Australian Government
Department of Defence
Defence Science and
Technology Organisation

Application of Bayesian Updating to the Risk Analysis of Aircraft Structures

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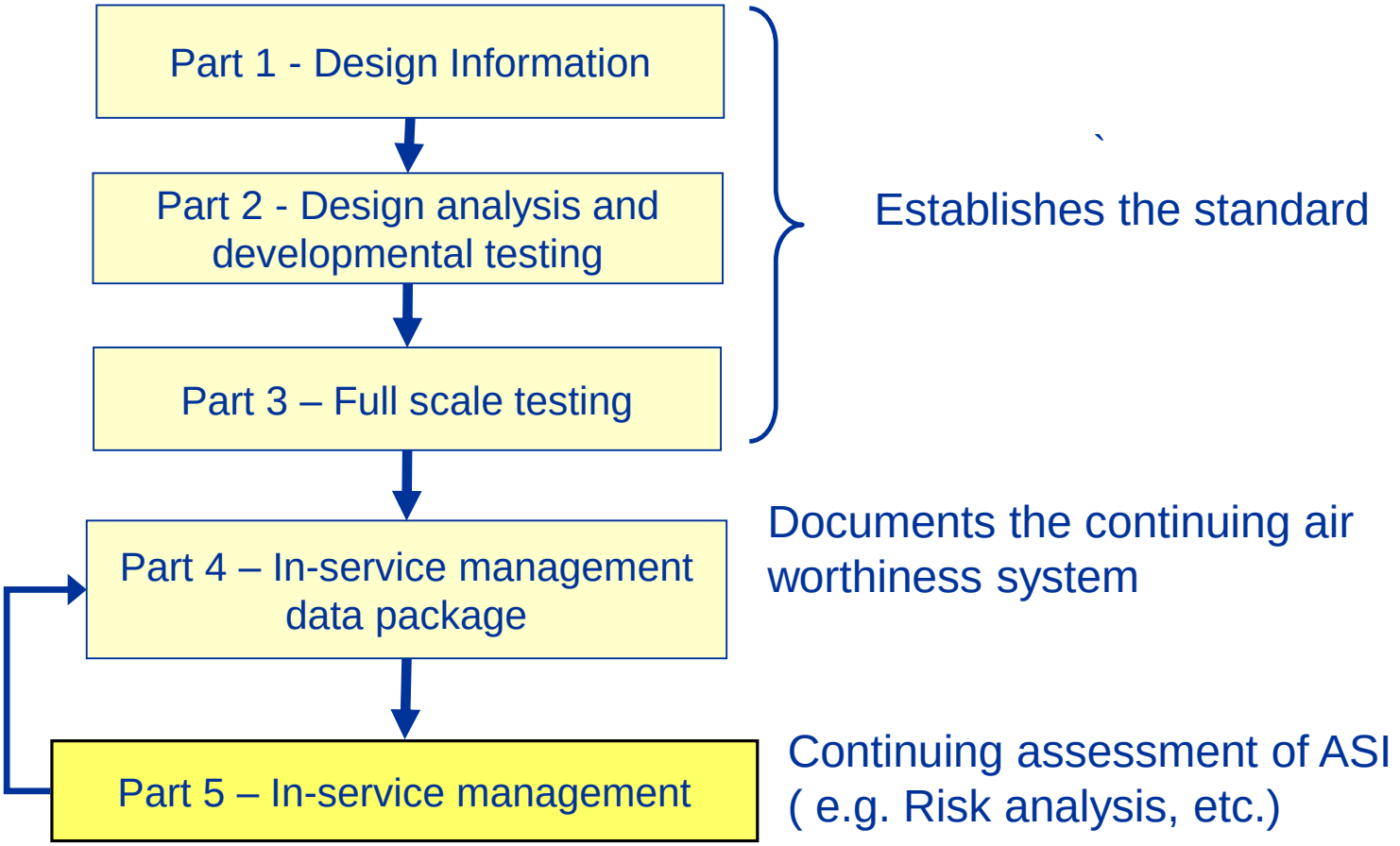
Outline of the presentation

- Relevance of Probabilistic Risk Analysis (PRA) to aircraft structural integrity assessment and management of military aircraft
- Data required for PRA
- The use of successful flights to improve PRA results using Bayesian updating
- Conclusion

Application of probabilistic risk analysis

- Complement the Damage Tolerance Analysis
- Determine inspection intervals
- Selection of NDI technique
- Aid in making decision on component replacement
- Aid in deciding (military) aircraft retirement

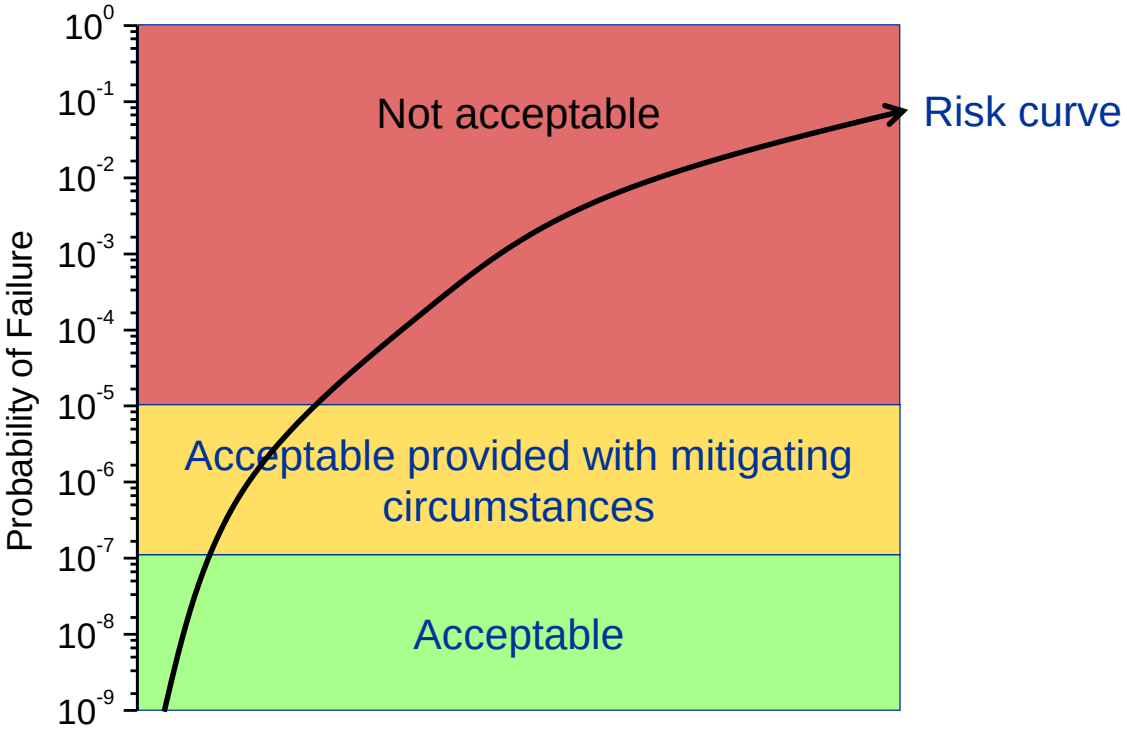
Role of probabilistic risk analysis in ASIP



Aircraft Structural Integrity Program (ASIP) Parts

Quantitative Hazard Probability

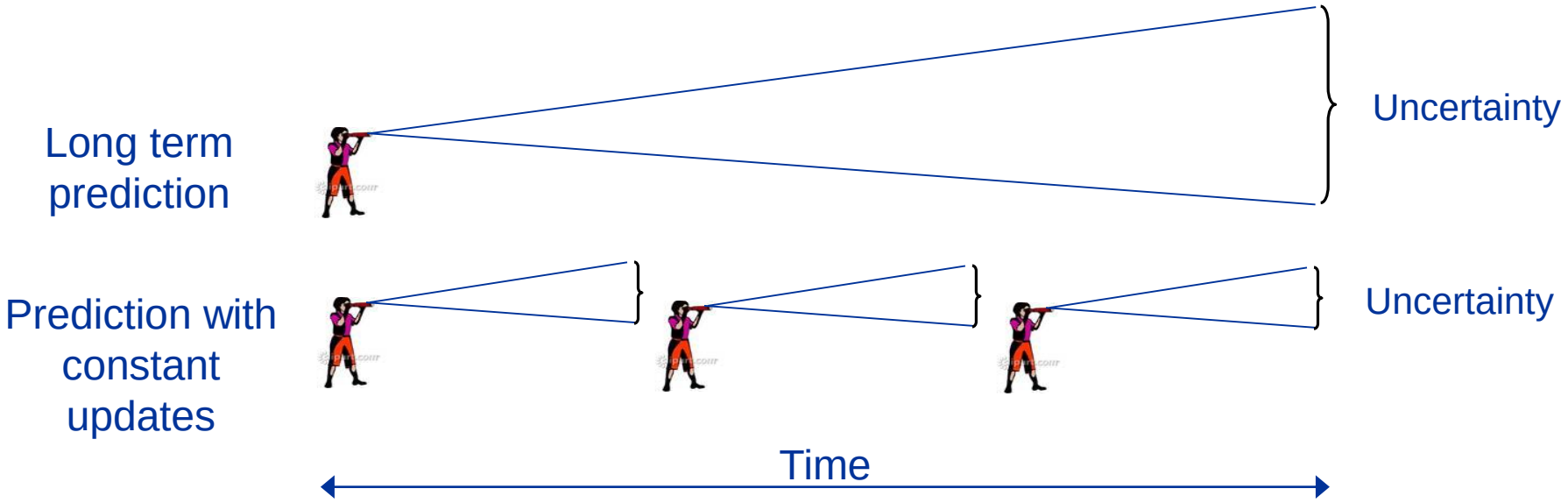
MIL-STD 1530C :



Probabilistic risk analysis provides a quantitative measure for the specific hazard level

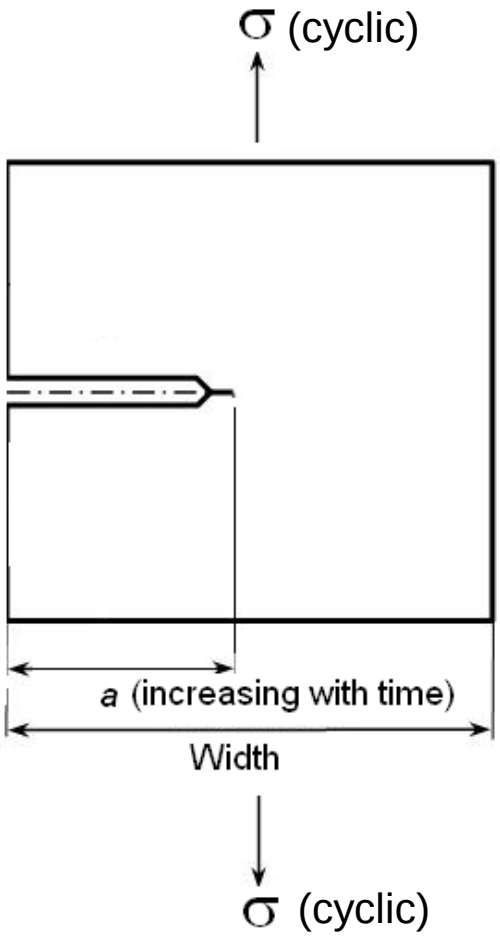
Challenges in probabilistic risk analysis

- Predicting too far ahead increases uncertainty



☞ Incorporating new observation into the data improves prediction

Risk analysis of fracture



- Risk - probability of failure or unstable fracture
- Failure occurs when;

$$\sigma \geq \text{Residual strength , RS}$$

- Residual strength decreases with increase of crack size

Parameters needed to conduct a risk analysis of fracture

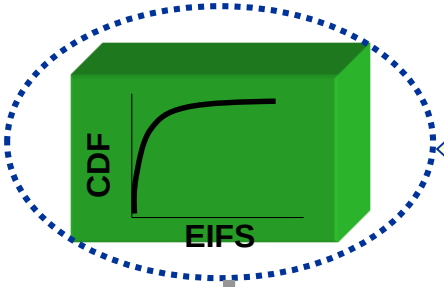
- EIFS distribution
- Master crack growth curve
- Residual strength curve
- Peak stress exceedance curve

Probabilistic Risk Analysis of Fracture – (Parameters)

What parameter to update?

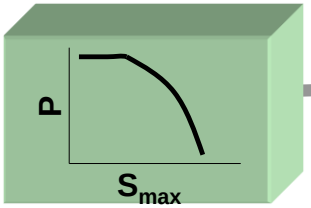
Focus of this presentation

EIFS given as distribution – suitable for inexpensive updates

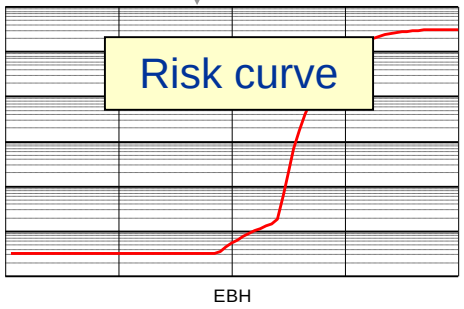


Highest influence to PoF values

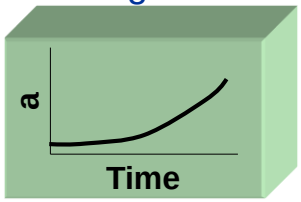
Peak stress exceedance



Lots of data no need for updates

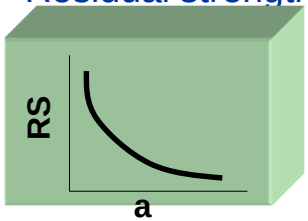


Crack growth curve



Need expensive testing to update

Residual strength



Material property (fixed)

What is Equivalent Initial Flaw Size (EIFS)?

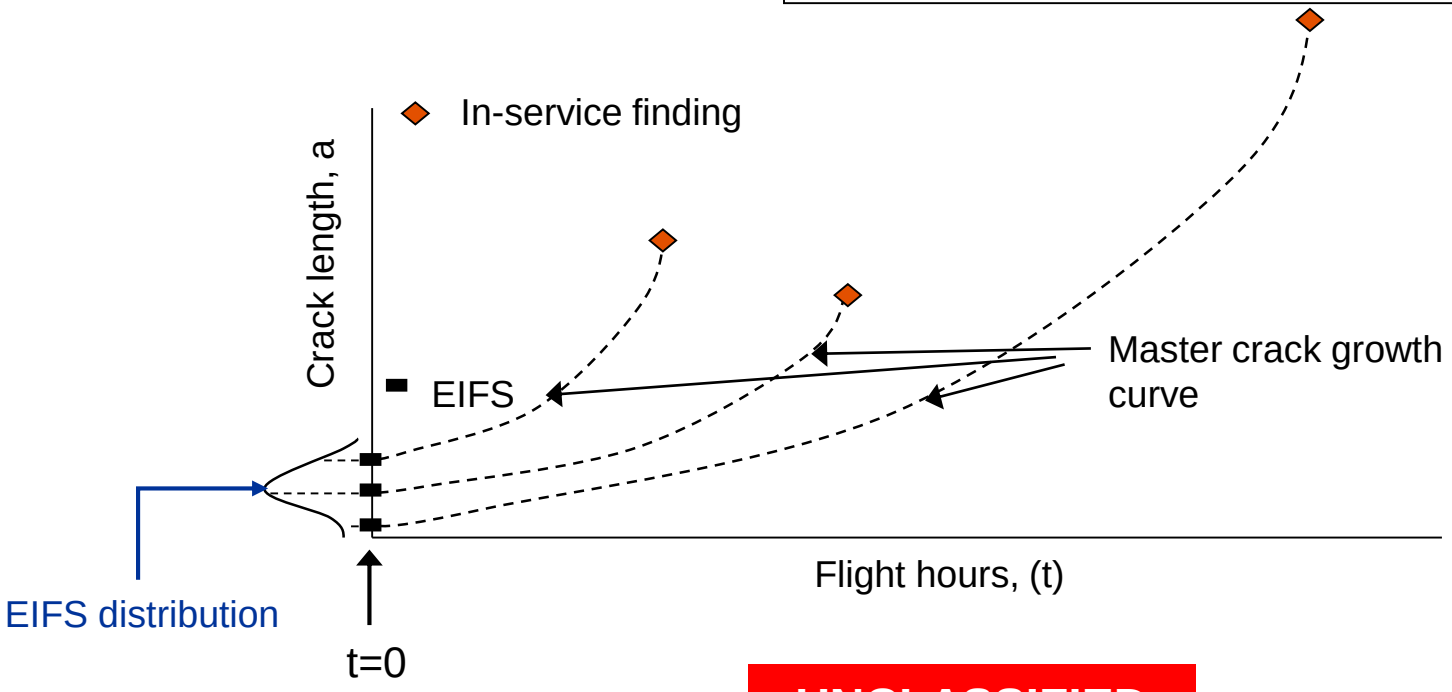
- a fictitious crack size used to describe the size of a crack at the beginning of its fatigue life (time zero)
- dependent on crack growth curve
- not material property

How the master crack growth curve is obtained ?

Analytical modeling $\Leftarrow \frac{da}{dN} = f(\Delta K, R)$

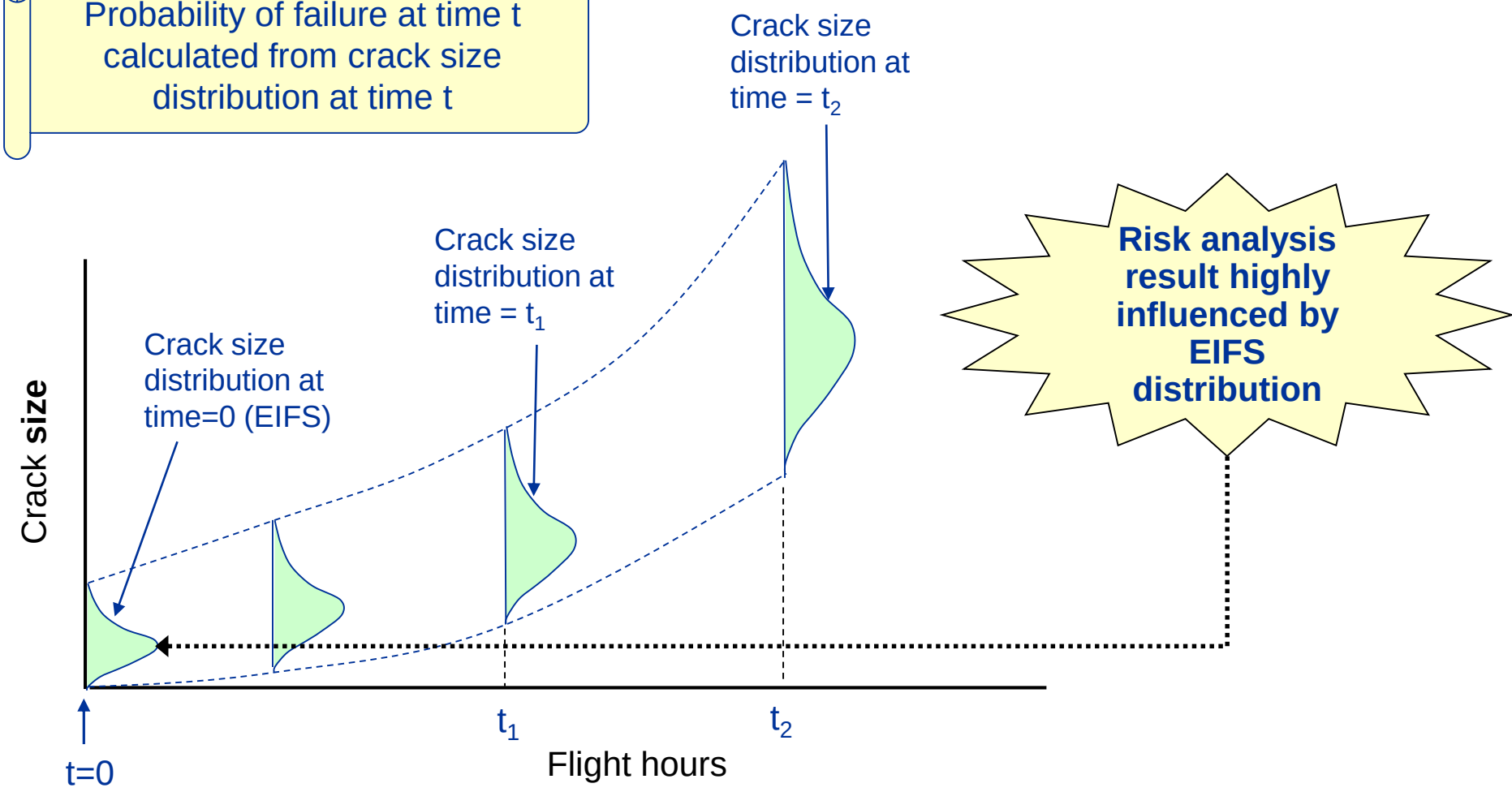
Scaling based on usage severity factor (USF)

Master crack growth curve for a specific location



Influence of EIFS distribution to the Probability of failure

Probability of failure at time t calculated from crack size distribution at time t



Ways of updating the EIFS distribution

Updating EIFS distribution

More data from - teardown inspection

Very expensive

Bayesian update using flight hour data

Observed outcome (Fail or Safe)

Inexpensive

Bayesian updating concept

Which should be given more importance?

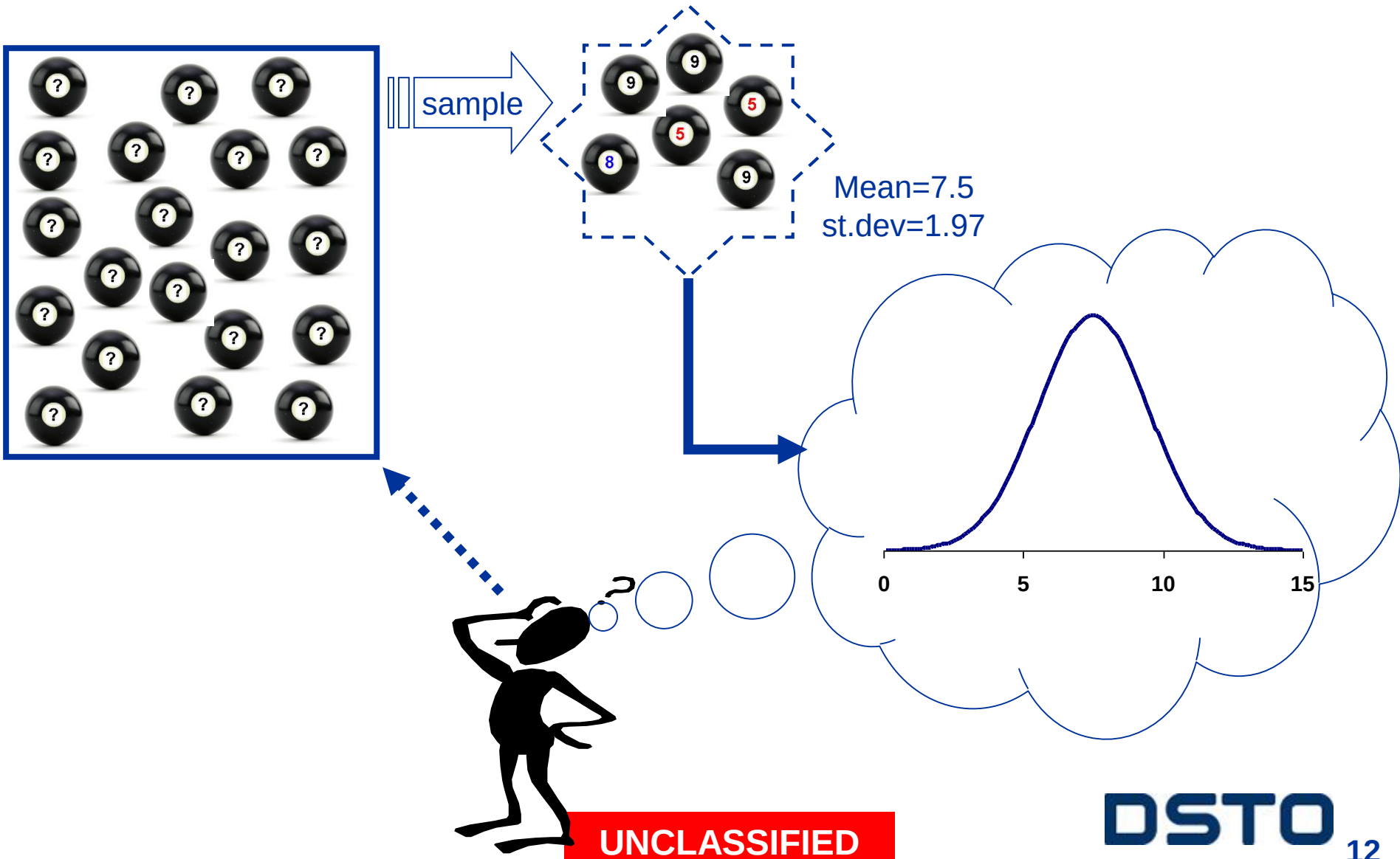
Limited actual data ← Testing, sampling

Or

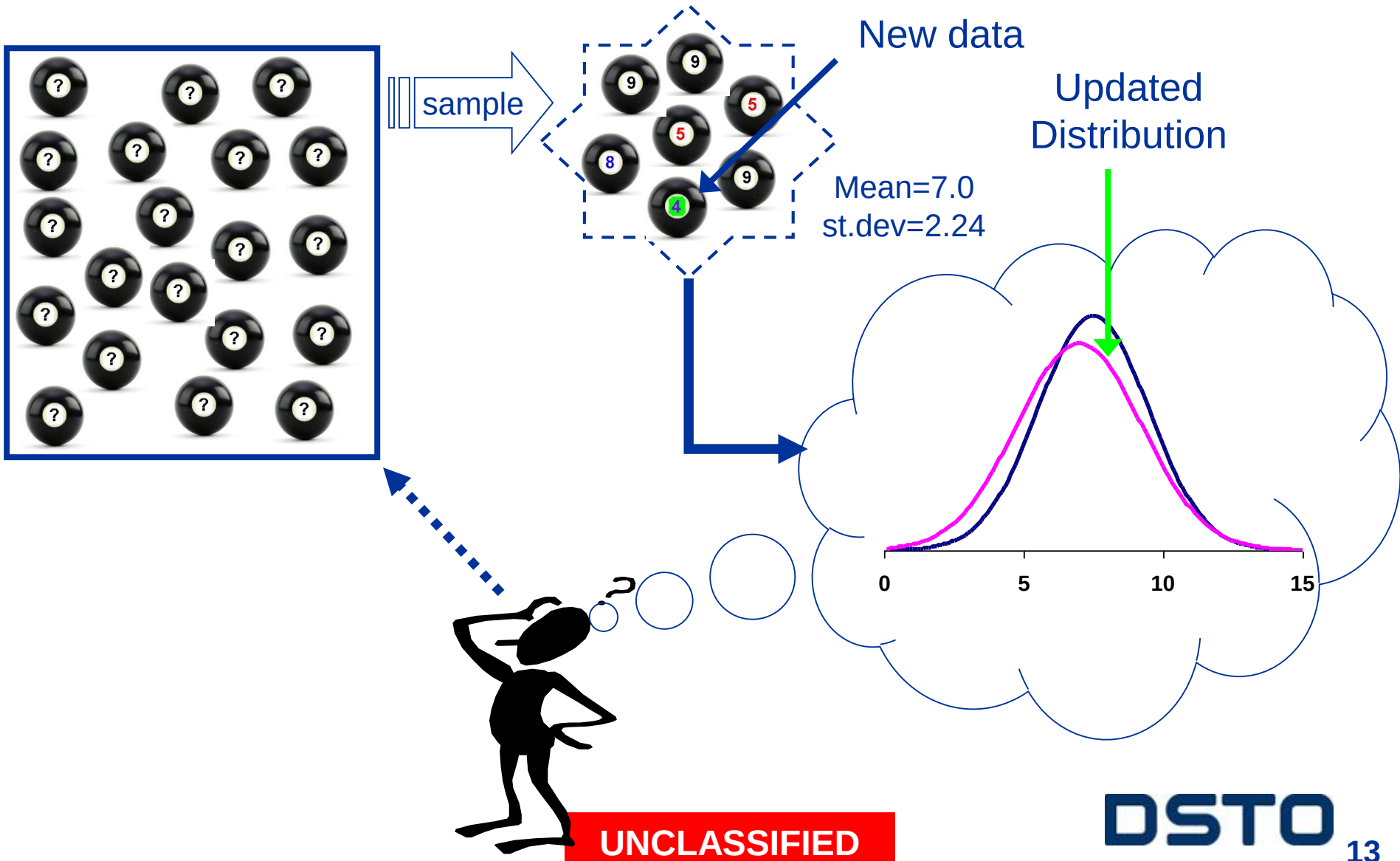
Biased judgement ? ← Experience, engineering judgment, etc.

Bayesian statistics combines both

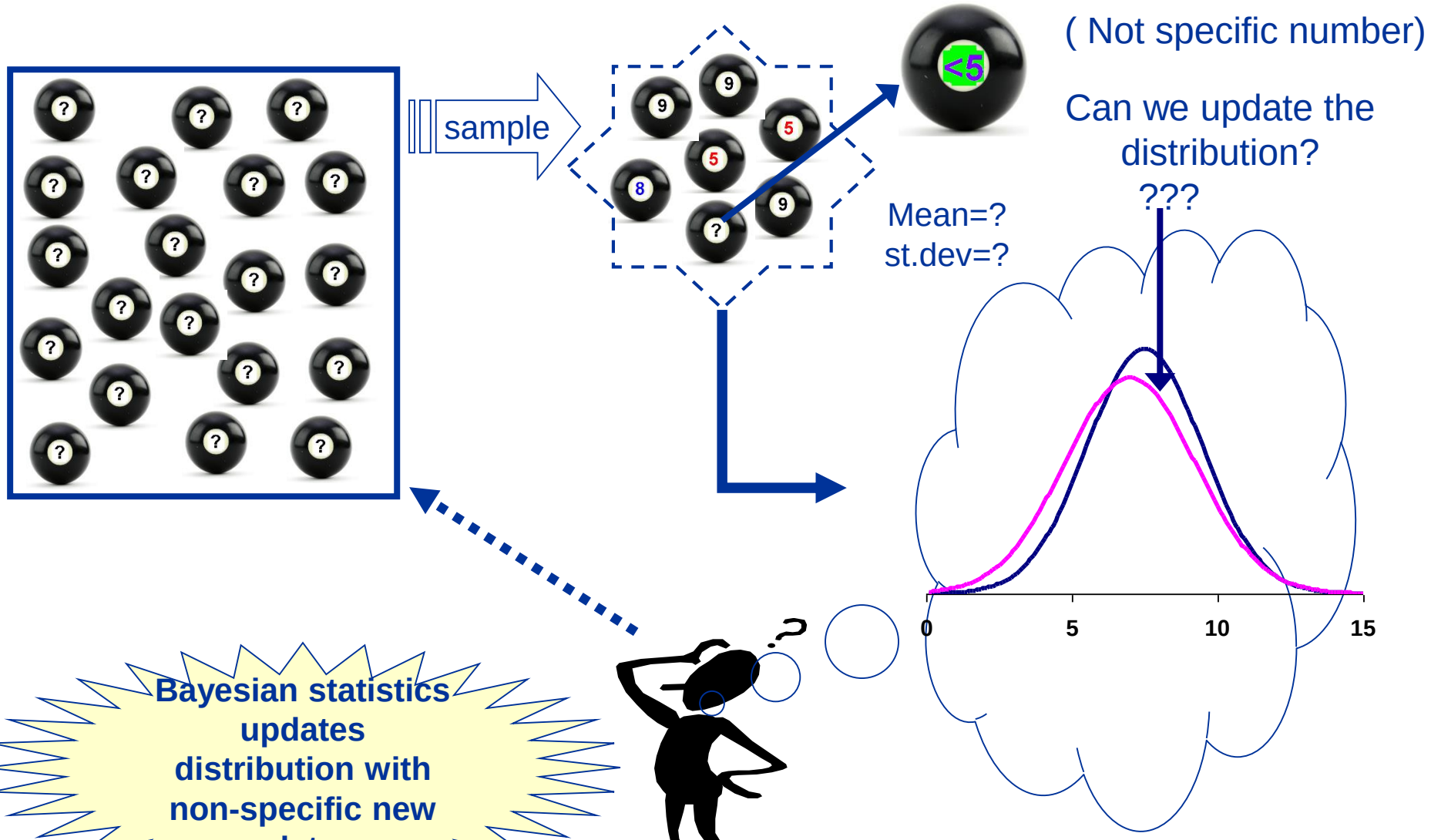
Classical (frequentist) statistics



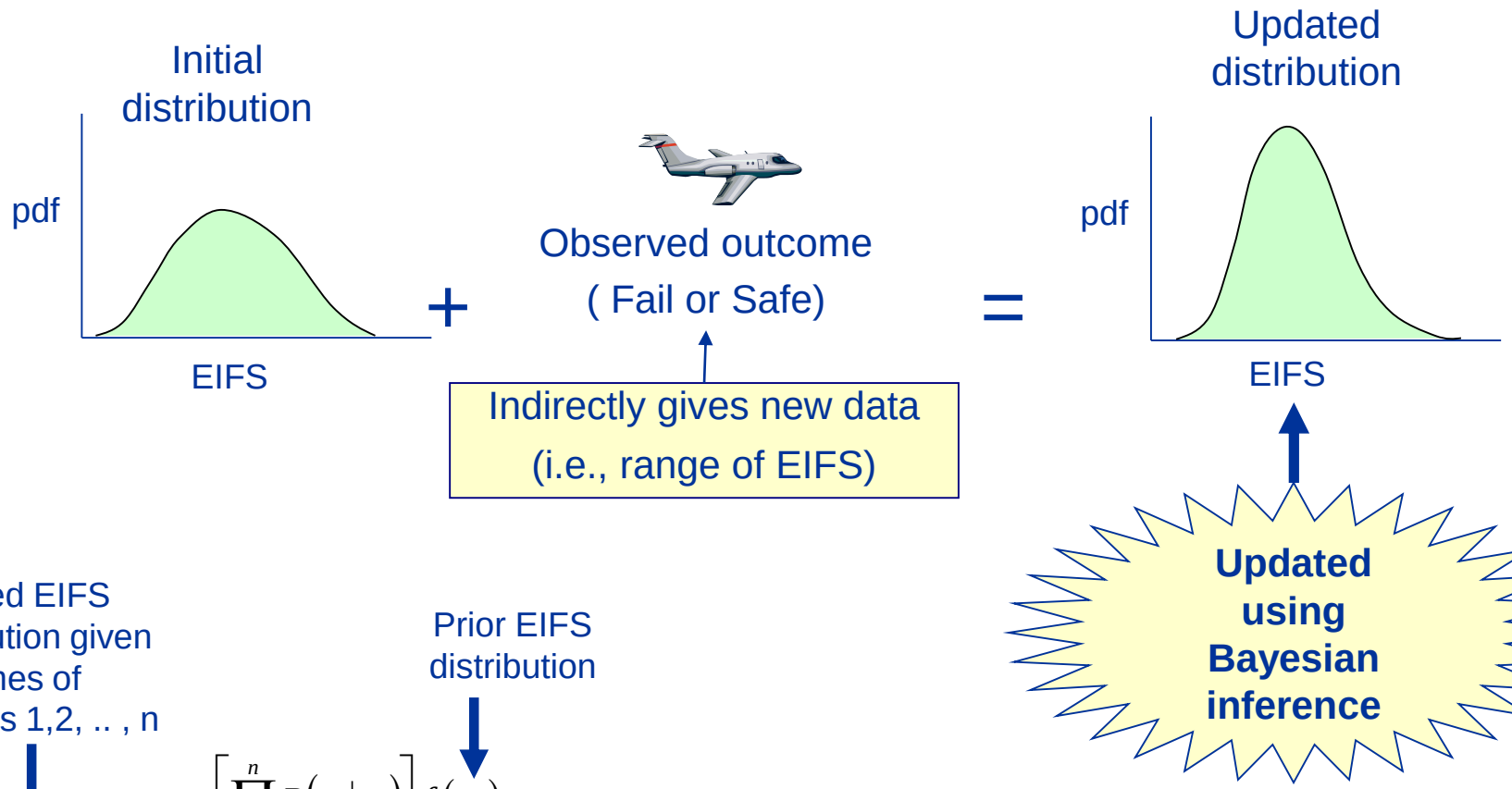
Classical (frequentist) statistics



Bayesian statistics



Updating the EIFS distribution using flight hour data



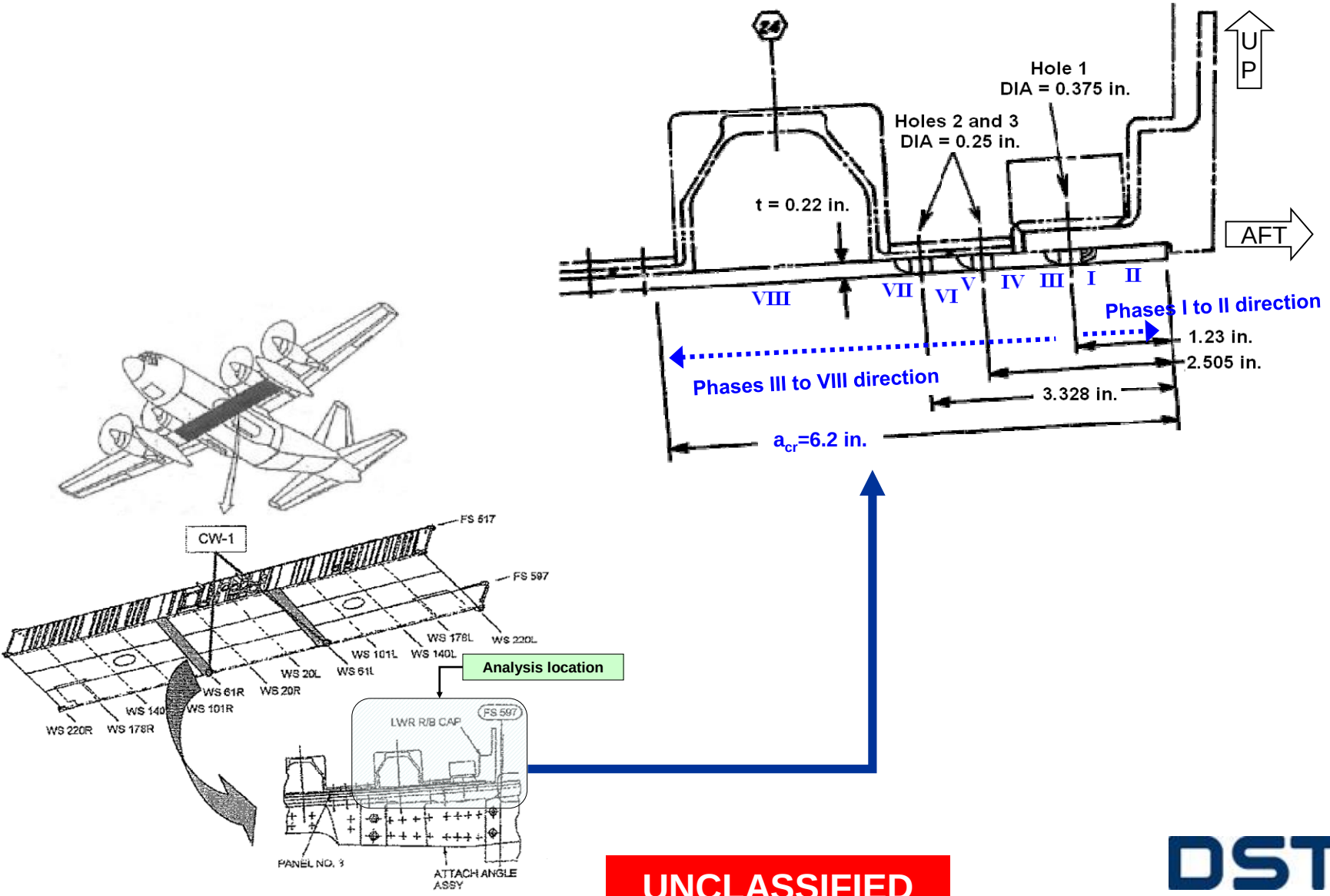
Updated EIFS distribution given outcomes of aircrafts 1,2, .. , n

Prior EIFS distribution

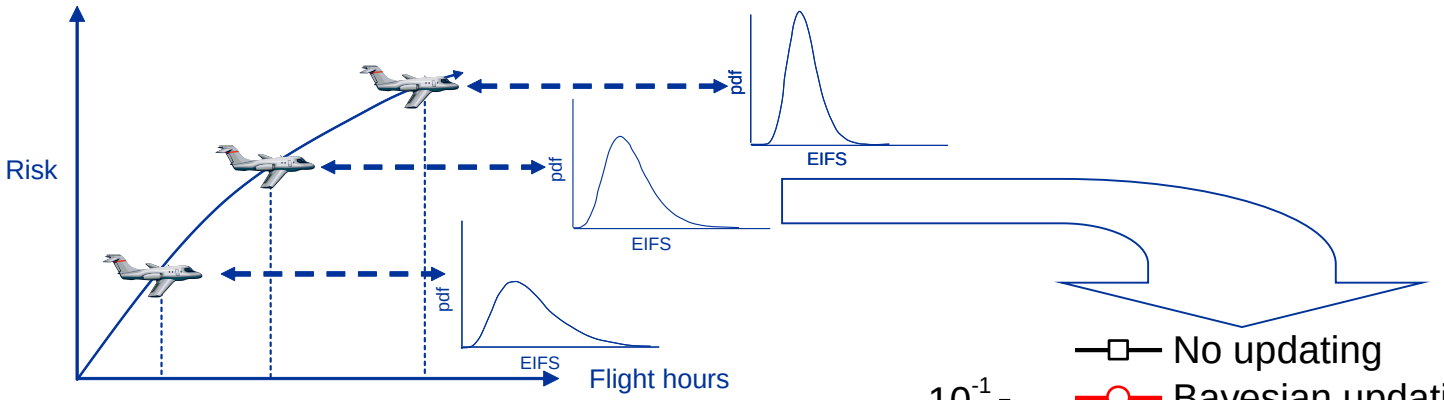
$$f\left(a_0 \middle| x_1, x_2, \ldots, x_n\right) = \frac{\left[\prod_{k=1}^{n} P\left(x_k \middle| a_0\right)\right] f\left(a_0\right)}{\int_0^{\infty} \left[\prod_{k=1}^{n} P\left(x_k \middle| a_0\right)\right] f\left(a_0\right) \mathrm{d}a_0}$$

Expected outcome of aircraft k , given EIFS a_0

Probabilistic Risk Analysis of C130-H CW-1 Location

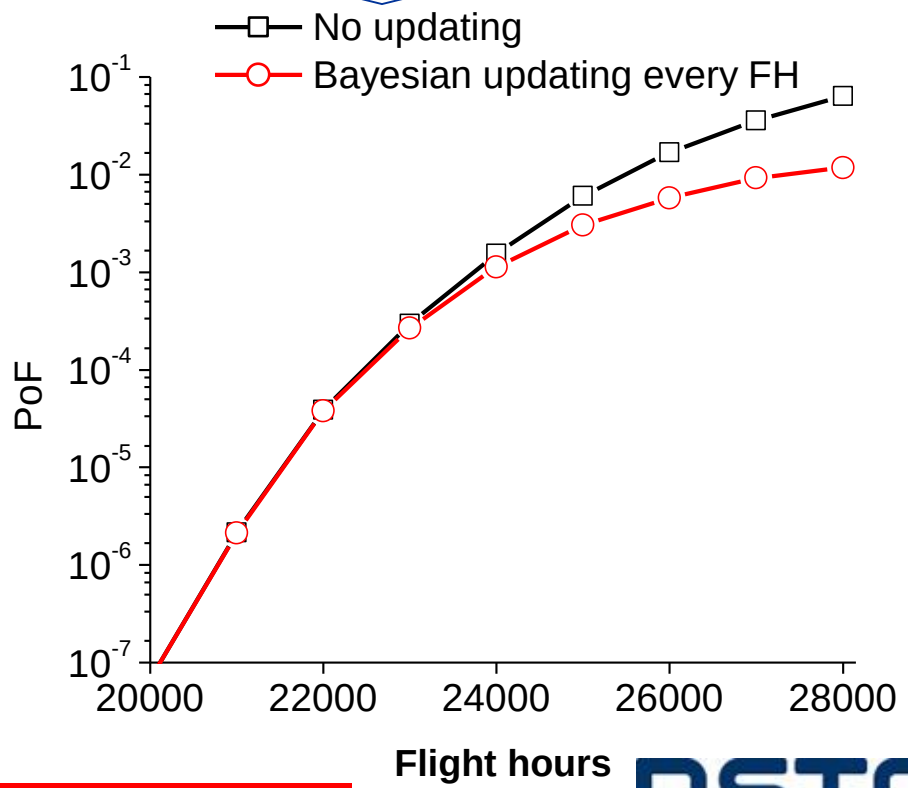


1) Bayesian aircraft risk updating

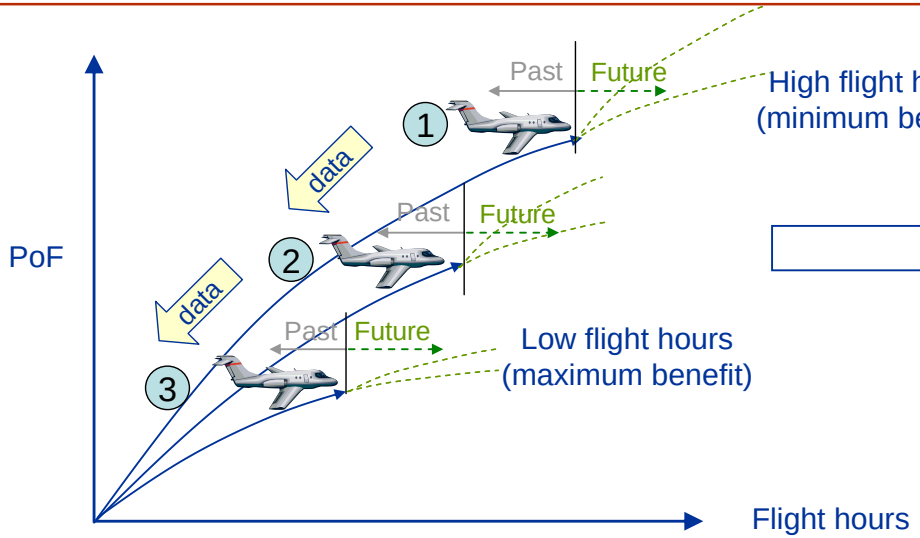


High flight hours – high reduction

Low flight hours – Low reduction

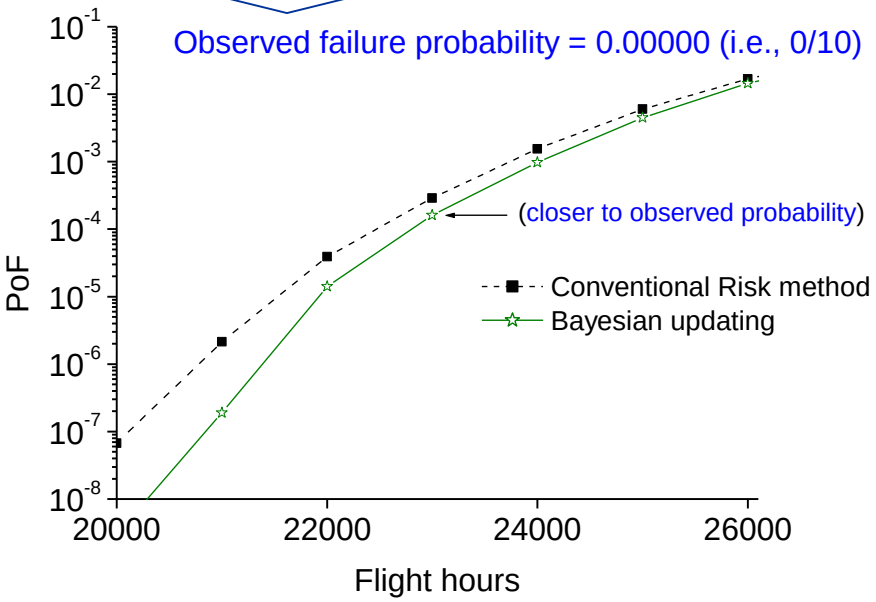


2) Bayesian fleet risk updating (no failure observed)

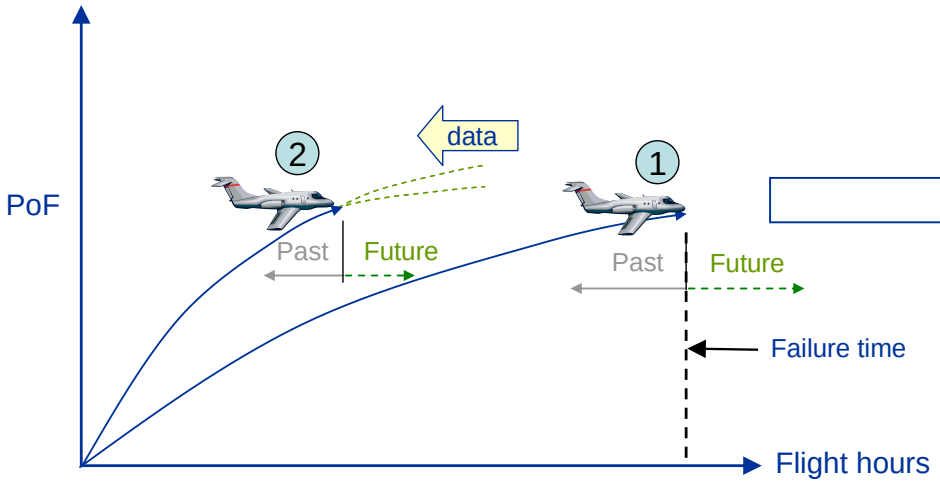


Case 1: No failure in a fleet

- Big reduction of risk for low flight hours aircraft
- Low reduction or risk for high flight hours aircraft
- Updated risk closer to observed PoF than conventional risk output

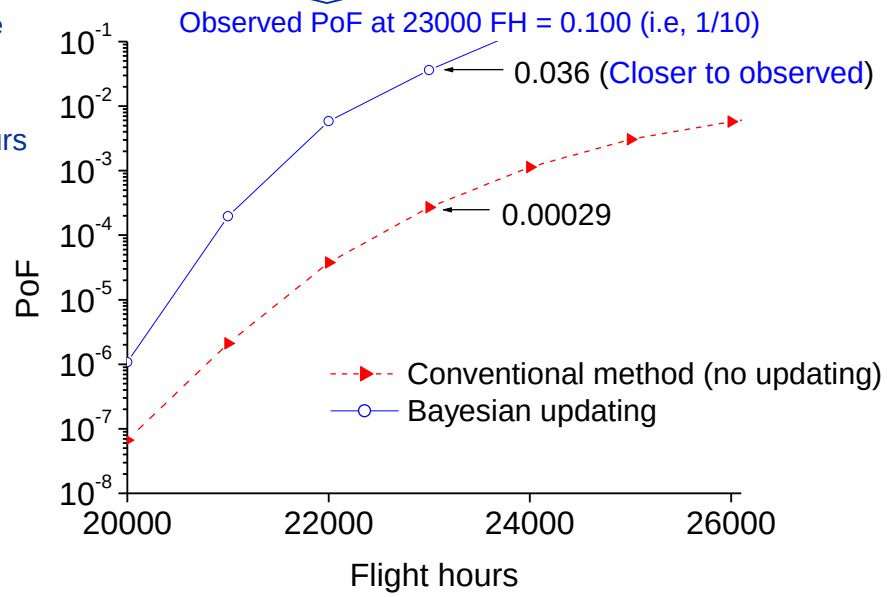


2) Bayesian fleet risk updating (failure is observed)



Case 2: Failure observed in one member of the fleet

- ➔ Big increase of risk
- ➔ Updated risk closer to observed PoF than conventional risk output



Conclusions

- Updating risk analysis results can be done by utilising flight hours information
- Bayesian updating using the flight history of a particular aircraft being analysed only marginally improved the prediction for that aircraft.
- Bayesian fleet updating using fleet data shows a moderate risk reduction when no failure is observed and significant increase of risk values when failure is observed in a fleet.
- The Bayesian fleet updating risk values closer to observed PoF than conventional risk results.
- Risk of failure is not constant over the flight history and must be reviewed when more data become available

Questions ?

DSTO

Updating the EIFS distribution by Bayesian inference

Posterior EIFS distribution given outcomes of aircrafts 1,2, .. , n

Prior EIFS distribution

$$f\left(a_0 \middle| x_1, x_2, \ldots, x_n\right) = \frac{\left[\prod_{k=1}^{n} P\left(x_k \middle| a_0\right)\right] f\left(a_0\right)}{\int_0^{\infty} \left[\prod_{k=1}^{n} P\left(x_k \middle| a_0\right)\right] f\left(a_0\right) \mathrm{d}a_0}$$

Expected outcome of aircraft k , given EIFS a_0

DSTO