

Annex A

DISCUSSION OF CAUSE FAILURE RATES AND CONDITIONING FACTORS RELATING TO MID AIR COLLISION AS A RESULT OF TECHNICAL FAILURE.

Hazard 27A

1. Cause Zx1: Asymmetric Thrust (EA: Prop)

5.655 x 10⁻⁴. To be validated.

- a. Multiple Partial Right Hand Engine Control failures:

2.232 x 10⁻⁹

- b. Single Engine Locked in Surge:

1.040 x 10⁻⁴

- c. Incorrect Provision of Right Hand Throttle signal

5.00 x 10⁻⁵

- d. Single Right Hand Engine Control Failure

3.801 x 10⁻⁴

- e. H9: Insufficient Fuel to Engine leads to Incorrect Thrust

1.215 x 10⁻⁵

- f. 1 FOD/NOD to Right Hand Engine (anything other than air. Includes birdstrike)

1.931 x 10⁻⁵

Cause A11:

9.798 x 10⁻⁶

2. To be validated.

3. Hazard 27B

4. Cause Z2

1.344 x 10⁻³

- a. **RHWR Failure (EA: CommsDAS).** It would be extremely difficult to obtain usable RHWR failure information that could cause degraded homing facility. In addition, the Homing facility on RHWR is not particularly accurate and certainly would not be used as a primary source for collision avoidance. In the view of the CommsDAS EA, the possibility, of RHWR failure should be acknowledged but the probability should be set to zero.

- b. **TACAN Failure (EA: AvFS).** Failure of TACAN leading to MAC revolves around the failure of TACAN to provide a range and bearing to an aircraft that is transmitting (for example a tanker aircraft). The TACAN has not changed in over 12 years and outdates LITS. LITS was trawled for TACAN failures from 01 Jan 2001 to 04 Sep 13. During this 12 year period, the Tornado Fleet flew 324263:00 Fg Hrs and 824 faults were recorded. 113

can be discounted for the following reasons: duplication (including ADFs and Lims), required for cannibalisation and NFF. This leaves 711 actual faults. These were not sifted further to discount which of these could not have feasibly led to MAC

$$711/324263 = 2.1 \times 10^{-3}.$$

c. **HSI Failure (EA: AvFS).** The HSI unit has not changed in over 12 years and outdates LITS. LITS was trawled for HSI failures of this display from 01 Jan 2001 to 04 Sep 13. During this 12 year period, the Tornado Fleet flew 324263:00 Fg Hrs and 174 faults were recorded. 66 of these faults were discounted for the following reasons: duplication (including ADFs and Lims), required for cannibalisation and NFF. This leaves 108 actual faults.

$$108/324263 = 3.33 \times 10^{-4}$$

d. **RADAR A-A Failure (TNR Pack Only) (EA: AvFS).**

i. The TNR Pack NSN has not changed in over 12 years, although individual LRUs have. It is not possible to deduce from LITS which individual LRUs were replaced in order to resolve RADAR A-A issues. Therefore, only TNR data has been reviewed at this time. LITS was trawled for TNR pack failure rates, from 01 Jan 2001 to 04 Sep 13. During this 12 year period, the Tornado Fleet flew 324263:00 Fg Hrs and 1102 faults are recorded. 938 can be discounted for the following reasons: duplication (including ADFs and Lims), required for cannibalisation and NFF. This leaves 164 actual faults. Of those faults only x7 were found to directly relate to RADAR A-A issues.

$$7/324263 = 2.16 \times 10^{-5}.$$

ii. Further research required based on individual LRUs to add to the above A-A statement. However, even if the probability of a Radar failure contributing to Air to Air issues was 1; it does not bring the probability of H27B out of the incredible region and does not change the order of magnitude of the probability of H27 occurring.

iii. Mitigations against failure of TNR leading to MAC are use of SIFF, RHWR, Comms, ATC and a good lookout.

e. **FLIR Failure (EA: CommsDAS).** It is felt unlikely that a FLIR failure would directly contribute to collision with another aircraft given its (lack of) usage during the day and the fact that it's failure is mitigated by use aircrew SOPs. Also, NVGs are available as is TFR. However, using LITS, based on the total number of FLIR failures since 2003 (124) over 275,433.6 FHs, the probability associates with FLIR failure is

$$4.5 \times 10^{-4}.$$

f. **Comms Failure (Undetected) (EA: CommsDAS).** The DDP has been used to obtain worst case MBTF figures for SCoT radios. This value is pessimistic because not every failure would lead to a total loss of comms. Figures for PTR 1751 have not been included as SCoT will be fleet fitted (except trainers) and it is difficult to obtain failure data for CagNet and Havequick that could be useable in determining what would constitute a total loss of comms. It is judged that it would not be any worse than the probability for SCoT. Again, the CommsDAS EA is mindful of the fact that aircrew SOPs would significantly reduce the likelihood of comms failure leading to mid-air collision. The declared failure rate for Comms Failure (Undetected) is:

$$1.667 \times 10^{-4}$$

g. **Failure of TIEC (EA: CommsDAS) leading to MAC.**

i. It is felt unlikely that a TIEC failure would directly contribute to collision with another aircraft. However, the failure mechanism of TIEC that would lead to MAC is: 'Erroneous but believable JTIDS track data + Erroneous but believable JTIDS PPLI data'. The culmination of the two would be: 'erroneous but believable TIEC positional information': The associated probability law with the TIEC Pan SRR is

$$1.63 \times 10^{-4}.$$

ii. It may be of use to note that BAES added a condition factor to this hazard of 'Aircrew fail to apply SOPs for safety of flight' which was 1.0×10^{-7} .

h. **Failure of CWS.** The Tornado GR4 will be modified with CWS in order to guard against MAC. This will only help in non-close formation situations and therefore can only be applied to H27B. The failure of CWS could feasibly contribute to a lack of awareness following technical failure, leading to MAC and therefore, when CWS is introduced into service, it's failure probability will be added to the H27B fault tree.

5. **Cause Z3**

$$3.81 \times 10^{-4}$$

a. **SIFF (EA: AvFS).**

i. LITS was trawled for SIFF failure rates, from 14 Dec 11 to 04 Sep 13, based on first fit of the SIFF BS3.0 (Mod. 02532) in Dec 11. During this period, the Tornado Fleet flew 34096:55 Fg Hrs and 24 SIFF BS 3.0 faults were recorded. Of these 4 were No Fault Found (NFF) and the Fault cleared during Investigation (CB recycles) for another 7, leaving 13 actual faults.

$$13/34096 = 3.81 \times 10^{-4}.$$

ii. Failure of SIFF my result on other aircraft being unaware of Tornado. As mitigation, the Tornado itself is link 16 equipped, the aircrew should know SIFF has failed and ATC should know where both aircraft are and divert one or both of the aircraft.

b. **Failure of Anti-collision and Navigation Lights (EA: ArmElect) leading to MAC.**

i. Anti Col Light Failure: a trawl of LITS suggests a Failure Rate of 1.77×10^{-5} per FH for complete failure, or 1.412×10^{-4} for a single failure (upper or lower).

ii. Nav Light Failure: a trawl of LITS shows that there have been no recorded instances of total Nav light failure for the period 01 Jan 10 to 04 Sep 13. However, there have however been 7 occurrences in this period of either LH, RH or Fin Nav light failures, giving an occurrence rate of 8.239×10^{-5} or 1 occurrence every 12,136 fg hrs.

iii. While Anti Col Lights are obviously the most important system, it is suggested that, for the ac not easily visually detectible, a combination of Single failure Anti Col Light is combined with a single failure of a Nav Light should be considered: (assuming worst case that they are both on the same side of the aircraft and that that is the side visible to other aircraft)

$$\text{i.e. } 1.412 \times 10^{-4} \times 8.239 \times 10^{-5} = 1.16 \times 10^{-8} \text{ per FH.}$$

iv. **(NB.** It is felt that the risk of collision with another airborne system is significantly higher on Ops and it would be a surprise if any related the analysis (inc 1 Gp Op risk)

did not indicate that this was at least a cat B risk when assessed at the accident level. On Ops, the ac will likely to be reliant on convert lighting. The probability of this failure is expected to be around 1×10^{-3} with the predominant failure mechanism being Human Factors - failure to turn the system on. A baseline for HF errors is often taken to be around 3×10^{-3} , I doubt that the system reliability of this system will significantly change this figure as it's likely to be a similar order of magnitude to Nav light Failure i.e. 1×10^{-4} .)

Conditioning Factors

H27A

6. Formation Collision Factor considers:

- a. The Proximity of Aircraft in Formation: 70% of time flying is spent in formation. 5% of this time is spent in close formation.
- b. A directional Factor: an estimate of 10% is given to an affected aircraft turning towards another aircraft in formation following a loss of control of the aircraft.
- c. The damage caused following a collision in formation which leads to the loss of Tornado (in formation). This was derived from historical data regarding aircraft losses following mid air collision. At least 1 Tornado is declared Category 5 following every MAC that has occurred when in formation.

$$70\% \times 5\% \times 10\% \times 1 = 0.0035$$

7. The following were considered but not applied to H27A:

- a. A CF to take account of human error or a human not being able to react to an event in time. If add, this factor would be likely to be 3×10^{-3} .
- b. A CF to take account of the fact that not all losses of control lead to a MAC.
- c. A CF to take account of the fact that, even with an appropriate directional change, an actual MAC would depend upon the magnitude and rate of change of asymmetric thrust.
- d. A CF to take into account the fact that the required directional change would have to occur at exactly the same time as the affected aircraft was in close formation with the other formation aircraft.

H27B

8. Non-Formation Collision Factor considers:

- a. Proximity of Aircraft not in Formation: Derived from Air proximity Reports concerning General Aviation (1.82×10^{-6}), Commercial Aviation (6.83×10^{-7}) and non-formation military aircraft (1.37×10^{-6}).
- b. The damage caused following a collision in formation which leads to the loss of Tornado (in formation). This was derived from historical data regarding aircraft losses following mid air collision for General Aviation (0.5) and non-formation military aircraft (0.8). As a Tornado has not hit a Commercial aircraft, there was no historical data to review. Therefore it was considered that every Tornado involved in a MAC with Commercial aviation would be declared cat 5.

$$1.82 \times 10^{-6} \times 0.5 + 1.37 \times 10^{-6} \times 0.8 + 6.83 \times 10^{-7} \times 1 = 2.69 \times 10^{-6}$$

9. Human Error/inability Factor taken from Def Stan 0056 Iss 2:

3×10^{-3} .

10. The following were considered but not applied to **H27B**:

- a. Individual equipment environmental CFs concerning Day/night and weather etc.
- b. CF for multiple equipment failure prior to MAC.

H27 Summary of Conditioning Factors

H27A	
Proximity factor 3.5%	0.035
Directional Factor	0.1
Collision Conditioning factors	
Military aircraft in formation	
Proximity	0.0035
Loss	1
Total Collision CF	0.0035

Not Applied:

CF for non-affected aircrew reaction	3.0E-03
Minor loss of control	Not determined
Minor asymmetry in thrust	Not determined
Consideration of 4D factor	Not determined

H2 7B	
HF Error Rate 3.0E-03	3.0E-03
Collision Conditioning factors	
Non-formation military aircraft	
Proximity	1.37E-06
Loss	0.8
Total CF	1.10E-06
Commercial Aviation	
Proximity	6.83E-07
Loss	1
Total CF	6.83E-07
General Aviation	
Proximity	1.82E-06
Loss	0.5
Total CF	9.10E-07
Total Collision CF	2.69E-06

Not Applied:

Individual equipment environmental CFs concerning Day/night and weather etc	Not Determined
CF for multiple equipment failure prior to MAC	Not Determined

H27 Summary of Cause probabilities:

H27A	
H27A Z1 (Asymmetric thrust)	5.855E-04
H27A A11	9.798E-06
H27A Sum	5.753E-04
Apply Proximity factor	2.014E-05
Apply Directional factor	2.014E-06
Apply Collision CF	2.014E-06

H27B	
RHWR	0.000E+00
TACAN	2.100E-04
HSI	3.330E-04
Radar	2.160E-05
FLIR	4.500E-04
Comms	1.667E-04
TIEC ((leading to MAC))	1.630E-04
CWS	
H27B Z2 Sum	1.344E-03
SIFF	3.810E-04
Lights (leading to MAC)	1.160E-08
H27B Z3 Sum	3.810E-04
H27B Sum	1.725E-03
Apply HF Error Rate	5.176E-06
<i>Apply Control: CWS</i>	
Apply Collision CF	1.392E-11

H27	
H27 Total = H27A + H27B	2.014E-06

