

ACCELERATED LIFE TESTING (ALT) - WEBINAR

Speeding up failure to understand failure ...



Workbook

Presented by

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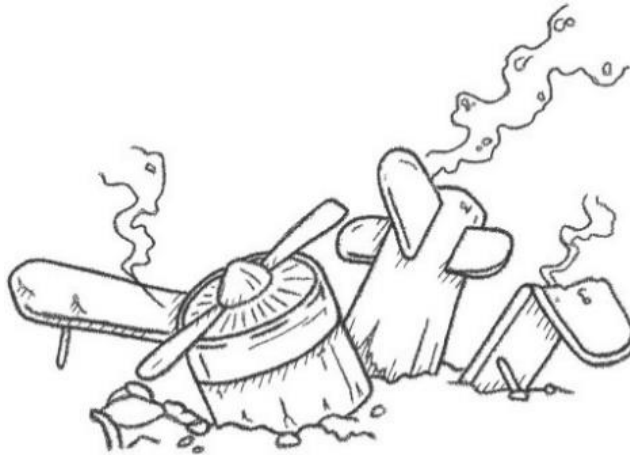
Founder and director of Acuitas Reliability

Co-founder of www.is4.com education

Author of books on how to do 'reliability stuff'

Still learning

Reliability engineering is all about preventing failures occurring – like the one below ...



Depending on what phase of production we are involved in, reliability engineering might be focusing more or less on improving versus understanding the ways our product or system can **fail**.

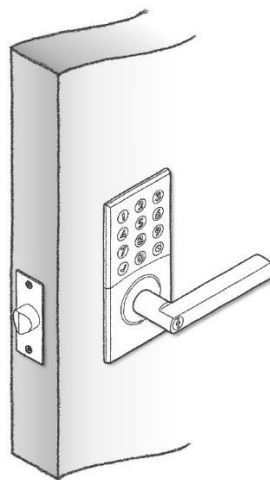
... measuring ^{or analyzing} reliability CAN be important ...

... but not nearly as important as *DESIGNING IN RELIABILITY* ...

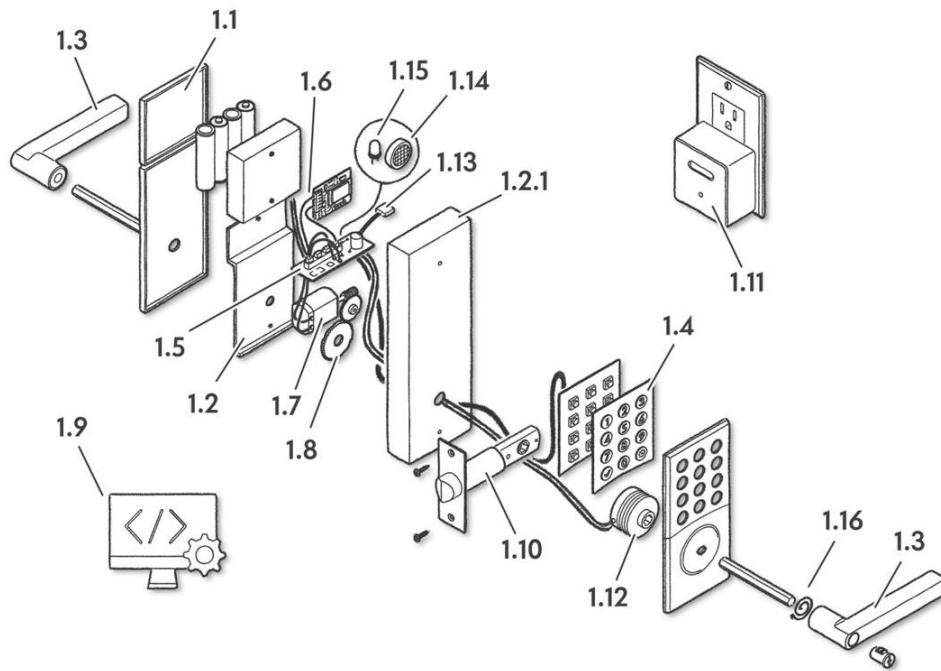
Reliability engineering happens when we incorporate simple and effective design characteristics from the very start. Every problem (no matter how technologically complex your 'thing' is) has a range of solutions. The cheapest and easiest are ALWAYS those that can only be solved using a design characteristic BUILT INTO YOUR FIRST DESIGN.

It is only when you are forced to redesign something without 'affecting' other components that fixes become complex and expensive.

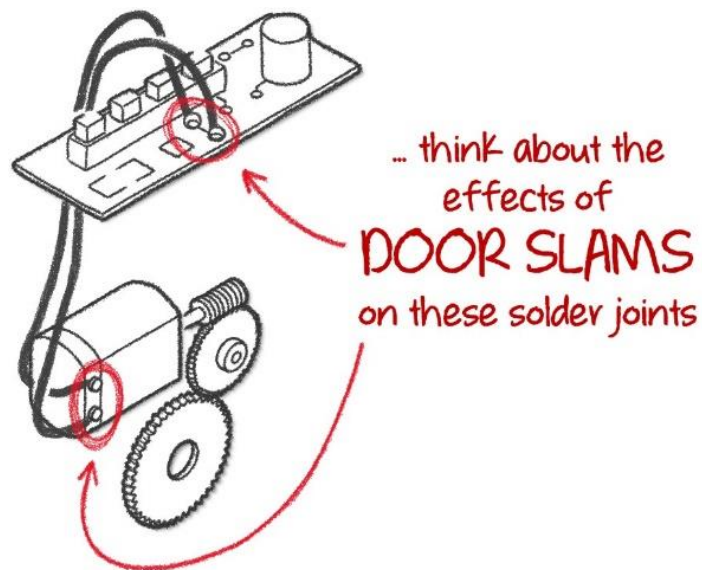
Think about a smart lock, which combines traditional 'mechanical' lock technology with contemporary 'smart' technology.



At the heart of the system is an electric motor controlled by electronic circuitry to transition the lock to or from a locked or unlocked state. Electric motor failure is 'critically bad.'



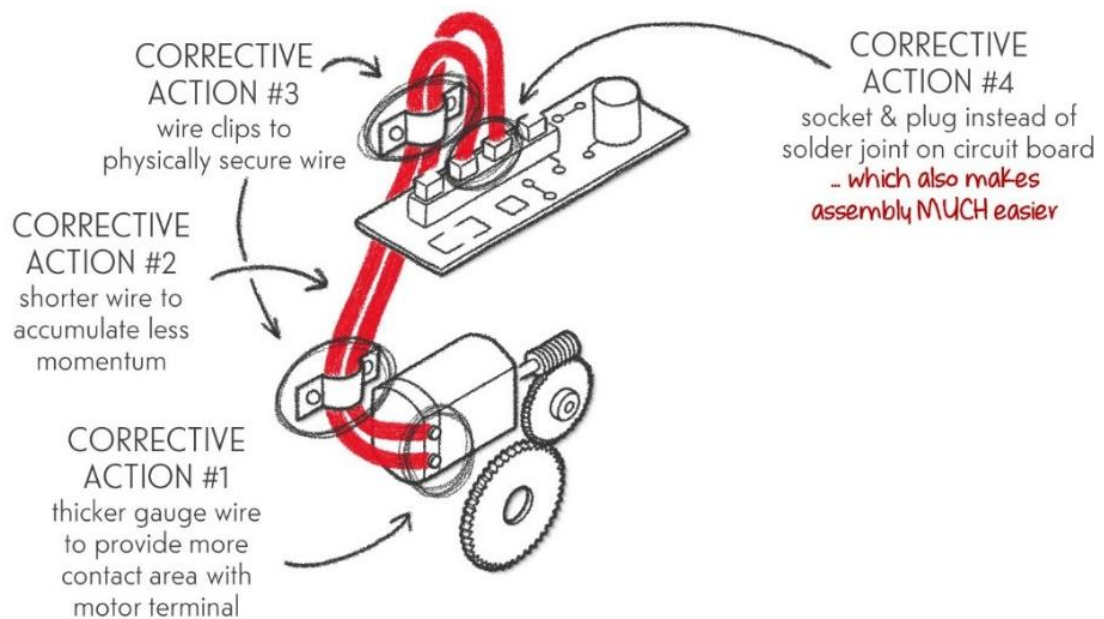
When we design something that is 'novel' or 'cool' we can often overlook the simplest of things. Like electric cables that connect the electric motor to the Printable Circuit Board (PCB). A **BUILD-TEST-FIX** approach means building a prototype that uses soldered cable that is not resilient to shock loads that are generated when a user or customer slams the door shut.



Perhaps qualification testing will uncover this critical design flaw ... as our lock needs to be able to withstand multiple shock forces when the door it is installed on is slammed (which a significant number of our future customers will no doubt do.) Unsecured cables in our smart lock that are only physically restrained with solder is a recipe for failure.

But instead of doing that, the smart lock's design team did 'smart' reliability engineering and perhaps conducted either a **FMEA** or a **FMECA**. The key outputs are a set of **corrective actions**

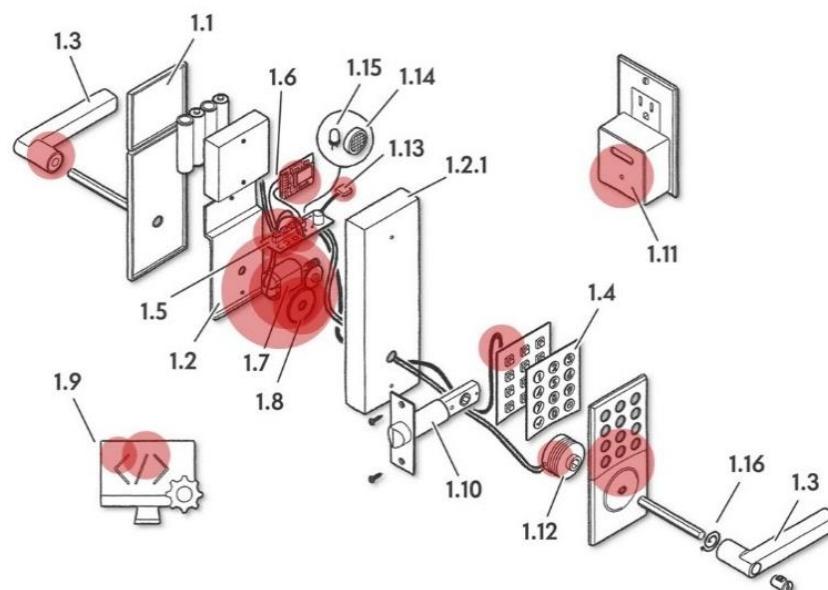
that address the design, manufacture, maintenance or anything else that can improve reliability. And look how simple and inexpensive they are.

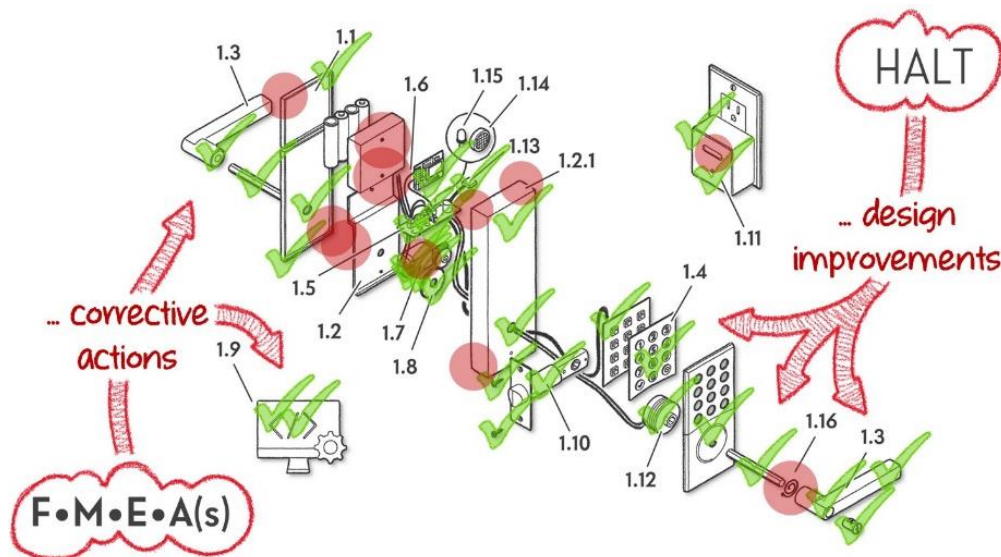


None of these design changes are complex or expensive *as long as they were thought of at the start*. Which is something that a **BUILD-TEST-FIX** approach can't do. **This is how we make reliability happen.**

IMPROVING reliability

Let's also say that we have conducted a **system FMEA**, and several **design FMEAs**, to identify a prioritized list of **failure modes** and **mechanisms**. Or ... the **VITAL FEW**. They are represented with red circles in the illustration on the right. There are of course hundreds of ways our smart lock can fail, so these represent the failures that matter the most.





The first iterations of the **reliability design cycle** involve implementing **FMEA corrective actions** and design improvements based on **HALT** (and other **exploratory tests**) to efficiently improve reliability. These improvements and **corrective actions** are represented with green ticks in the illustration on the left.

MEASURING reliability

Let's now say that we have created a robust (and almost certainly **reliable**) design by continually focusing on the **VITAL FEW** weak points throughout the production process. Now it might be time to measure **reliability**. We might need to know (for example) what material we should use in certain applications to ensure our smart lock **reliability** meets certain targets. Once we have selected our material, we might need to then understand (for example) what the **warranty reliability** is. And by **warranty reliability** I mean the probability that a smart lock will endure the **warranty period**.

So let's say that the **warranty period** is 2 years. One approach to testing the **reliability** of our finished (or at least mature) smart lock prototype is to get a number of them and test them for two years. The number of smart lock still working at the end of this test to estimate smart lock **reliability**. But...

... we can't test our smart lock for 2 years ...

*... our company won't make any money from their sale for this
2 year period ...*

... our competitors will dominate the market ...

*... it will be too late to make design changes by then anyway (our design and
manufacturing teams will now be doing something else) ...*

So what can we do?

ACCELERATING testing

Accelerated Life Testing (ALT) is all about increasing a stress to decrease the **Time to Failure (TTF)** in a reliability test to understand what the **TTF** would be in 'operational conditions.' This has to be done in a 'scientific' way. We need to know what effect increasing stress has on **TTF**.

***ALT** is a term that is often used in a very generic (or 'throwaway') context.*

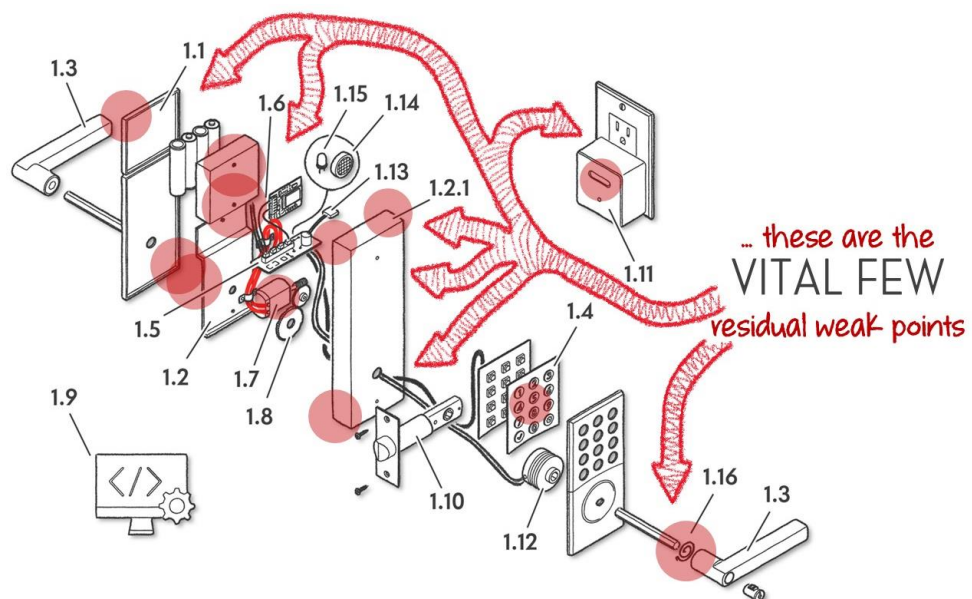
*Don't have time? ... we can simply do **Accelerated Life Testing (ALT)**!*

However, there are a couple of pre-requisites for any successful ALT program.

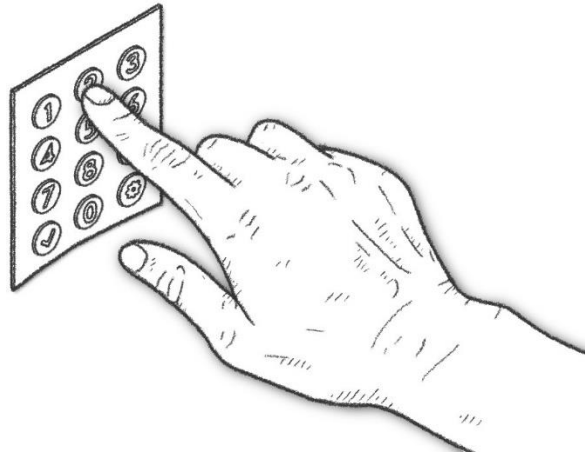
- 1. You must **KNOW HOW** your product fails. Or ... you must understand the **VITAL FEW** weak points of your system*
- 2. You must be able to **MODEL HOW** your product fails*
- 3. You must **UNDERSTAND THE CONDITIONS** in which your product will normally be used*
- 4. You must not change the **CONFIGURATION** or **STATE** of your product by increasing the stress.*

The last one is very important. There is not point in increasing temperature until your product melts. This changes the state of your product. A molten product is (usually) not possible during normal operating conditions. So a test where you force your product to melt is not useful.

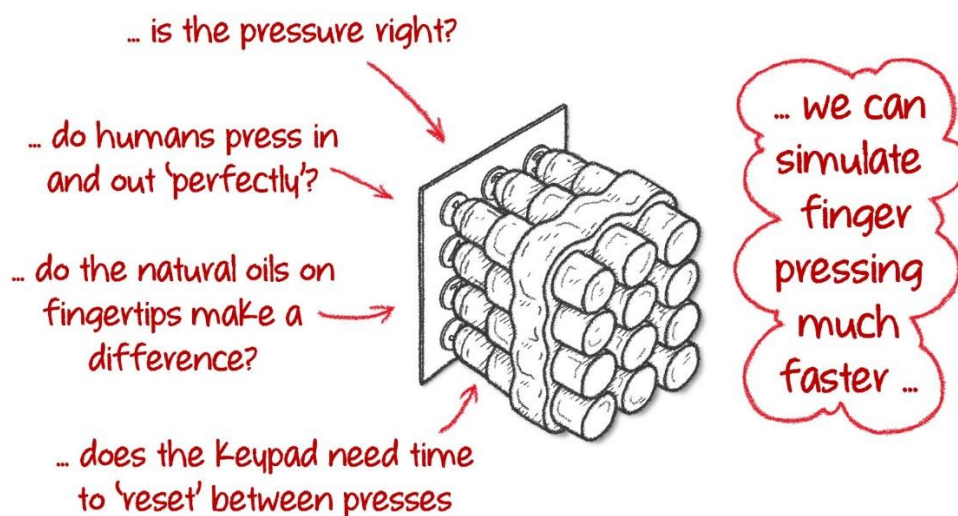
For example, after rigorous design, we now have the following smart lock with the remaining **VITAL FEW** weak points that are known and well understood.



One of the residual **VITAL FEW** weak points resides in the keypad. This doesn't mean that the smart lock is **unreliable**. It simply means that when it does **fail**, it might involve the keypad failing. So remembering that we are interested in understanding the **reliability** of our smart lock after two years (the **warranty period**), how can we mimic two years worth of use?

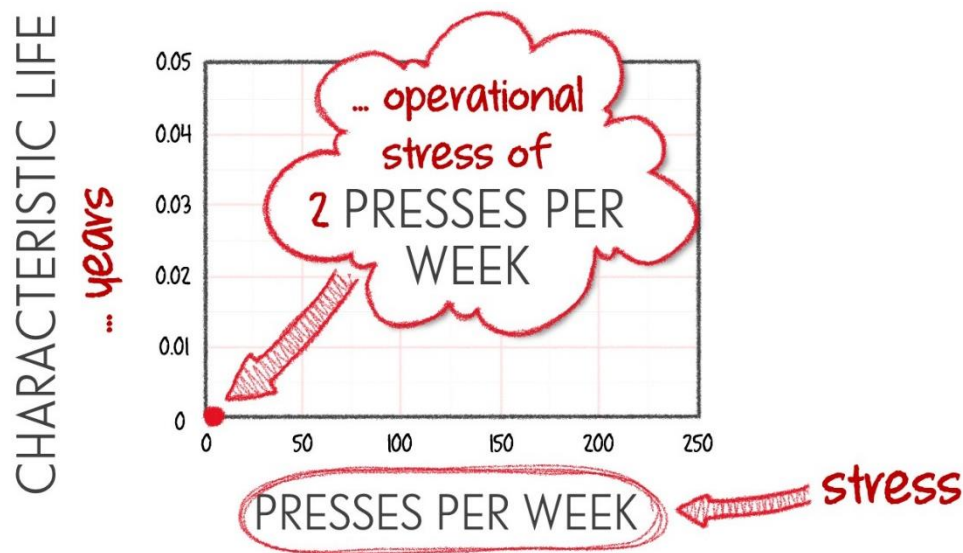


Let's say we develop a use case where we believe each key on the keypad will be pressed (on average) twice a week. Then we might be able to build a 'key pressing' test rig to simulate each key being pressed. However, the test rig allows us to do this much faster. But ... you should always be careful that you precisely mimic the real world conditions ...

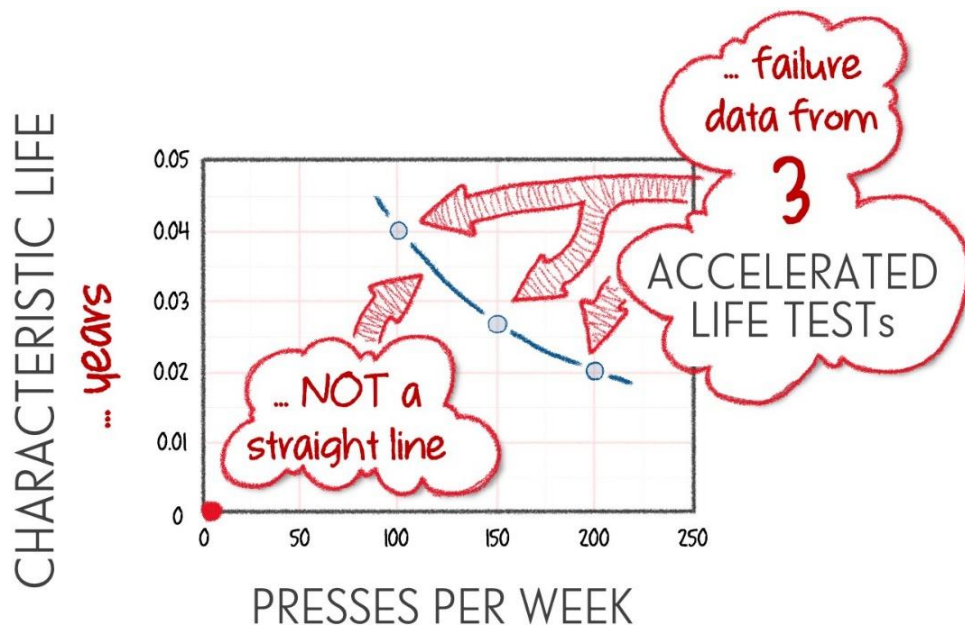


it's all about creating a STRAIGHT LINE

Let's say we are going to use our key pressing test rig to conduct **ALT**. We are going to increase the **stress** the keypad experiences by increasing the frequency of key presses. We can then conduct a number of tests to identify how long it will take to fail at these higher **stresses**. We can use the chart below to visualize these results.

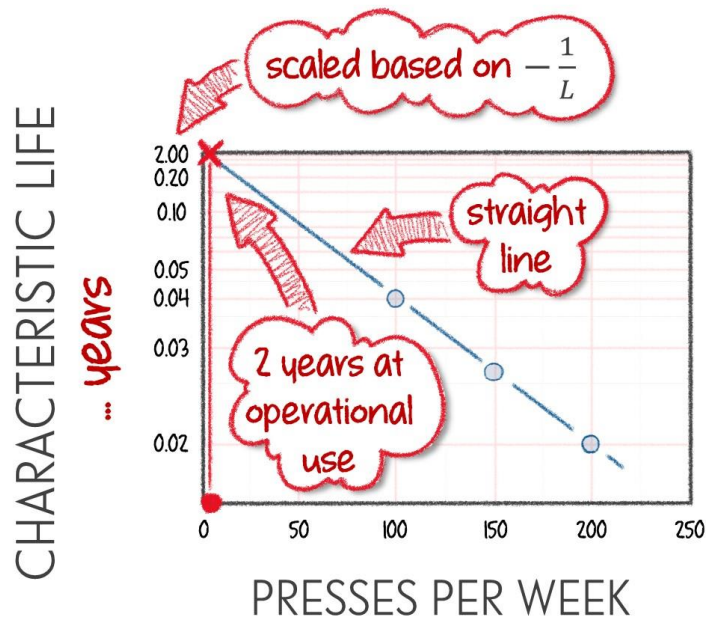


So let's say we picked three higher (**accelerated**) **stresses** and tested our keypad until it failed.

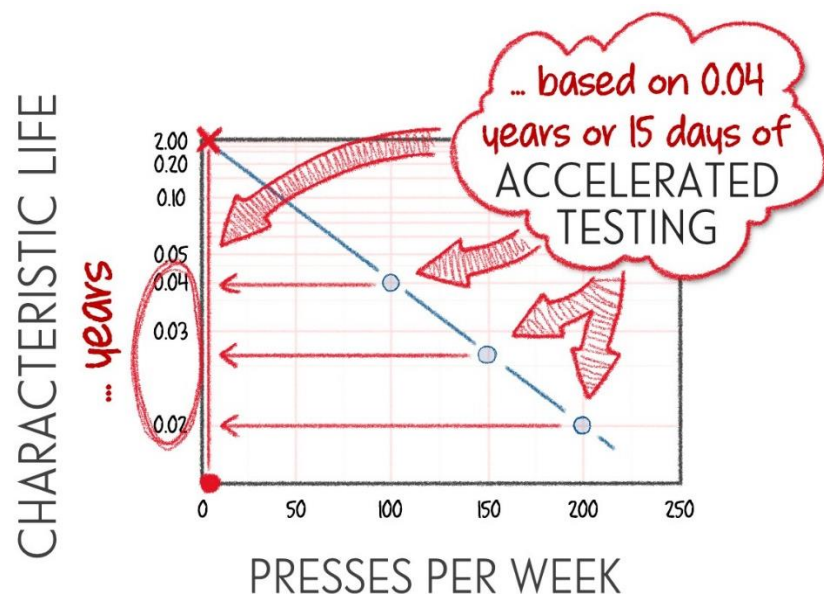


Why is it important to note that the data does not trace out a straight line? Because it means we can't project this curvy line back to the operational stress of two presses per week (at least not easily). And more importantly, the curvy line means we might not understand the relationship between stress and **characteristic life**.

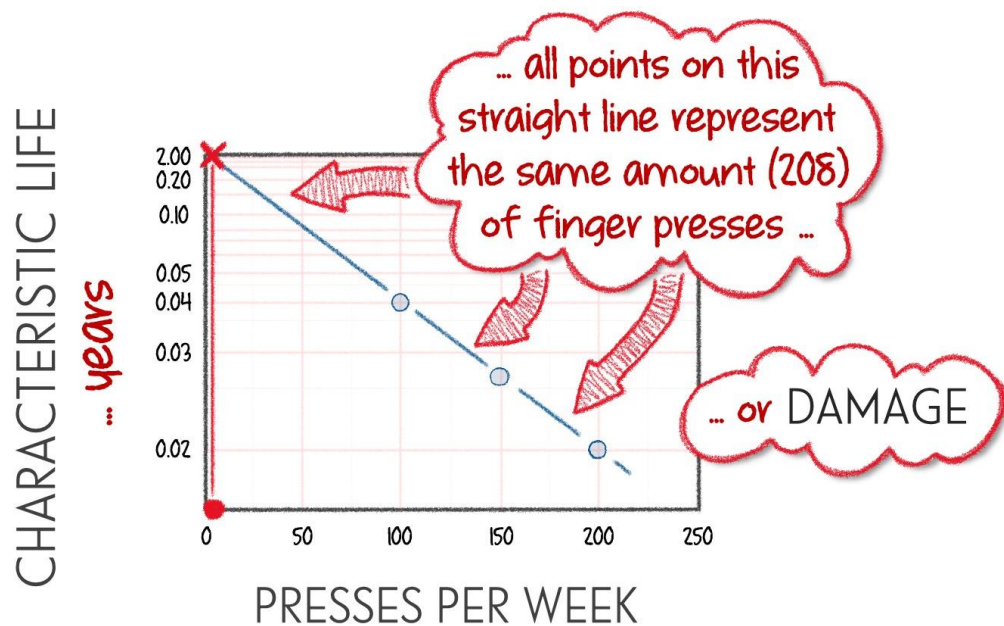
But what we can do is scale the axes of our chart above to get this straight line. This allows us to project our 'line of best fit' back to the operational use conditions. In this case, our **ALT** data suggests our keypad will fail at 2.00 years. Given that this is also our **warranty period** ... this is bad!



The benefit of this testing is that it didn't take very long to get this result because we increased (or **accelerated**) stresses by creating a test rig that was able to simulate lots of finger presses.



So how and why did we scale the vertical axis to create a straight line through **accelerated life data**?



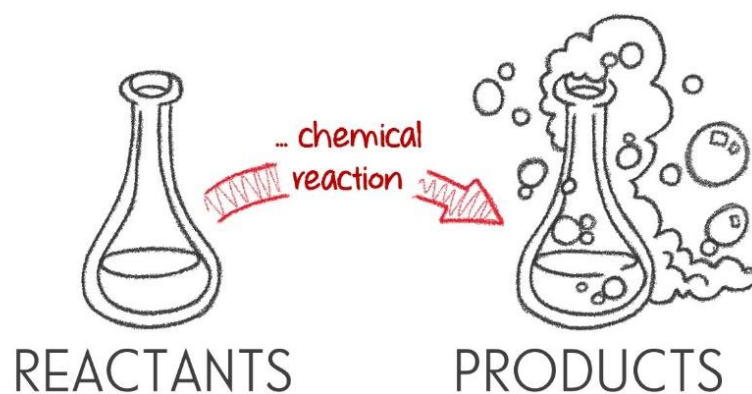
If we (believe we) understand how our thing will **fail**, then we might be able to **model** it. Based on that **model**, we might be able to create an **accelerated life chart** (like the one above) that ensures that IF **failure** follows our model, then it creates a straight line.

So not only does the straight line help us project back to operational use conditions, that straight line confirms that our model is correct.

... what about MORE COMPLEX FAILURE MECHANISMS?

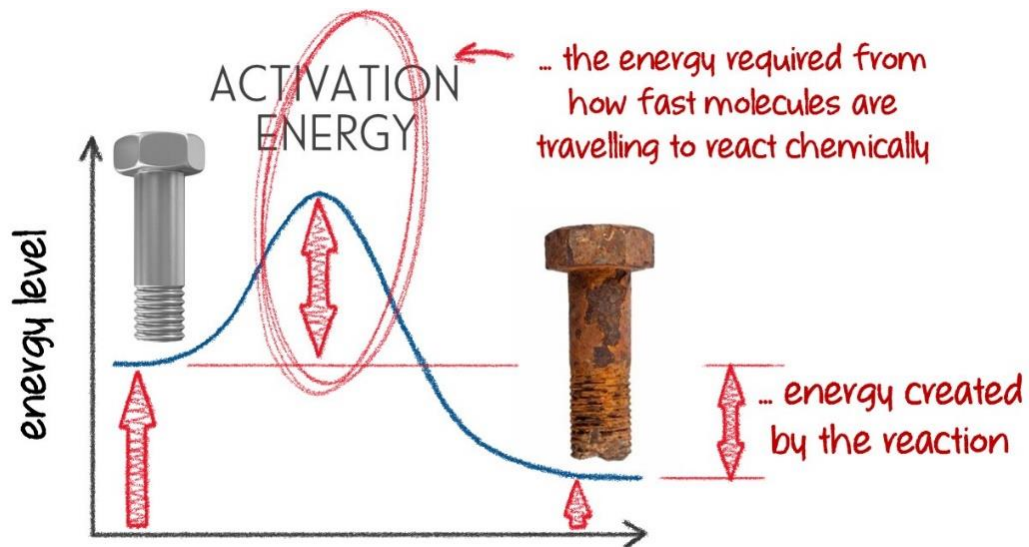
Let's start with looking at **failure mechanisms** that are based on **chemical reactions**. There are lots of them out there. Corrosion, diffusion, and lots of others. We know that one of the ways our keypad might fail is due to rubber degradation ... which is a **chemical reaction**.

So what happens in a **chemical reaction**?



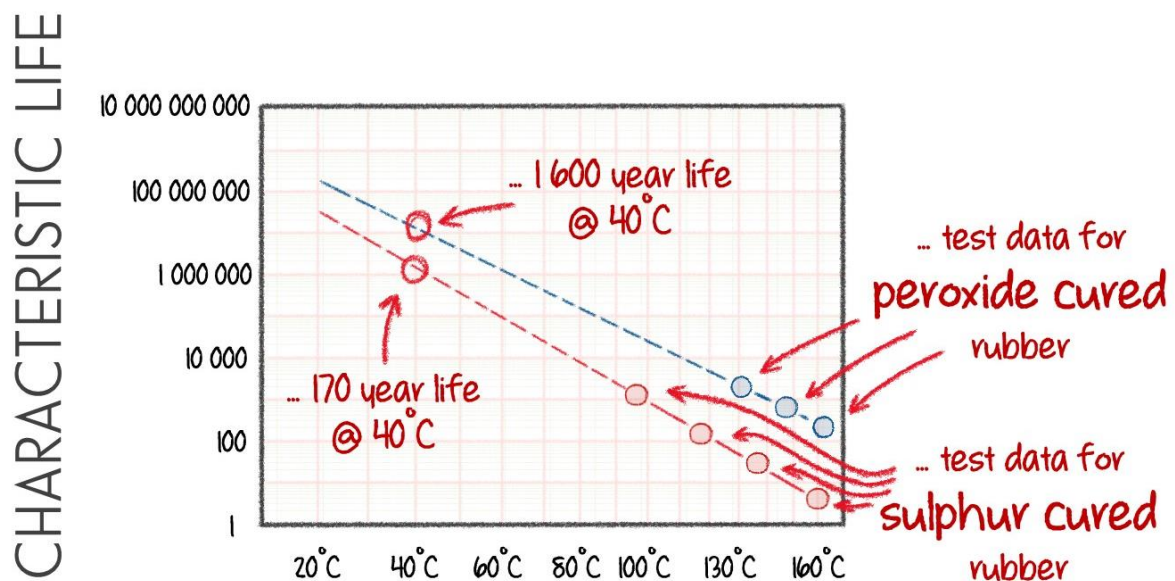
... reactants *WANT* to become PRODUCTS ...

Why is this? Because products exist in a lower energy state. And states of lower energy is where everyone and everything wants to go. Just like a ball 'wants' to roll down a hill. But when it comes to **chemical reactions**, there is a little barrier for the **reactant** when it is at the top of this hill.



So to speed up the reaction, we need to give more and more energy to the **reactant**. And one way of doing this is to increase the temperature of the **reactants** which makes the molecules travel faster. Which means they have more energy.

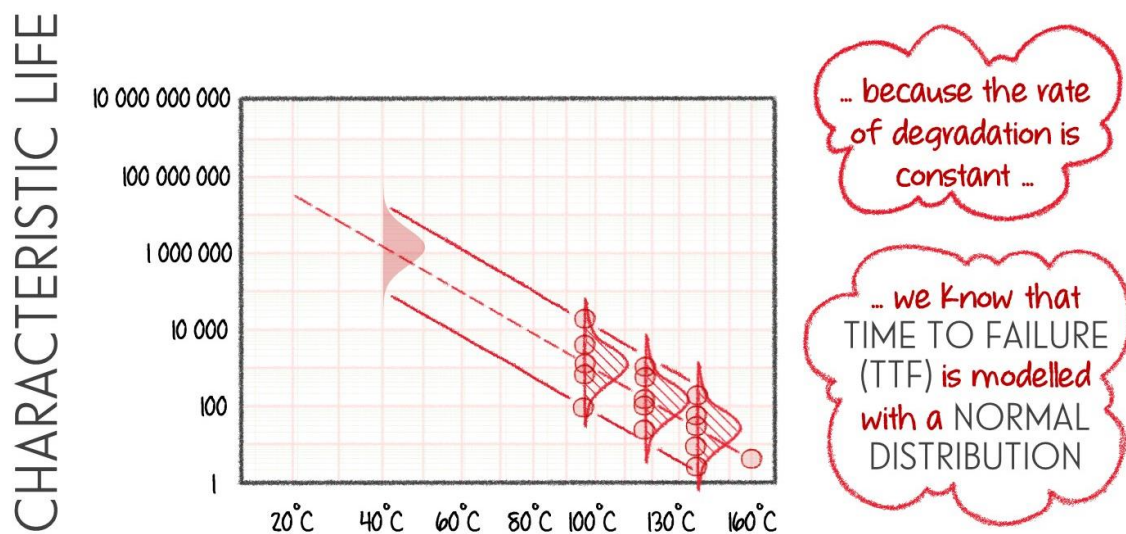
For chemical reactions, there is a well known accelerated life chart that allows us to increase temperatures in order to project back to operational use conditions (illustrated below). The vertical (characteristic life) axis is scaled logarithmically, and the horizontal (stress or temperature) axis is scaled using a negative inverse. This allows us to compare different rubbers to help us select the one that is the most robust for our smart lock.



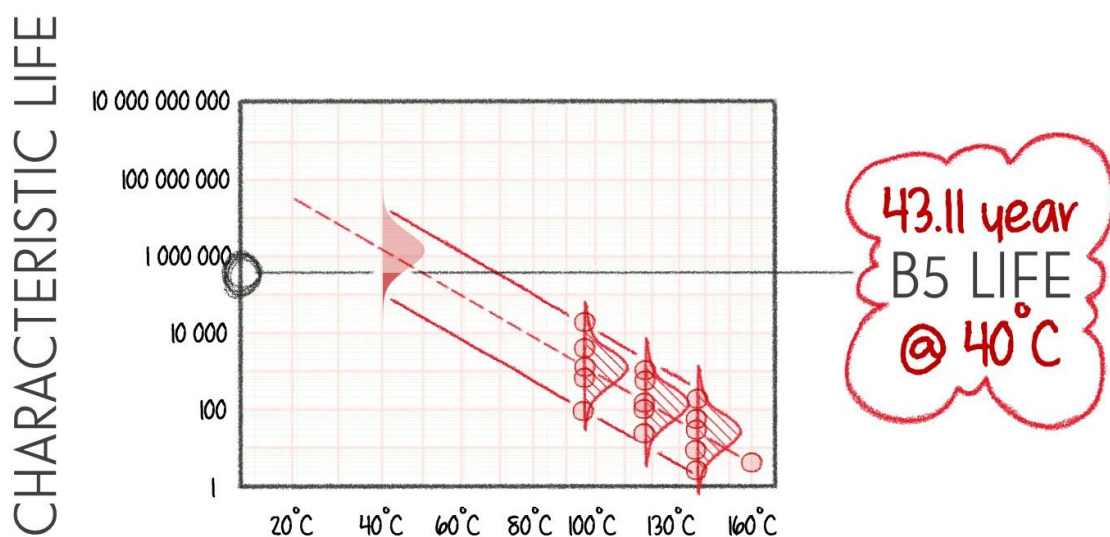
... but these are just BEST GUESSES

Sometimes we need more than best guesses when it comes to understanding **TTF**. For example, let's say that the peroxide cured rubber (the most **reliable**) was unavailable, or perhaps very expensive. The predicted 170 year life of the sulphur cured rubber is 'good,' but we also know that **failure** is a random process. Some rubber products will **fail** before 170 years. Some will **fail** after. How far 'before' 170 years will the first products **fail**?

ALT can help. Instead of testing only one component at each increased (or **accelerated**) **stress**, we can test multiple components. This allows us to fit a **probability distribution** that can also be projected back to real world conditions.



The '**bell curve**' at 40 °C above allows us to calculate the time by which we expect 5 % of our rubber components to fail (also known as the '**B5 life**')



... so how did we get this CHEMICAL REACTION ACCELERATED LIFE CHART?

It starts with knowing HOW your component will fail. There is a well-known model (**Arrhenius model**) that relates the increased temperature to rate of **chemical reaction**.

ACTIVATION ENERGY

$$k = Ae^{-\frac{E_a}{kT}}$$

... the rate of the reaction (which is the frequency of collisions that have enough energy to cause the chemical reaction) → k

... constant for each chemical reaction → A

... Boltzmann's constant $1.3806504 \times 10^{-23}$ Joules per Kelvin → k

temperature in degrees Kelvin → T

E_a → ACTIVATION ENERGY

We can rearrange this equation to get ...

$$\frac{C}{L} = Ae^{-\frac{E_a}{kT}}$$

... some constant → C

... the CHARACTERISTIC LIFE → L

And we can rearrange it further to get ...

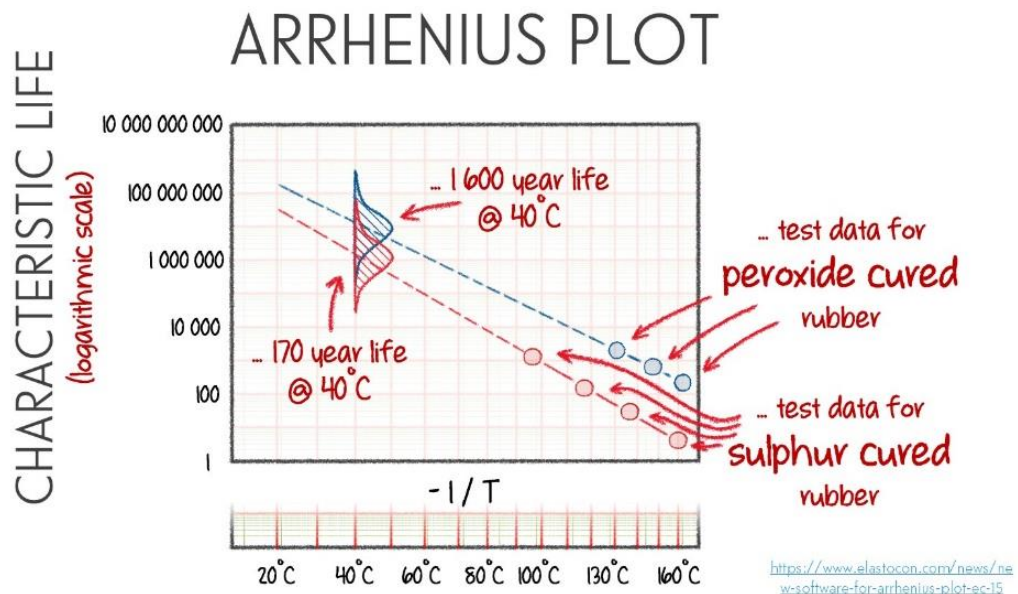
$$\ln L = \ln c - \ln A + \frac{E_a}{k} \left(\frac{1}{T} \right)$$

... the reason we did this was because we can now create a **straight line** (.. even if this is not obvious right now)

You can see that the left hand side is in terms of the logarithm of the **characteristic life** (hence the logarithmic scale of the vertical axis). You can see that on the right hand side, the equation for the straight line is in terms of the inverse of the temperature. To ensure that the temperature increases along the horizontal axis (as this aligns with how we view most charts), we make this a negative inverse scale. The line is still straight.

In this example, we can expose different rubbers to higher temperatures to see how long it takes for them to **fail**. We can then use this data to predict how long they will last in actual use conditions.

This means we can accelerate 'degradation' by factors (in this case) of 10 000. So testing is fast and meaningful. The accelerated life chart for chemical reactions is also known as an Arrhenius plot.

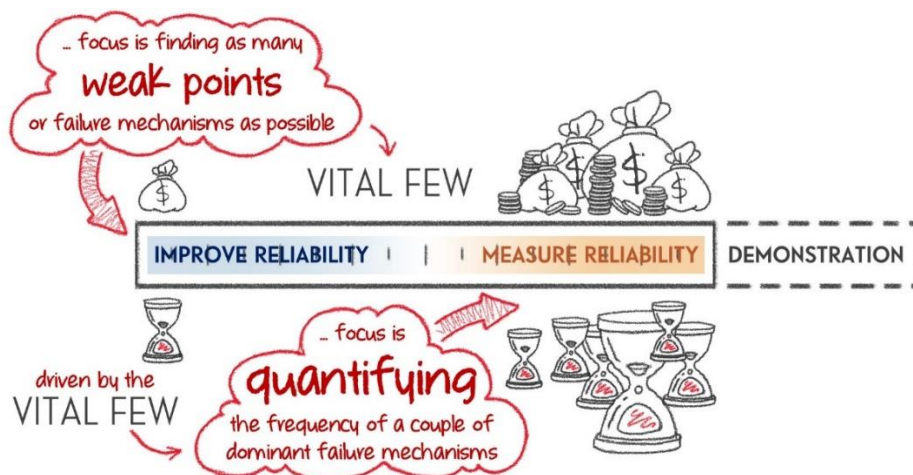


The data on the bottom right-hand corner of the chart doesn't take very long to gather as the temperature has been increased. We can see that because the data creates a straight line, the **Arrhenius model** appears to be a good fit.

We also know that because chemical reactions are typically constant, the **normal distribution** should model any randomness in the **TTF**.

start by UNDERSTANDING your DECISION

Reliability testing typically falls on a continuum that starts at **improving reliability** and finishes at **measuring reliability**. Plenty of tests are a combination of both. One key difference is that **measuring reliability** can be longer and more expensive as it typically requires lots of (potentially difficult to gather) data.



At the extreme of measuring is **demonstration**. This is categorized on its own, as **demonstration** testing typically means you test your product or system as a whole in 'use' conditions with no scope to accelerate testing. This means that any information you learned during design and other tests needs to be 'ignored.'

Tests that focus on **improving reliability** are all about finding the **VITAL FEW** ways your product or system will fail. This includes design weak points. This sort of testing includes **discovery** or **exploration testing** that pushes our products or systems to failure to find these **VITAL FEW**.



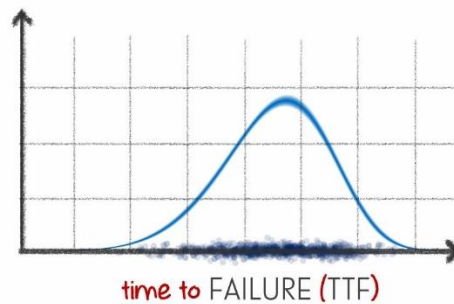
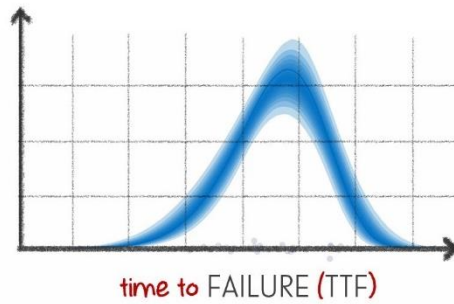
A well-known example of test that are focused on improving reliability is **Highly Accelerated Life Testing (HALT)**. A Qualmark Typhoon 4.0 HALT chamber is illustrated on the left. The chamber contains a table upon which systems and components can be secured and then subjected to random vibrations (with six degrees of freedom) up to 75 g RMS. It can also rapidly cycle temperature between 200°C to -100°C. The temperature cycling simulates cycling stresses as adjacent components have different coefficients of thermal expansion.

A circuit board that is being subject to **HALT** is illustrated on the right. A capacitor has just dislodged. The idea is that vibration and thermal stresses are increased systematically until the first failure is observed. The system is then repaired, and testing continues until a prioritized list of likely failure mechanisms emerges. Or ... the **VITAL FEW**.



HALT is not ALT ... even though the sound similar.

HALT involves increasing well known stresses in a controlled, but not scientific way. We keep increasing the stress to identify **WHAT** will break. This can help us then understand **HOW** our product will fail. Which can then help us create and **ALT** on that part of our product in order to measure how long it will take before our product fails. **HALT** can't measure, it can only point us in the right direction.



ALT is a test that **measures reliability**. We have already looked at how we need lots of data and the right **model** to increase the **confidence** we have in our test conclusions.

There are certain 'tricks' we can use to increase confidence or otherwise accelerate measuring tests. But these tricks all rely on knowing the **VITAL FEW** ways our thing will fail.

So the type of test comes back to the **decision** you are trying to inform.

