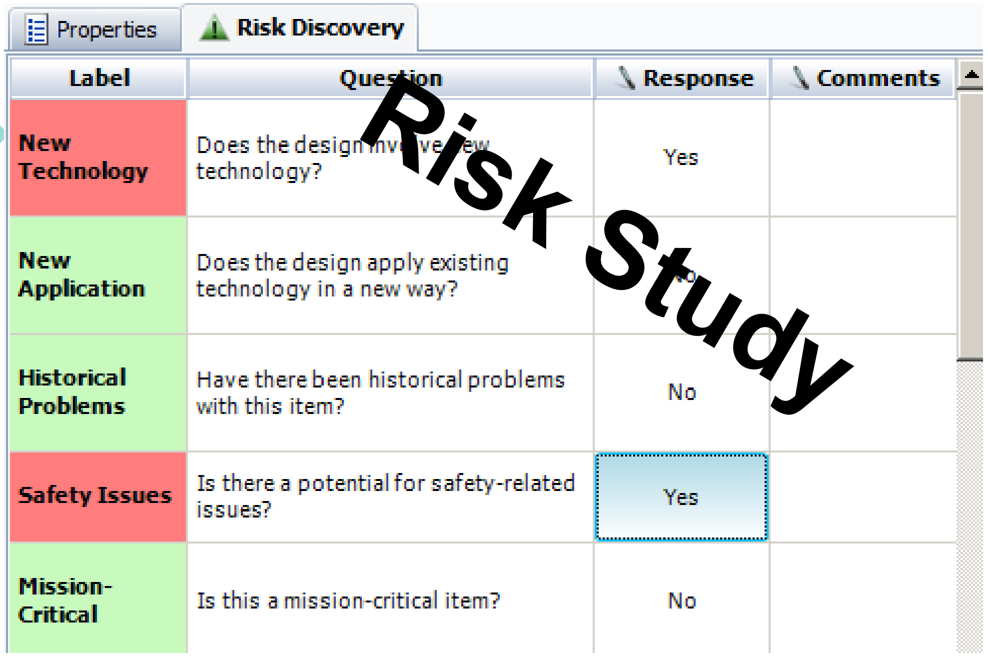


Function	Failure	Effect	Si
torage energy during peration (KW/ hr).	Recharge rate below 10% at -40° F and or 100° F for period of five years.	Customer dissatisfaction (expected replacement at five years).	8
bility to crank starter at W/ Sec (Load ischarge).	Discharge below 10% of specification at -40° F or 100° F for period of five years.	Customer dissatisfaction (expected replacement at five years).	8

Very early in the concept phase of the System design the Severity of each Functional Failure can be ranked 1 to 10

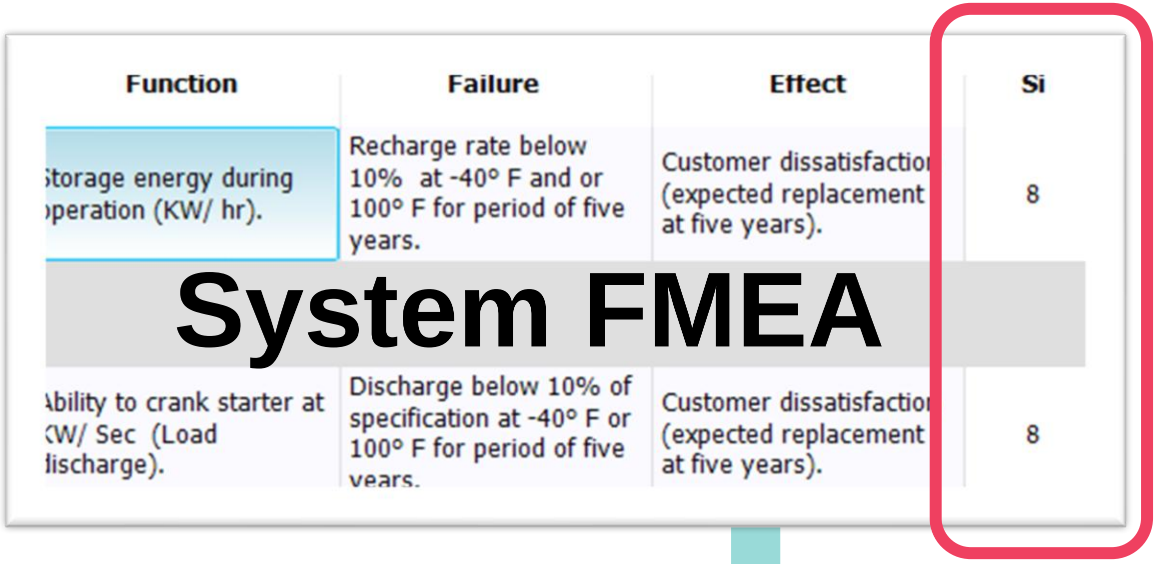
Risk Discovery ranks the different Sub Systems and highlights areas of weakness





Label	Question	Response	Comments
New Technology	Does the design inv ve ew technology?	Yes	
New Application	Does the design apply existing technology in a new way?	o	
Historical Problems	Have there been historical problems with this item?	No	
Safety Issues	Is there a potential for safety-related issues?	Yes	
Mission-Critical	Is this a mission-critical item?	No	

System level Failure Modes and Effects Analysis (FMEA)



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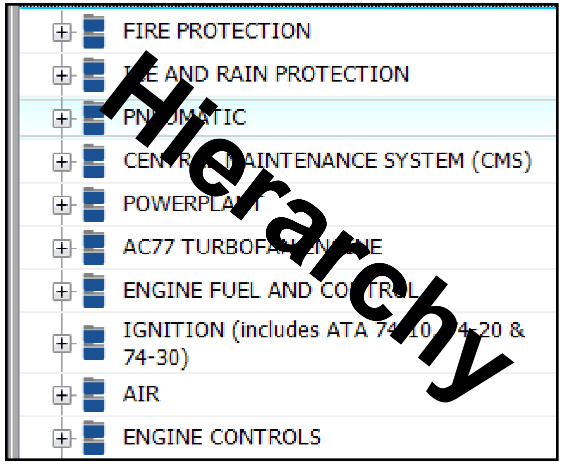
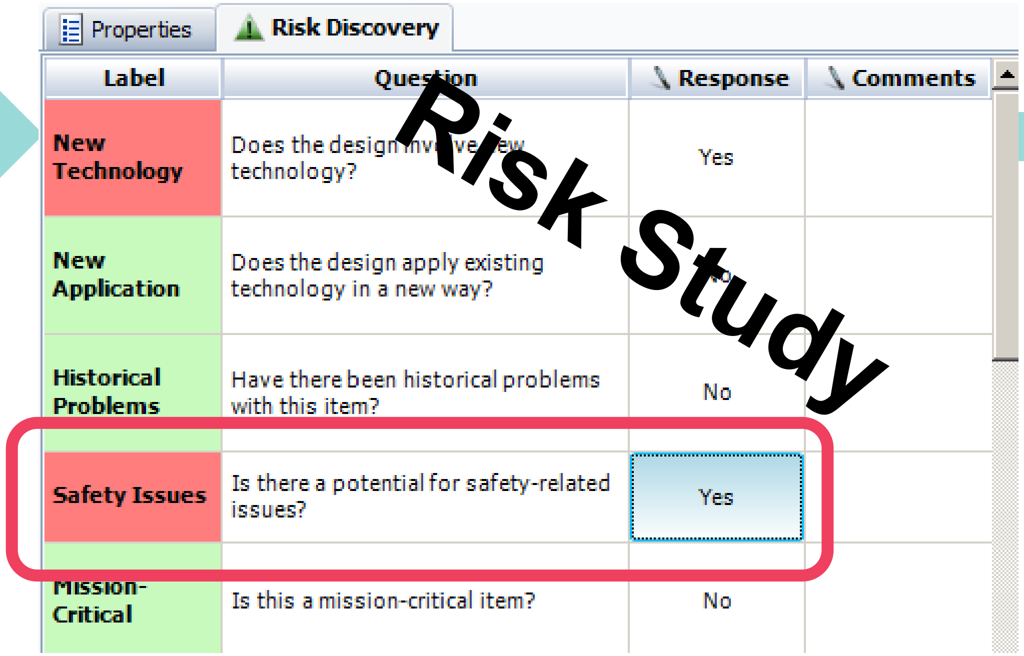
Risk Discovery ranks the different Sub Systems and highlights areas of weakness

Risk + High Severity = Focal point





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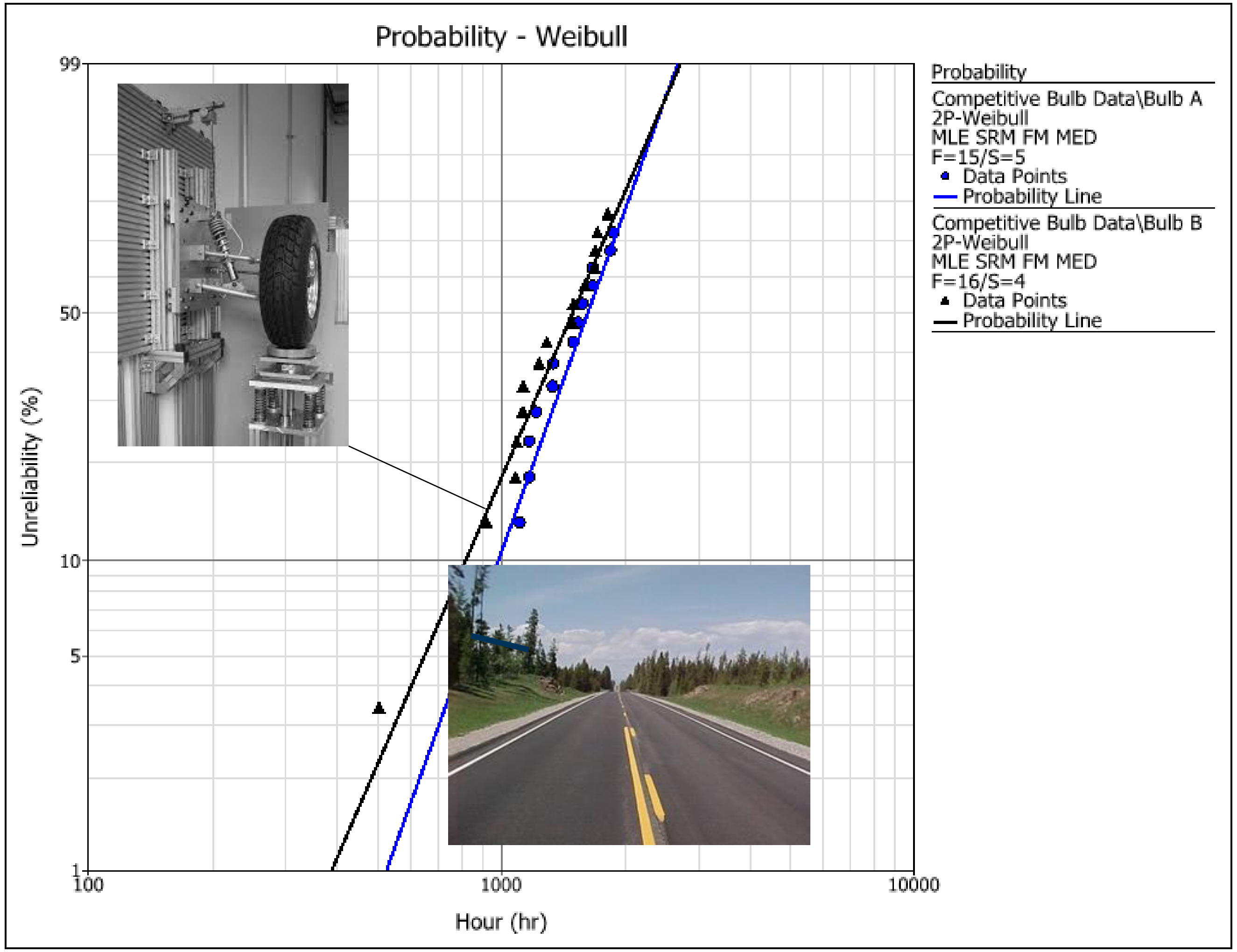
Reliability Study – Data Collection

From highest risk, work on each and research what is known from all availably resources.

Failure times, suspensions or time without failing

Environmental and Usage Conditions



Reliability Policy – Red Flags

System Hierarchy | FMRA

Name	Reliability Policy	Target Reliability	Reliability (Analytical)
Projector	Inherit	0.9950	0.5707
Plug	Inherit	0.9900	0.9958
Transfer power from outlet to projector	Inherit	0.9900	0.9960
No power to projector	Inherit	0.9900	0.9960
Plug disconnected	Plug disconnected	0.9900	0.9960
Fuse	Inherit	0.9900	0.9998
Protect projector circuits from high power issues	Inherit	0.9900	0.9998
No power to projector	Inherit	0.9900	0.9998
Over voltage conditon	Over voltage conditon	0.9900	0.9998
Switch	Inherit	0.9900	0.8100
Control power to projector	Inherit	0.9900	0.8100
Switch fails open	Inherit	0.9900	0.8100
Broken contact	Broken contact	0.9900	0.8100
Lamp	Inherit	0.9900	0.7548
Provide light for image transfer	Inherit	0.9900	0.7548
Lamp burns	Inherit	0.9900	0.9566
Overload	Overload	0.9900	0.9980
Aging	Aging	0.9900	0.9604
Hot Spots (due to over touching of lamp)	Hot Spots (due to over touching o...	0.9900	0.9980
Lamp shatters	Inherit	0.9900	1.0000
Over pressure	Over pressure	0.9900	1.0000
Overheat	Inherit	0.9900	0.7939
Extended operation	Extended operation	0.9900	0.8100
Dirty filter	Dirty filter	0.9900	0.9801
Filament breaks	Inherit	0.9900	0.9940
Shock	Shock	0.9900	0.9960
Vibration	Vibration	0.9900	0.9980
Lens	Inherit	0.9900	0.9604
Transmit focused light energy to screen	Inherit	0.9900	0.9604

Properties

Identifiers
- Image
- Name
- Category
- Part Numb
- Supplier
- Application
- Description
- Comments
- Keywords

Other Item Properties

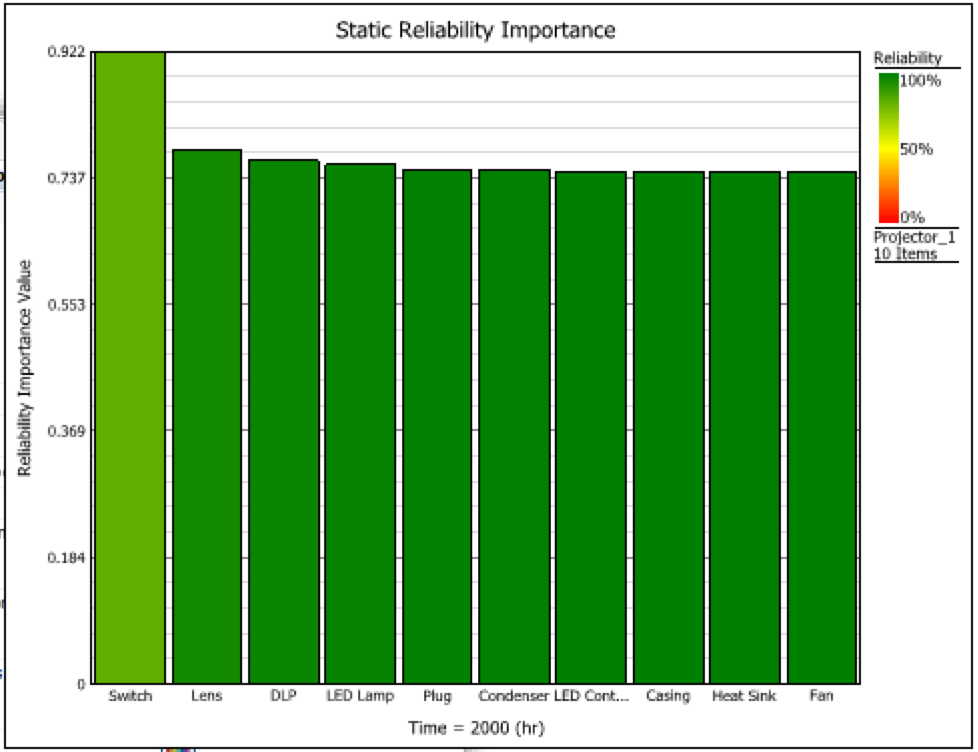
Operation
- Operating Time: 2000 (Hr)
- Current Age: 0 (Hr)
- Duty Cycle: 1

Reliability Policy
- Type: Inherit

Reliability
- Target Reliability: 0.995
- Current Reliability: 0.5707

Push to Metrics

History



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Risk Priority Number (RPN)

- The final part of the FMEA can be completed;
  - Causes, route cause or translations from physics of failure
  - Occurrence/Frequency [Oi] – Reliability Policy
  - Detectability [Di]
  - RPN
    - All high RPN scores lead to raising test plan actions

	Function	Potential Failure Mode	Potential Effect(s) of Failure	SEVi	Potential Cause(s) of Failure	OCCi	Current Design Controls	DETi	RPNi	Recommended Action(s)
1	Supply Voltage 1.2v for 85Ah	Thermal runaway	Lost of primary function for a single cell (7,-) Propagation beyond individual cell, catastrophic failure of the entire pack and potential damage to surroundings (9,-)	9	Short circuit due to overcharge or overdischarge	3	Current limiting by fuse	2	54	
2					Internal short circuit due to battery recharging in low temperature	2	Module temperature monitoring	2	36	
3					Electrolyte vaporization due to high storage temperature	3	Pressure detection	4	108	
4					Failure of the separator due to repeated charge-discharge cycling	4	Charge discharge current monitoring	2	72	
5					External short circuit	4		2	72	
6					External mechanical abuse	3		4	108	
7					Aging due to electrochemical cycling	2	SOH monitoring	2	36	
8		Does not supply specified voltage of 1.2v	Sub optimum performance (7,-)	7	Aging due to degradation of electrode properties caused by electrochemical cycling	6	SOH monitoring	2	84	
9					Accelerated degradation due to trace contaminants	2	Quality control	5	70	
10					Residual mechanical stress induced by the packaging the cell	5	Durability test	3	105	

Highest RPNs?

Risk Priority Number (RPN)

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  - Occurrence/Frequency [Oi] – Reliability Policy
  - Detectability [Di]
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Understand root cause;
What is the Physics of failure [PoF] ?

Test Plan – Actions for high RPN's

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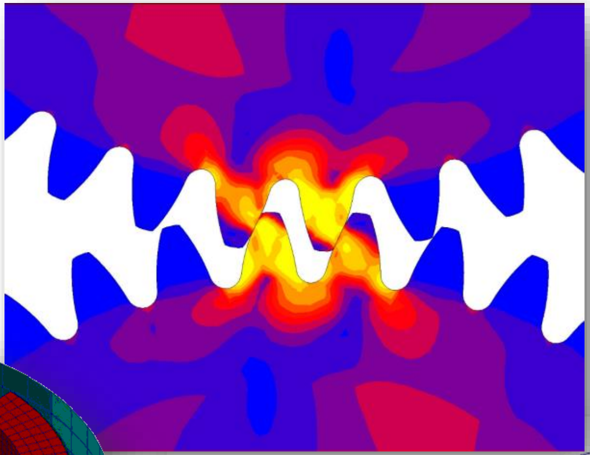
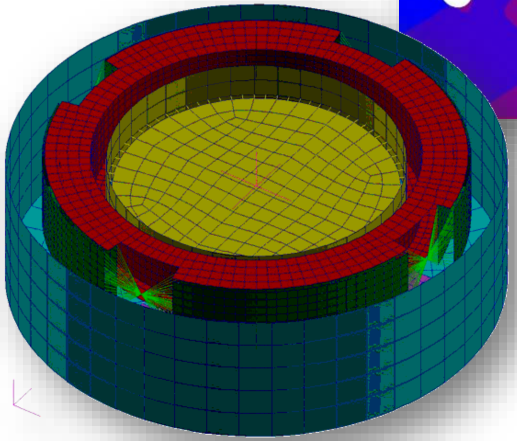
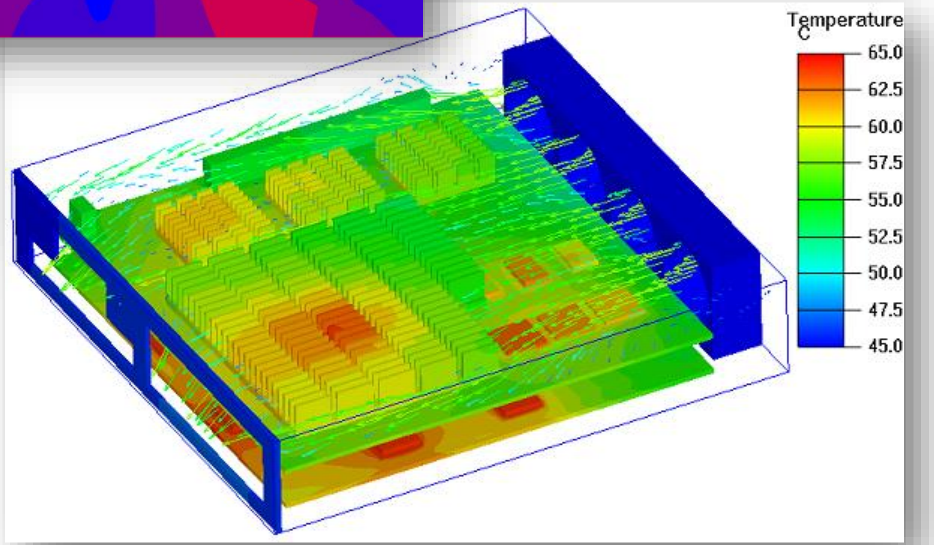
FMEA vs Physics of Failure (PoF)

- Is analysis of the route cause is Qualitative, PoF is Quantitative using data driven design tools to study known failure mechanisms.

- Design tool Examples;
  - Computer-aided Design (CAD) Drawings
  - Finite Element Analysis (FEA)
  - Solid Modeling
  - Dynamic Simulation
  - Fatigue Analysis
  - Thermal Analysis
  - Accelerated Testing
  - Simulation







“Analytical Models” based on underlying “Constitutive Equations”

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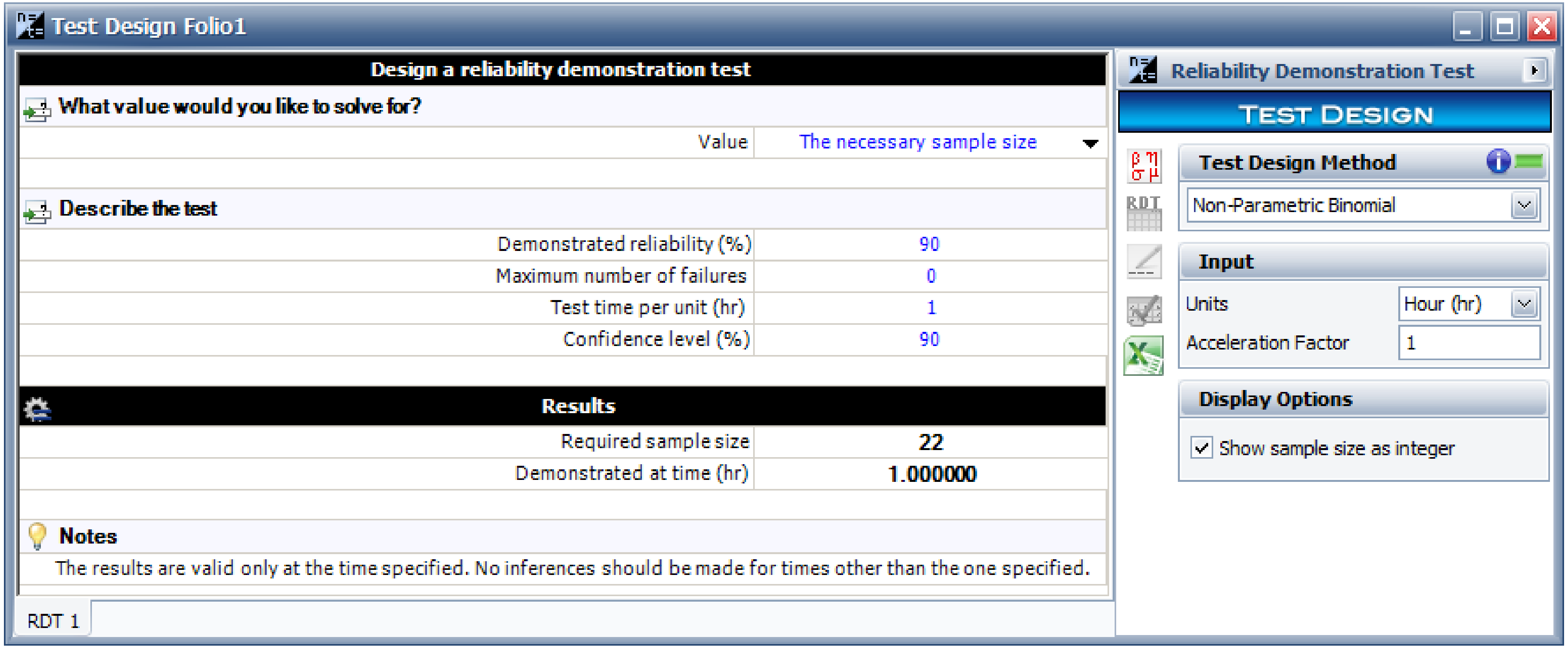
Example - Non-Parametric Binomial

- How many units are needed to demonstrate a required reliability at given time with a level of confidence?



22 Samples, without failure, for 1 hour test life

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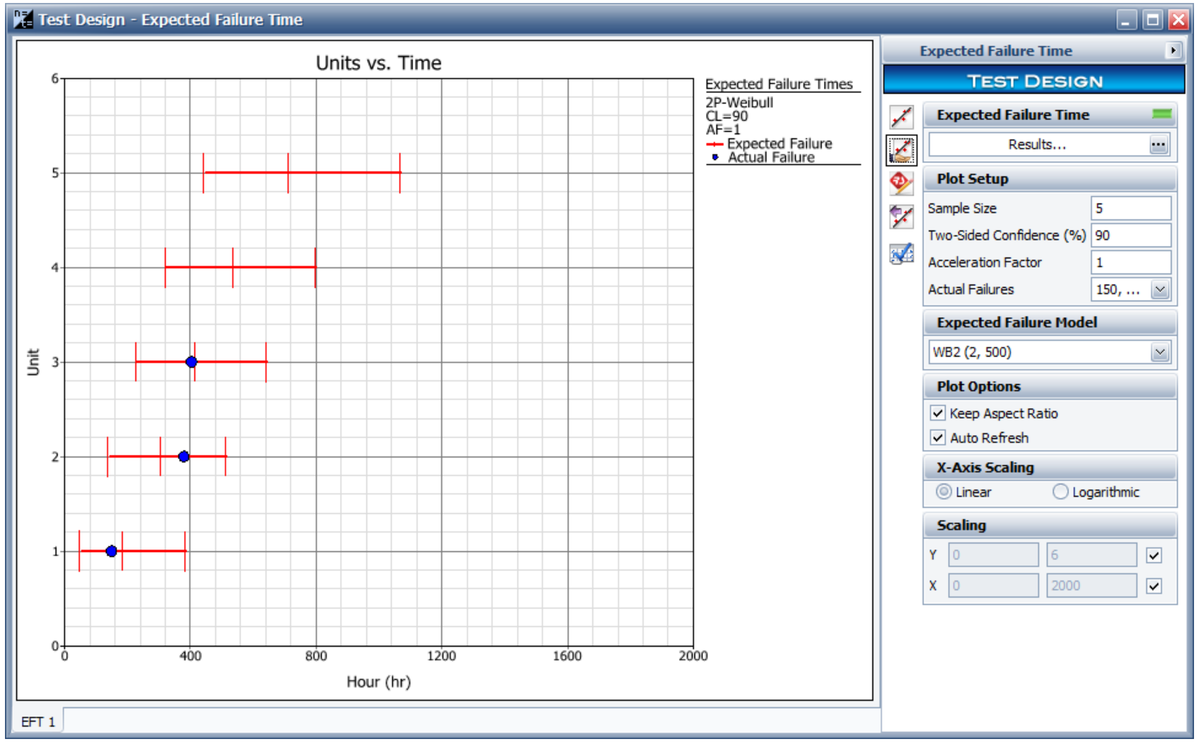
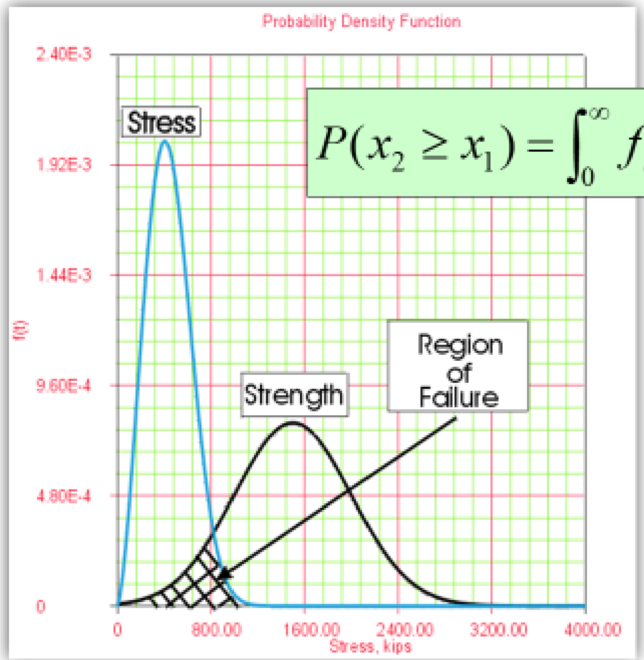
Tracking a Test Plan

- Often assumptions or historic data are used in test planning. How can you know if you are executing to plan or if something has changed?
  - In Weibull++, choose **Home > Insert > Test and Planning > Test Design** and choose the **Expected Failure Times Plot** option



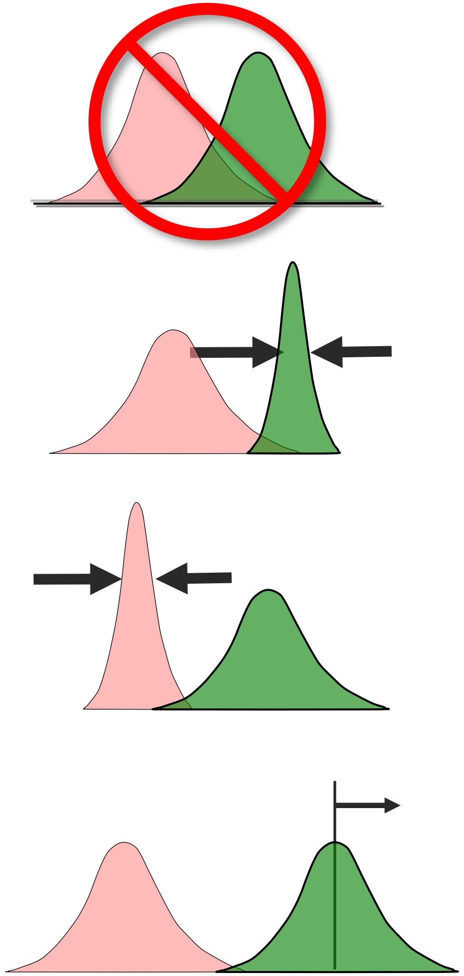
"Design for Reliability" 4 lines of defense…

Stress-Strength Analysis



$$P(x_2 \geq x_1) = \int_0^{\infty} f_{strength}(x) \cdot R_{stress}(x)dx$$

Calculate the Probability of the Stress exceeding Strength (Unreliability)

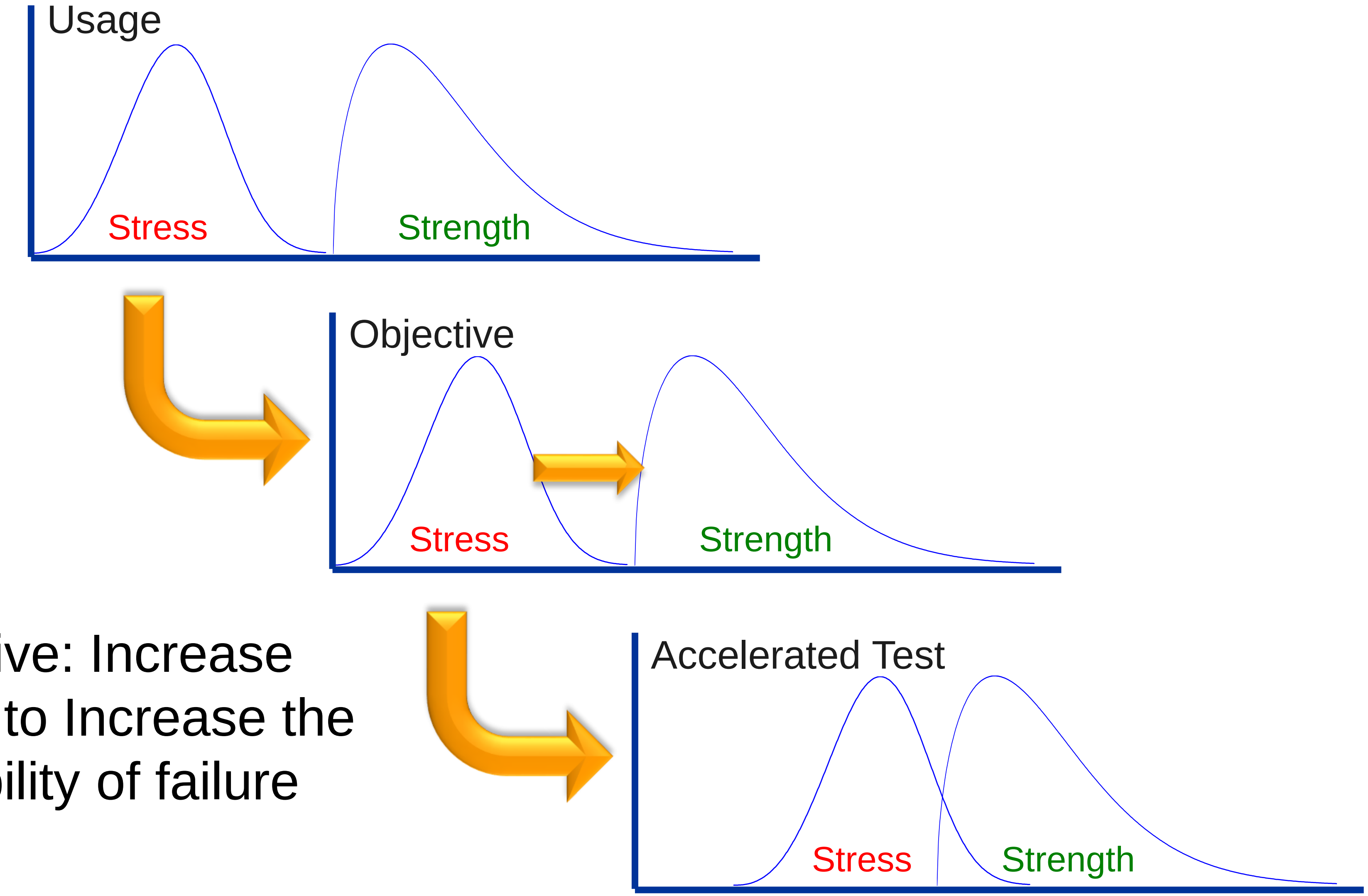


1. Design Out Failure Mechanisms
2. Reduce Variation in Product Strength
3. Reduce Effect of Usage/Environment
4. Increase Design Margins

"Wouldn't it be better to try to design out failure modes?"   YES!

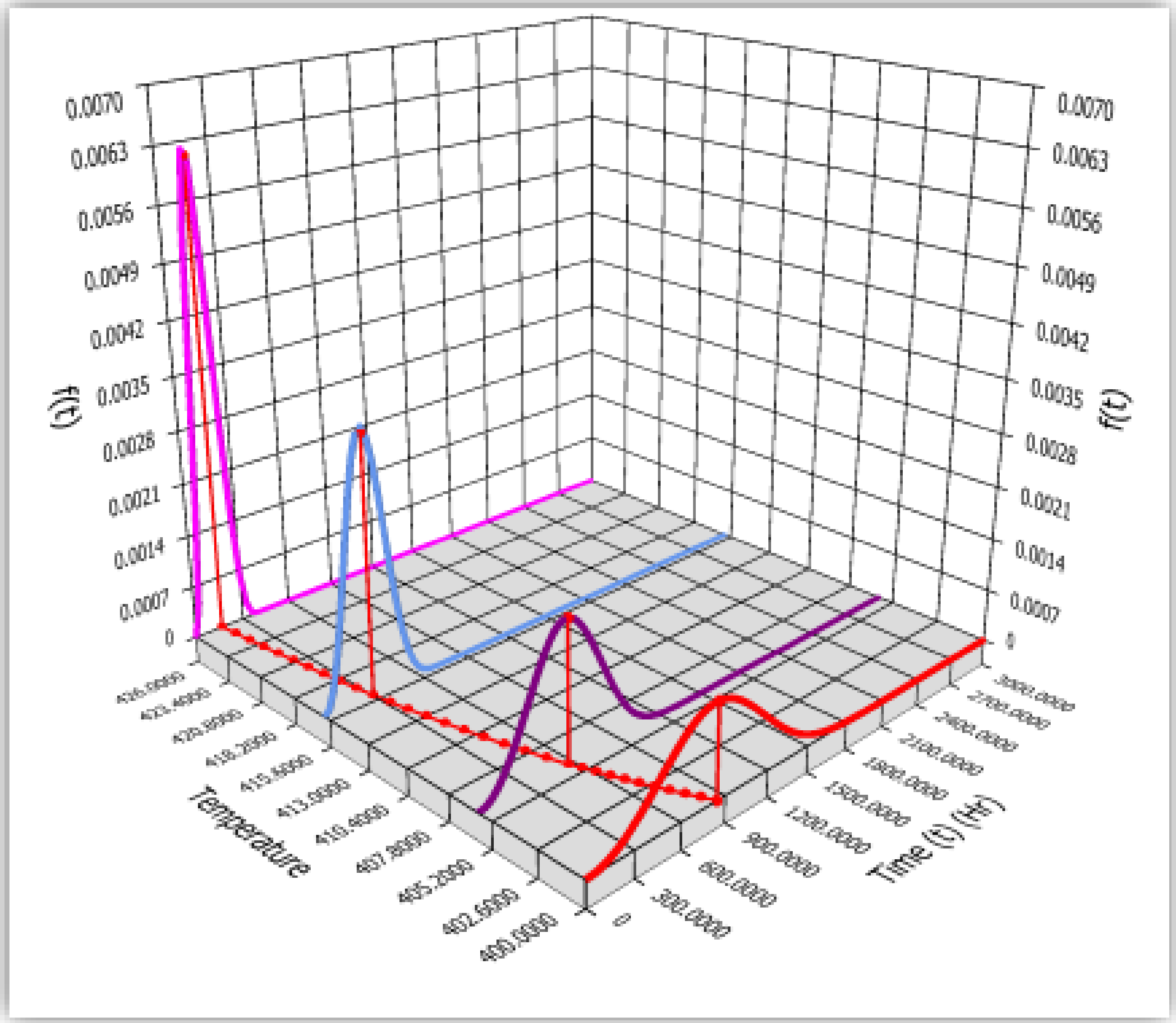
Design out failure is first line of defense

Stress in an ALT

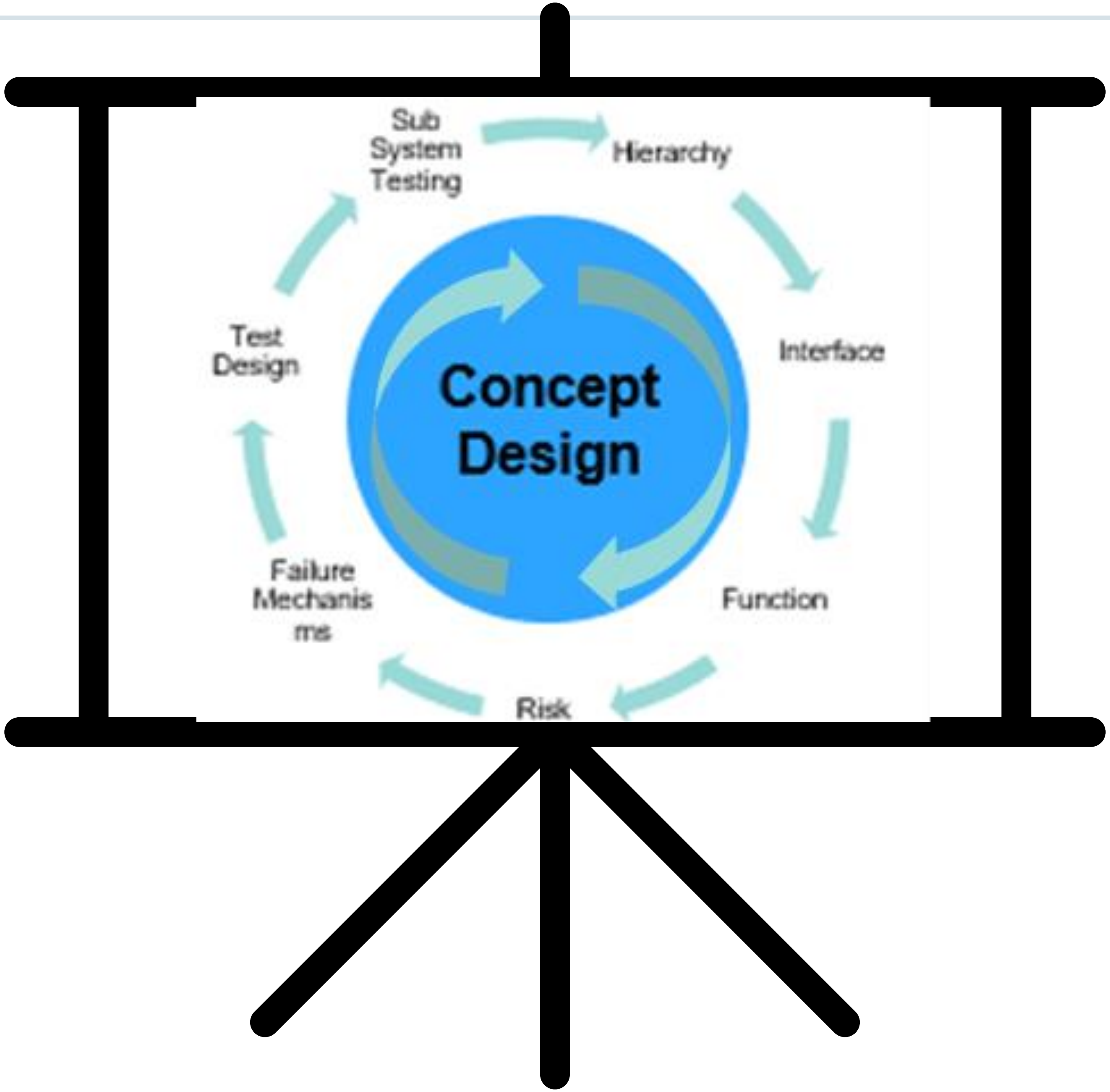


Objective: Increase Stress to Increase the probability of failure

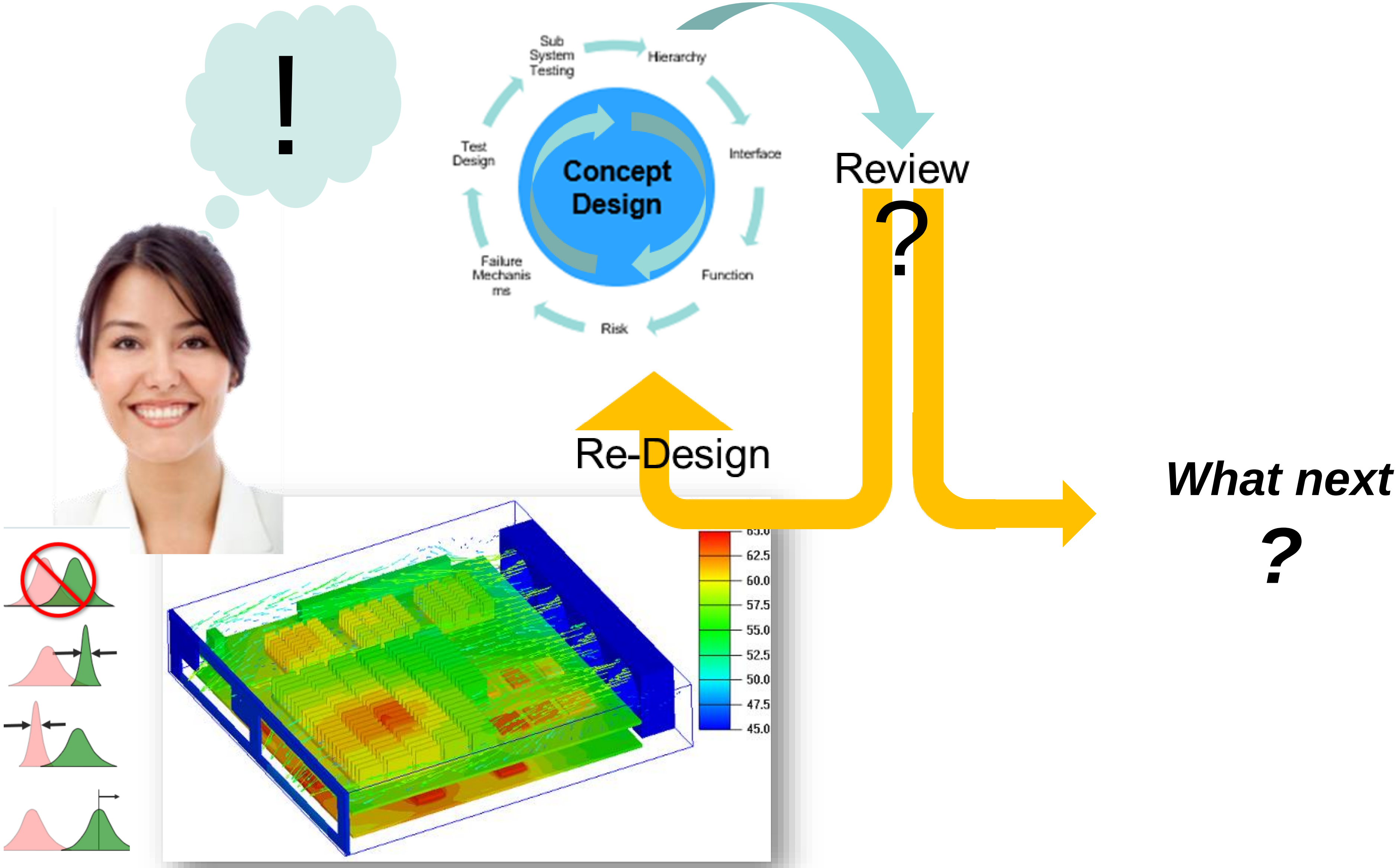
pdf vs. Time vs. Stress Relationship



Reliability Process Summery

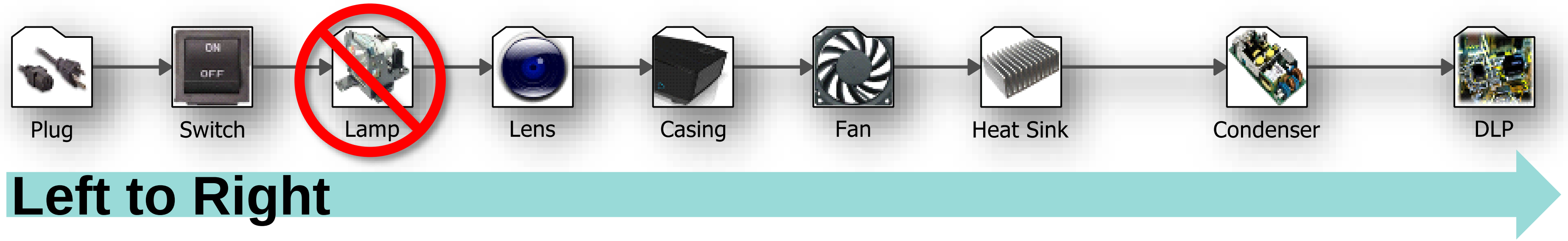


Sub-System Reliability Improvement

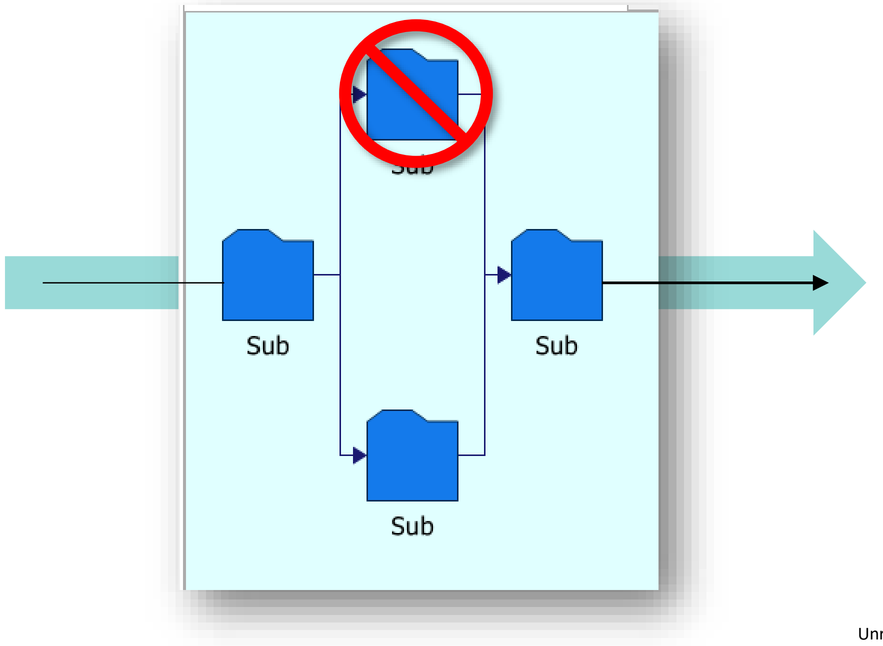


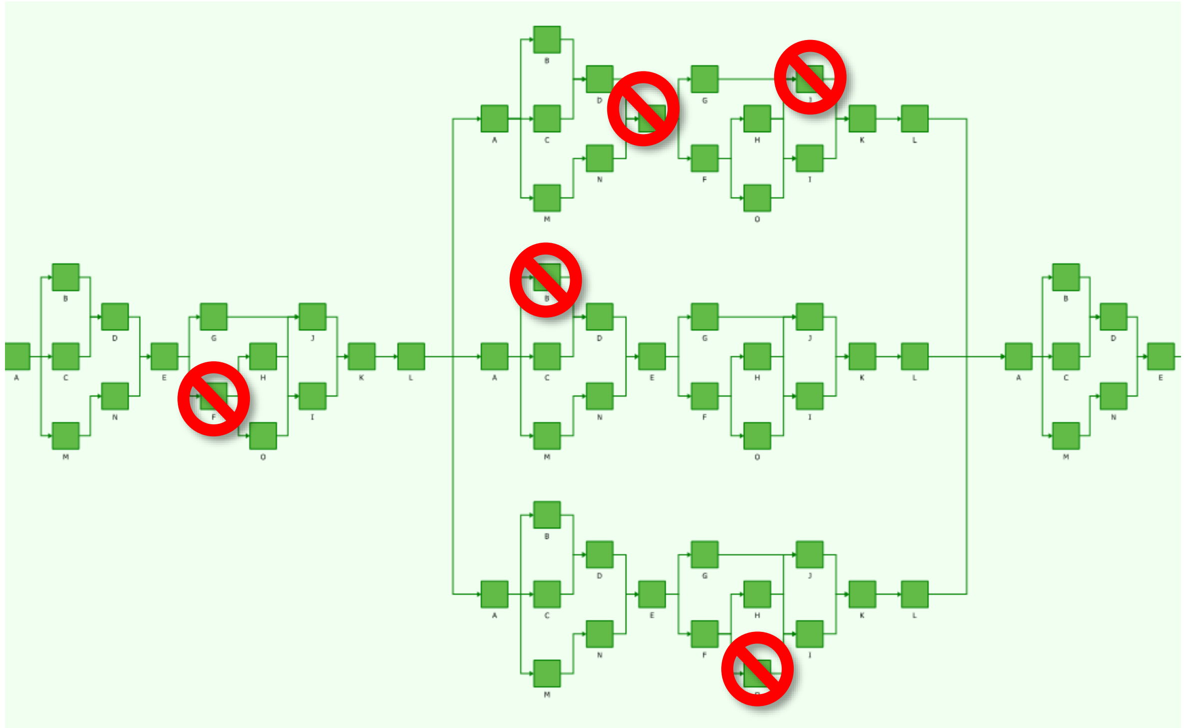
Reliability Block Diagram (RBD)

- FMEA is serialized, singular failures.



- Low Reliability red flag items if can not be Improved consider redundancy.





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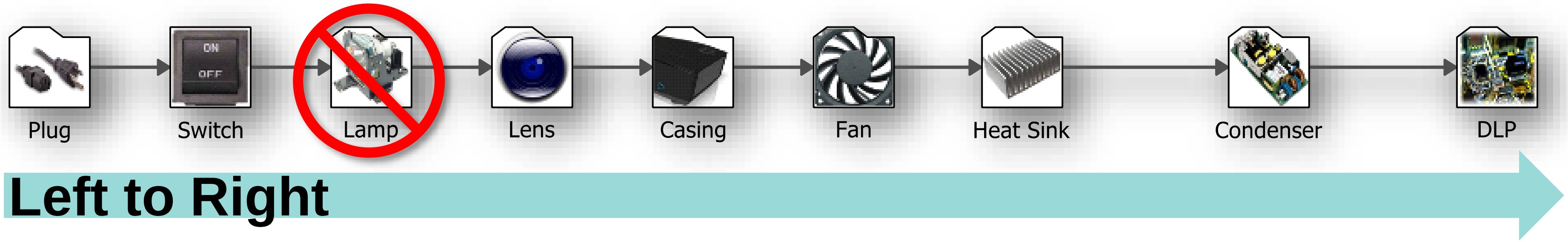

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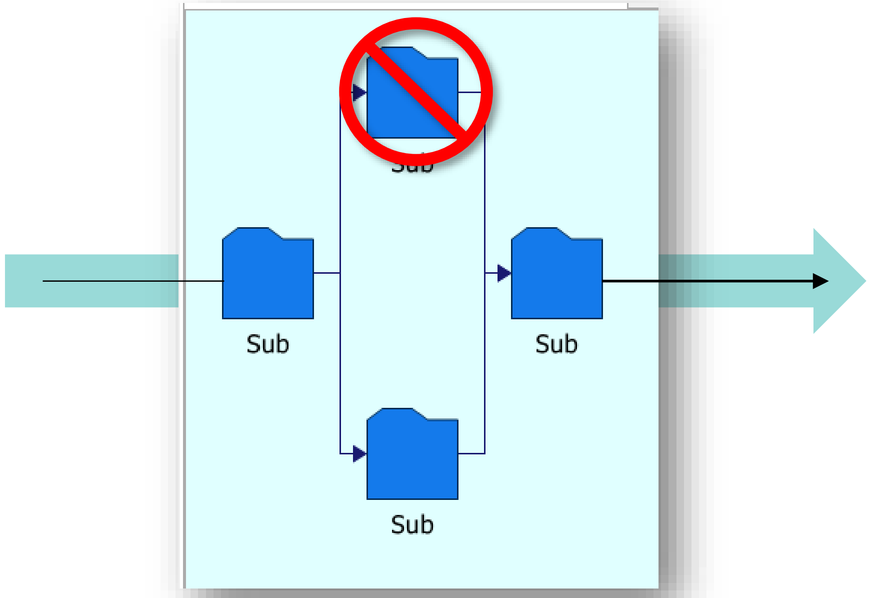
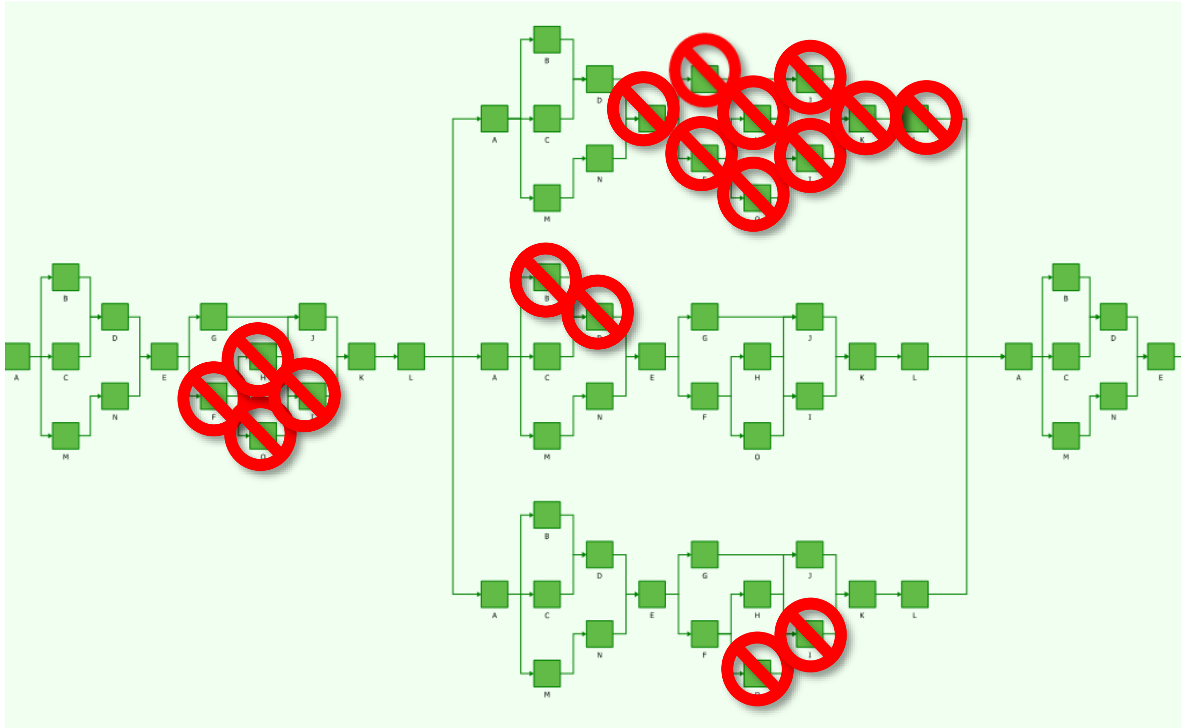
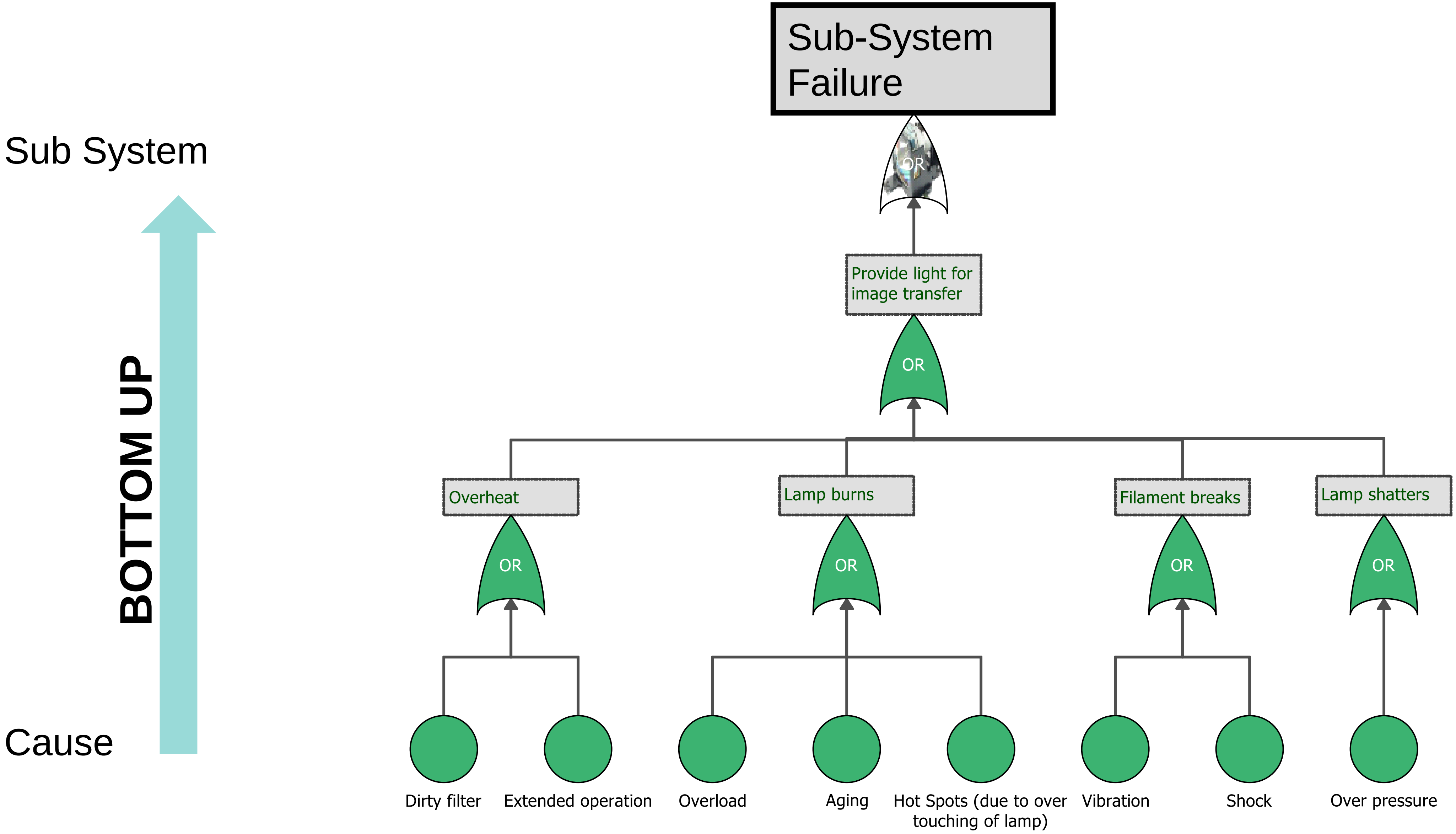




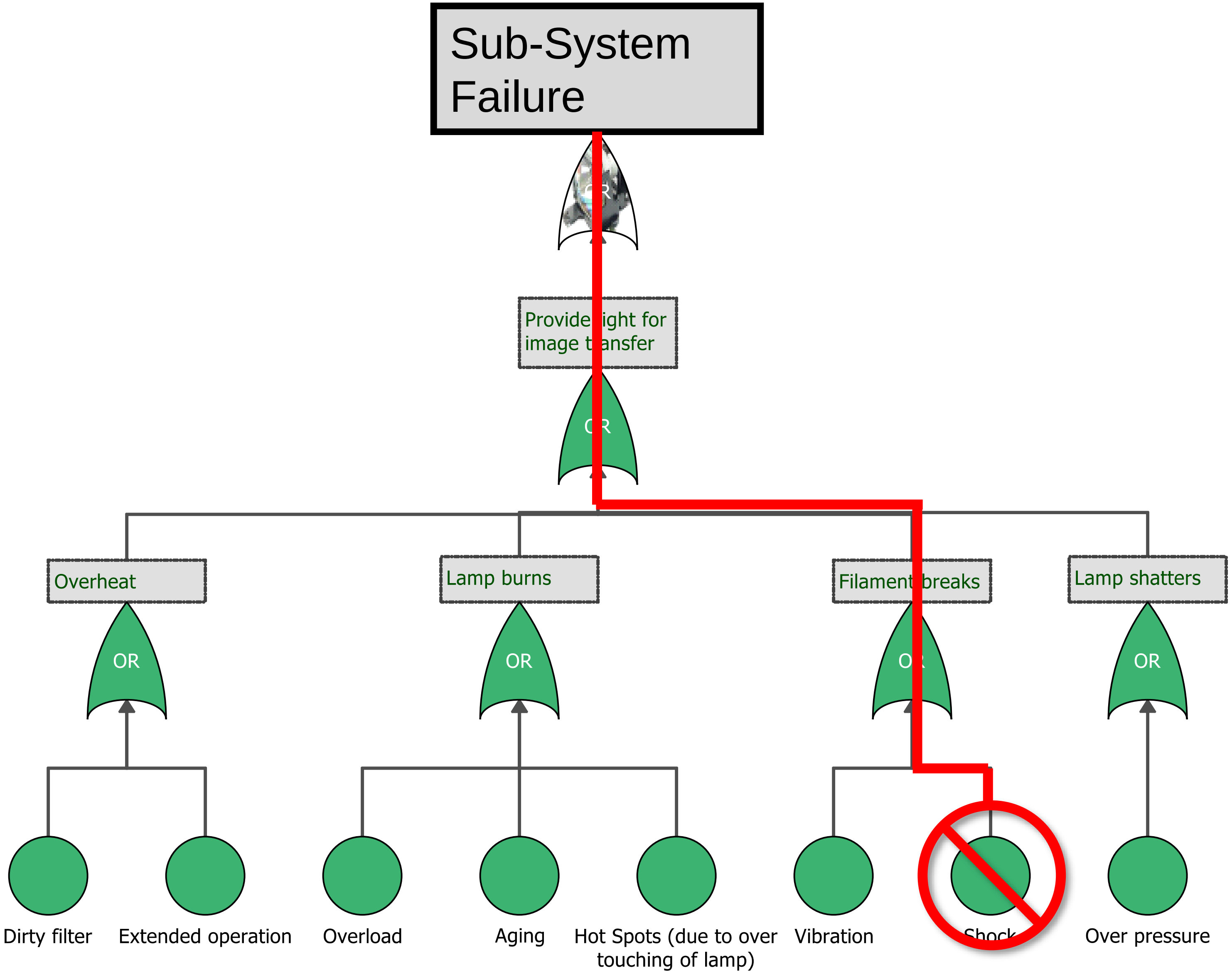
Reliability Fault Tree Analysis (FTA)



Reliability Fault Tree Analysis (FTA)

Sub System

Cause



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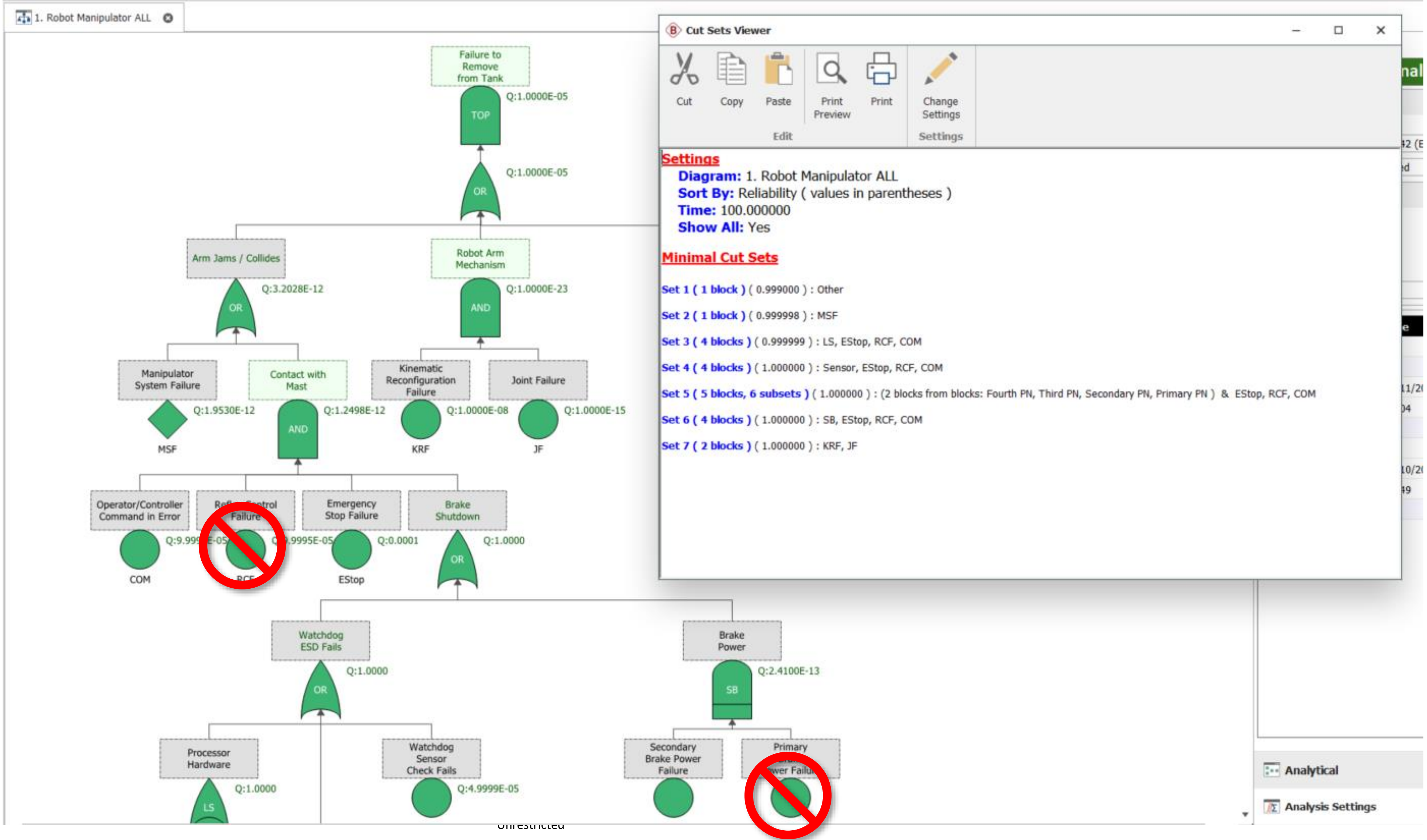
Reliability Fault Tree Analysis (FTA)

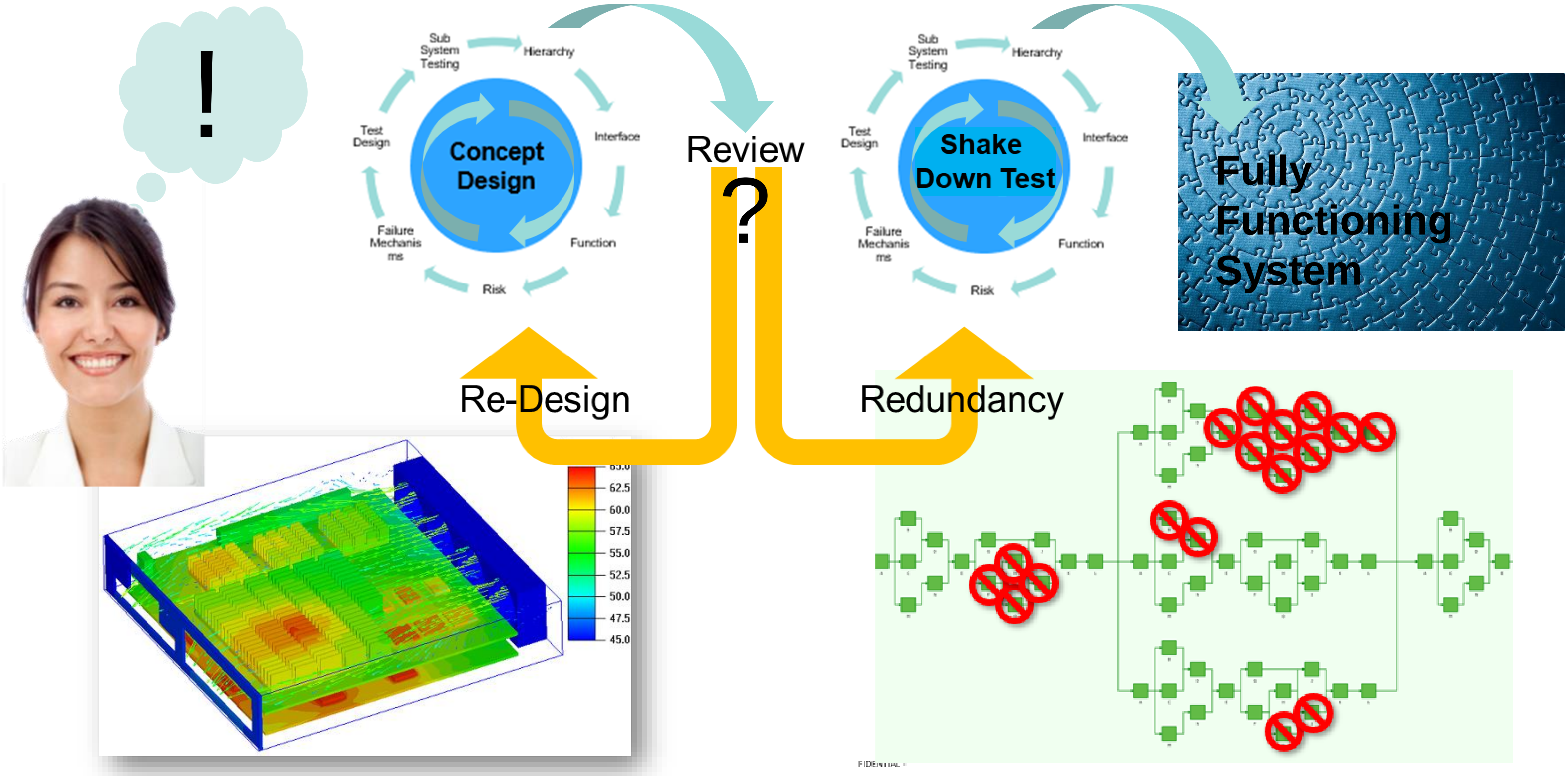
Low Reliability red flag items if can not be Improved, then look to include redundancy. [AND]

Sub System

BOTTOM UP



System Summary



Thank You

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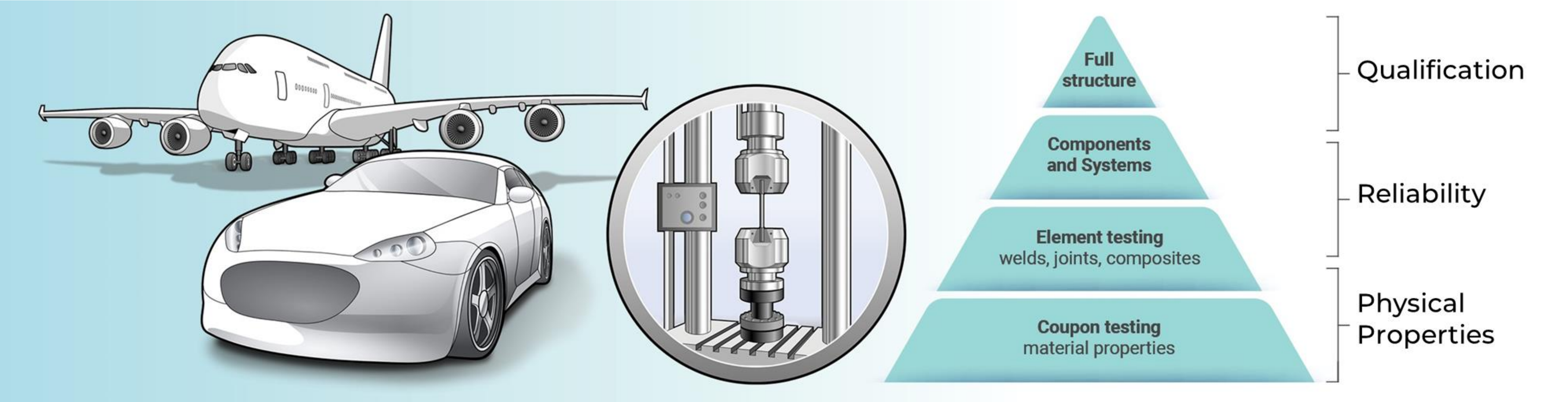

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