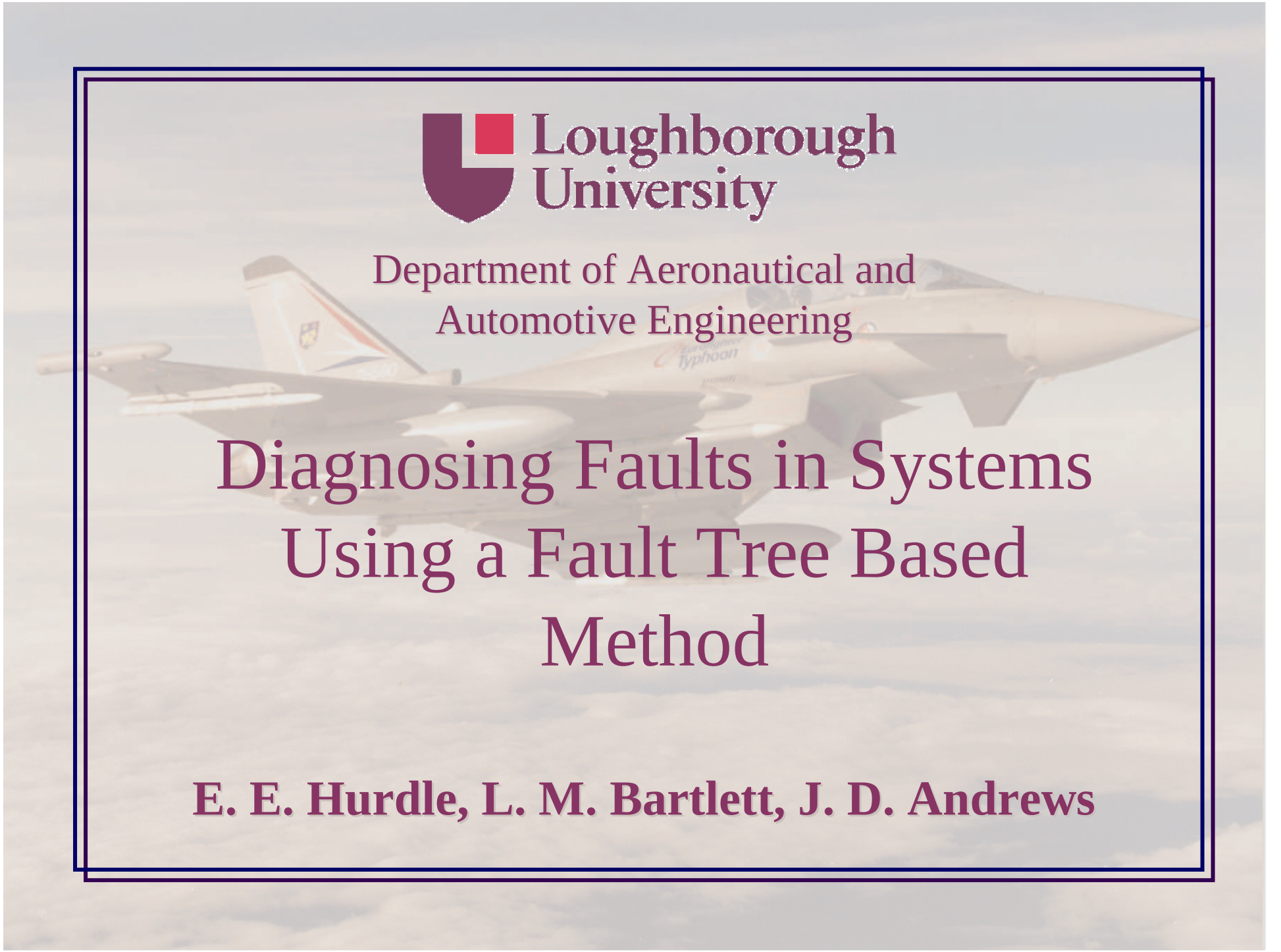

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Diagnosing Faults in Systems Using a Fault Tree Based Method

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Presentation Contents

1. Background and Introduction
2. Development of the fault tree based method
   - Example Water Tank Level Control System
3. Discussion of Results
4. Conclusions

1. Background

- Fault Diagnosis:
  - The process of identifying the cause of a malfunction by observing its effect on a system

- The increased complexity of modern day systems has made the diagnosis of faults a more difficult task to perform
  - Quick rectification is required in order to:
    - reduce the time taken for a system to resume normal service
    - minimise the effects of failure on the system

1. Background

- Fault diagnosis can be performed in two different ways:
  - Testing for faults at specific points in time
  - Monitoring the system continuously to detect for faults as and when they occur
- Testing for faults at specific points in time:
  - Sequential testing
  - Heuristic search algorithms
  - FMEA
- Monitoring the system continuously to detect for faults as and when they occur:
  - Statecharts and fault trees
  - Genetic algorithms

1. Introduction

- Method for diagnosing single or multiple faults in systems using Fault Tree Analysis (FTA)
  - Used to explain deviations in sensor outputs
  - System failure described in terms of component states
  - Needs a model of expected system behaviour
    - Sensor observations
    - System parameters

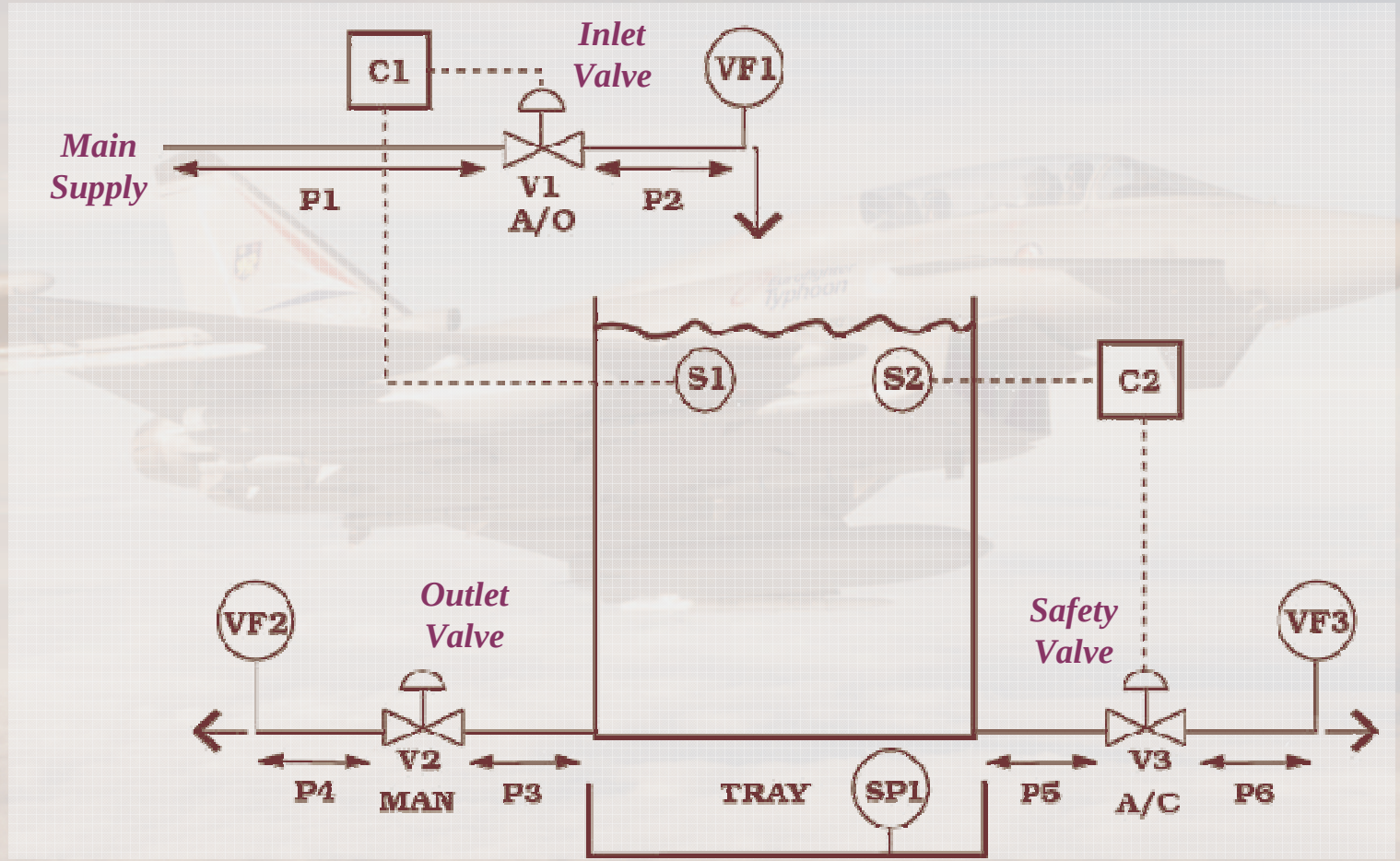
1. Generalised Method

- Obtain readings from sensors and calculate parameters
- Develop non-coherent fault trees for each sensor reading
  - AND, OR and NOT logic
- Compare monitored parameters for different sensor types where possible. If they do not agree they are unreliable
  - Direct comparison of readings or use of readings to calculate parameters
- Obtain a model of system behaviour in order to identify how the system should be behaving

1. Generalised Method

- Perform analysis to obtain potential causes of failure
- Remove working states from the potential causes
  - Only failed component states need to be considered
- Check potential causes against sensors reading true to the operating mode
  - Remove causes of failure that contradict these sensor readings
- If there is more than one possible potential cause of failure, use importance measures to obtain the most likely outcome

2. Water Tank Level Control System



2. Water Tank Basic Events

- Potential Component Failures:

Code	Component
P_iB $(1 \le i \le 6)$	Pipe P_i is Blocked
P_iF $(1 \le i \le 6)$	Pipe P_i is Fractured
V_iFC $(1 \le i \le 3)$	Valve V_i Fails Closed
V_iFO $(1 \le i \le 3)$	Valve V_i Fails Open
S_iFF $(1 \le i \le 2)$	Sensor S_i Fails Full
S_iFVH $(1 \le i \le 2)$	Sensor S_i Fails Very High
S_iFH $(1 \le i \le 2)$	Sensor S_i Fails High
S_iFN $(1 \le i \le 2)$	Sensor S_i Fails Normal

Code	Component
S_iFL $(1 \le i \le 2)$	Sensor S_i Fails Low
S_iFE $(1 \le i \le 2)$	Sensor S_i Fails Empty
C_iFH $(1 \le i \le 2)$	Controller C_i Fails High
C_iFL $(1 \le i \le 2)$	Controller C_i Fails Low
TR	Water Tank Ruptured
TL	Tank Leaks
NWMS	No Water from Main Supply

- Potential Phases:

ACTIVE	Flow Phase Through Valve V2
DORMANT	No Flow Phase Through Valve V2

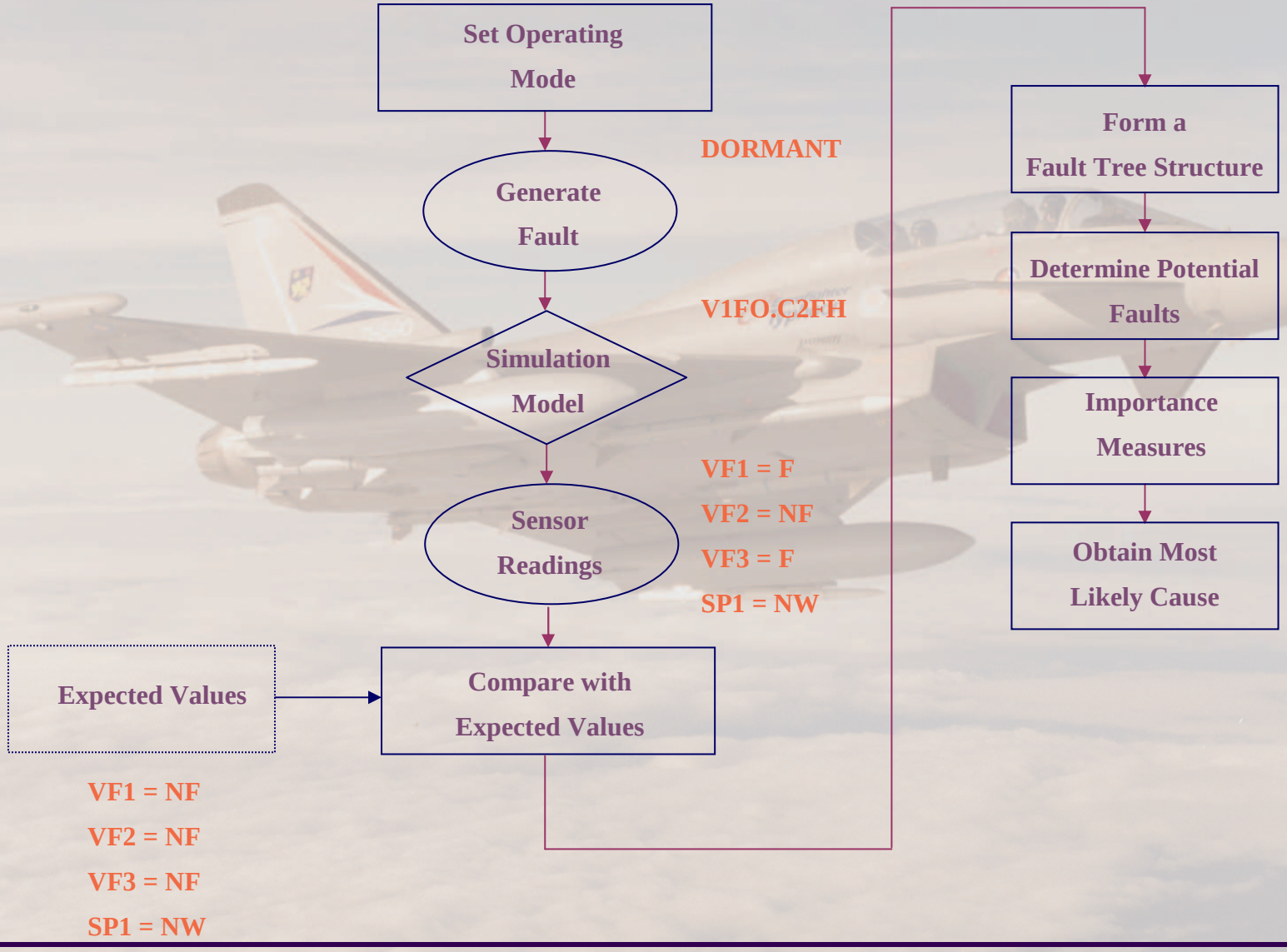
2. Operating Assumptions

- Flow into the tank through V1 has the capability to be greater than flow out of the tank through V2
- P5 and P6 have cross-sectional areas that are twice the size of the other pipes in the system
- If a rupture occurs in the tank then flow out through the rupture is greater than flow into the tank at V1
- Flow into the tank is greater than flow out of a leak in the system
- Initial conditions have the water level as normal

2. System Information

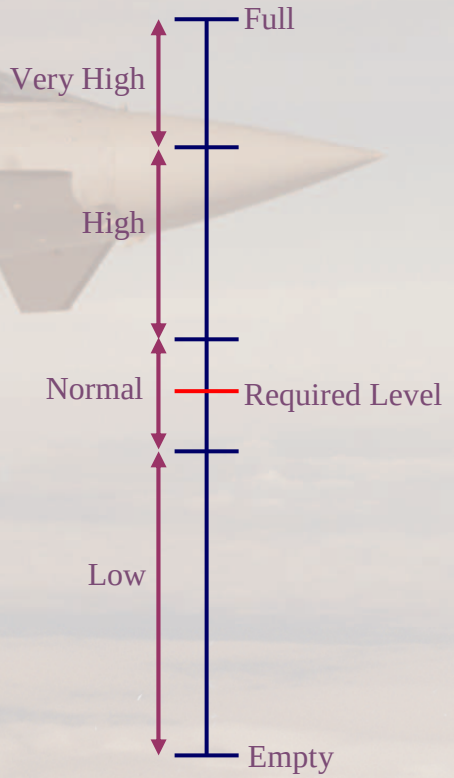
- Readings from VF1, VF2, VF3 and SP1
  - In addition can be used to generate system states:
    - The level of water in the tank
    - The rate of change
- Sensor readings from the level sensors S1 and S2 are also used in the system analysis
    - Read the level of water in the tank
    - Read the rate of change

2. Model Flow Diagram



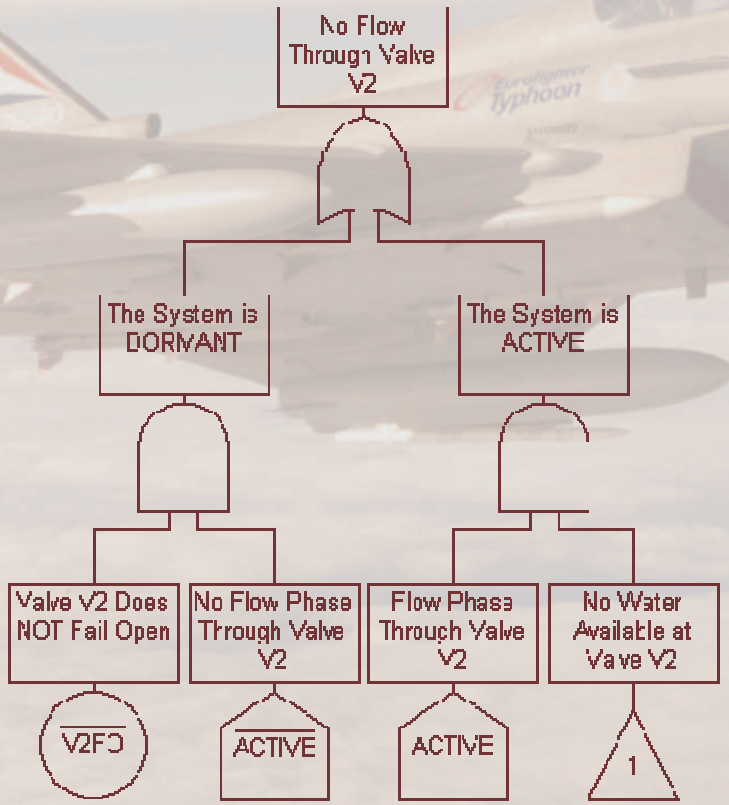
2. Expected System Behaviour

Mode	Height	Scenario	VF1	VF2	VF3	SP1	Rate Of Change
ACTIVE	Empty	4	Flow	Flow	No Flow	No Water	$\dot{h} > 0$
ACTIVE	Low	4	Flow	Flow	No Flow	No Water	$\dot{h} > 0$
ACTIVE	Normal	12	No Flow	Flow	No Flow	No Water	$\dot{h} < 0$
ACTIVE	High	12	No Flow	Flow	No Flow	No Water	$\dot{h} < 0$
ACTIVE	Very High	10	No Flow	Flow	Flow	No Water	$\dot{h} < 0$
ACTIVE	Full	10	No Flow	Flow	Flow	No Water	$\dot{h} < 0$
DORMANT	Empty	8	Flow	No Flow	No Flow	No Water	$\dot{h} > 0$
DORMANT	Low	8	Flow	No Flow	No Flow	No Water	$\dot{h} > 0$
DORMANT	Normal	16	No Flow	No Flow	No Flow	No Water	$\dot{h} = 0$
DORMANT	High	16	No Flow	No Flow	No Flow	No Water	$\dot{h} = 0$
DORMANT	Very High	14	No Flow	No Flow	Flow	No Water	$\dot{h} < 0$
DORMANT	Full	14	No Flow	No Flow	Flow	No Water	$\dot{h} < 0$



2. Fault Tree Construction

- Non-coherent fault trees were used in the analysis
  - Constructed using AND, OR and NOT logic
  - System Observation points and level sensor readings are described in terms of the component failures and working states



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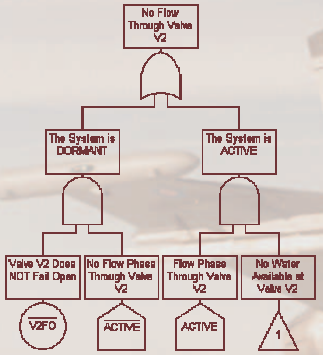

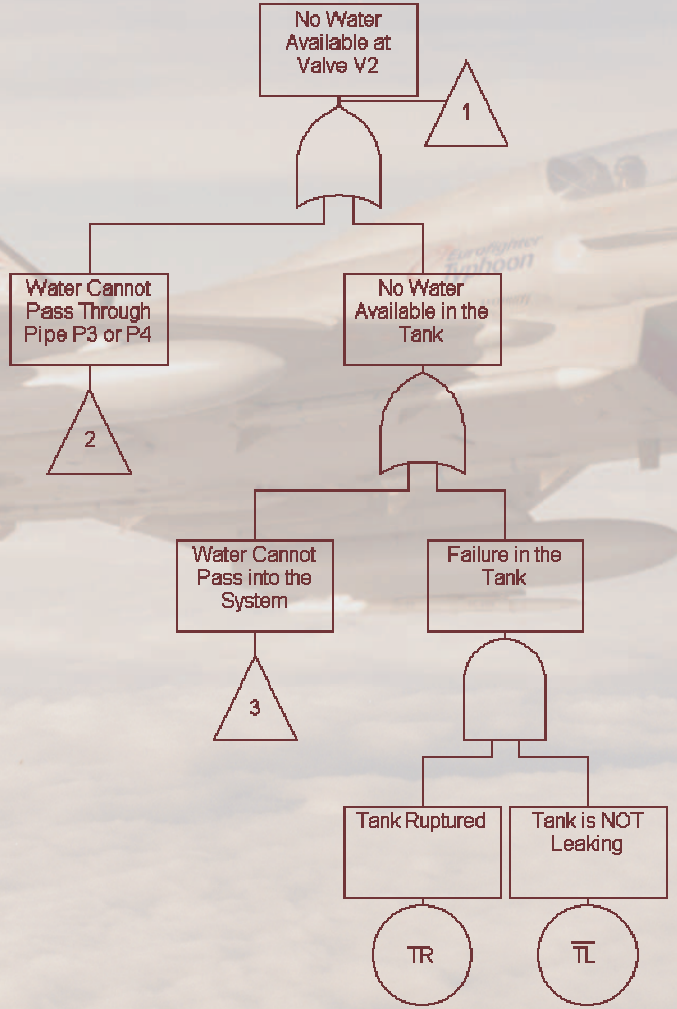

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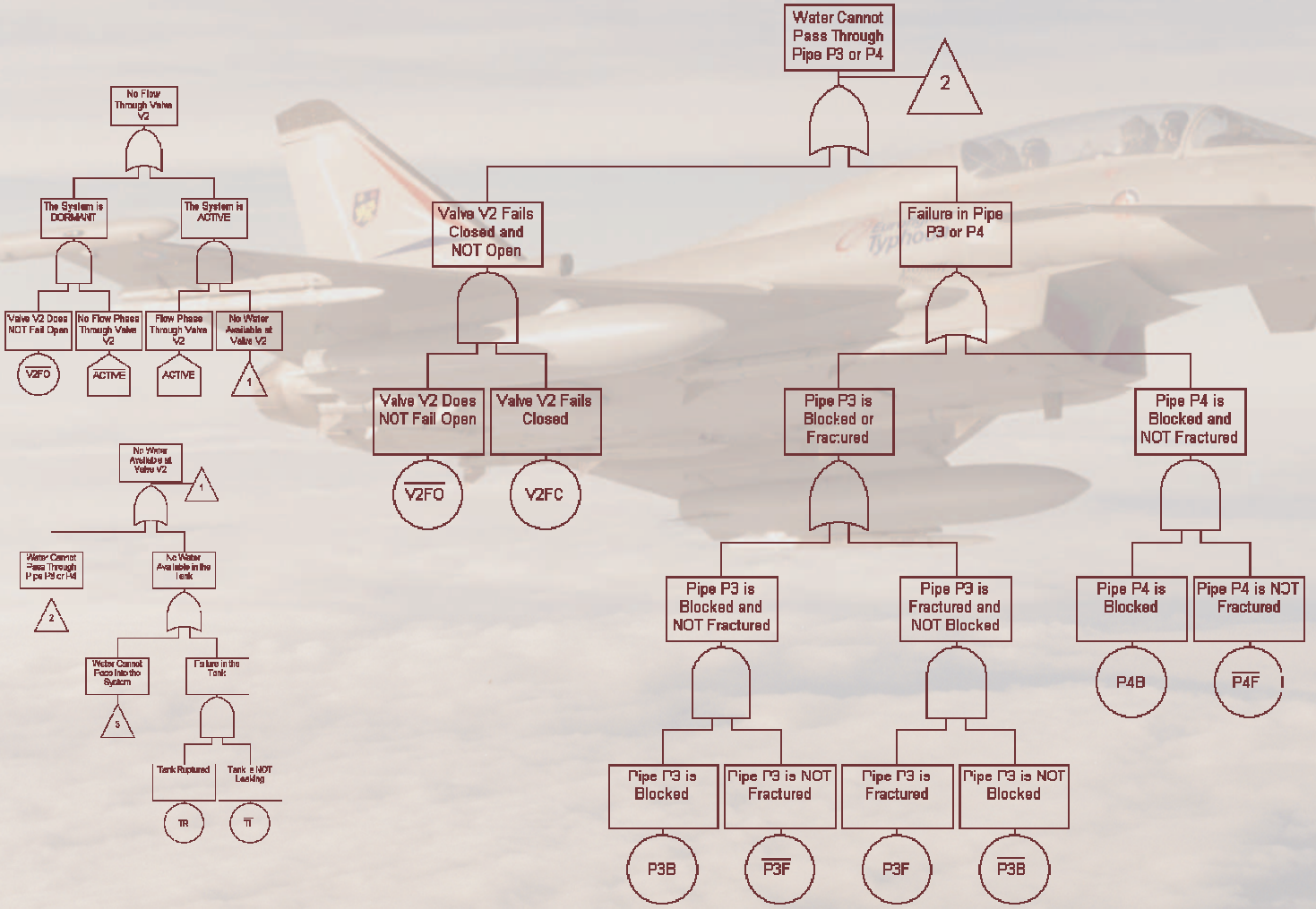

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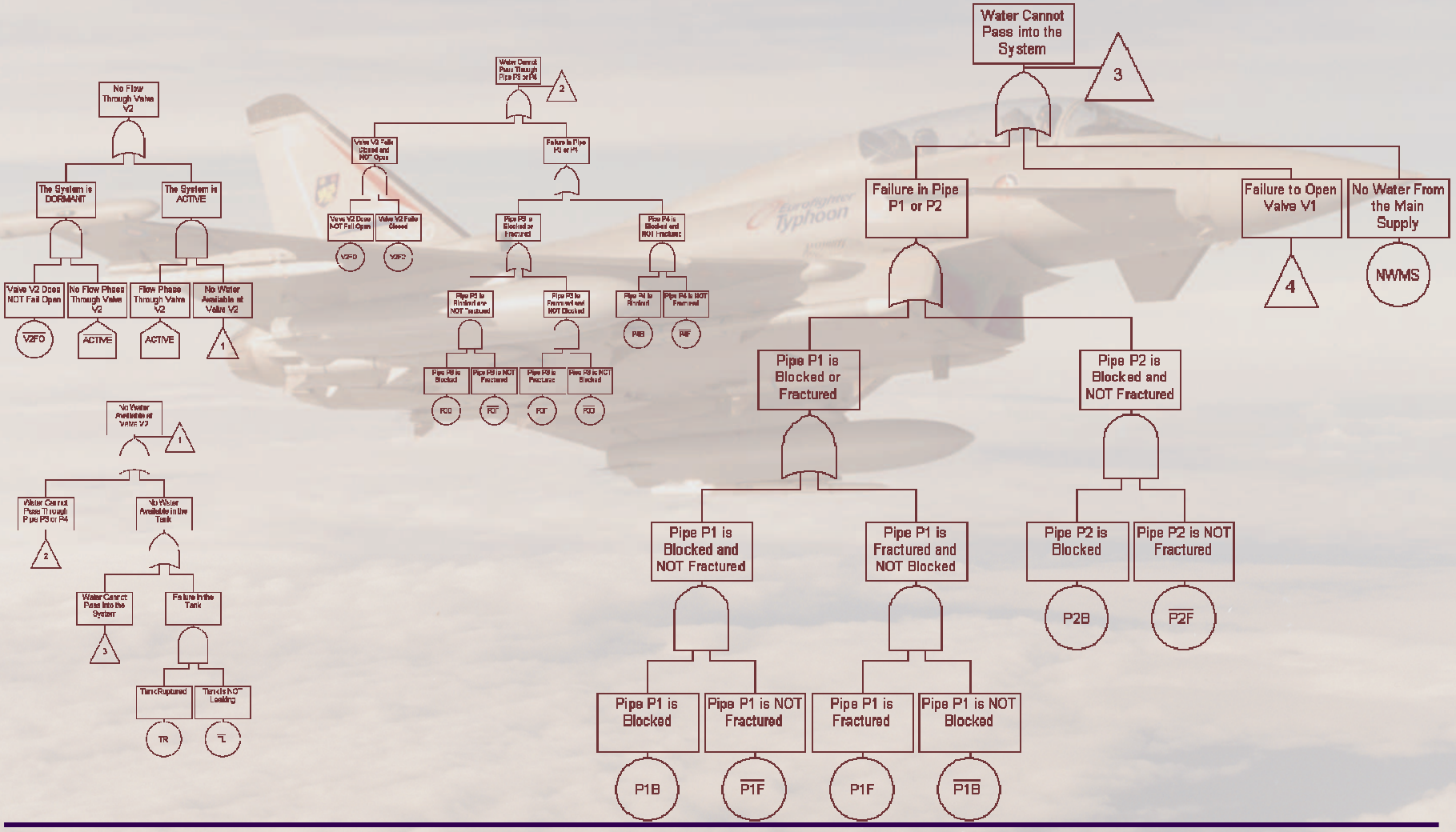

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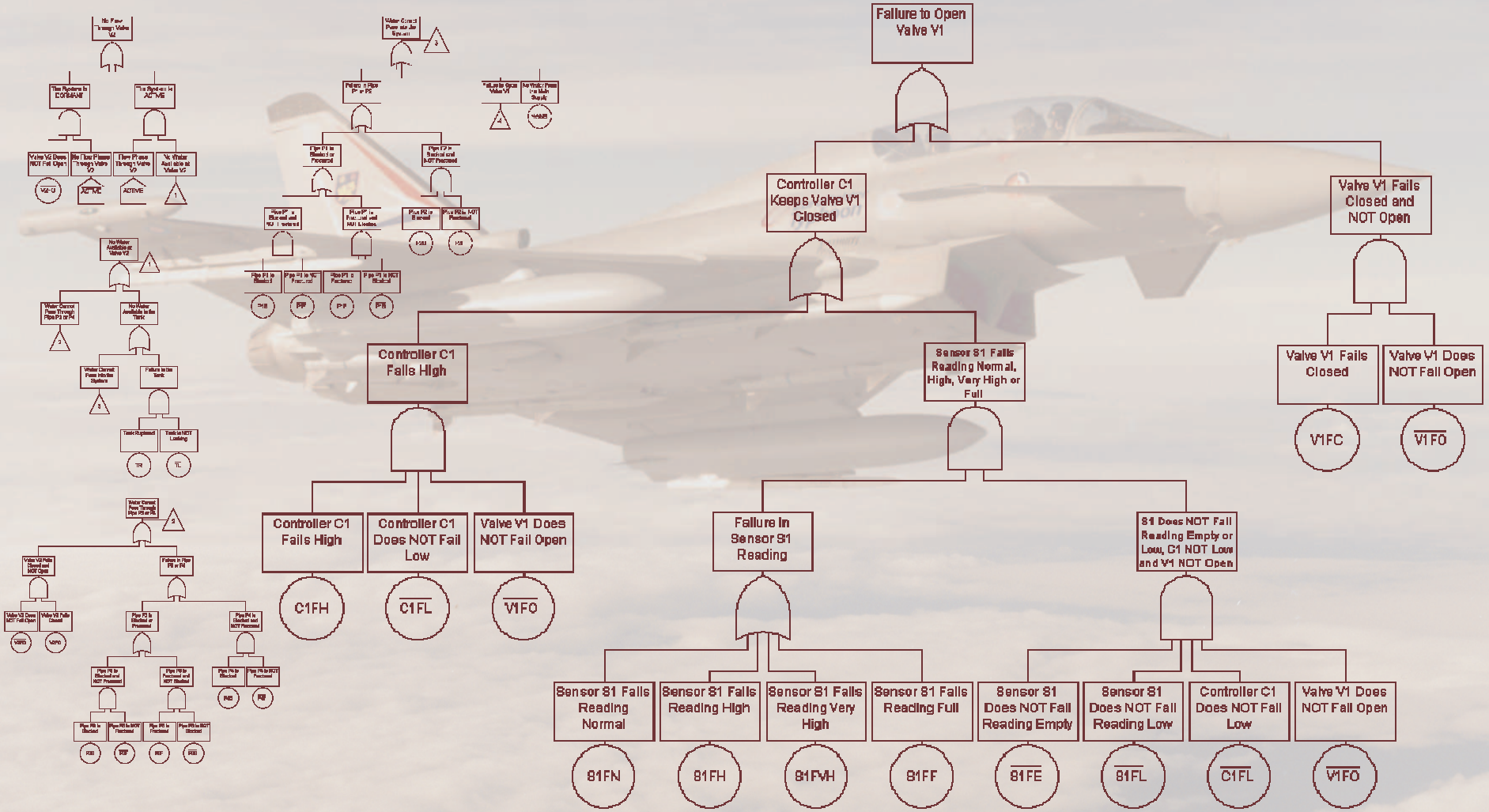


2. Fault Tree Construction

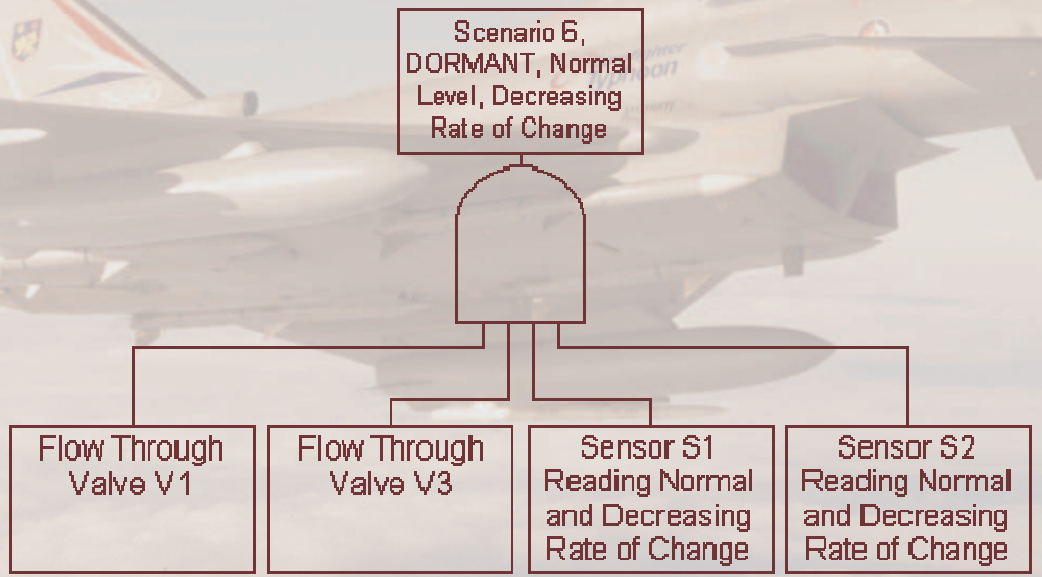
- Non-coherent fault trees were used in the analysis
  - Constructed using AND, OR and NOT logic
  - System Observation points and level sensor readings are described in terms of the component failures and working states

- Potential causes of failure for No Flow Through Valve V2:

1) V2FC
2) P3B
3) P3F
4) P4B
5) TR
6) C1FH
7) NWMS
8) V1FC
9) S1FN
10) S1FH
11) S1FVH
12) S1FF
13) P1B
14) P1F
15) P2B

2. Top Event Structure

- Look for the causes of the deviation (use a coherent top event structure and non-coherent fault trees), then check these individually against those from the sensor readings which are true to the operating mode



- Check potential causes of failure in this case against flow through V2 and water in the overspill tray

3. Scenario Top Event Structure

- DORMANT Operating mode with Height = Normal
- Induced Failure: V1FO.C2FH

Scenario	VF1	VF2	VF3	SP1	HEIGHT	RATE	S1/S2 HEIGHT	S1/S2 RATE
EXPECTED	NF	NF	NF	NW	*h = Normal*	$\dot{h} = 0$	*h = Normal*	$\dot{h} = 0$
ACTUAL READING	F	NF	F	NW	*h = Normal*	$\dot{h} < 0$	*h = Normal*	$\dot{h} < 0$

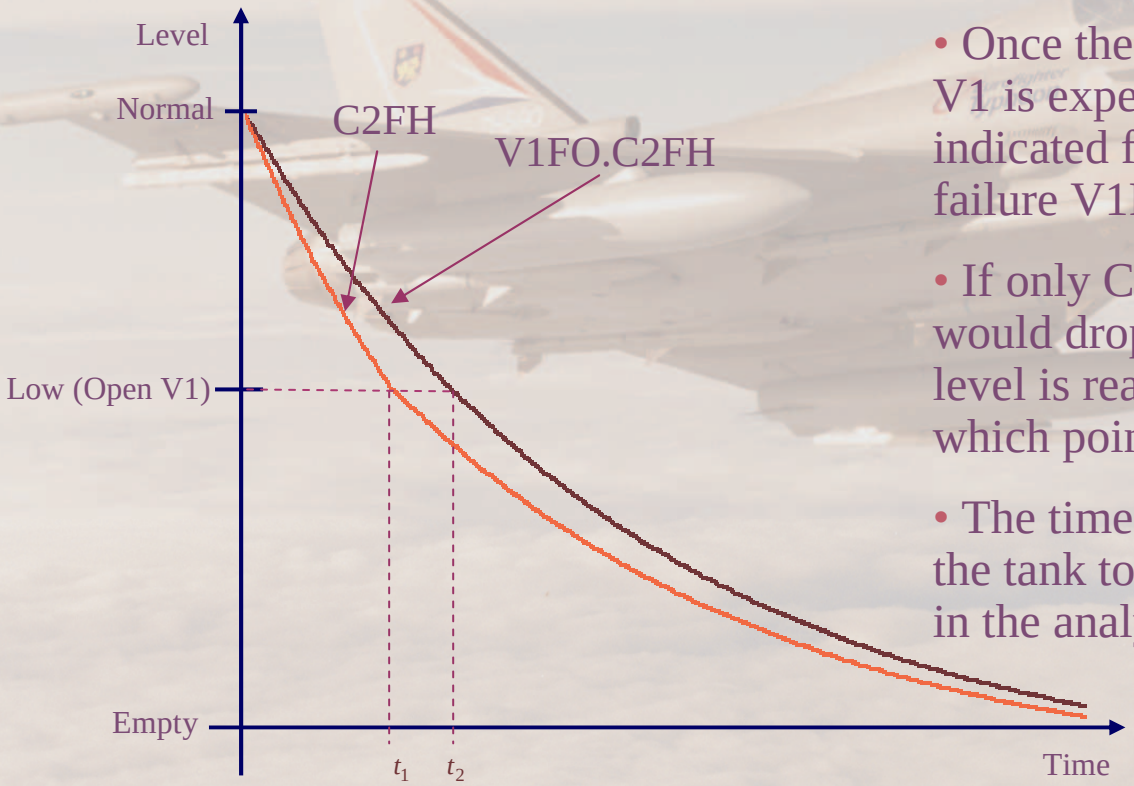
- Potential Causes:

Number	Potential Causes
1)	V3FO.-V3FC.-P5B.-P5F.-P6B.-V1FC.-P1B.-P1F.-P2B.-S1FE.-S1FL.-S1FN.-S1FH.-S1FVH.-S1FF.-S2FE.-S2FL.-S2FN.-S2FH.-S2FVH.-S2FF.-TR
2)	C2FH.-V3FC.-C2FL.-P5B.-P5F.-P6B.-V1FC.-P1B.-P1F.-P2B .-S1FE.-S1FL.-S1FN.-S1FH.-S1FVH.-S1FF.-S2FE.-S2FL.-S2FN.-S2FH.-S2FVH.-S2FF.-TR

- Method has not obtained the exact cause of failure in this case
- The two induced failures can be the cause of both deviated sensor readings
- Timing will need to be taken into consideration

3. Dynamics

- DORMANT Operating mode with height = Normal
- Induced Failure: V1FO.C2FH

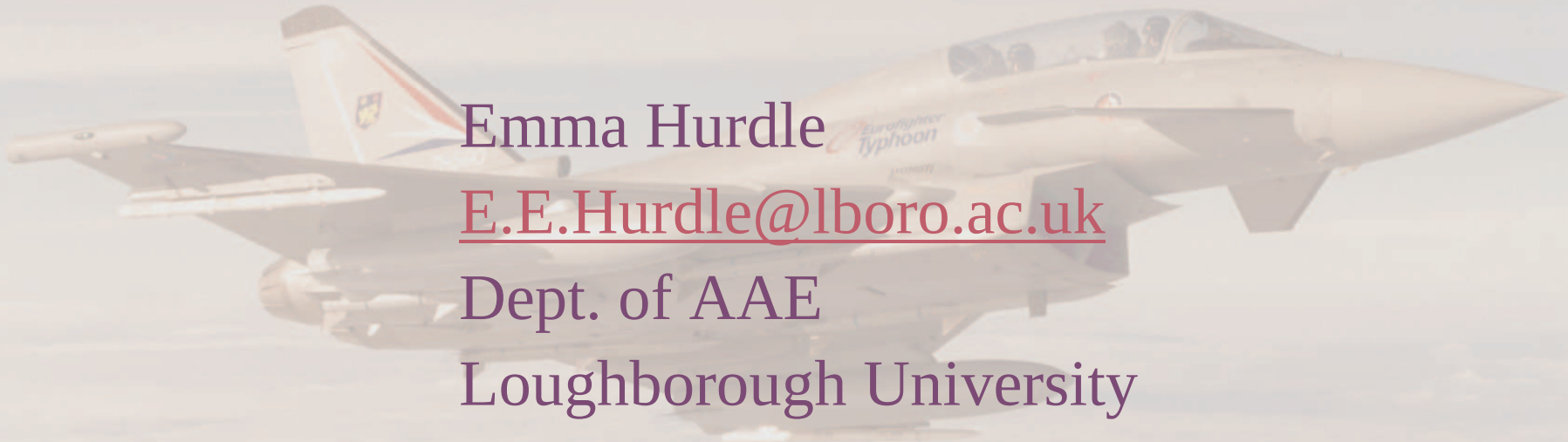


- Once the level reaches 'Low' flow in at V1 is expected, so a failure will not be indicated from t_2 onwards for the induced failure V1FO.C2FH
- If only C2FH is induced then the level would drop at a faster rate, until the 'Low' level is reached (at time t_1 in this case), at which point V1 is opened
- The time taken for the level of water in the tank to drop may need to be considered in the analysis

4. Conclusions

- The method obtained in general is good at diagnosing faults in systems
- The checking mechanism ensures that the potential causes of failure do not conflict with the sensors reading true to the operating mode
- Reliable and unreliable sensor readings can be identified by comparing the level and rate of change of the height of water in the tank obtained from each different set of sensor readings
- Further research is required to try and overcome problems such as the tool not identifying all failures induced
  - The time taken for the level of water in the tank to drop may need to be considered in the analysis

Questions?



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