Towards a Probabilistic Engine Conceptual Design

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Motivation:

Realistic gas turbine engine designs are subject to various sources of uncertainty, such as *production scatter* and *performance deterioration*. Accounting for these uncertainties during the conceptual design phase can mitigate technical risk, reduce development time and cost, as well as pave the way for a robust optimal engine conceptual design.

Research Question:

What is the technical risk imposed by production scatter and performance deterioration uncertainties on a deterministically optimised engine design, running at realistic operating conditions?

Methodology:

System level uncertainty is estimated using Monte Carlo simulations for a number of *probability distributions* of each principle engine component, as described by Kyprianidis [1].

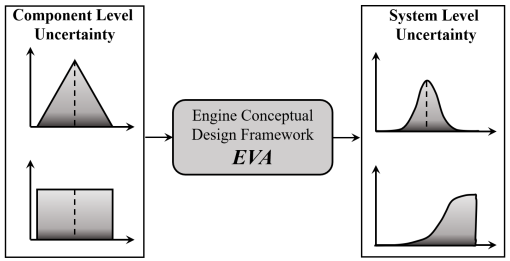

Figure 1 Flowchart of the probabilistic engine design

Technical risk of a probabilistic conceptual engine design is quantified by the following metrics:

a. Normalized probabilistic mean value (%)

$$\widetilde{\mu_{X_i}}^{prob} = 100 \times \frac{\mu_{X_i}^{prob} - X_i^{det}}{X_i^{det}}$$

b. Normalized probabilistic standard deviation (%)

$$\widetilde{\sigma_{X_i}}^{prob} = 100 \times \frac{\sigma_{X_i}^{prob}}{X_i^{det}}$$

where X_i^{det} is the deterministic value of each performance parameter i, while $\mu_{X_i}^{prob}$ and $\sigma_{X_i}^{prob}$ are mean value and standard deviation of the probabilistic engine design, respectively.

Results:

Technical risk has been quantified in a conventional geared turbofan engine with EIS 2035 for:

- <u>Two realistic operating conditions;</u>
  (i) engine simulation at constant high-pressure spool speed N4, and **(ii)** at constant low-pressure turbine inlet temperature T47
- <u>Two sources of uncertainty;</u>
  (i) performance deterioration and **(ii)** production scatter

Uncertainties inserted to the framework are described by the type of distribution and the min, max and expected values, as described in Zaccaria et al. [2]:

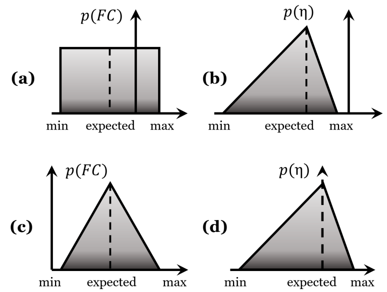

Figure 2 Probability distributions for **(a)** flow capacity at performance deterioration; **(b)** isentropic efficiency at performance deterioration; **(c)** flow capacity at production scatter; **(d)** isentropic efficiency at production scatter

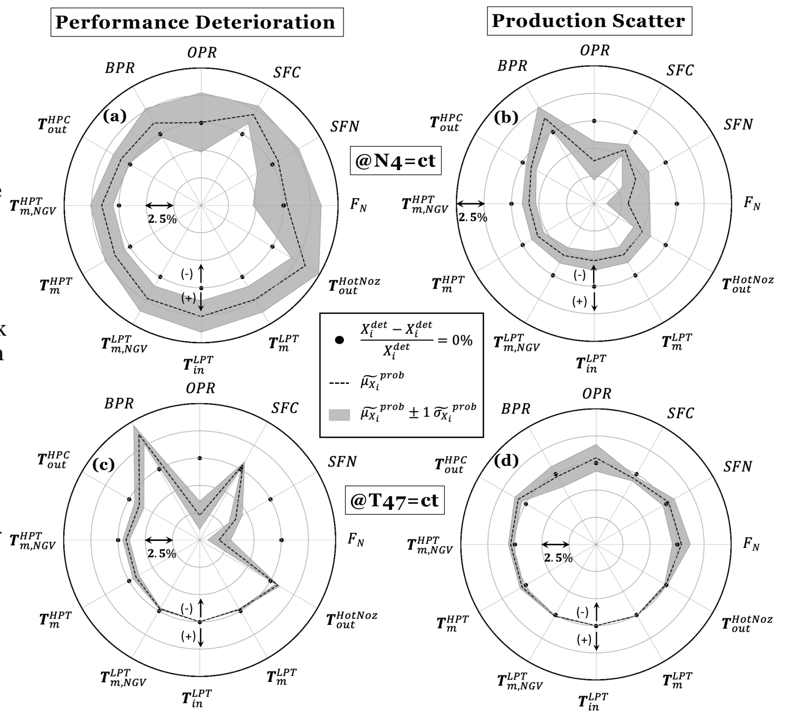

Figure 3 Probabilistic engine design properties when estimating: **(a)** Performance deterioration at constant N4; **(b)** Production scatter at constant N4; **(c)** Performance deterioration at constant T47 and **(d)** Production scatter at constant T47

Major Findings:

- Uncertainty due to performance deterioration leads to higher temperatures, imposing **certification and lifing issues** at critical operating points
- Both sources of uncertainty at constant N4 result in **SFC shortcomings**
- Engine simulation at constant T47 demonstrates reduced probabilistic standard deviations compared to constant N4
- Metal and gas temperatures are barely affected by either sources of uncertainty when running at constant T47

Future work:

- Impact of "uncertainty of uncertainty" on technical risk through a probabilistic engine conceptual design
- Component decomposition analysis for the contribution of each gas turbine component on the overall uncertainty

Key References:

[1] Kyprianidis, K, (2019), "*On Gas Turbine Conceptual Design*", PhD Thesis, Cranfield University.

[2] Zaccaria, V., et al., (2018), *"Fleet Monitoring and Diagnostics Framework Based on Digital Twin of Aero-Engines."* ASME Turbo Expo 2018, Oslo, Norway.