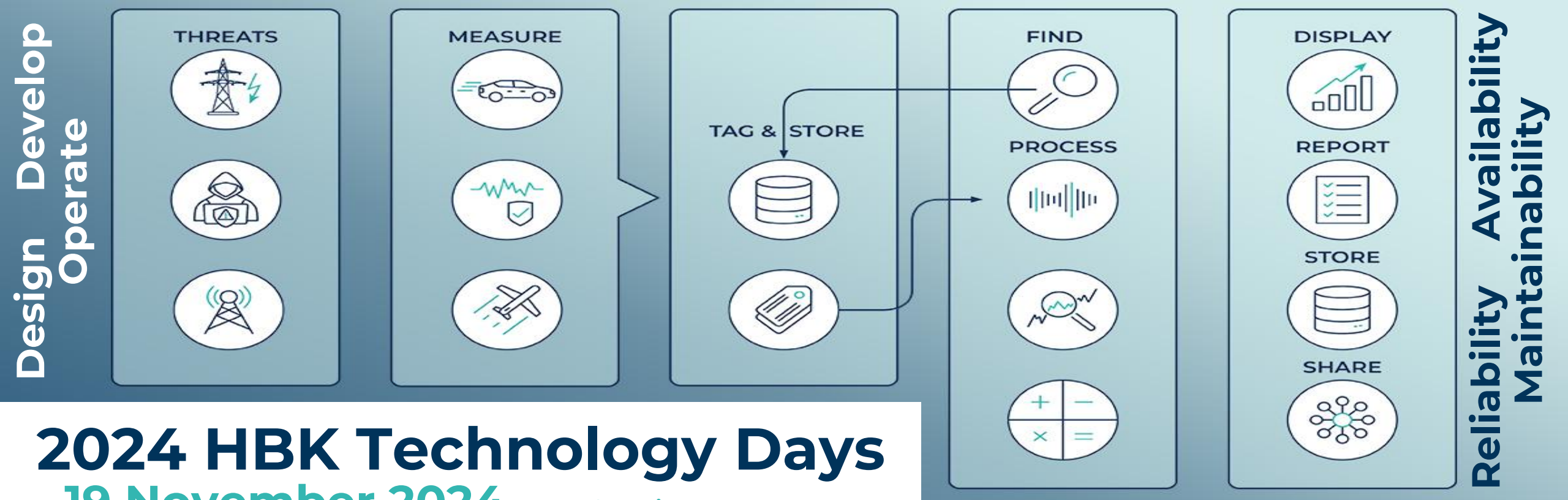


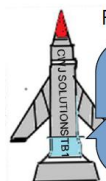


2024 HBK Technology Days

19 November 2024

Session 5: Reliability Engineering from Limited Failure Data

TB1 Space Plane Project



Flight Cycle target steps

Fuel up

Launch

Turn back

Vertical Land

Vent

Repair, Replace, Report, Review, Ready?



Programme Stage B – modified from lessons learnt and made ready for unmanned missions to Thunderbird 5

1 failure;

- Stability issue during landing due to flight control malfunction.
- Vehicle was recovered for inspection and investigation.
- o0o---
- Flight control hardware, no fault found / software issue detected and corrected.

- Life data analysis for failure probability compliance

Chris Wynn-Jones,
Senior Application Engineer – Reliability, HBK

Life data analysis for failure probability compliance

▲ Abstract

- Failure probability compliance in reliability engineering ensures systems meet specified reliability standards by assessing and managing the likelihood of failures. Ideally this process includes comprehensive testing, statistical analysis, and strict adherence to engineering protocols to minimize risks and enhance system dependability.
- However, when learning how life data analysis can be used to assess the reliability and failure probability of a product or system it is useful to consider case studies with minimal available failure information. This presentation describes just such a case study for the overall probability of failure and conditional probability of failure for next flight, of a new rocket engine through development and testing to entry into service.

Life data analysis for failure probability compliance

- ▲ About the presenter, Chris Wynn-Jones,
Senior 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 the host of the ReliaCast podcast series and an Application Engineer for ReliaSoft reliability software. He supports 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, systems or services.

Tuesday 19 November : Session 5 : Reliability Engineering from Limited Failure Data

LIFE DATA MODELLING FROM LIMITED FAILURE DATA

Chris Wynn-Jones
Application Engineer - ReliaSoft



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TB1 Space Plane Project

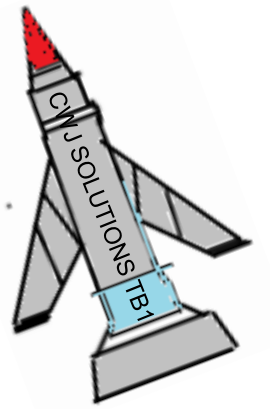
We are a rocket engine company selected to help improve a legacy.

▲ Customer

- Lady Penelope and Jeff Tracy from International Rescue

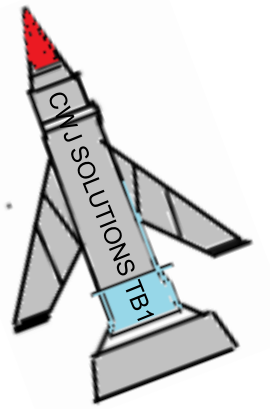
▲ Task

- Thunderbird 1 - Currently a vertical take off aircraft for missions in atmosphere
- Develop an engine solution for Thunderbird 1, capable of flying for a period of time in a Vacuum
- TB1 will perform manned and unmanned missions to Thunderbird 5 (Space Station).
- International Rescue wants to be ready for any Emergency in Space!



TB1 Space Plane Project

We are a rocket engine company selected to help improve a legacy.



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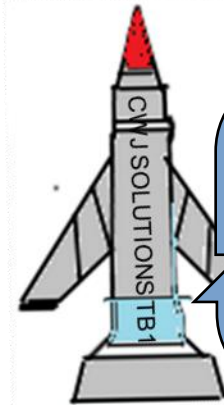


Thunderbird 1 Space Plane - Requirements

- Thrust at Sea Level, no less than: 7,500 kN
- Thrust in Vacuum, no less than: 8,000 kN
- ...
- LDA for Failure probability compliance @ 99% confidence;
 - o fixed failure probability of 0.31 @ 15 flights
 - o failure probability of 0.10 @ next 15 flights
- ...
- Payload expected to be up to 8,000 kg
- Vertical take-off and land capability

- **LDA for Failure probability compliance @ 99% confidence;**
 - o **fixed failure probability of 0.31 @ 15 flights**
 - o **failure probability of 0.10 @ next 15 flights**

TB1 Space Plane Project



Flight Cycle target steps

Fuel up

Launch

Turn back

Soft landing

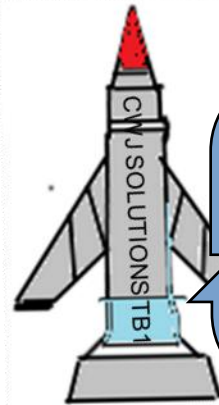
Vent

Repair, Replace, Report, Review, Ready?



Programme Stage A – proof of concept - 15 flights;

TB1 Space Plane Project



Flight Cycle target steps

Fuel up

Launch

Turn back

Soft landing

Vent

Repair, Replace, Report, Review, Ready?



Programme Stage A – proof of concept - 15 flights;

1 failure;

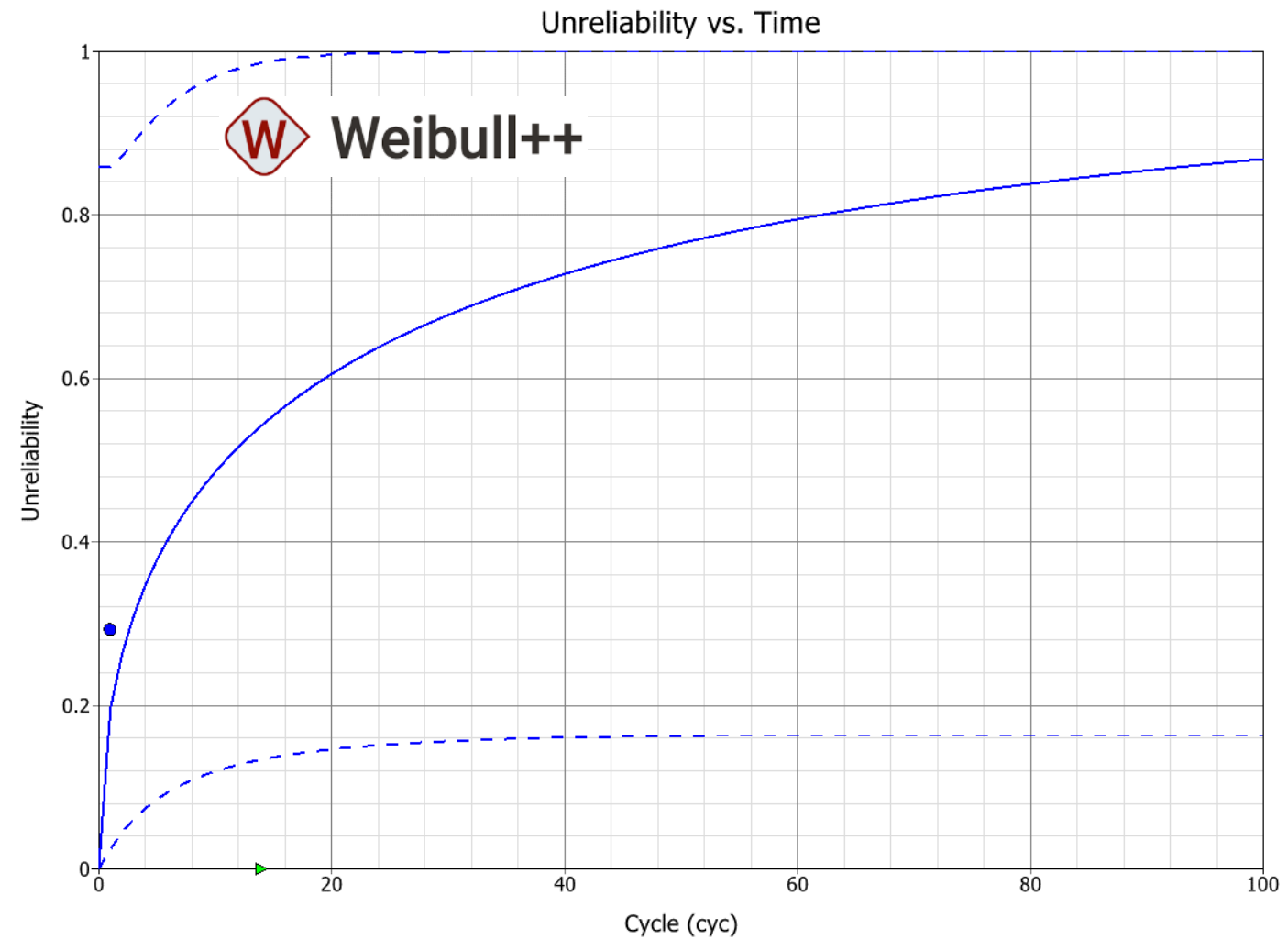
- Control surfaces lost (Tail fins) reasons unknown, lost control and crashed, see freeze frame marked X.
 - Next frame the test vehicle suffered a rapid disassembly.
- o0o---
- After investigation was complete the remaining flights got the green light to continue and were a success!



Rocket Engine Reliability Data

Programme Stage A (15 Flights/1 failure)

- Failure probability (C=99%) v1.0;
 - $Q(t=15 \text{ cyc}) = 99\% / M=55\%$
 - $Q(t_1=15 \text{ cyc} | t_2=15 \text{ cyc}) = 99\% / M=28\%$



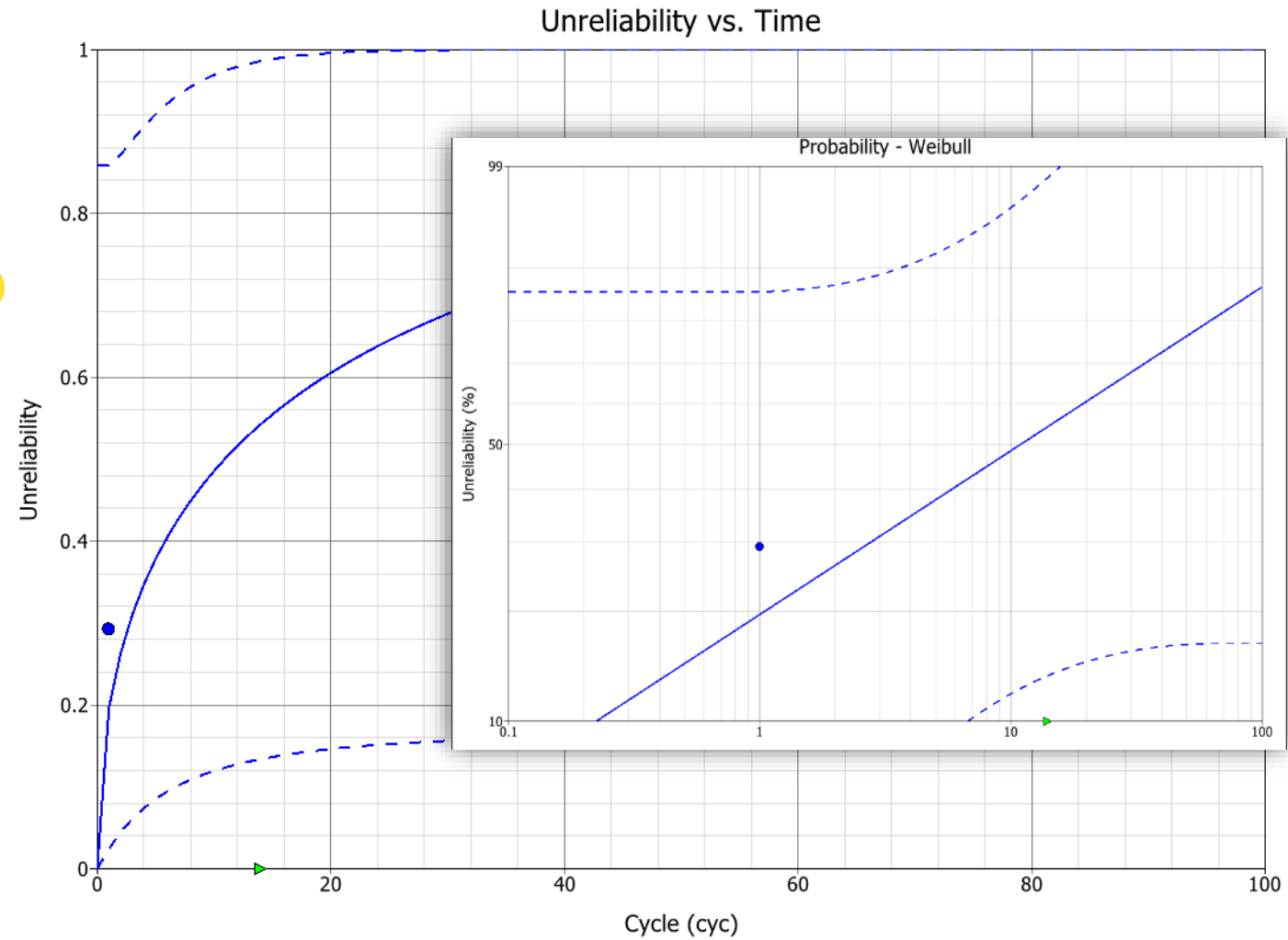
Requirements

- Failure probability compliance @ 99% confidence;
 - failure probability of 31% @ 15 flights
 - failure probability of 10% @ next 15 flights

Rocket Engine Reliability Data

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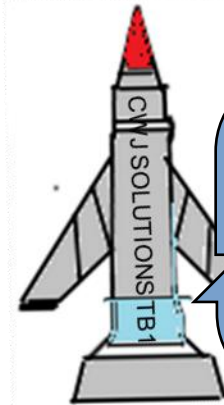


Requirements

- Failure probability compliance @ 99% confidence;
 - failure probability of 31% @ 15 flights
 - failure probability of 10% @ next 15 flights

93% Success Rate!

TB1 Space Plane Project



Flight Cycle target steps

Fuel up

Launch

Turn back

Vertical Land

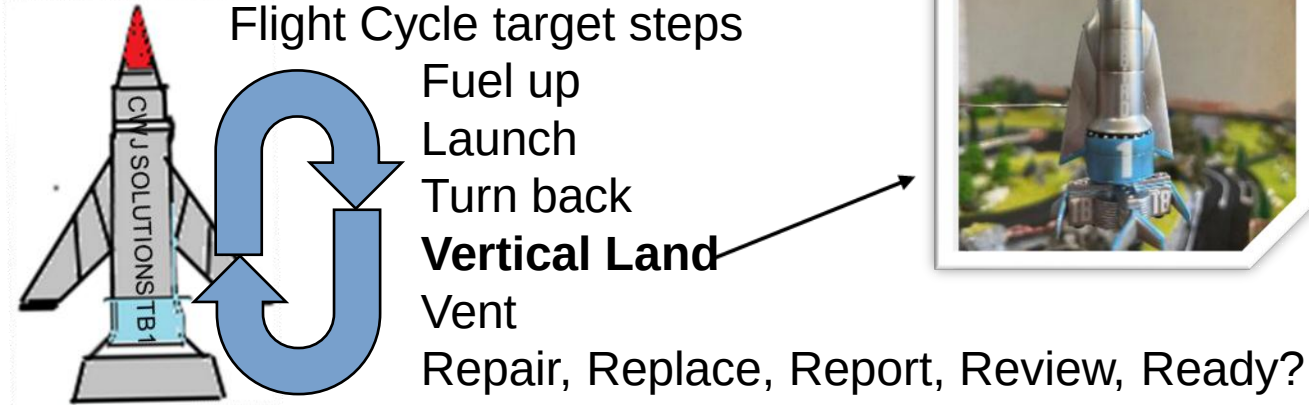
Vent

Repair, Replace, Report, Review, Ready?



Programme Stage B – modified from lessons learnt and made ready for unmanned missions to Thunderbird 5

TB1 Space Plane Project



Programme Stage B – modified from lessons learnt and made ready for unmanned missions to Thunderbird 5

1 failure;

- Stability issue during landing due to flight control malfunction.
- Vehicle was recovered for inspection and investigation.

---o0o---

- Flight control hardware, no fault found / software issue detected and corrected.

Rocket Engine Reliability Data

Programme Stage A (15 Flights/1 failure)

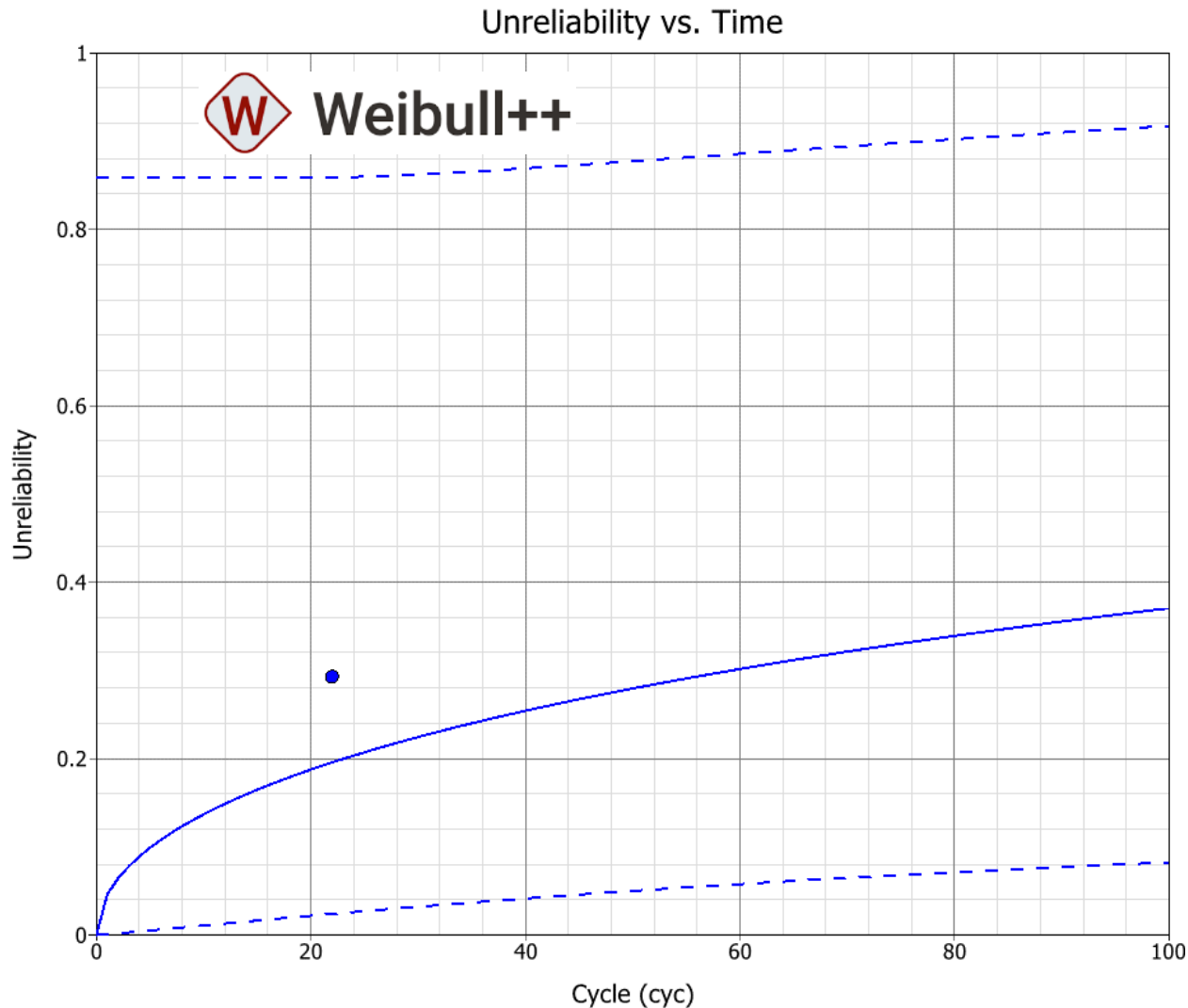
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Programme Stage B (310 fights/1 failure)

- Failure probability (C=99%) v1.0 + EIS 1.0;
 - Prob. of Failure, upper $Q(t=15 \text{ cyc}) = 86\% / M=17.3\%$
 - Cond. Prob. of Failure, upper $Q(t_1=15 \text{ cyc} | t_2=15 \text{ cyc}) = 51.7\% / M=9.3\%$

Requirements

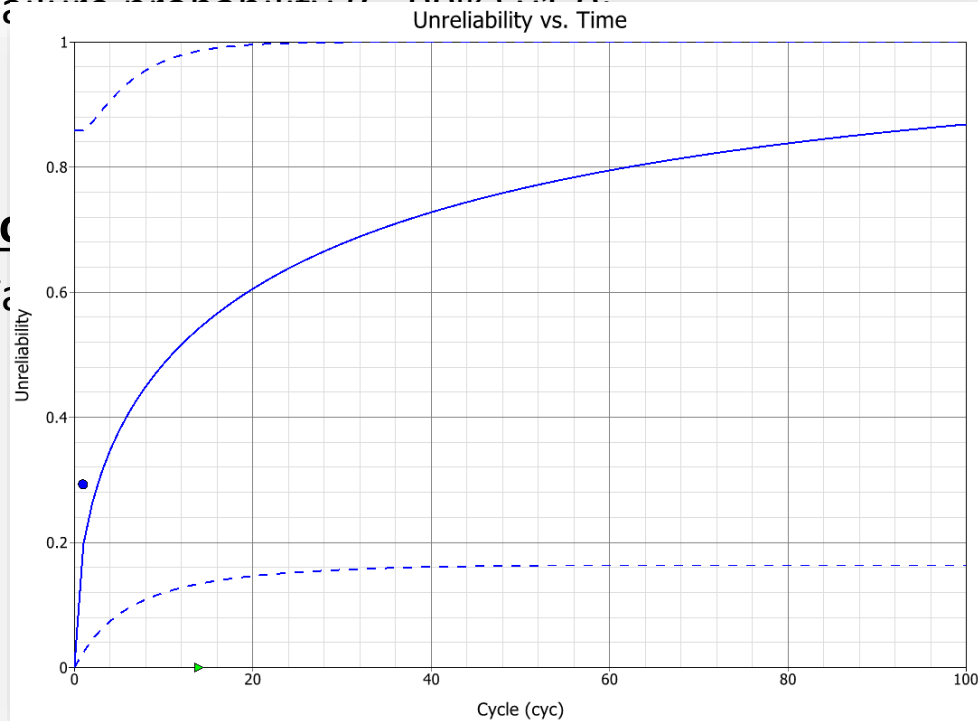
- Failure probability compliance @ 99% confidence;
 - failure probability of 31% @ 15 flights
 - failure probability of 10% @ next 15 flights



Rocket Engine Reliability Data

Programme Stage A (15 Flights/1 failure)

- Failure probability (C 99%) = 1.0%



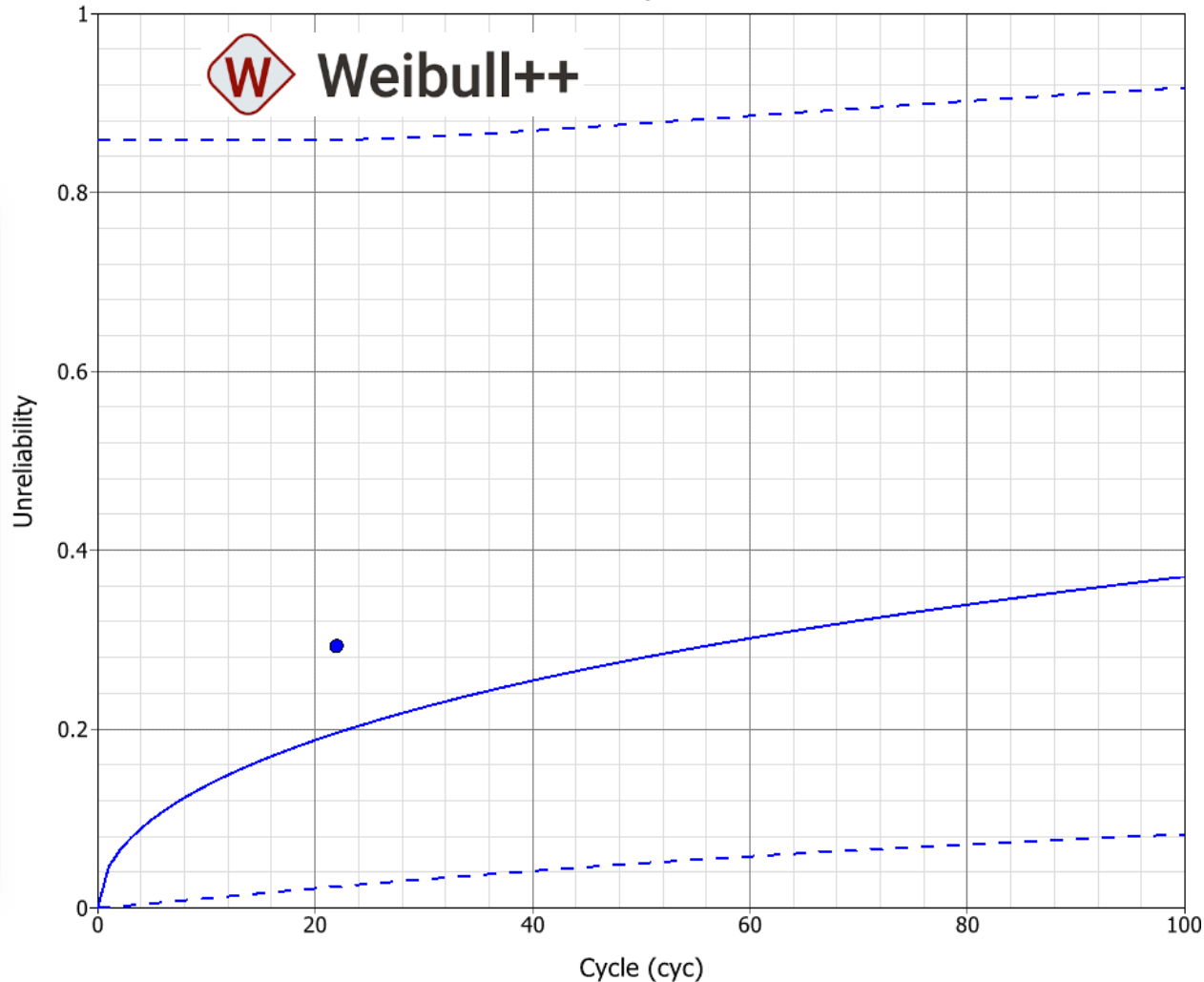
Pro

- Failure probability (C 99%) = 1.0%
- 3% (yc)

Requirements

- Failure probability compliance @ 99% confidence;
 - failure probability of 31% @ 15 flights
 - failure probability of 10% @ next 15 flights

Unreliability vs. Time



Rocket Engine Reliability Data

Programme Stage A (15 Flights/1 failure)

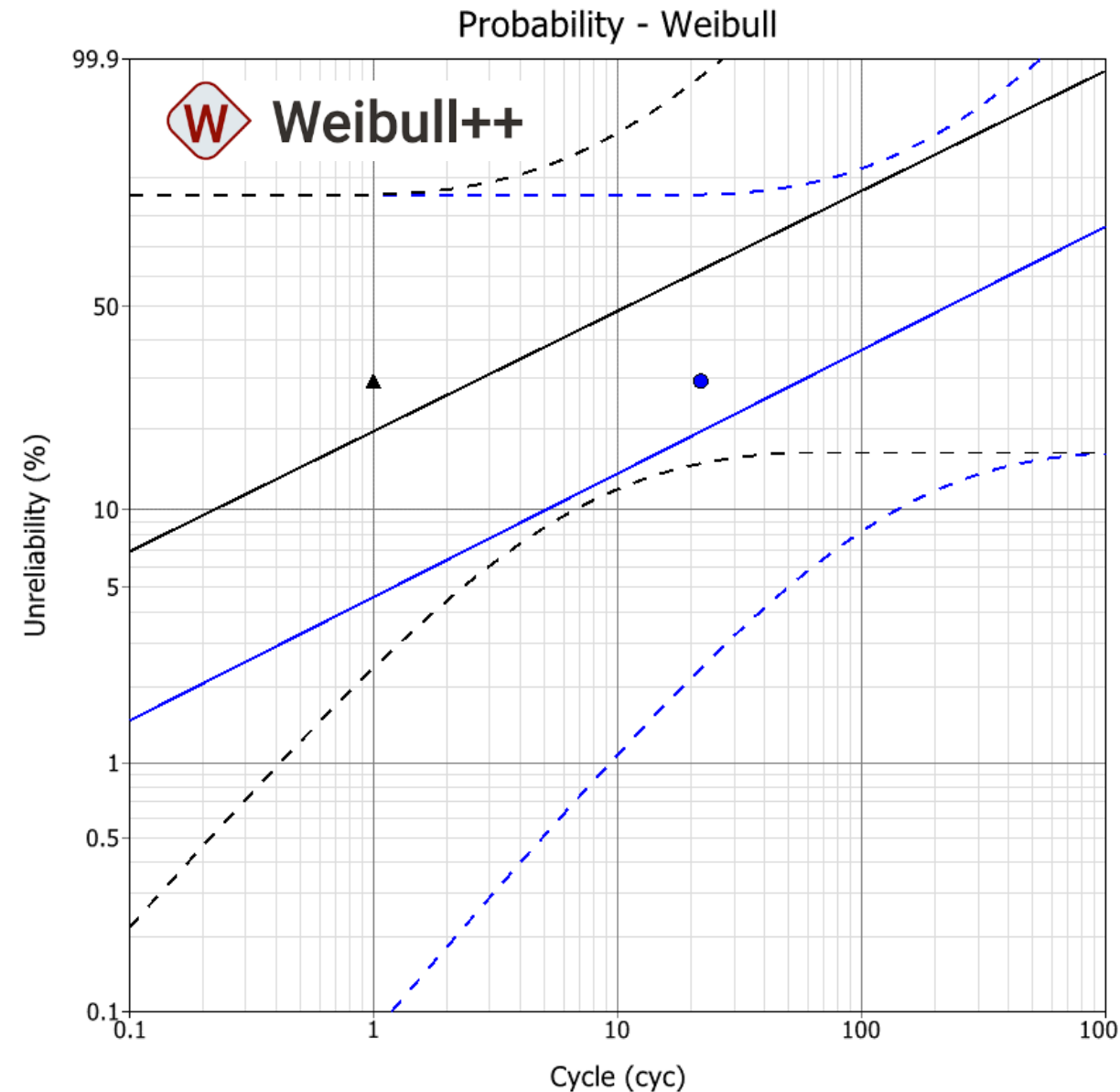
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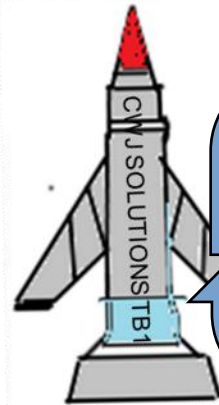
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Requirements

- Failure probability compliance @ 99% confidence;
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TB1 Space Plane Project



Flight Cycle target steps

Fuel up

Launch

Turn back

Land

Vent

Repair, Replace, Report, Review, Ready?

Programme Stage C – modified from lessons learnt
and continue unmanned missions to Thunderbird 5



Rocket Engine Reliability Data

Programme Stage A (15 Flights/1 failure)

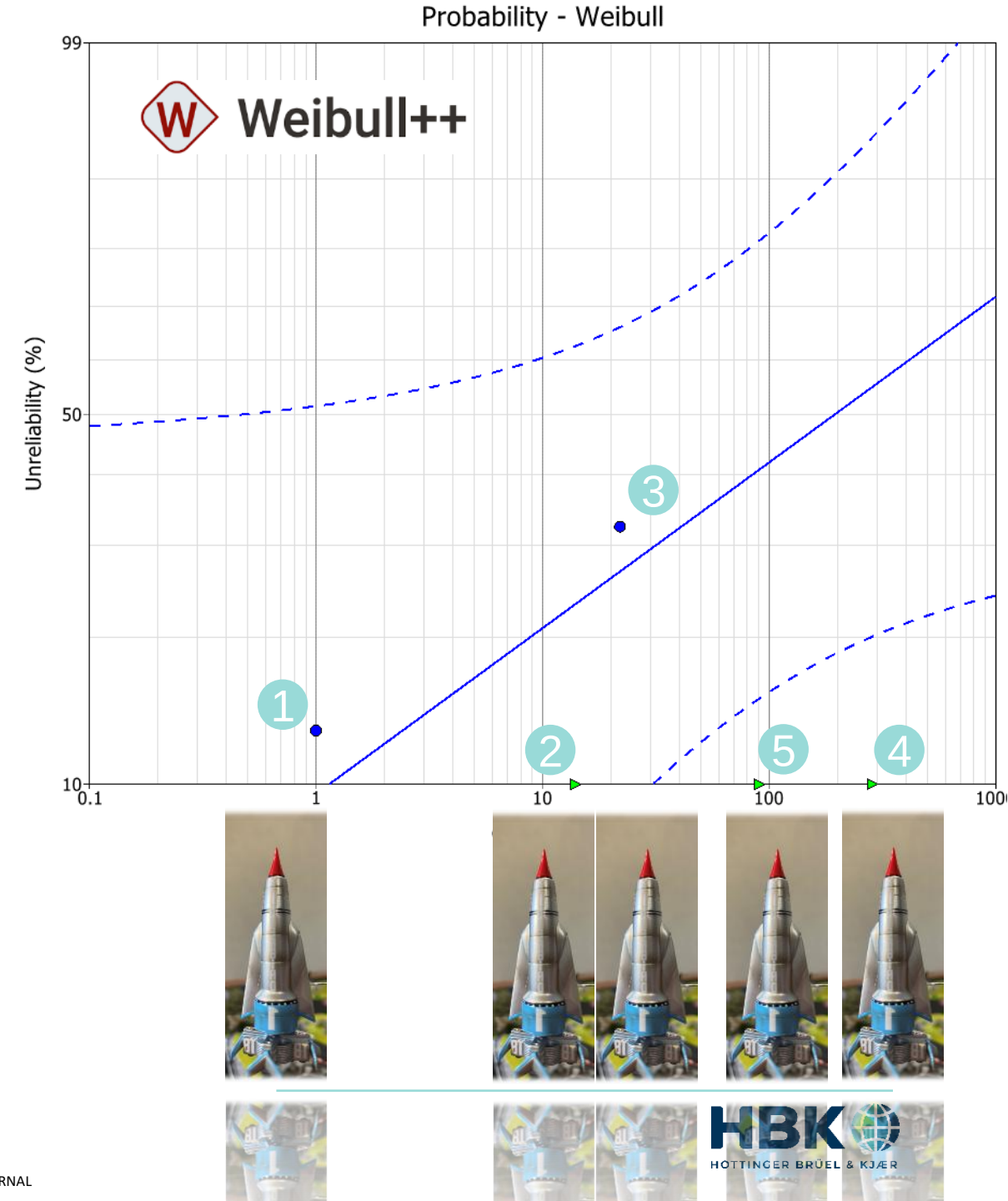
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Programme Stage C (91 flights/0 Failure)

- Failure probability (C=99%) v1.0 + EIS 1.0 + EIS 2.0;
 - Prob. of Failure, upper $Q(t=15 \text{ cyc}) = 85\% / M=13.4\%$
 - Cond. Prob. of Failure, upper $Q(t_1=15 \text{ cyc} | t_2=15 \text{ cyc}) = 46.6\% / M=6.6\%$



Rocket Engine Reliability Data

Programme Stage A (15 Flights/1 failure)

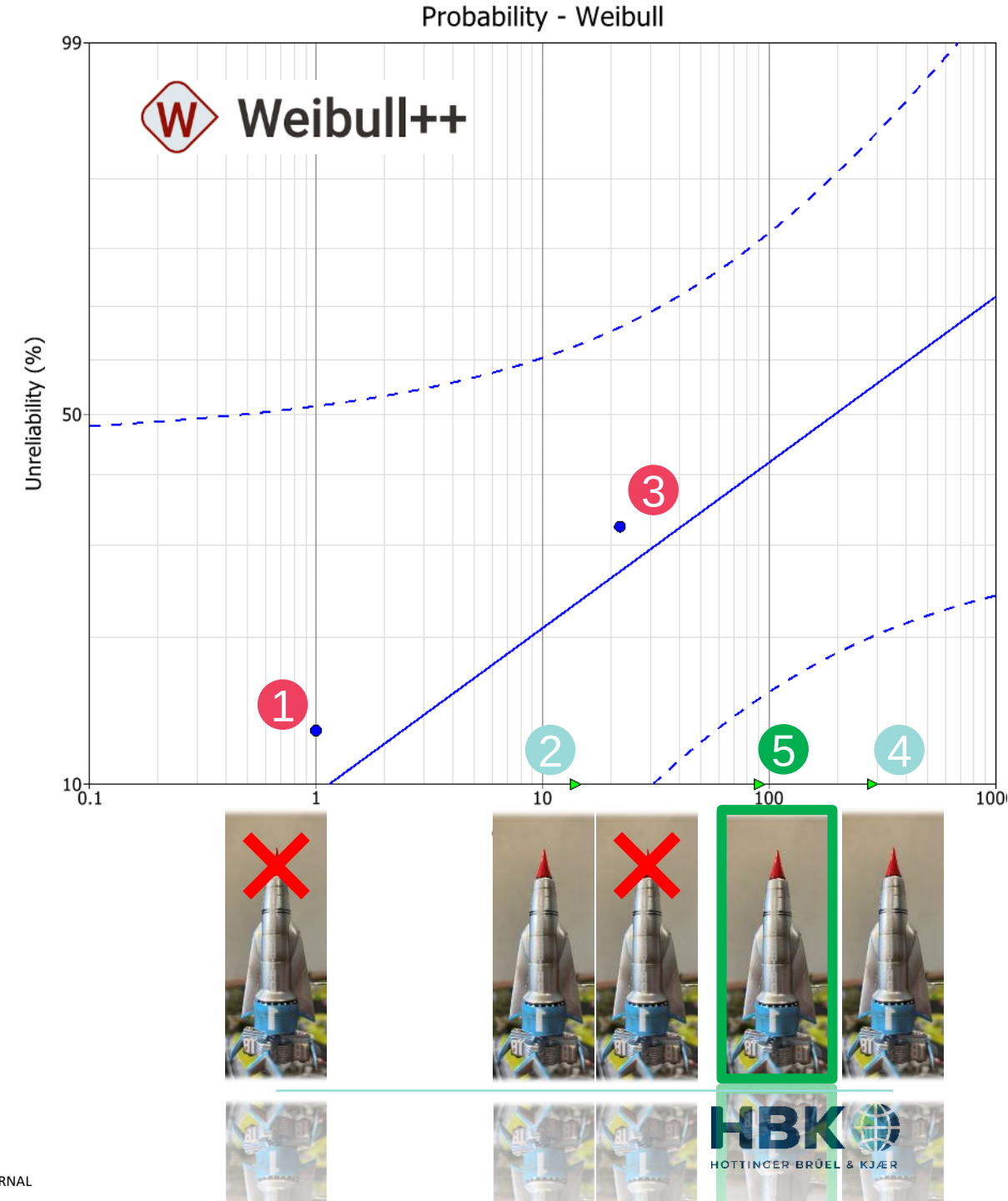
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- probability of 31% @ 15 flights
- probability of 10% @ next 15 flights



Rocket Engine Reliability Data

Programme Stage A (15 Flights/1 failure)

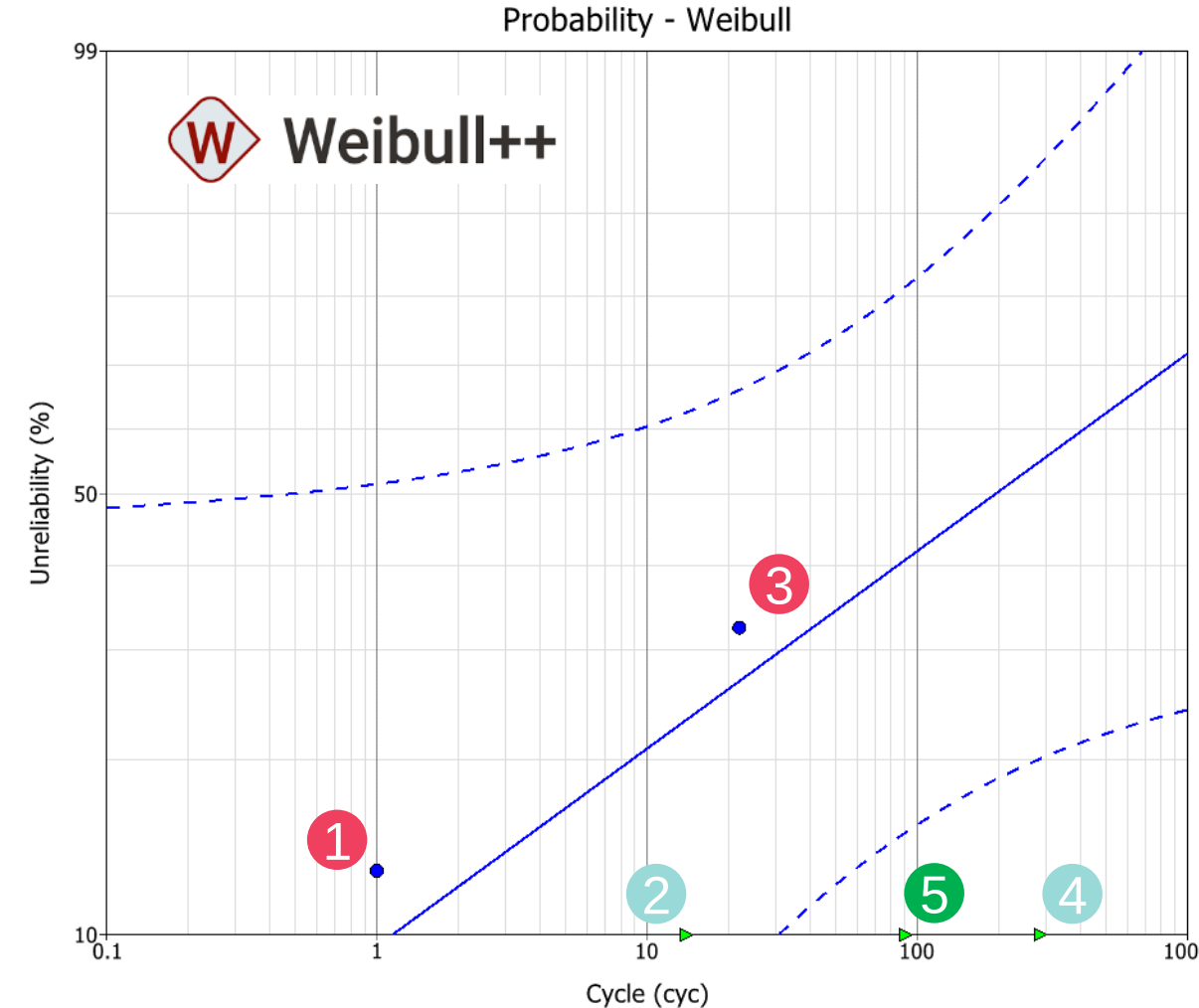
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**Approx = 6000 flights + 20 failures or
explore other options with ALTA**

Real life publicly available data – SpaceX Falcon 9



Real life publicly available data – SpaceX Falcon 9

Over 14 years

[12-Nov-24]

402 launches:

Success rate: 99.25%

Failures: 2



X.com images

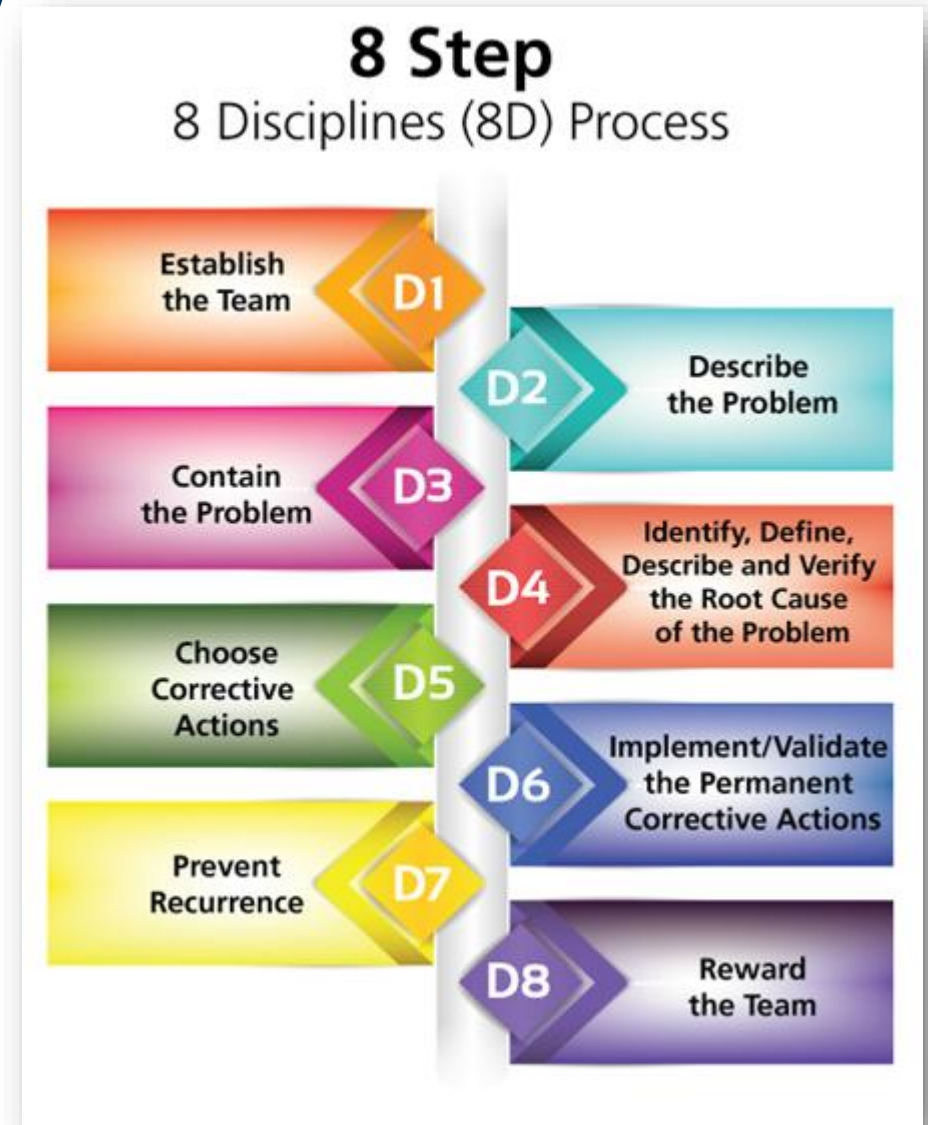
Dragon stacked and ready for lift off!



X.com images

Reliability Improvement Opportunity

- Design reviews
- Process reviews
- Dev/Prod Testing Feedback
- In-service Repair and Replace
- Report and Prevent, FRACAS



Simplification increases MTTF, speeds up maintenance time...reducing cost!



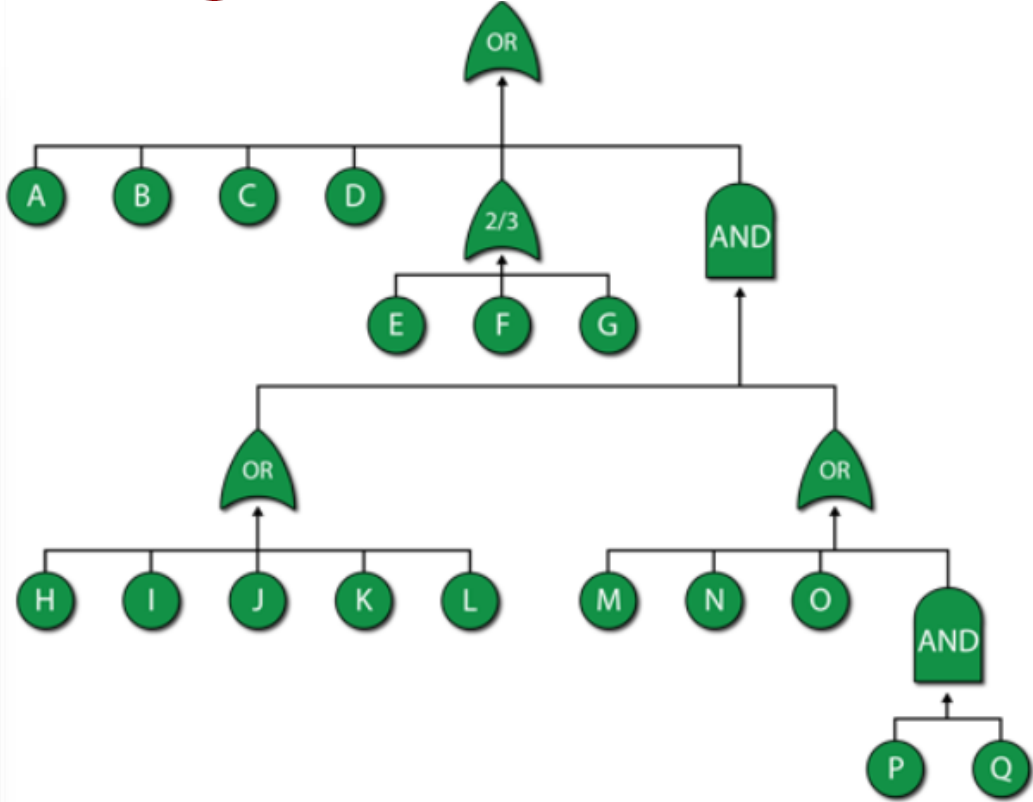
 **λPredict**

 .com images

AND / Redundancy – Engine flame out, Is this mission critical?



B BlockSim



.com images



ReliaSoft®

Chris Wynn-Jones

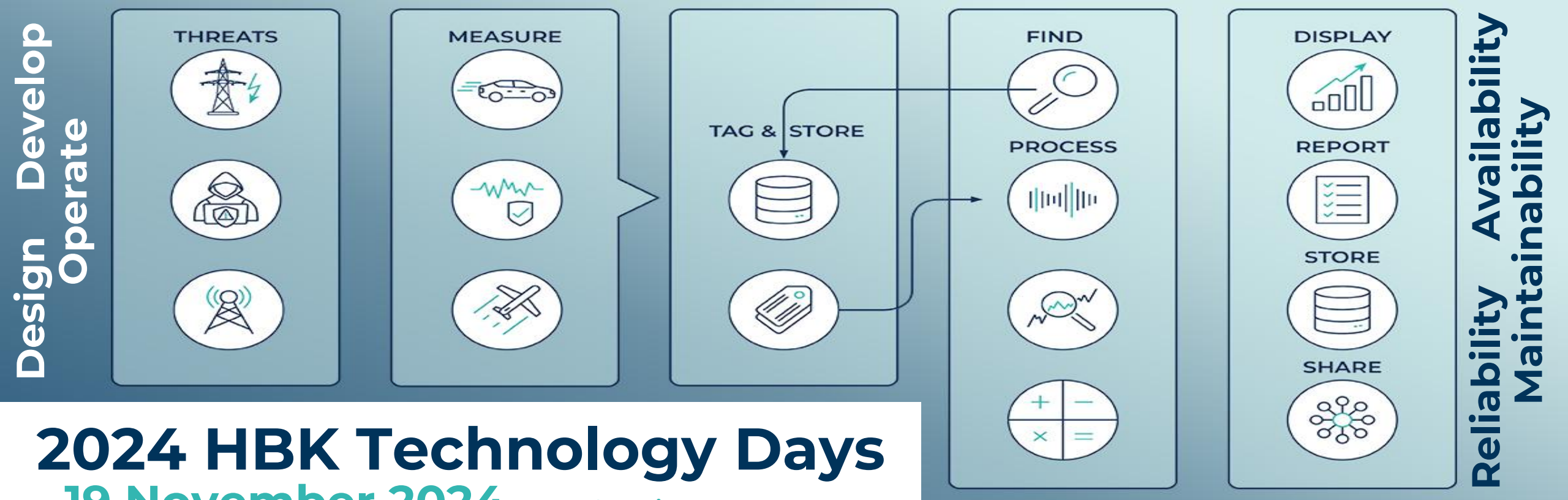
Application Engineer

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07496 676655

Chris.wynn-jones@hbkworld.com

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2024 HBK Technology Days

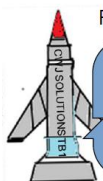
19 November 2024

Session 5: Reliability Engineering from Limited Failure Data

- Life data analysis for failure probability compliance

Chris Wynn-Jones,
Senior Application Engineer – Reliability, HBK

TB1 Space Plane Project



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Turn back

Vertical Land

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