Dynamic safety and degradation analysis of an aircraft internal air system

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Abstract

The modelling of the dynamic behaviour of engineering systems offers an invaluable insight in the evolution of degradation and response of systems to failure and represents an essential step to lay the basis for resilience analysis. While traditional risk analysis methodologies, such as Fault or Event Trees, lack the ability to represent dynamic features and component dependencies, alternative simulation techniques offer such capability at the cost of higher computational complexity.
This study proposes a Petri Net (PN) model of the internal air system of a jet engine, whose malfunction may result in the structural damage of the turbine disc. The analysis predicts the evolution of the degradation of critical system components, considering on-wing repairs, and their collective impact on the structural safety of the engine. The results are analysed both for critical and healthy degradation states, to offer a complete understanding of the system behaviour with the potential for further design and maintenance optimization.

Introduction

The internal air system of a jet engine entails all those air flows that, while not contributing directly to the thrust of the aircraft, plays an essential role in the safe and efficient operation of the engine, such as providing adequate turbine cooling [1]. A malfunction of this subsystem could result in the turbine disc structural damage. The proposed PN simulates the system throughout the course of a 20000 flight hour period, at the end of which a complete aircraft overhaul is required. Inspections and light duty servicing are instead carried out on-wing at regular intervals (i.e. every 7000 flight hours). The PN models the deterioration of components affecting the performance of the internal air system, which can be organized in five categories:

- Control system: uses two control channels and two temperature sensors, whose signals are cross-checked while it is operating to control the bleed valves.
- Bleed valves: according on the temperature sensor readings, three valves are set up to let air into the engine bypass duct. If they don't provide the necessary air flow, it could lead to engine surge, overheating, or poor starts. Zone thermal data obtained from several flights are used to identify their dysfunction: in this case the valves can be replaced on-wing during servicing.
- Pipes: air is delivered to the turbine case plenum using six primary connections. Cracks prevent the pipes from delivering the required amount of air, with consequences correlated to the severity of deterioration (i.e. crack size). While badly damaged pipes can be replaced on-wing, small cracks cannot be seen during inspection.
- Nozzle Guide Vanes: direct the airflow as needed for the cooling of the turbine. Different levels of deterioration are predicted to result in medium-sized to large leaks, which might cause the engine to overheat. The presence of hot streaks might hasten the development of holes, however nozzle guide vanes deterioration cannot be detected or fixed on-wing.
- Turbine Seal: prevents the air from escaping the system, balancing the flow between the front and back cavities. Different levels of seal wear are taken into consideration in this instance as

well: the deterioration is detected through the measurement of the zone temperature signal or during major overhauls.

Analysis and Results

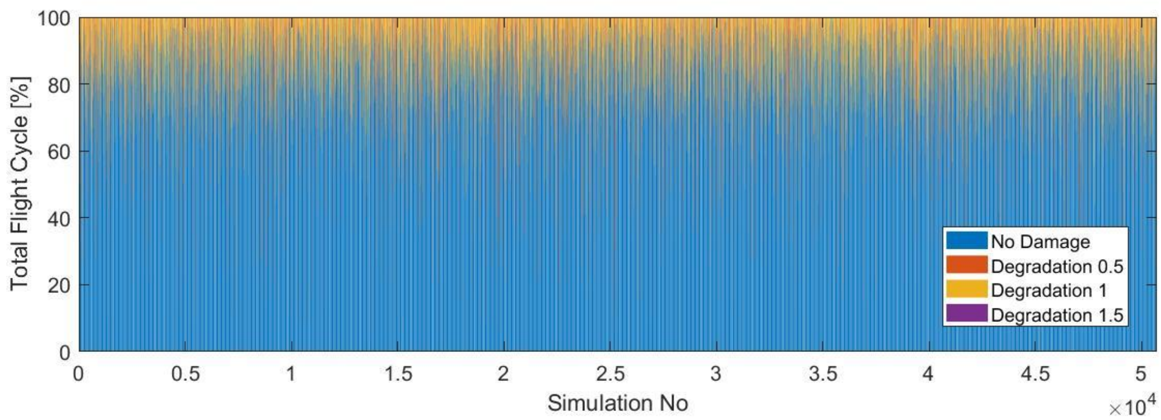
The proposed Petri Net that was analysed over more than 400,000 Monte Carlo simulations. The output obtained were investigated both in terms of system failure and degradation. In the first case, several possible response of the system were identified, as shown in Table 1: in about 2.6% of cases, the system entered turbine overheat. However, in more than 90% of these cases this resulted in the grounding of the aircraft. Only less than 0.013 % of simulations resulted in the failure of mitigation measure and structural damage.

Table 1. Probability associated with possible states of the system

System Response	Probability
Turbine Overheat	2.64×10^{-02}
Aircraft Grounded	2.39×10^{-02}
Limited Dispatch Interval not Completed	2.64×10^{-03}
Limited Dispatch Interval not Completed (end cycle)	2.26×10^{-03}
System not repairable by on-wing servicing	1.09×10^{-04}
Disc Damage	1.29×10^{-04}

Over 15% of simulations ended with the system being in some degraded state. However, in 80% of these cases, the degradation was under the safety threshold: Fig.1 shows the portion of total flying hours spent in each degradation state for almost 51,000 simulation ending in a degraded but healthy state.

Figure 1 Portion of total flight hours spent in each degradation state



Acknowledgement

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References

[1] Rolls Royce (2015). The jet engine. John Wiley & Sons.