Dynamic Modelling of a Jet Engine Internal Air System

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Silvia Tolo*, PhD
John Andrews*, Prof.
Ian Tatcher**
David Stamp**
*University of Nottingham, UK
**Rolls-Royce, UK

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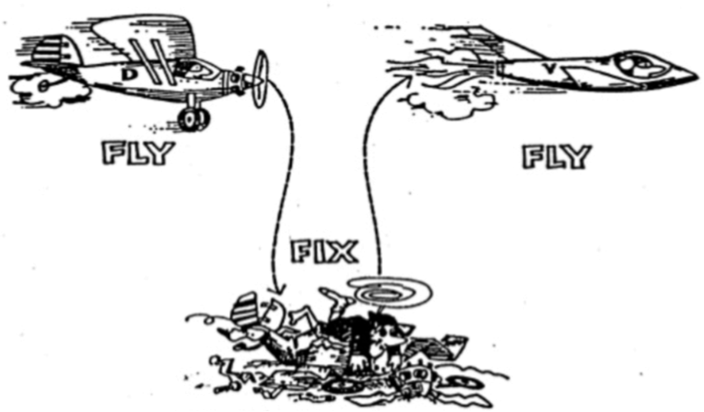
Overview and Outline

- Introduction
- Case-study Overview
- Model
- Analysis
- Results
  - Failure Response
  - Degradation
- Conclusions

Introduction



- **High level of automation and control technology**
  → systems are un-negligibly dynamic

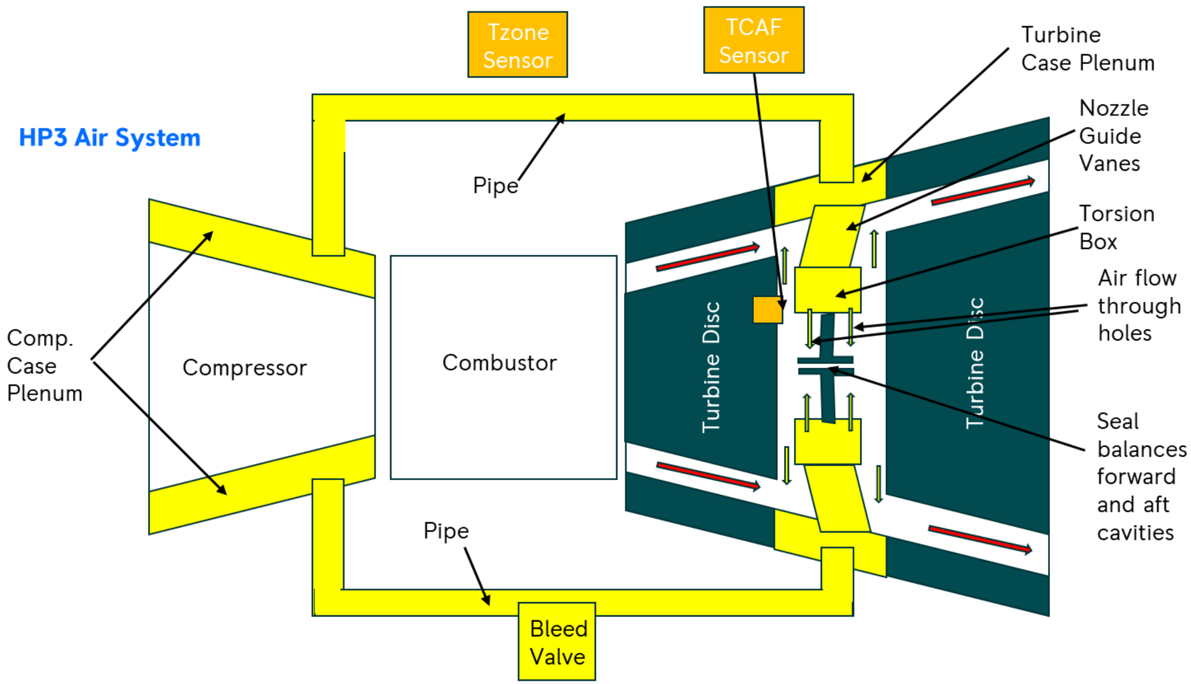
  → human-technology interface

  → maintenance strategies are increasingly complex

- **System Degradation**
  → system behaviour changes along its life-cycle

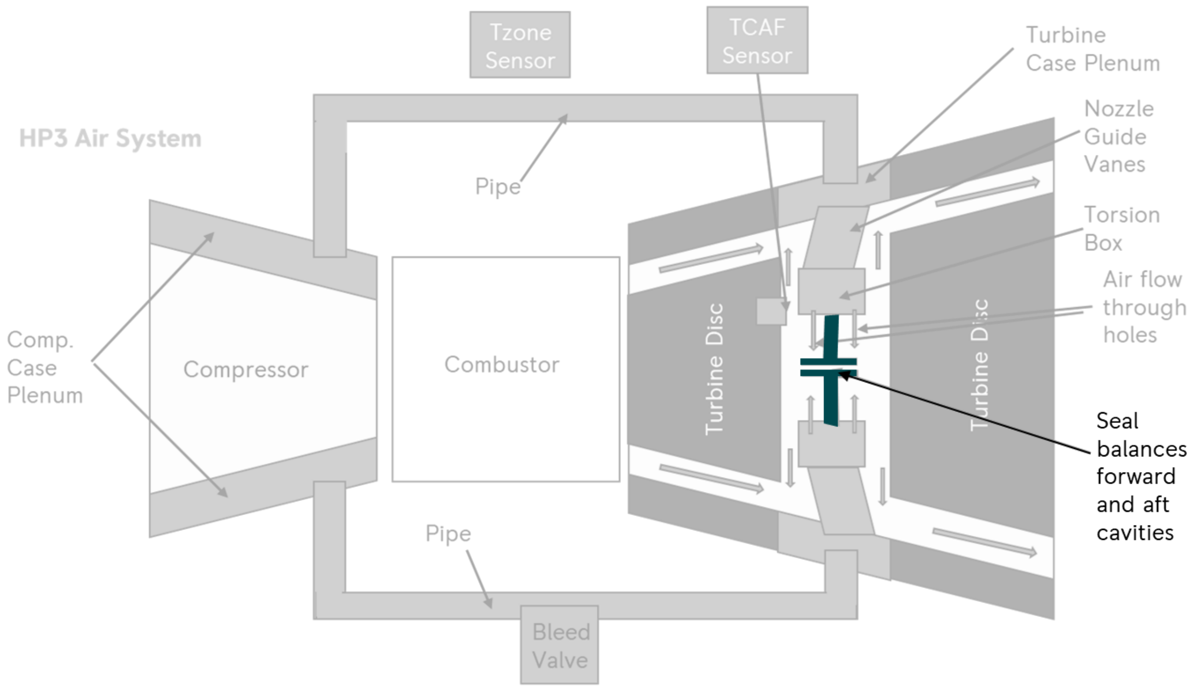
- **Uncertainty and Modelling**
  → conservatism comes at a cost

Case-Study Overview



- Risk of Engine Overheat
- Between Overhauls (20000 flight hours)
- On-wing Maintenance (7000 flight hours)
- Four major contributions:
    - Pipe failure
    - Bleed Valves failure
    - Nozzle Guide Vanes
    - Turbine Seal

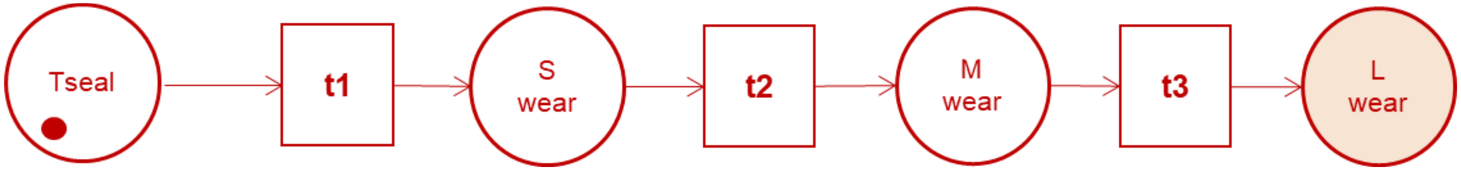
Model – Turbine Seal



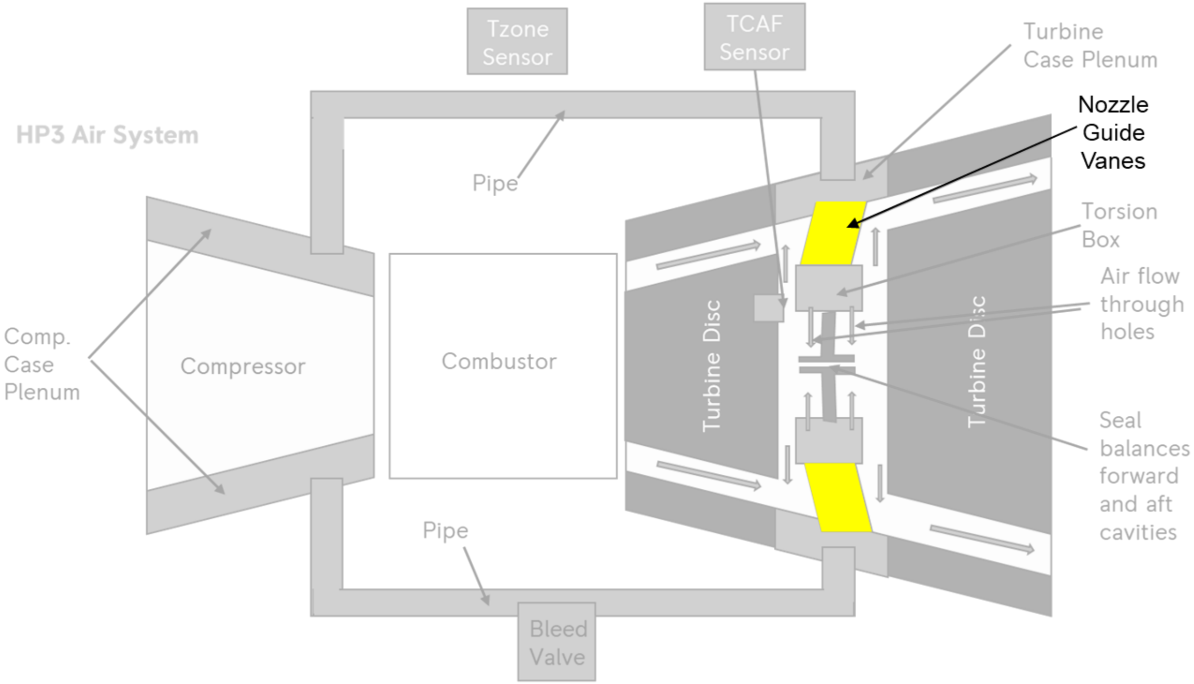
Replaced in-shop during overhaul

- Small wear
  - →negligible
- Medium Wear
  - →no overheat contribution
  - →detectable (overhauls)
- Major Wear
  - →overheat contribution
  - →detectable (overhauls)

Model – Turbine Seal



Model – Nozzle Guide Vanes



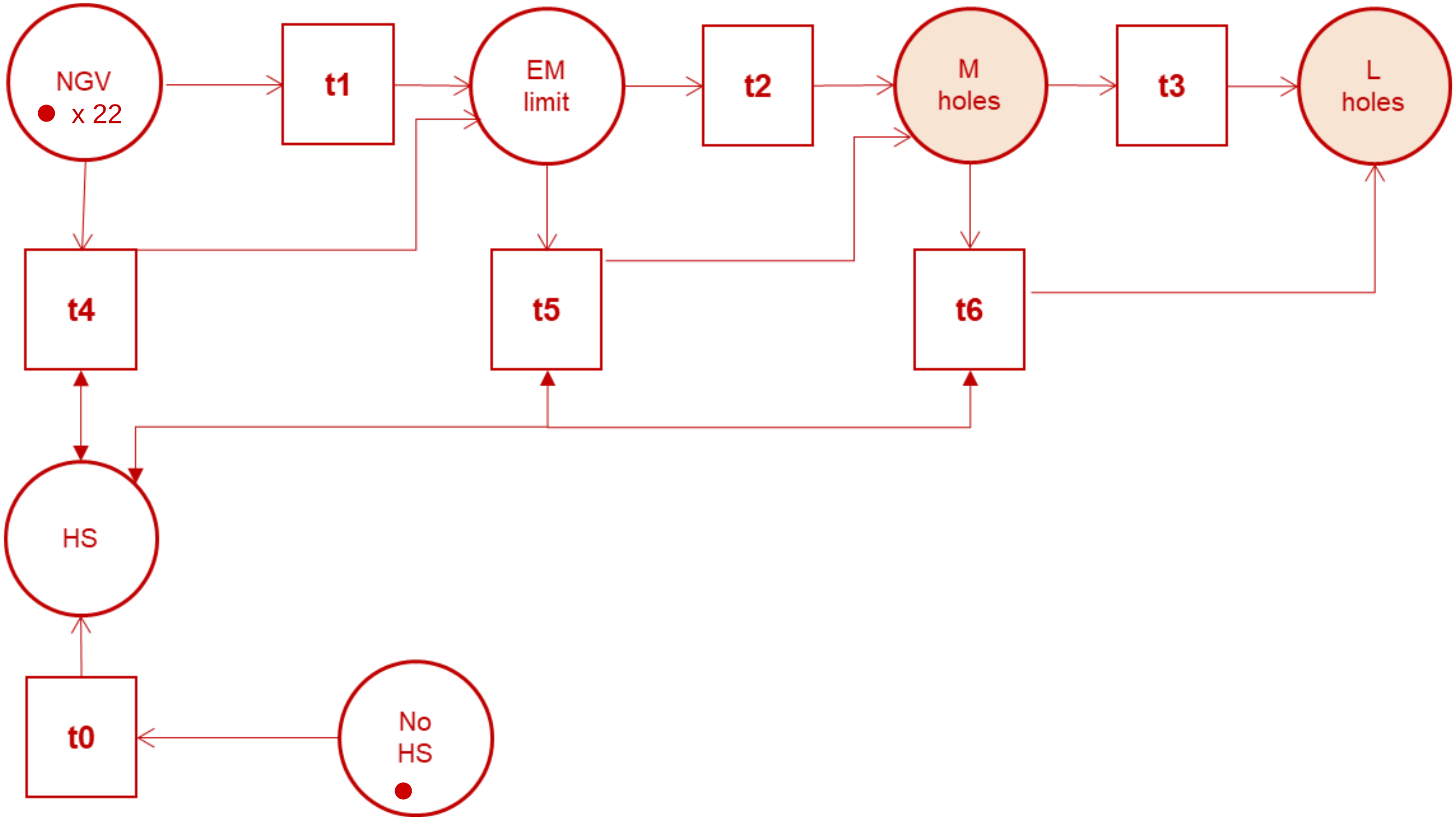
Replaced in-shop during overhaul

- Fails Engine Manual limit
  →negligible

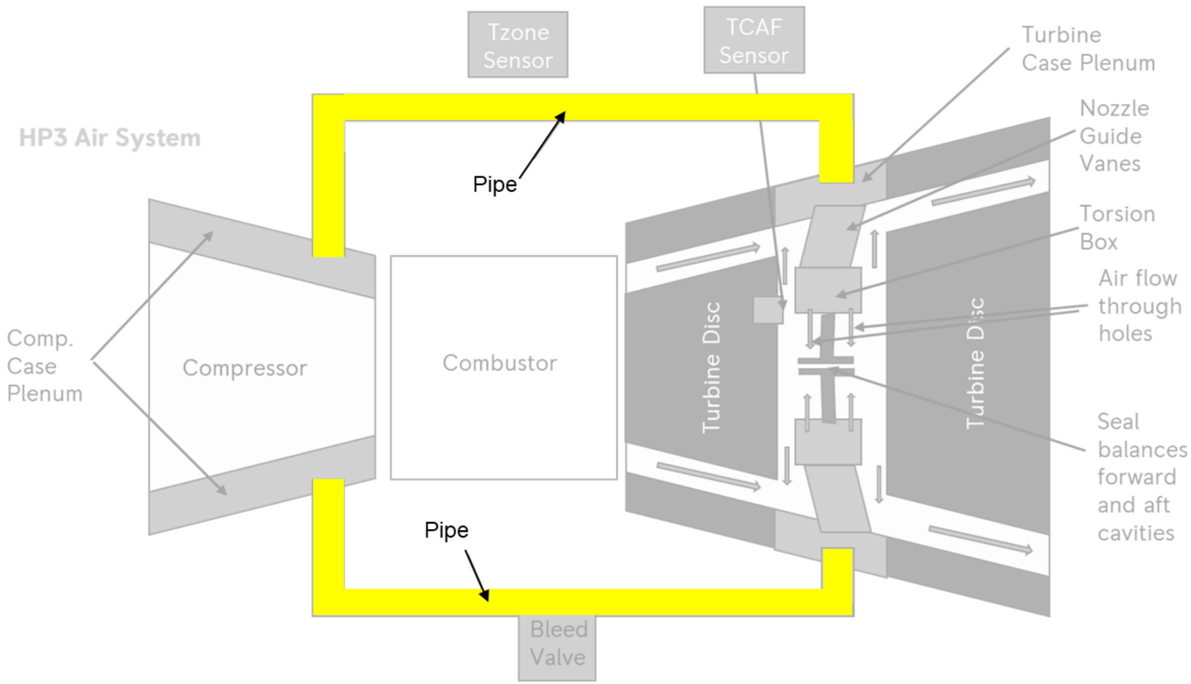
- Medium Hole
  →contribute to overheat
  →affected by **hot streaks**

- Large Crack
  →contribute to overheat
  →affected by **hot streaks**

Model – Nozzle Guide Vanes



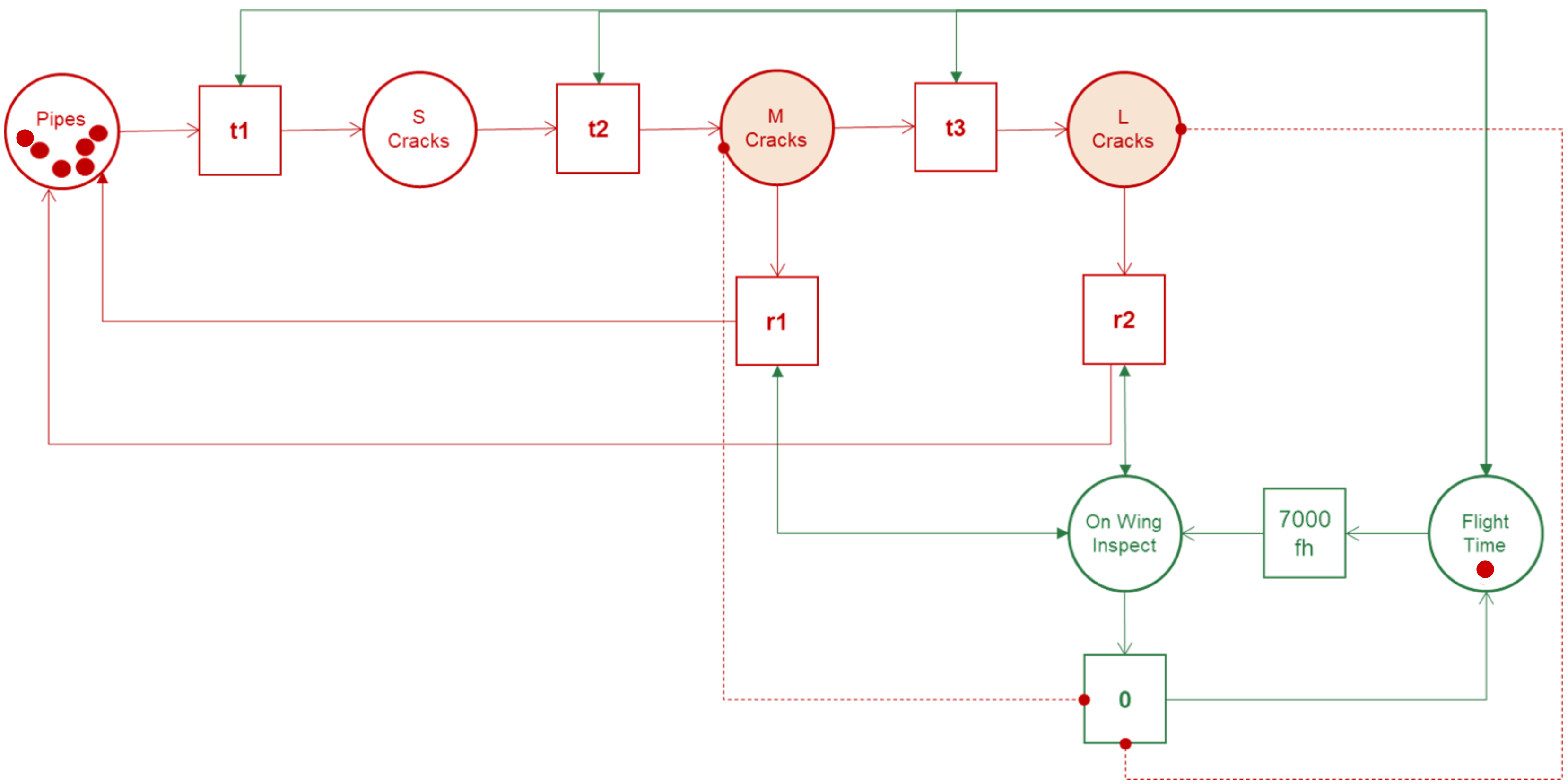
Model - Pipes



On-wing maintenance replacement

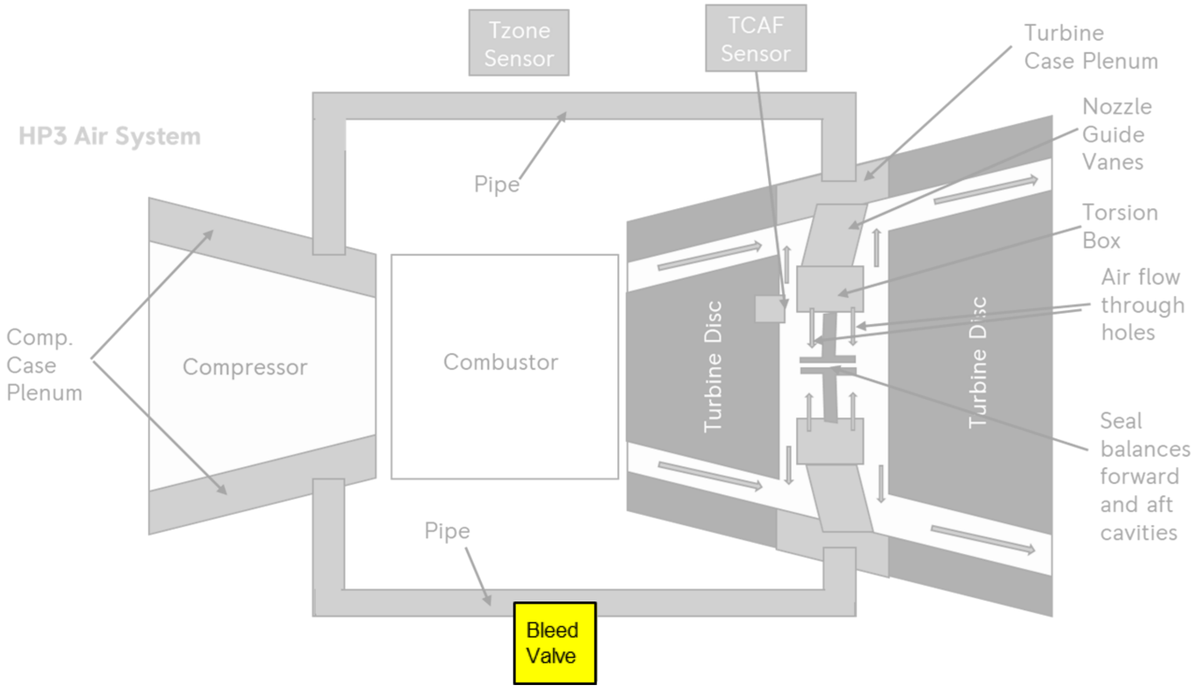
- Small Crack
  - →negligible
  - →not detectable
- Medium Crack
  - →overheat contribution
  - →detectable
- Large Crack
  - →overheat contribution
  - →detectable

Model - Pipes



Pipes
t1
S Cracks
t2
M Cracks
t3
L Cracks
r1
r2
On Wing Inspect
7000 fh
Flight Time
0

Model – Bleed Valves



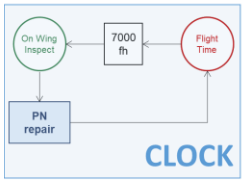
- Fail open
  - →leaks air into bypass
  - →detectable after 3 flights

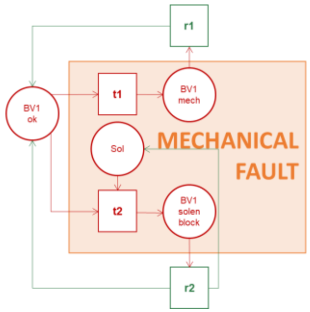
- Fail closed
  - →affects provision of air
  - →detectable after 3 flights

<u>150 flying hours dispatch</u>

<u>On-wing maintenance replacement</u>

Model – Bleed Valves





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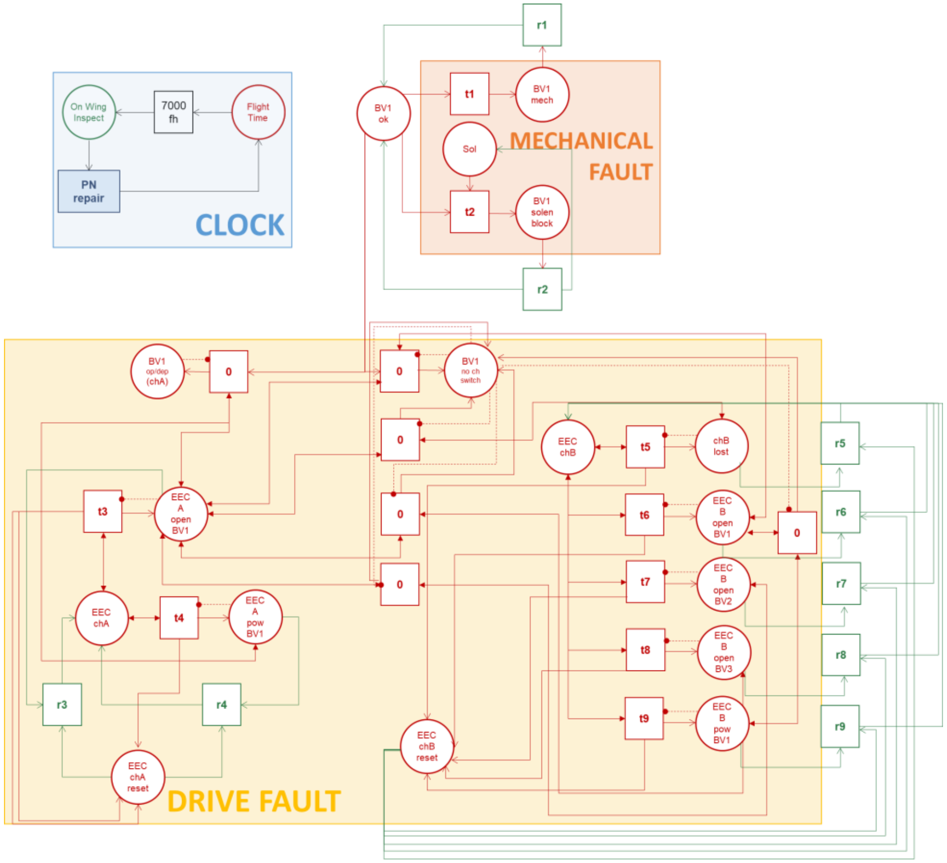

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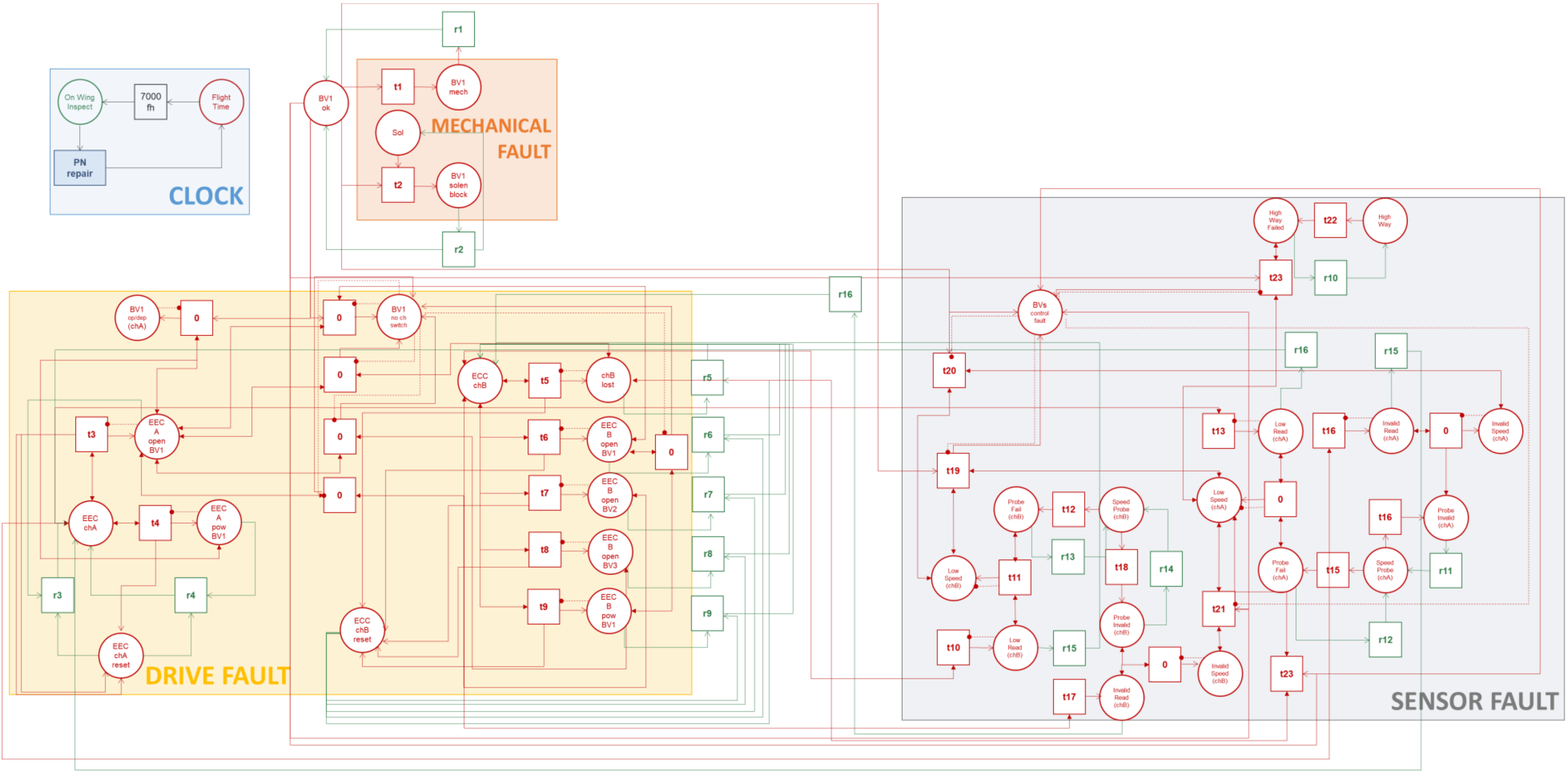
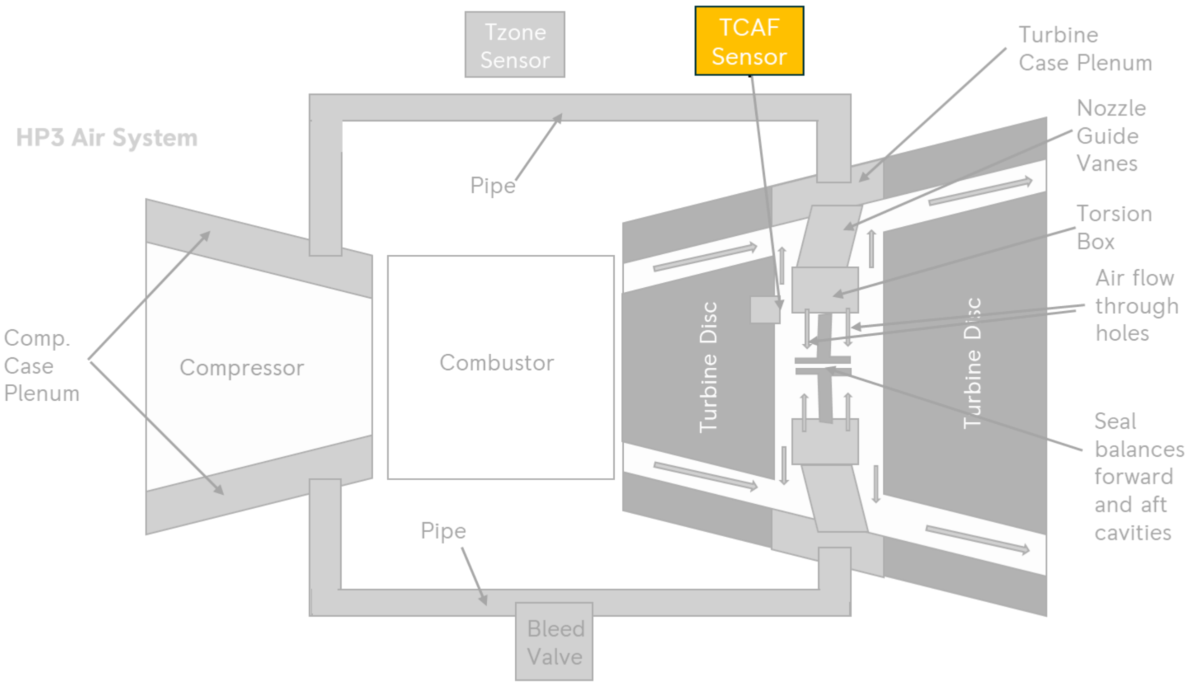


Model – Limited Dispatch

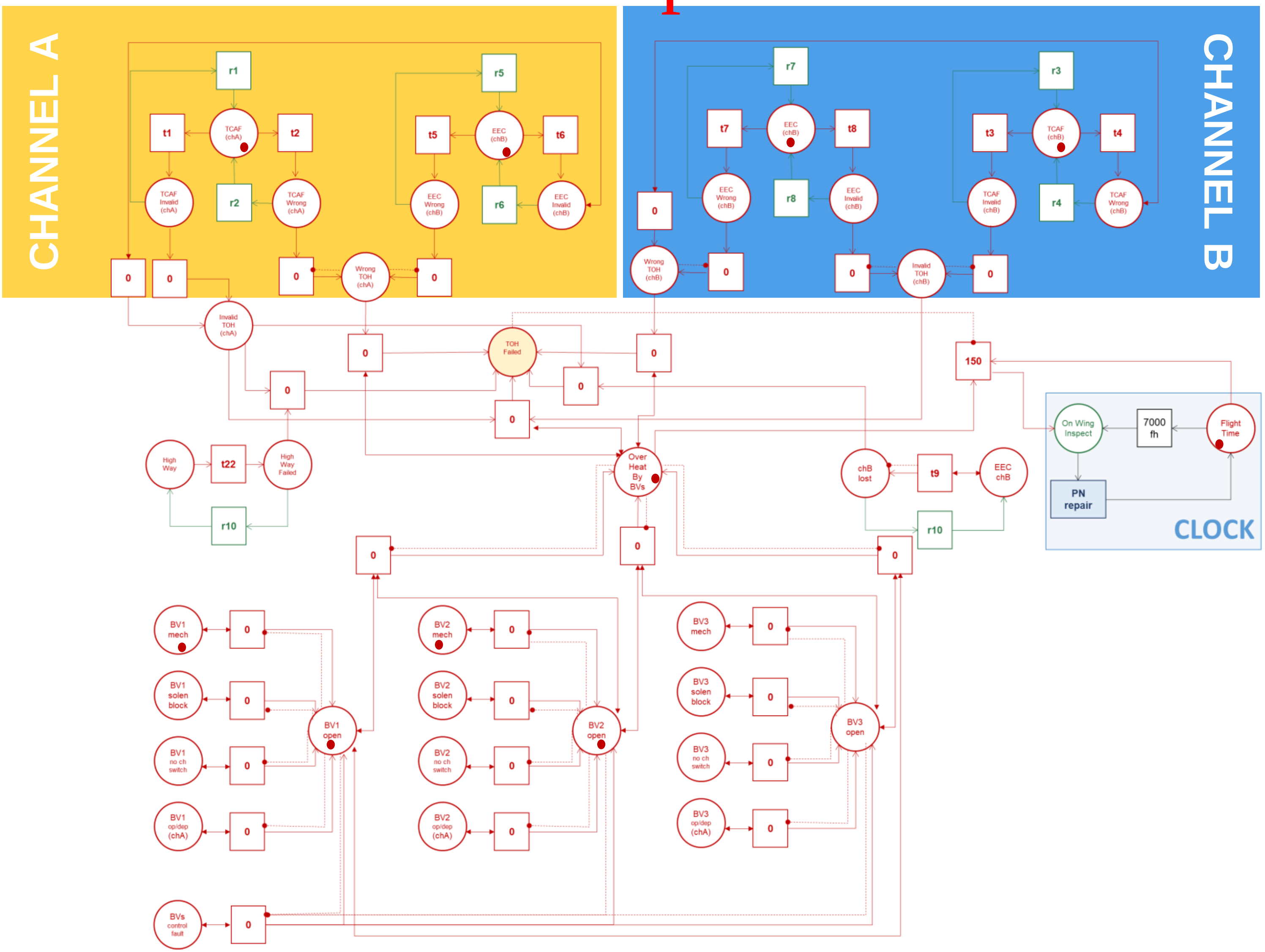


- Electronic Engine Controller
- Detects BVs malfunction
- Cross-referenced channels

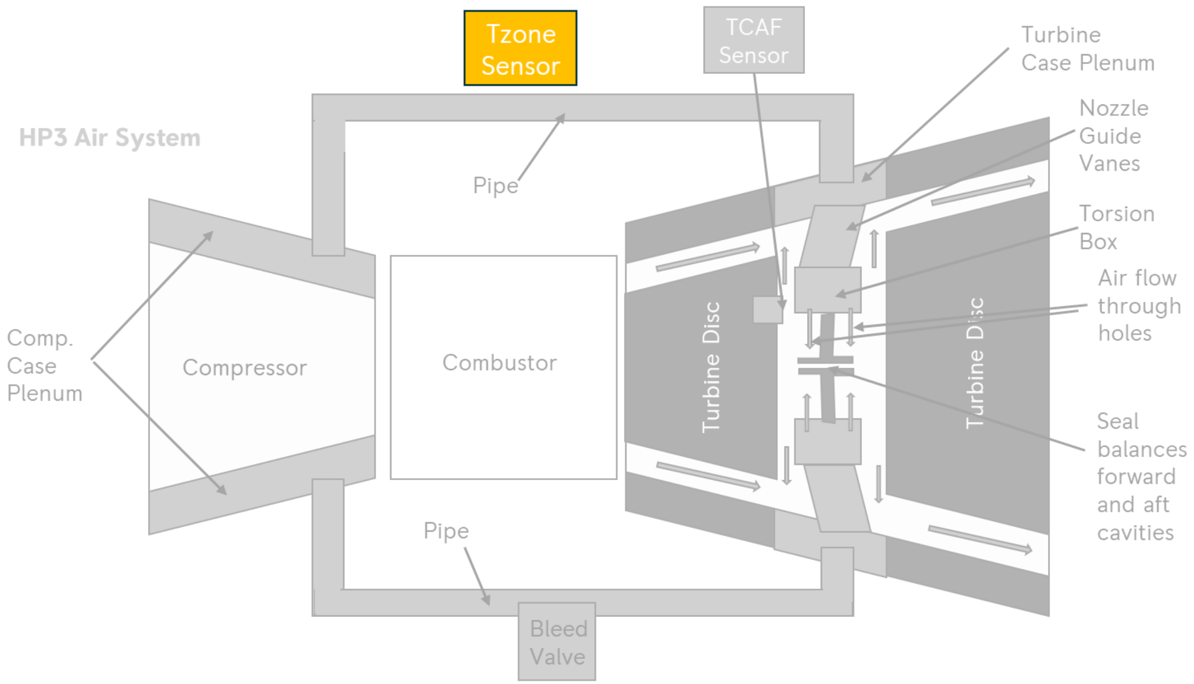
<u>150 flying hours dispatch</u>

<u>On-wing maintenance</u>

Model – Limited Dispatch



Model – Limited Dispatch

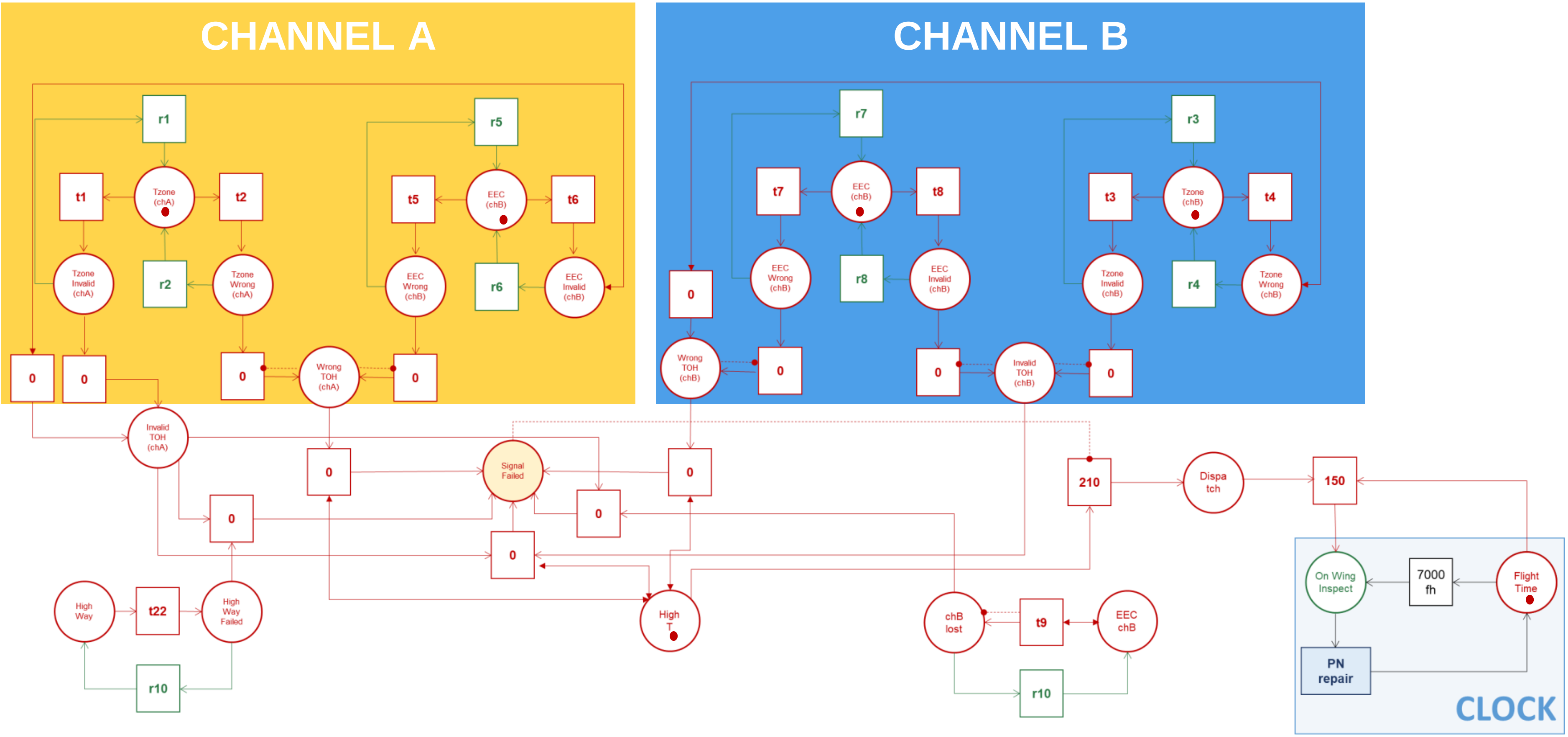


- Electronic Engine Controller
- Detects leaks
- Cross-referenced channels

<u>150 flying hours dispatch</u>

<u>On-wing maintenance</u>

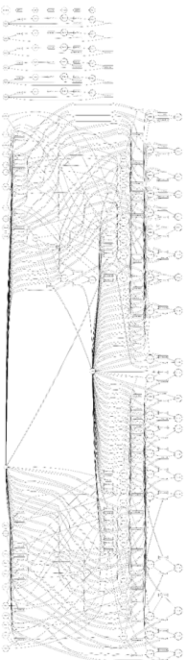
Model – Limited Dispatch

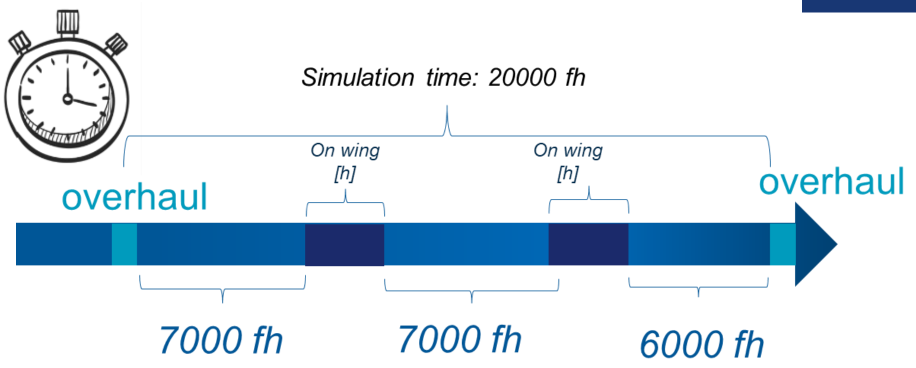


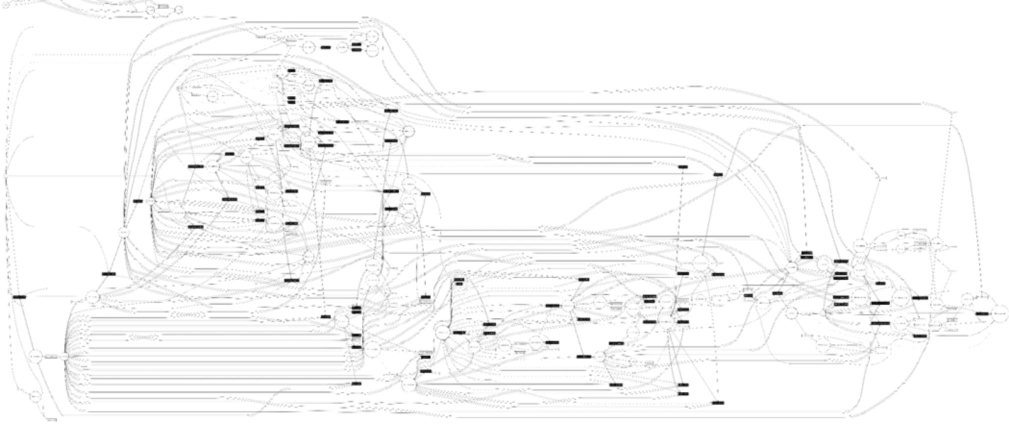
Analysis – Overview

Petri Net Model:

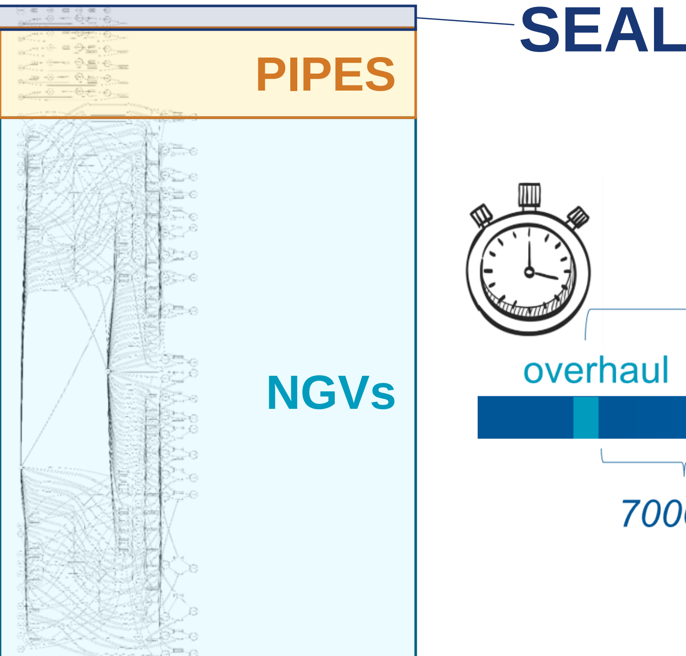
- 194 Places
- 302 Transitions







Analysis – Overview



Petri Net Model:

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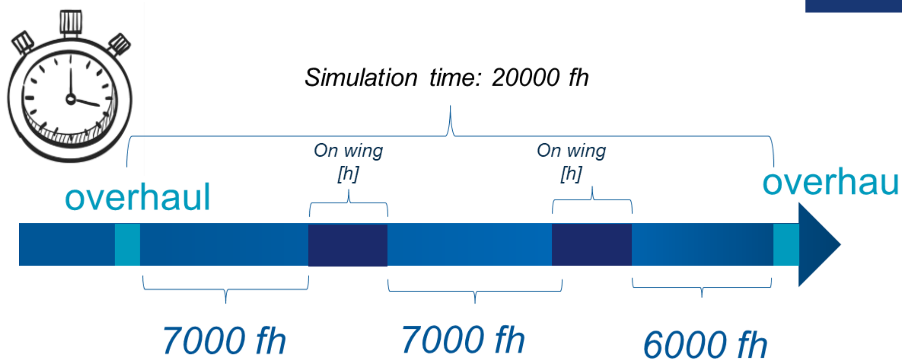
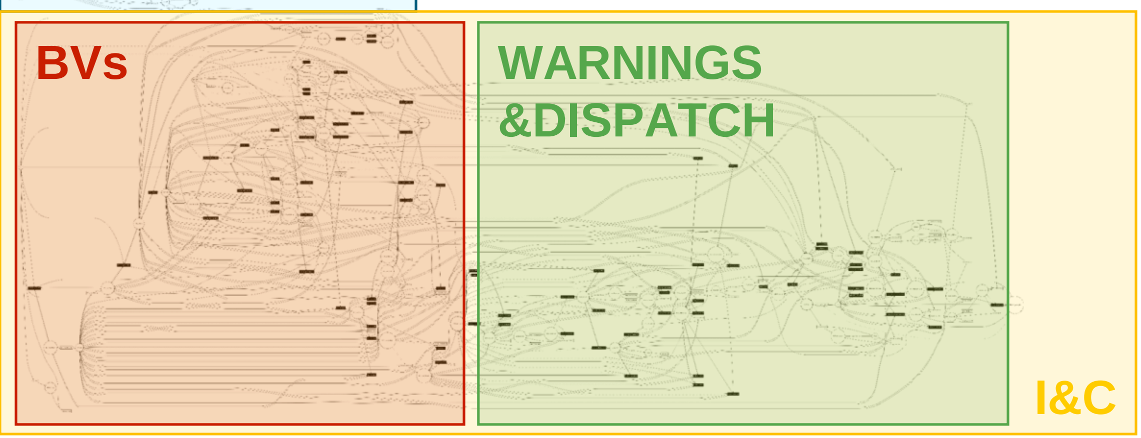


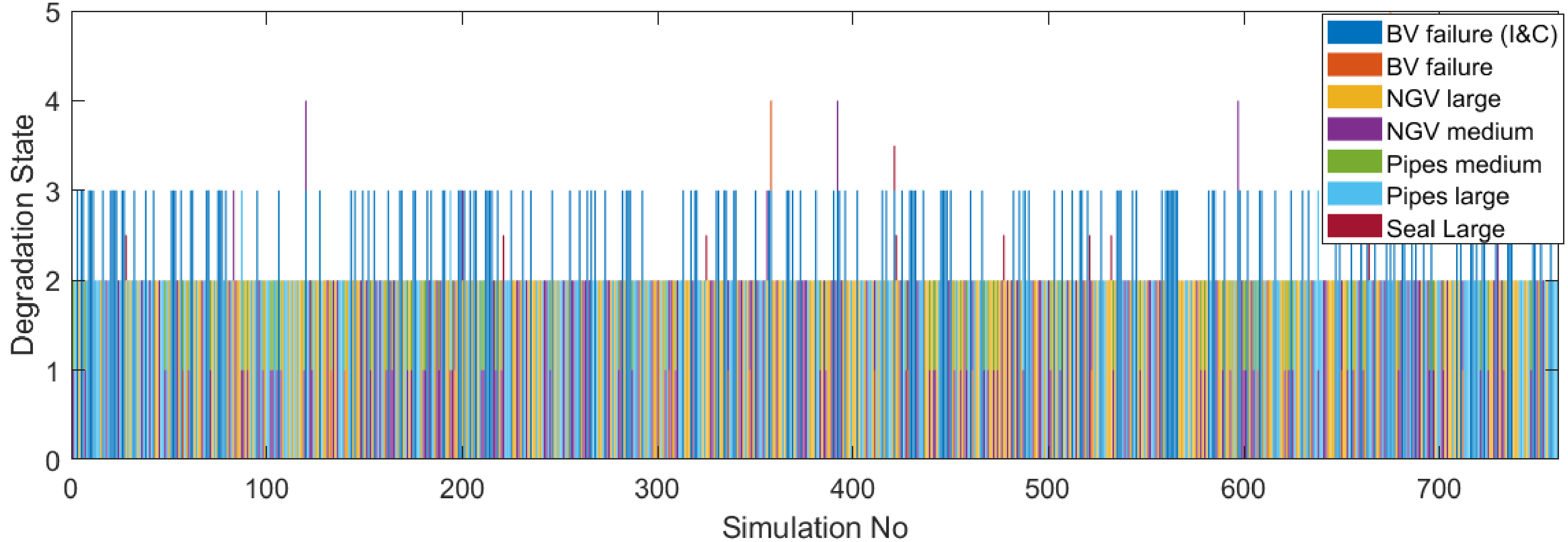


Failure Contribution:

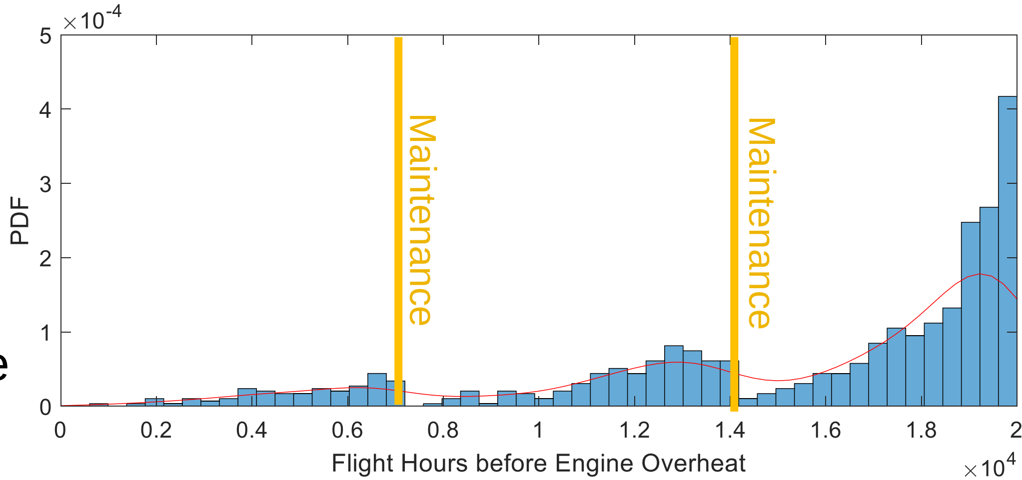
- Pipe (medium) →1
- Pipe (large) →2
- BV (open) →1
- Seal (large) →0.5
- NGV (medium) →1
- NGV (large) →2

Threshold = 2

Results – Failure Response

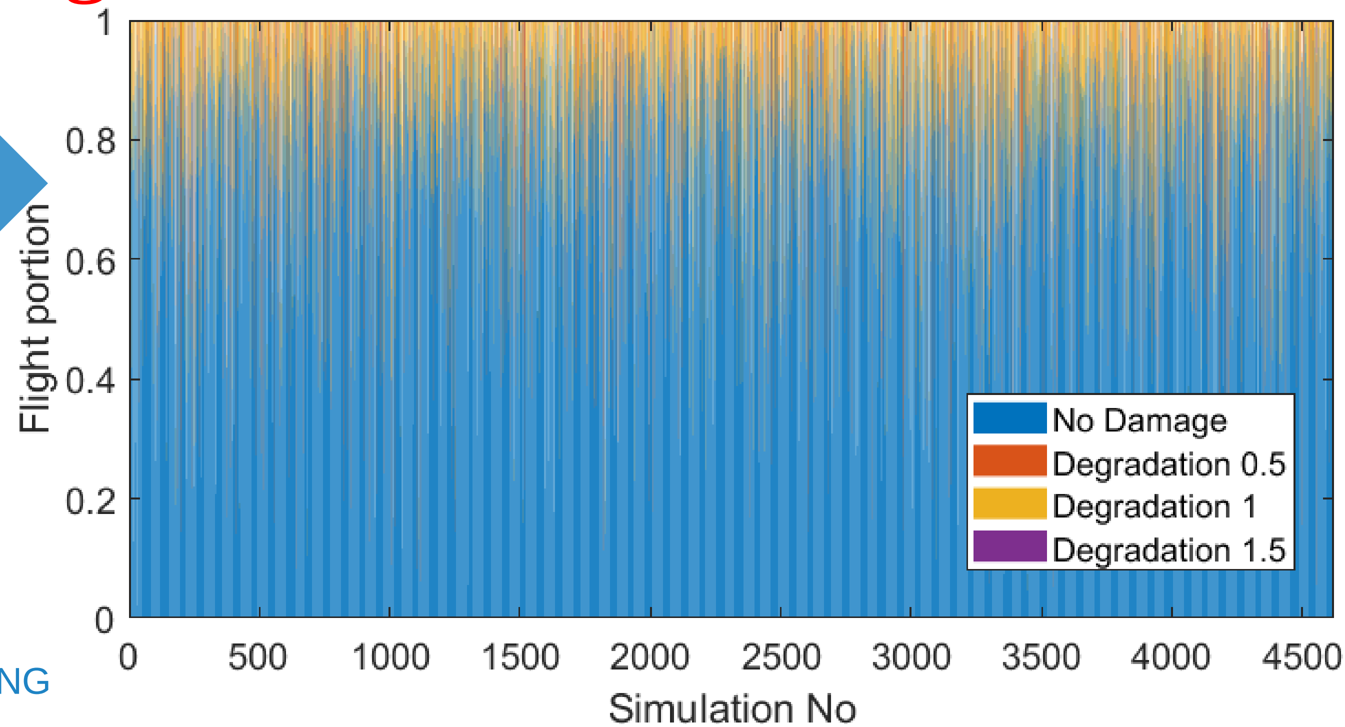


- Over 30,000 simulations
- 2.5% reached safety threshold
- Only 0.0164% led to disc damage
- 74 ‘missed’ dispatches (0.24%)
- 0.013% not repairable by maintenance

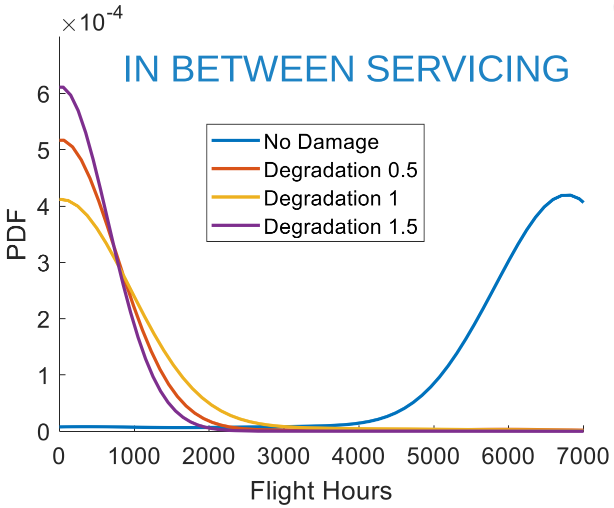


Results - Degradation

Over 15% of cases ended up in a degraded state



IN BETWEEN SERVICING



On average, for successful system cycles:

- 0.9% flight hours spent in state 0.5
- 1.9% flight hours spent in state 1
- 0.04% flight hours spent in state 1.5

Conclusions

- PN model of a jet engine internal air system
- *On-wing* and *In-flight* system behaviour
- Dynamic components degradation and dependencies
- System response to failure
- Insight system degradation
- Analysis of the dynamic progress of failure
- Future work will expand current model

  (e.g., Torsion Box, Turbine and Compressor Case Plenums)