Virtual Testing at Knorr-Bremse

Dr. Frank Günther
Martin Kotouc

15. Deutsches LS-Dyna Forum
October 16, 2018

Right here, 14 yrs, 2 days, 1 hr ago…

3tes Deutsches LS-DYNA Forum '04

	Keynote Lecturers
10.00	Recent Developments in LS-DYNA - I J. Hallquist (Livermore Software Technology Corporation - LSTC)
11.15	Fluid - Structure- Interaction - A Still Challenging Topic Prof. E. Ramm, C. Förster, S. Genkinger (Universität Stuttgart); Prof. W. Wall (Universität München)
11.45	Simulationsgestützte Kompensation der Rückfederung Prof. K. Roll, K. Wiegand (DaimlerChrysler AG)
12.15	Robust Design for Crash at DaimlerChrysler Commercial Vehicles CAE F. Günther (DaimlerChrysler AG); H. Müllerschön (DYNAmore GmbH); W. Roux (LSTC)

DAIMLERCHRYSLER

Robust Design for Crash
at DaimlerChrysler Commercial Vehicles CAE

3. LS-DYNA FORUM 2004
October 14/15, Bamberg

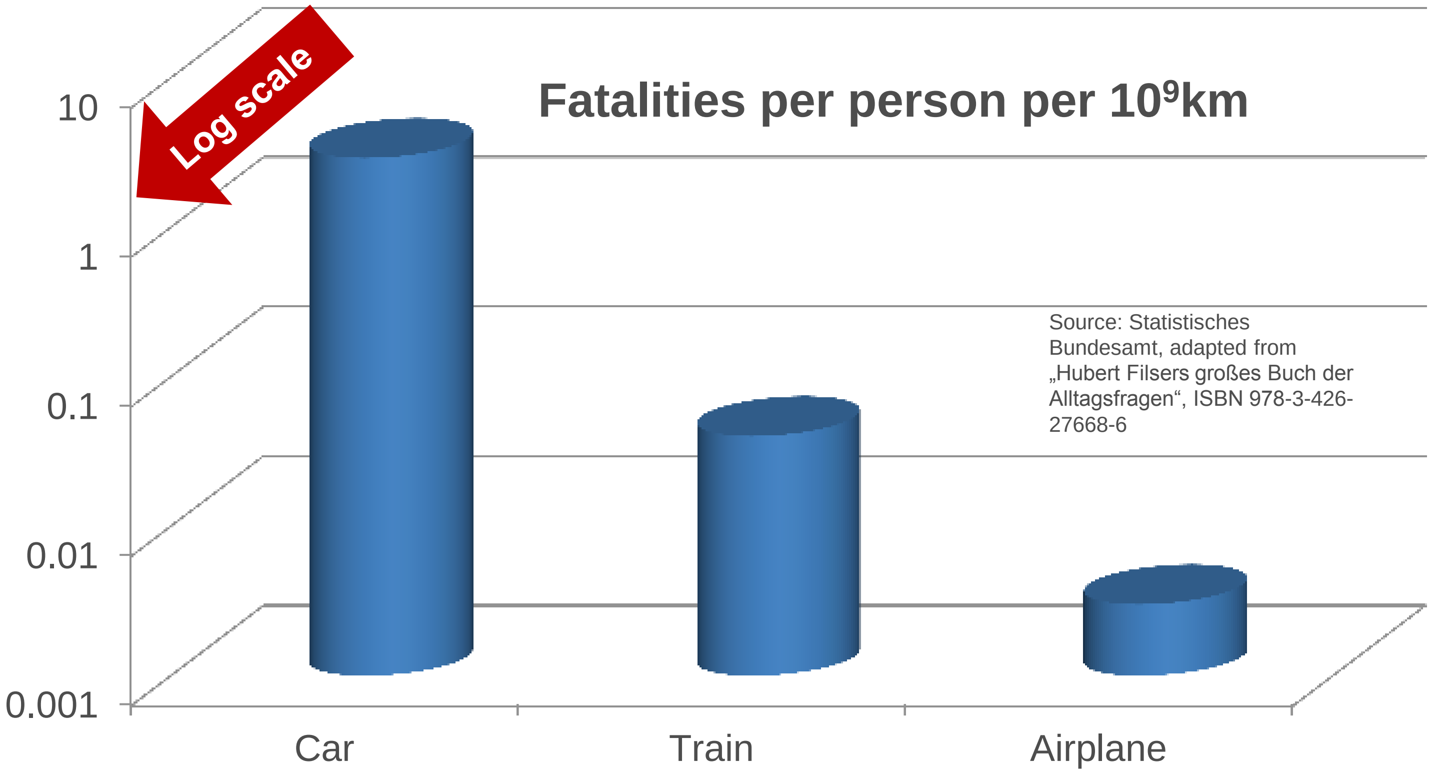
Frank C. Günther (DaimlerChrysler AG/Knorr-Bremse)
Heiner Müllerschön (DYNA*more* GmbH)
Willem Roux (Livermore Software Technology Corporation)

Virtual Testing at Knorr-Bremse

Agenda

- Boundary conditions for Virtual Testing in the Railway industry
- The significance of probability for Virtual Testing
- Virtual Testing at Knorr-Bremse

Accident statistics in Germany



Means of trans-portation	Fatalities per person per 10^9km
Car	2.9
Train	0.04
Airplane	0.003

While all means of transportation have reached very high levels of safety, the relative safety of trains and airplanes is usually underestimated by the general public.

What do these numbers mean for product validation?

	Car	Train	Remarks
Fatalities per person per 10^9km	2.9	0.04	
Typical design mileage [10^6km]	0.3	5	
Rough number of safety critical subsystems	10	10	Ballpark figure for illustration
Typical occupancy of vehicle	4	100	
Corresponding probability of failure for 1 subsystem over design mileage [ppm]	22	0.2	Since the statistics also include human error, the actual probability of technical failure needs to be even lower. 6σ corresponds to 3.4ppm

Compared to the automotive industry,
a typical train system needs to be validated for approx.:

- **$^{1}/_{100}$ probability of failure**
- **$10 \times$ design life**

All numbers are calculation examples for illustration only

How to transform high safety requirements and long design life into test cases for analysis and hardware testing

Design facilitates validation

- Redundancy: $\sqrt{0.2ppm} = 0.045\%$
- Use prescribed design rules
- Degraded modes can be identified and tested directly

Extrapolation

- Do a certain number of tests, fit a pdf and extrapolate to very small probabilities of failure => Extrapolation is always dangerous!
- Maybe use for relative comparisons and as a plausibility check

Test higher loads from experience

- Very common in both automotive and railway industry
- Usually expressed as a safety/overload factor in the railway industry
- Sometimes codified in industry standards, especially in the railway industry

Accelerated load profile

- Use knowledge of fatigue mechanisms to find an equivalent load spectrum that can be tested in less time.
- In the railway industry, there is a lot of optimism about the extent to which this can be done. E.g., IEC61373 vibration standard uses an acceleration factor of 15 000!

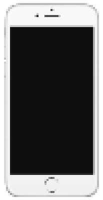
In the engineering project continuum, railway is a typical project business

Project business ⟷ **Product business**

Images: Wikipedia *) Since 2011 **) In 2014





Falkirk Wheel	ICE3 BR 403	Airbus A380	MB Actros	VW Golf	iPhone
1	50	205+	145 000+*)	409 000 per year**)	540 000 a day**)

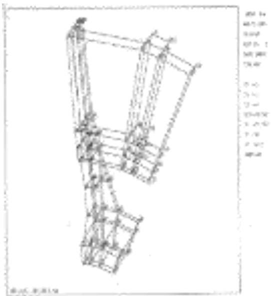
Project focus

- Reduce project costs and time including project driven development
  => small number of prototypes
- Delivery risk
- Driven by individual customer demand
  => Secondary effort to find a reusable solution

Product focus

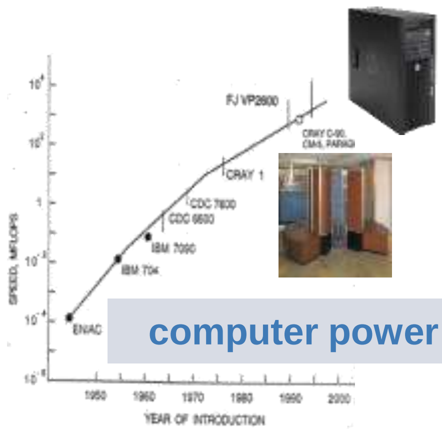
- Use development to reduce unit costs
  => sufficient number of prototypes
- Market Risk
- Driven by market demand
  => Secondary effort to offer individual solutions

Project business has driven early use of analysis

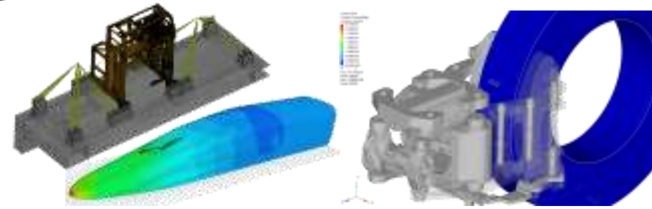


Structural Integrity

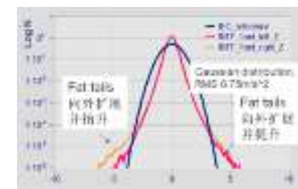
Early 80‘s



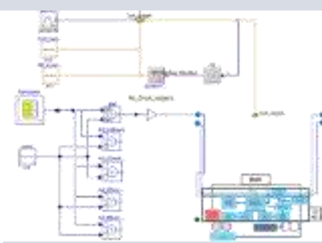
computer power

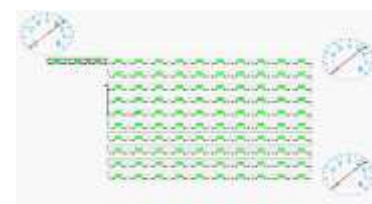


Structural integrity, virtual testing



Field tests, load spectra





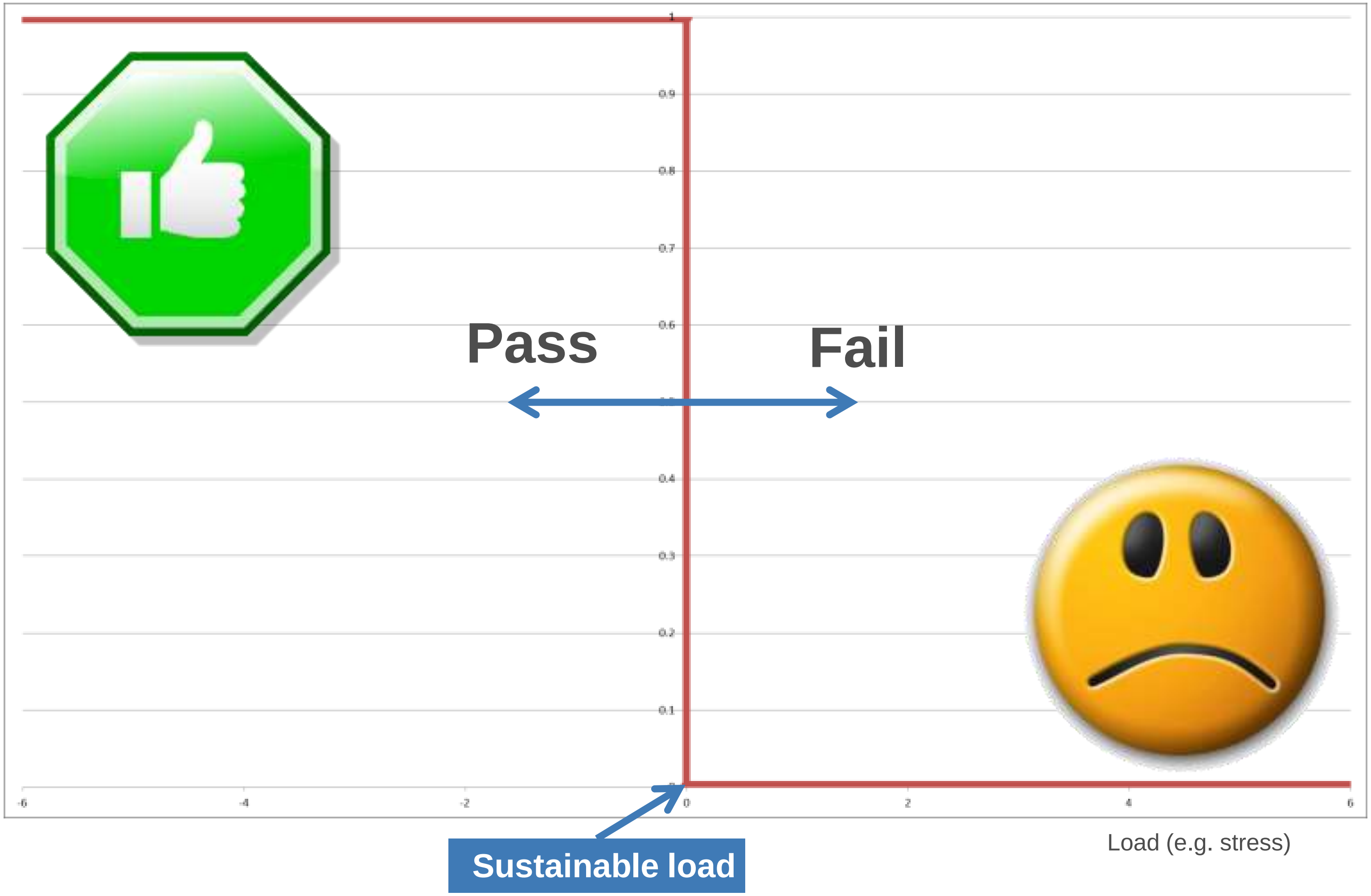
Multiphysics System Simulation

Today

Goals in project context

- Minimize risk
- Virtual test bench – economics of Railway sector require efficient and safe validation with small number of prototypes
- Early high quality in customer and development projects

Deterministic view of testing: Sustainable load separates pass & fail conditions



To illustrate the deterministic approach, consider this fictional, modern parable

The parable of deterministic test results

Bob is a senior FEA expert with Acme Industries, a small company that is the world market leader for a very specific type of widget.

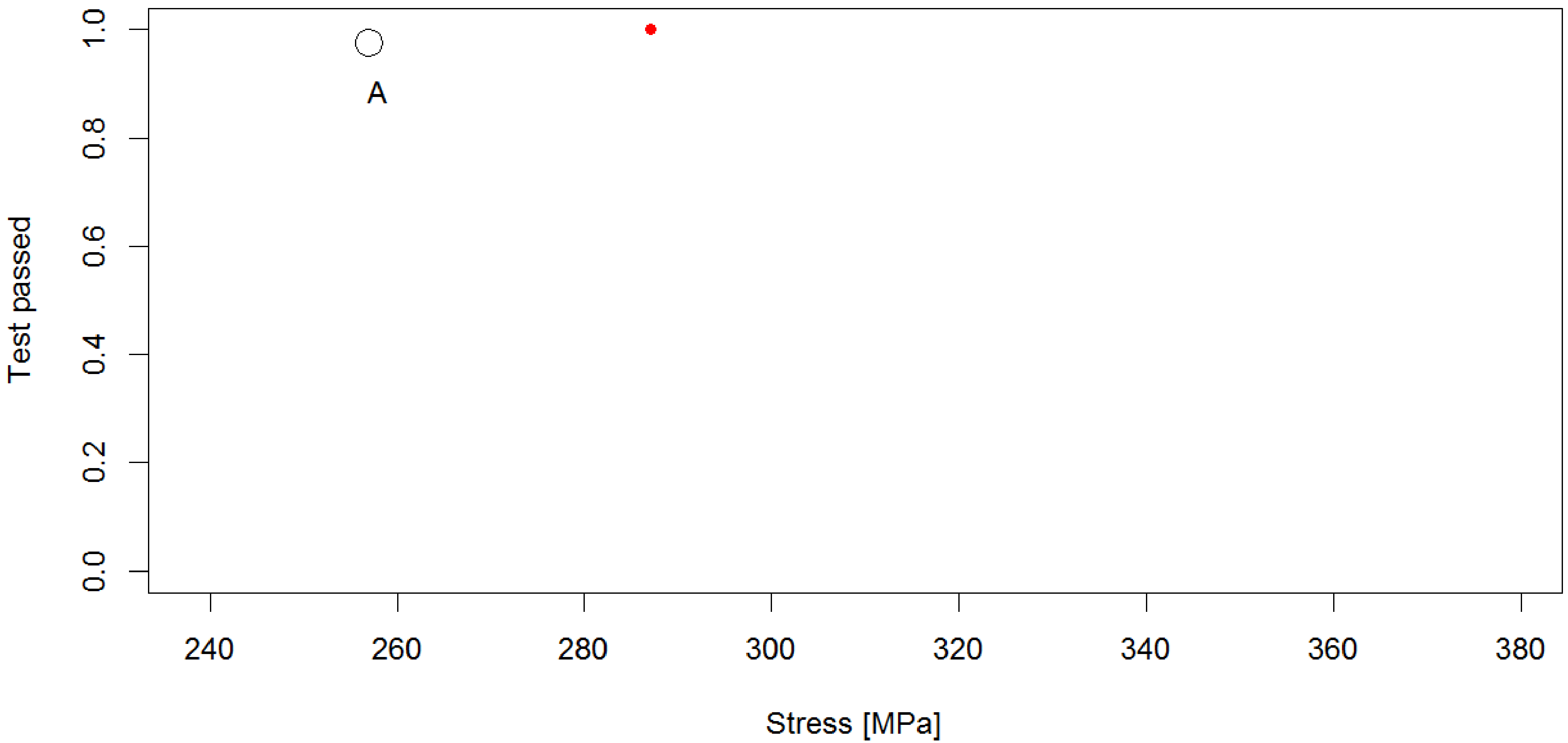
Alice, the VP of R&D at Acme, knows most customers expect verification through an independent test under the customer's close supervision.

She has established a three step V&V process for the widgets:

- Alice asks Bob whether a specific widget will pass the test. She wants to make sure potential issues can be identified and addressed ahead of costly hardware testing. But in Alice's experience, most tests are successful even when Bob tells her otherwise. So she frequently disregards his recommendations.
- A preliminary test is done because Alice wants to be 99% sure that the verification test will be successful.
- The verification test is done.

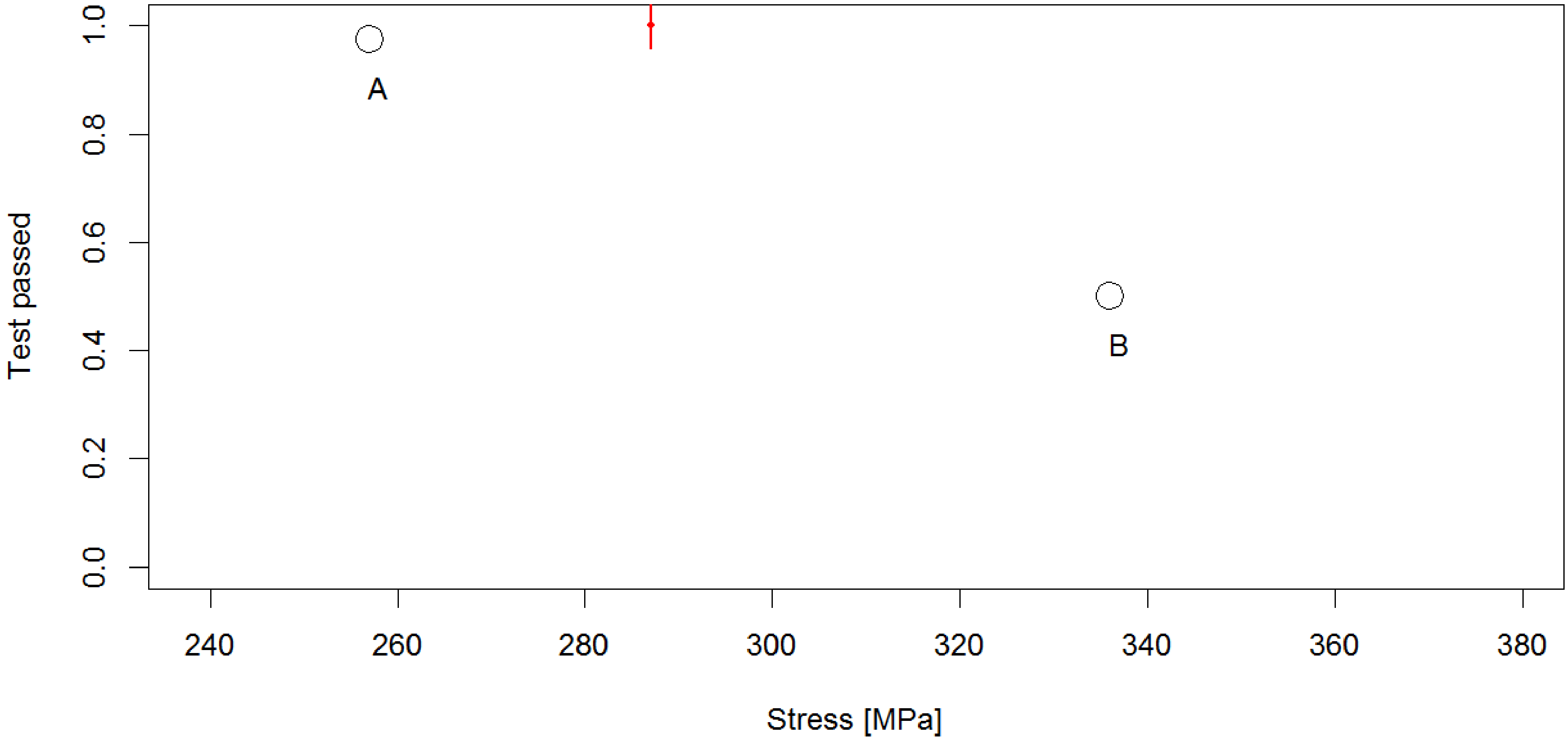
In the following slides, we will look at this verification process for one specific project.

The parable of deterministic test results: After the 1st test



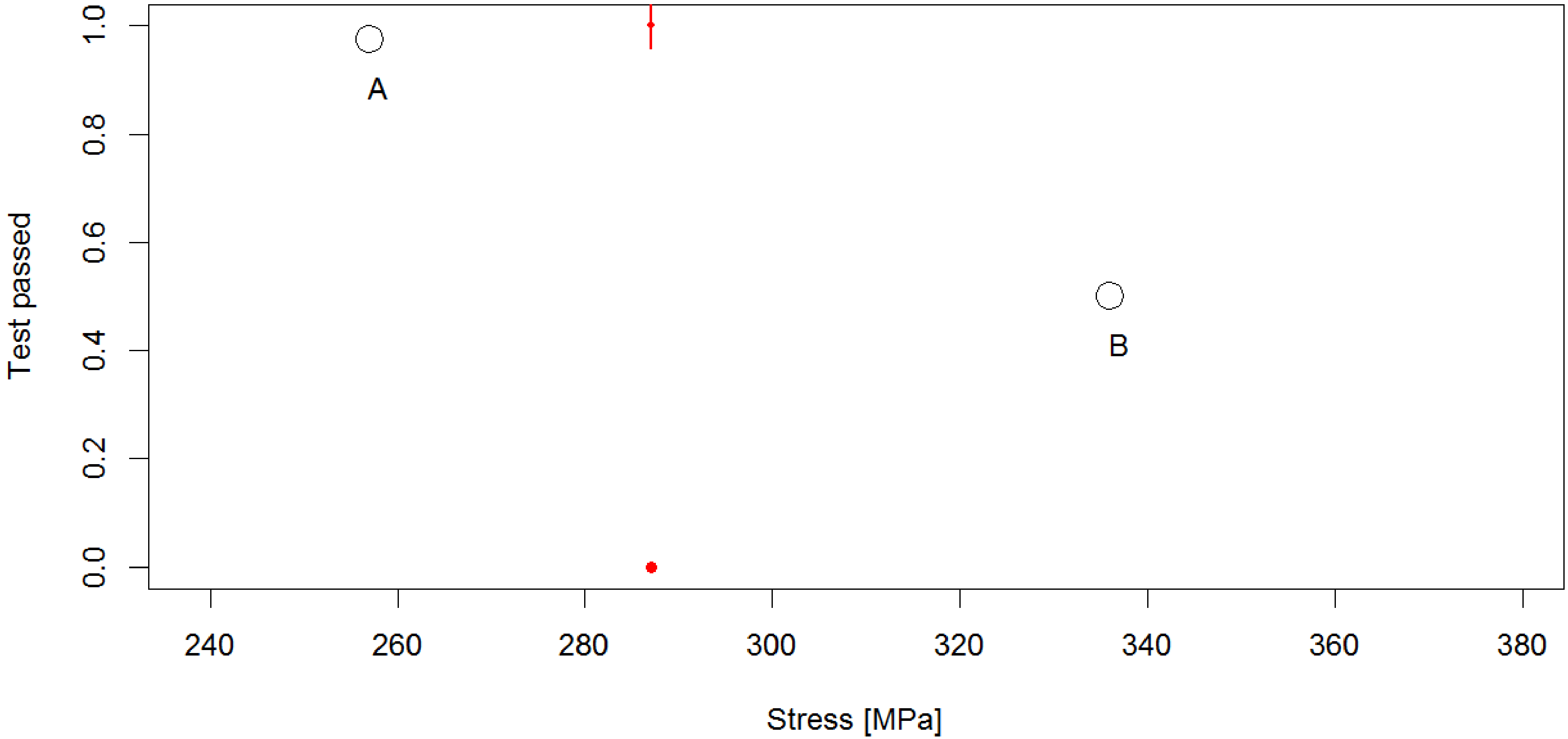
Bob calculates a stress of 287MPa.
The widget is specified as material grade A, which can sustain a stress of 257MPa.
Bob predicts it will fail. However, Alice decides to go ahead with the preliminary test anyway.
The test is successful.

The parable of deterministic test results: After the 2nd test



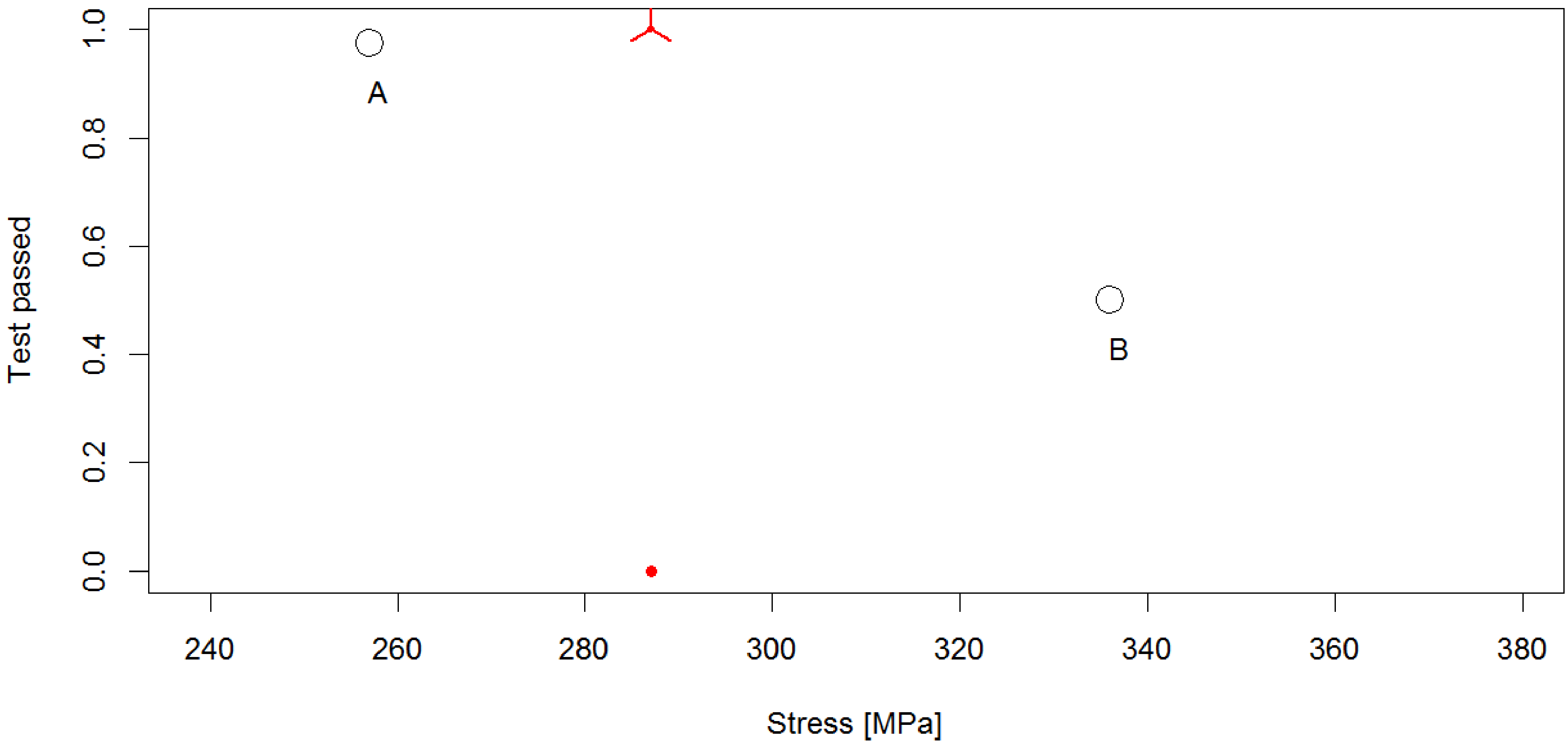
**To remove any lingering doubts due to Bob's FEA results, Alice orders a second test.
It is also passed. Maybe the widget's material grade is actually B.
Bob knows B can sustain a stress of 336MPa, and the test results would agree with his FEA.**

The parable of deterministic test results: After the 3rd test



With two successful preliminary tests, Alice is more confident than usual about the verification test. However, it fails. Alice has the broken widget lab tested. Its material parameters are within spec for A. But the lab also identifies a small flaw right in the area of highest stress concentration. Based on this finding, Alice convinces the customer to disregard the third test.

The parable of deterministic test results: After the 4th test



The verification test is repeated and passes.
V&V of the widget is complete.
Alice makes a mental note to audit the material supplier.

The parable of deterministic test results: After the 4th test

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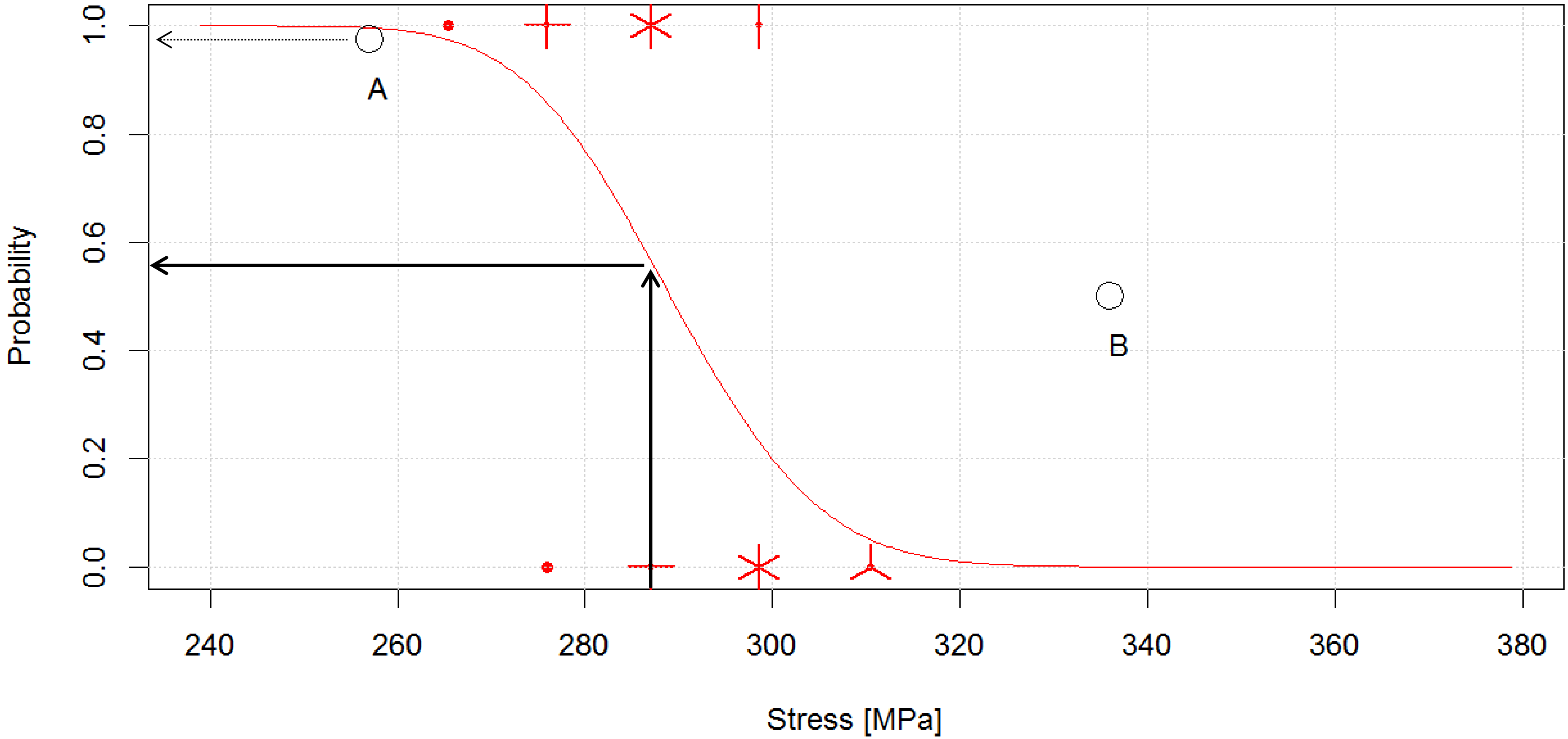
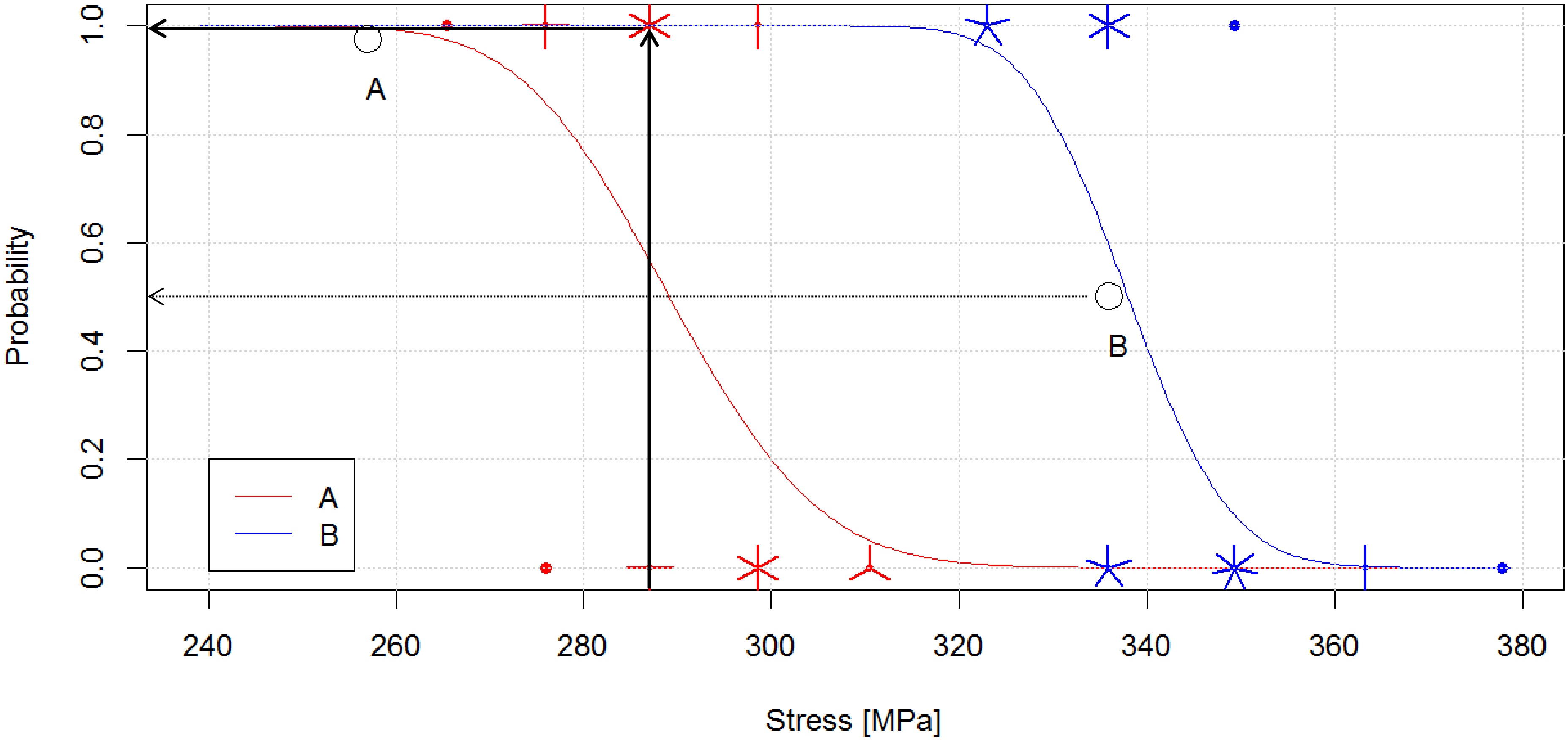
The parable of <u>stochastic</u> test results: After 27 tests



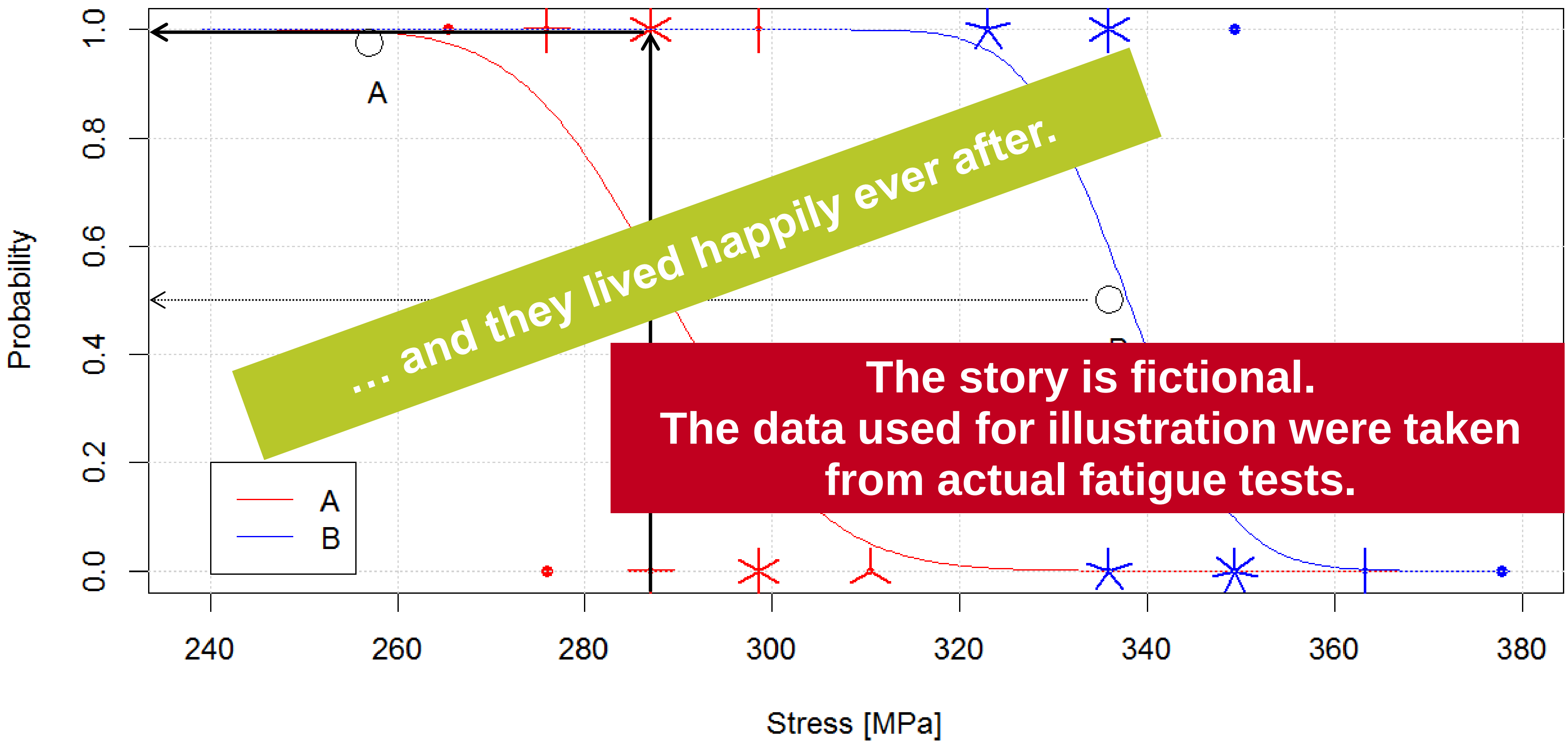
A long time ago, Bob took graduate level statistics and remembers learning about logistic regression. He convinces Alice to do more testing and fits a <u>Probability of Survival</u> curve. Bob's original data for material A were based on 97.5% PoS. They agree with his PoS curve. Bob concludes Alice only had a <60% chance of passing the verification test with material grade A.

The parable of stochastic test results: After 54 tests



Material B is also tested. Note that Bob's original data for B (but not A) were based on 50% PoS.
Bob's conclusion: If the widget is switched to material grade B,
Alice can be >99% sure the verification test will be passed.

The parable of stochastic test results: After 54 tests



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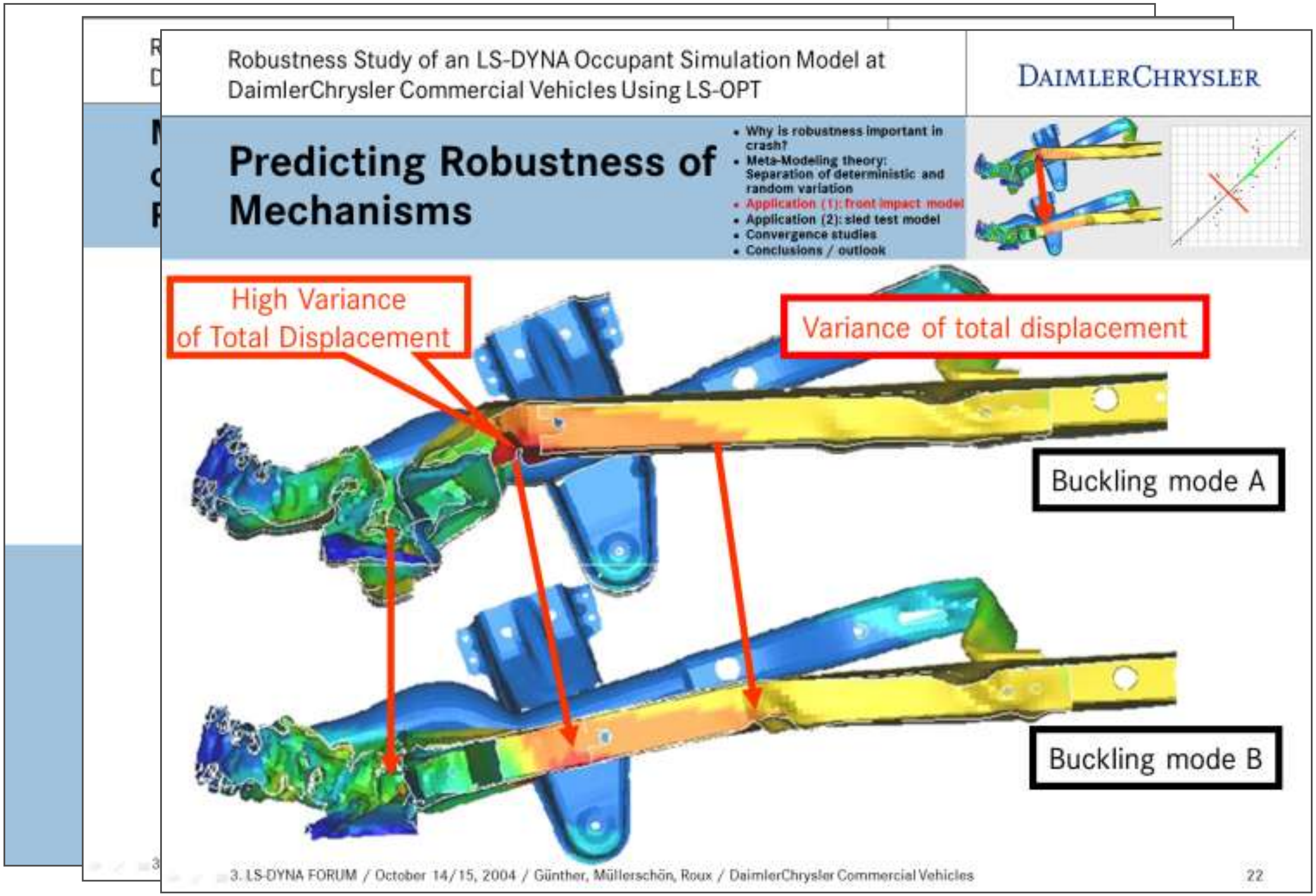
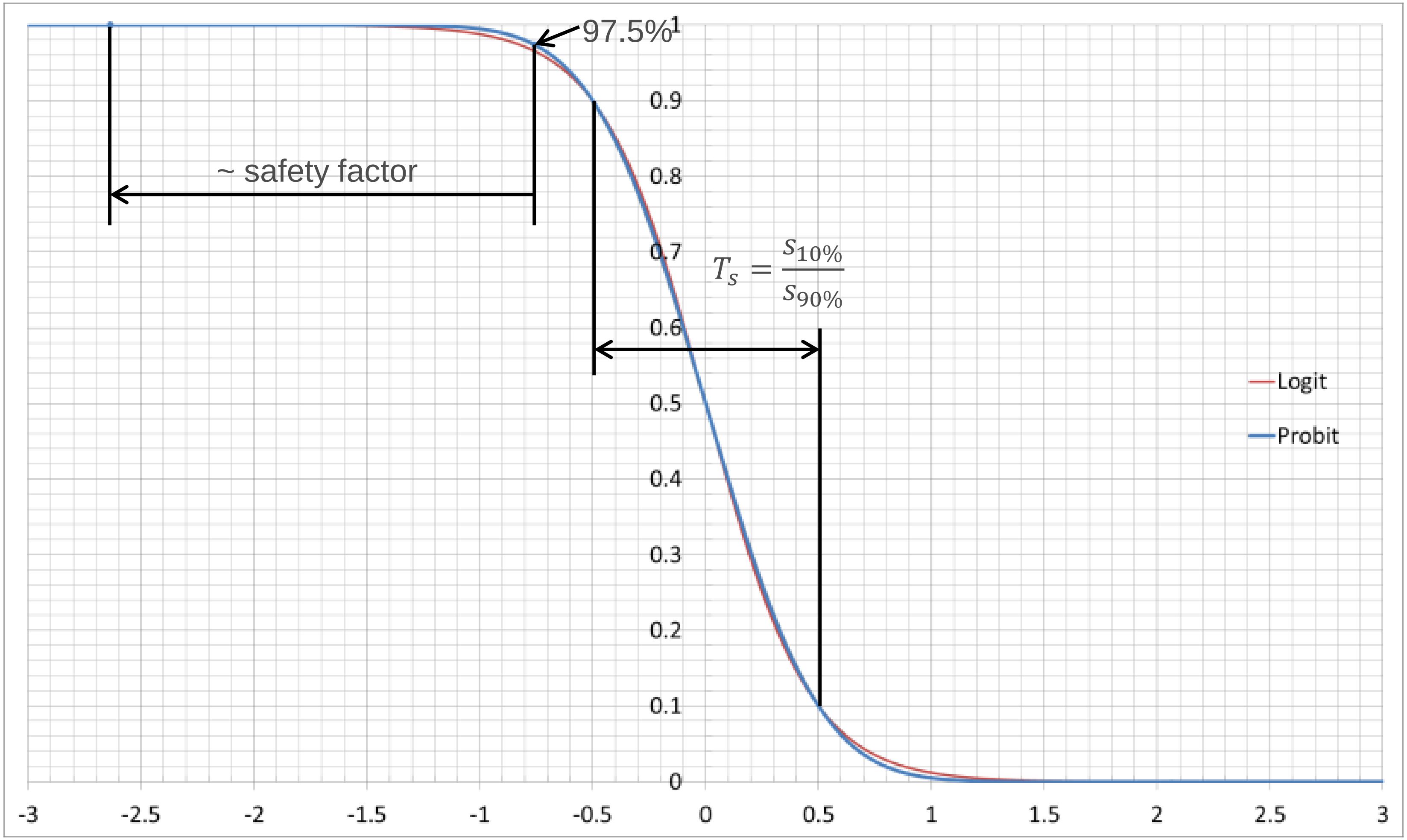
Stochastic behavior can be seen in all disciplines



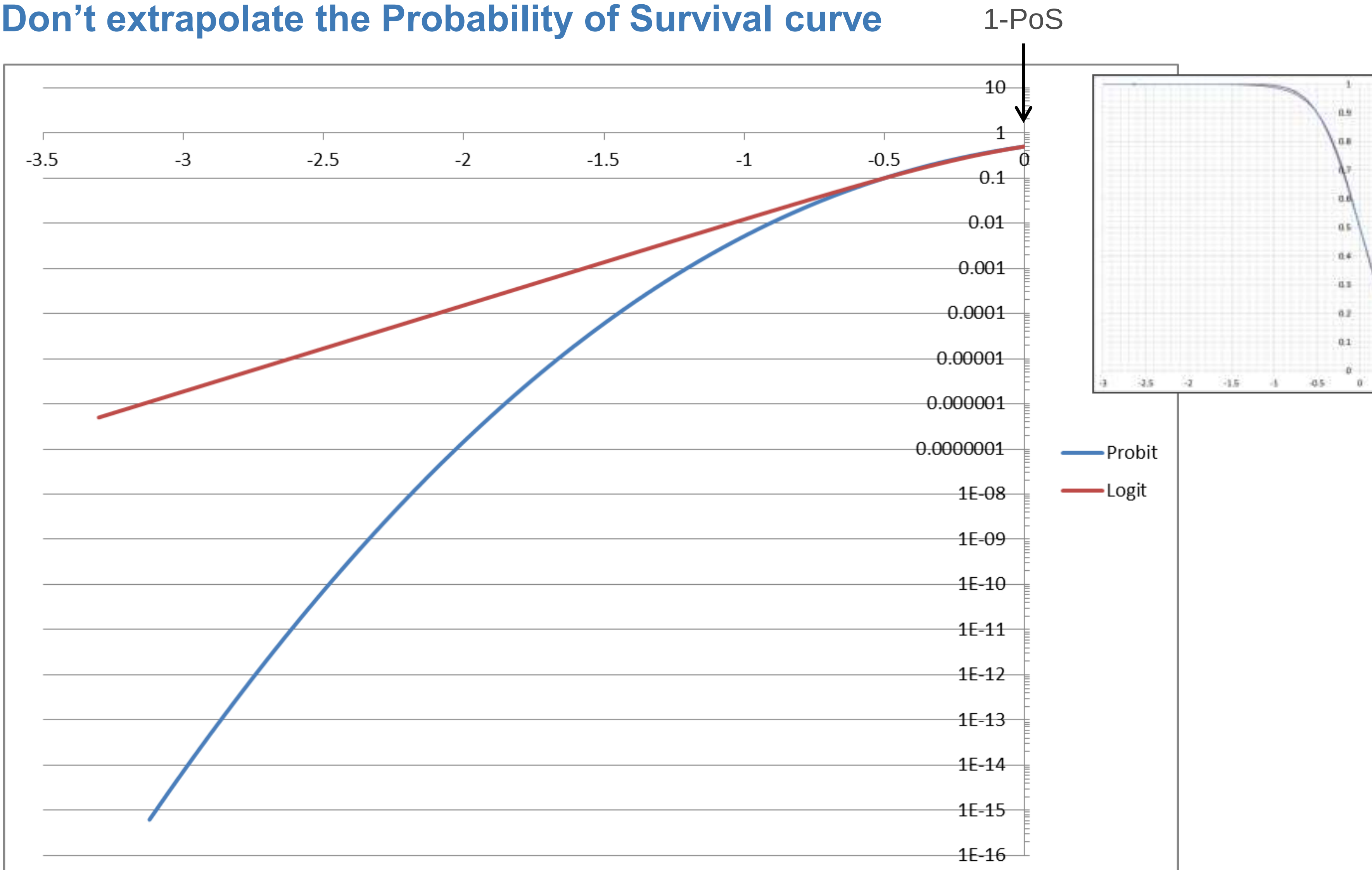
Taking a closer look at the Probability of Survival Curve



$$k = \frac{log \frac{s}{s_{50\%}}}{\log T_s}$$

$$\rightarrow s = s_{50\%} T_s^k$$

Don’t extrapolate the Probability of Survival curve



The bigger picture: verification can be hardware driven or simulation driven.

Hardware driven

Virtual test → Predict hardware tests → **Hardware tests** → Result of hardware tests (statistics) = verification result

First Time Right – reduction of development time

Simulation driven

Hardware tests (also from other projects) → Hardware tests validate virtual testing methods (statistics) → **Virtual test** → Result of virtual test = verification result

Purpose: Quality assurance of verification

Every day, more than a billion people all over the world rely on systems from Knorr-Bremse

Systems for Rail Vehicles

- High-speed trains
- Regional & commuter trains
- Metros
- LRVs
- Monorails
- Locomotives
- Passenger cars
- Freight cars
- Off-train

COMMERCIAL VEHICLE SYSTEMS

- Trucks
- Trailers
- Buses
- Engines
- Special vehicles

Product portfolio – varied sub-systems and additional services

ON TRAIN

OFF TRAIN

KNORR-BREMSE
- Braking Systems
- Windscreen Wiper and Wash Systems

IFE
- Entrance Systems

SIGMA / merak
- Air Conditioning

Microelettrica Scientifica
- Power Electrics
- Energy Metering

WESTINGHOUSE platform screen doors
- Platform Screen Doors
- Platform Edge Doors
- Safety Gates

KNORR-BREMSE

Systems for Rail Vehicles

PowerTech
- Auxiliary Converters
- Battery chargers

Selectron
- Train Control Management Systems

NEW YORK AIR BRAKE
- Freight and Locomotive Brake Control

RailServices
- Spare Parts and Overhaul Management
- Repair and Service

ZELISKO
- Rail Signalling Systems

Product portfolio – varied sub-systems and additional services

ON-TRAIN

High-Speed

Regional & Commuter

Metros

LRVs

Monorails

Locomotives

Passenger Rail Cars

Freight Cars

OFF-TRAIN

Off-Train

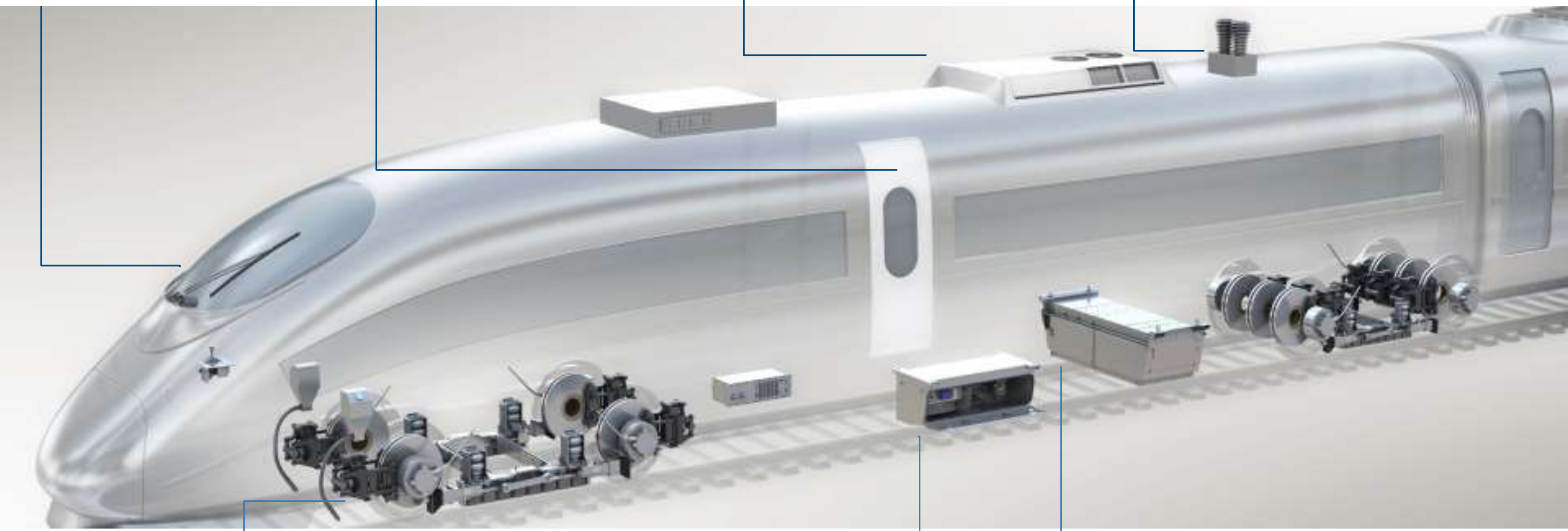
Product portfolio – High-Speed Trains

KNORR-BREMSE
- Windscreen Wiper and Wash Systems

IFE
Entrance Systems

SIGMA merak
HVAC

Microelettrica Scientifica
Power Electrics



KNORR-BREMSE
Braking Systems

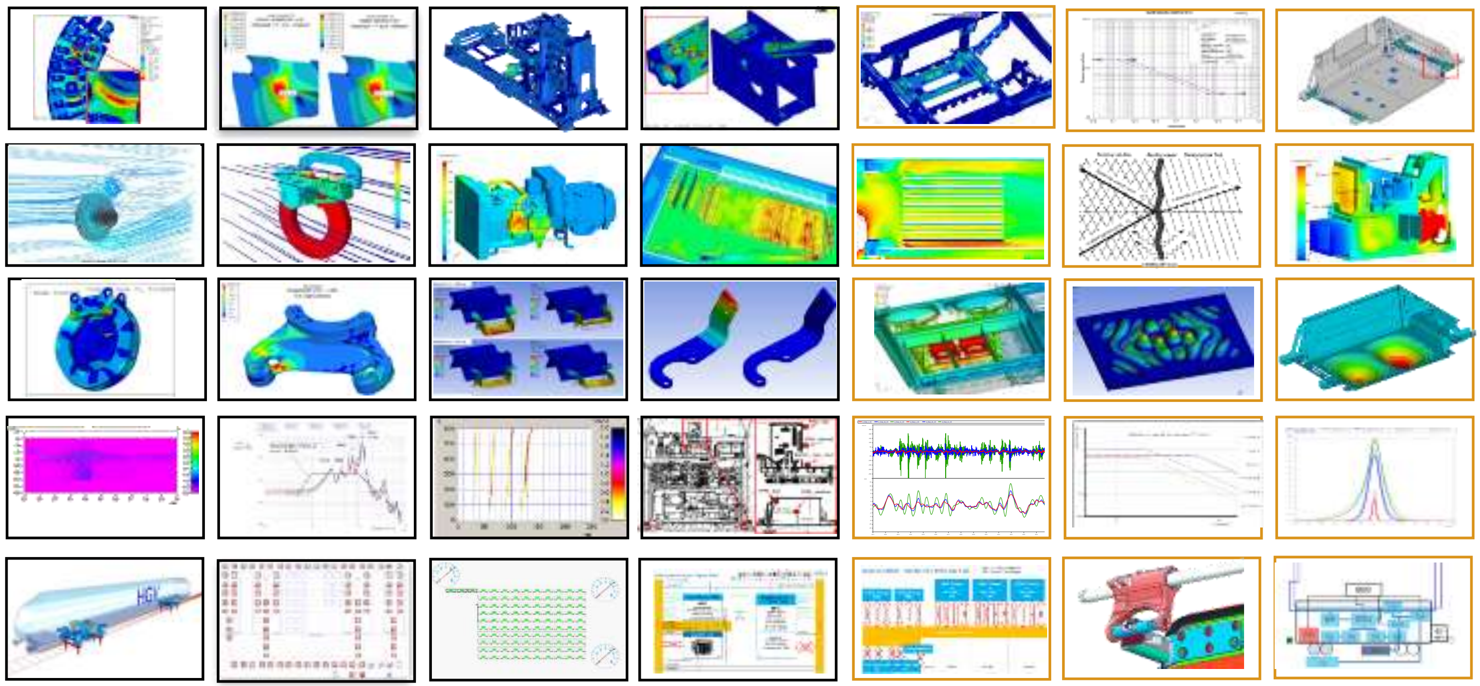
POWERTECH
Auxiliary Converters

RAILSERVICES
Modernization, Service and Support

Broad spectrum of products leads to broad spectrum of Virtual Testing

Cross sectional | **Brakes** | **Onboard Systems**

- Fatigue & Structural Integrity
- Fluid Mechanics & Thermodynamics
- Structural Mechanics & Dynamics
- Load Spectra & Environment
- Multiphysics Systems & Multibody Dynamics



Virtual Testing & Simulations

Brake Mechanics	Hydraulics	Pneumatics, Air Supply	Electronics Mechatronics	HVAC	Doors	Power Electronics
Brake Systems				Connected Systems		
Rail Services						

New Knorr-Bremse development center in Munich

https://www.youtube.com/watch?v=AvR6ZqMh4rU


Thank you for your attention.