EC-41-06-02-02

9 Jan 12

Sec EC

TORNADO COLLISION WARNING SYSTEM - REVIEW NOTE

References:

A. QinetiQ Tornado CWS Effectiveness Analysis dated 15 Dec 11.
B. DSTL CBA Tornado GR4 dated 13 Dec 11.

EXECUTIVE SUMMARY

Following PR11, the former SofS directed[1] that a Main Gate Business Case (MGBC) be prepared to decide whether the project to integrate a Collision Warning System (CWS) into UK Tornado aircraft remains *necessary and proportionate* in the light of potential decisions on the Tornado out-of-service date (OSD). Although the MGBC is not complete and will require full scrutiny prior to approval, sufficient data and modelling analysis has been generated to inform a judgment as requested by the former SofS. As time affects the cost/benefit equation, the issues are being presented as a Review Note (RN) in advance of the MGBC. Given the contentious nature of this project, consideration by the IAC is judged appropriate.

The last mid-air collision involving Tornado was in 1999, however, the Department has made policy commitments to CWS, and Airprox[2] incidents continue to cause concern. Modelling has suggested that the predicted Tornado collision rate per flying hour is 3 times that observed for UK General Aviation (GA)[3] and fitting a CWS would reduce the modelled rate below this GA comparator. However, further analysis suggests that the modelled Tornado mid-air collision risk is *Tolerable* for *Individual Risk-to-Life (RtL)*, under MAA regulations, and the cost-benefit case to fit CWS to reduce this risk further is not compelling. Nevertheless, the risk of collision between a Tornado and Commercial Air Traffic (CAT)[4], a multiple fatality event, presents a 'societal risk' that Health and Safety Executive (HSE) literature suggests to be intolerable, thereby providing justification to fit CWS. This RN seeks to make the case for the necessity and proportionality of the CWS project primarily on the grounds of mitigation of this societal risk, whilst acknowledging that risks against individuals and reputation are substantially reduced and those against policy are eliminated.

IAC endorsement of necessity and proportionality, ahead of any final consideration of societal issues by SofS, would maintain the momentum of the CWS endeavour, [redacted] and enable the MGBC to progress as a Category C project, thereby minimising any further delay and maximising the benefit of CWS.

ISSUE

1. Decision to progress with the Tornado CWS Project.

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[1] Email 20110620-Tornado-CWS-PR11-8-1-4-R-LIMDIS – SofS-PS to 2nd PUS-VCDS-PS
[2] An Airprox is a formal report filed by a crew where they consider that a risk of collision existed. The report is investigated by the appropriate authority.
[3] 'General aviation activities encompass private flying, aerial work and recreational flying involving all types of aircraft, together with corporate or business aviation where aircraft are operated by companies or organizations but do not carry fare-paying passengers.' (CAA website) spanning from gliders to business jet/twin turboprop aircraft.
[4] 'Commercial aviation or public transport activities are those for which passengers pay a fare, or payment is made for cargo to be carried' (CAA website). Whilst larger airliners operate across the UK, the analysis has considered CAT as an aircraft approximating to a Boeing 737-class, the most widely used type, and is representative of types which are increasingly encountered outside of controlled airspace.

RECOMMENDATIONS

2. The IAC is requested to confirm that:

a. The Tornado CWS project remains necessary and proportionate in order, primarily, but not exclusively, to reduce the societal risk of a collision with CAT.

b. The project should proceed to MGBC at the earliest opportunity and seek approval authority in full accordance with standard Category C procedures.

And is requested to note that:

c. Integration of CWS would reduce the risk of collision to a level below the closest civil comparator.

d. The analysis suggests that the modelled Tornado mid-air collision risk is *Tolerable*[5] for *Individual Risk-to-Life* and the cost-benefit case to fit CWS to reduce the risk further is not compelling.

e. DE&S estimate a 20% contractual risk probability of the CWS technical solution adding 6 months to schedule and/or ~£10M cost. This would further weaken the cost-benefit case.

f. The risk of collision between a Tornado and CAT presents a societal risk that HSE literature suggests to be intolerable.

g. MAA regulations require that where societal concerns are identified the SofS must be informed for consideration of the wider implications[6].

h. The Duty Holder accepts that the current risk of mid-air collision for the Tornado is Tolerable and ALARP, but has raised the risk to the Senior Duty Holder (SDH – Chief of the Air Staff) on the basis of societal concern.

i. No financial approval is being sought at this stage.

TIMING

3. Priority, for discussion in-Committee by the IAC on 15 Feb 12.

BACKGROUND

4. The Department has been committed to lowering the risk of a mid-air collision involving Tornado aircraft by use of a CWS since the 1998 SDR. Current Departmental policy is to introduce standards and management arrangements that are, so far as is reasonably practicable, at least as good as those required by legislation, even if military aircraft are exempt from the relevant provisions[7]. The International Civil Aircraft Organisation mandates that all aircraft in excess of 5700kg are fitted with a CWS (Tornado

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[5] As defined by MAA Regulatory Article 1210, Annex A, para 2, Figure 1.
[6] MAA Regulatory Article 1210, para 6 and Annex C paras 5 and 6 state that 'societal concern is a recognised factor in risk management when there is potential for public condemnation arising from accidents, particularly those involving significant numbers of people and/or vulnerable groups. This factor is generally significant in the context of aviation risks and acutely so for the management of risk to life in UK military aviation. Measures introduced to mitigate this class of risk need to be considered on a case-by-case basis and take into account the political dimension. If risk-to life is identified that the Senior Duty Holder (SDH) considers is of potential societal concern, the SofS must be informed for consideration of the wider implications before the SDH accepts such a risk. DG MAA must be informed in parallel when risks are referred to the SDH or SofS.'
[7] SofS Policy Statement contained within JSP 815 Annex A (Pt 1).

weighs ~14000Kg). UK military aircraft are exempted[8], yet all UK military transport, large ISTAR aircraft and many training aircraft[9] are already fitted with a CWS. As Airprox incidents continue to cause concern and a technical solution and relatively efficient integration opportunity is currently available, any mid-air collision could damage the reputation of the Department; particularly as the independent regulator has expressed concern[10]. The scenario most likely to trigger such consequences is a mid-air collision involving passenger carrying CAT, resulting in a large number of fatalities. The HSE define societal concerns due to the occurrence of multiple fatalities in a single event as societal risk[11]. Global examples of Fast Jet (FJ) collisions with CAT are minimal and no UK FJ has been involved in such a collision.

5. In Afghanistan, a mid-air collision by Tornado involving a troop-carrying military transport aircraft would arguably be of equal societal concern to any CAT incident within UK airspace, but with added strategic significance; the Op HERRICK mid-air collision risk is one of the Operational Duty Holder's (ODH – AOC 1 Gp) highest concerns. Given that CWS could be effective beginning in Jun 14, prior to the withdrawal from Theatre in ~2015, some potential for CWS to provide a limited period of benefit exists.

6. Up to PR11 and despite the lack of CWS, the ODH judged the overall Tornado collision risk to be *Tolerable* and ALARP based on there being, in-place, a viable project to deliver the system for Tornado. The decision to delete Tornado CWS in PR11[12] terminated work on the project and, on this basis, the ODH and SDH no longer judged the risk *Tolerable* and ALARP. The SDH then escalated the risk to the former SofS[13], whilst confirming that '*all other possible non-equipment mitigation measures to reduce the risk of a Tornado mid-air collision with any other aircraft have been exhausted.*'[14] DER directed that the case be presented to the IAC for consideration. The analysis in this RN considers solely the mitigation of the risk of a mid-air collision involving Tornado. The RN does not consider the relative benefit of mitigating other risks across Defence[15] that the IAC may consider to be of higher priority.

PROGRESS WITH THE TORNADO CWS PROJECT

7. DE&S competitively selected a TCAS II derivative, similar to those in use on other RAF aircraft. Whilst work is ongoing between BAE Systems and DE&S to define the content for a robust re-costing of the CWS implementation programme, no further BAE Systems information is available to support this RN, therefore DE&S has provided its internal estimates of how a revised CWS programme could be delivered:

a. Cost. Previous BAE Systems and associated programme activity costs have been extrapolated to generate the 'deterministic values' shown below which have not been subject to approval scrutiny and are thus indicative only:[16]

	2018 OSD Option[17]	Current 2021 OSD
Min	£51.1M	£46.5M
Most Likely	£54.5M	£48.5M

[8] UK Air Navigation Order 2009 Article 39(2) (detailed in Schedule 5). The Air Navigation Order is a statutory instrument pursuant to the Civil Aviation Act (1982).
[9] Hawk T2 aircraft are fitted with TCAS II, Tucano aircraft with TCAS I.
[10] MAA DG/03/01/MOD STRAT dated 13 Jun 11.
[11] From HSE Reducing Risks, Protecting People (R2P2), paras 25 & 136 define.
[12] RP-10-11 dated 4 Apr 11 – Planning Round 2011 – Implementation of Ministerially Endorsed Measures. Annex F ser 180 'Savings assumed but option reviewed in 3 month review'.
[13] The SofS is ultimately responsible for safety in Defence.
[14] CAS/02 dated 14 Jun 11
[15] Including the mid-air collision risk associated with Hawk T1, Typhoon, helicopters, or foreign aircraft operating in UK airspace.
[16] These costs can be considered rough equivalents to 10%, 50% and 90% figures. The 'Most Likely' costs were used in the CBA annotated as '50% Confidence' costs.
[17] Increased costs compared to the Current 2021 OSD due to more aircraft requiring standalone embodiment.

Max	£60.3M	£52.5M

b. Timescale. IAC endorsement of Tornado CWS proceeding as a Category C project from Feb 12 could enable an Aug 12 contract award. Timelines for the 2018 and 2021 OSDs are as follows:

i. [redacted].

ii. [redacted].

c. Risk. Industrial coherence developments may impact CWS cost and schedule implementation programme. Specifically, BAE Systems' 'Measure and Declare' stance adds technical and commercial risk to the programme. [redacted] risk that would otherwise need to be held by DE&S. DE&S considers an additional 6 months' schedule and £10M cost risk at around 20% probability as a realistic estimate.

8. The CWS project is based heavily on estimates derived from previous BAE Systems work established in a different industrial/commercial environment. Although there is undoubtedly risk associated with this project, DE&S judgement, supported by Dir CA, is that the CWS endeavour remains viable and IAC endorsement of the project as 'necessary and proportionate' [redacted] and help to accelerate the preparation of the MGBC.

COLLISION RISK MODELLING

9. Historically, the UK Tornado ground-attack fleet has suffered 9, CWS-relevant[20], mid-air collisions since its introduction in the early 1980's. Sixteen fatalities (including 4 civilian deaths) have resulted and 10 aircraft have been lost; the last mid-air collision occurred in 1999. Evidence suggests an improving trend in the UK Tornado mid-air collision record and reducing Airprox submissions (illustrated in Annex A). Several factors, including improvements in procedures, greater awareness, reducing fleet sizes (and flying hours) and changes to training practices (a greater proportion of medium level training) have contributed to this trend. However, Airprox reports continue to cause concern to the Duty Holder and the Regulator.

10. Future Tornado collision risks were analysed by QinetiQ using a probabilistic model for the time period from 2011 until OSD (2018 Option and planned 2021), with and without CWS fitted, at Reference A. This analysis determined the future risk to 1st and 3rd parties (military, GA and CAT) exposed to Tornado mid-air collision risk in UK uncontrolled airspace. The model can be plausibly validated against recorded Airprox incidents, but has some inherent limitations, arising particularly from a limited sample size of recorded collisions and the associated small mathematical probabilities. Additional risk-reduction approaches such as aircrew behaviours, airmanship or the use of air traffic services, are not considered within the model. Operational flying is not modelled directly, but the cost-benefit analysis (CBA) has been factored to account for this significant source of risk.

18 [redacted]

19 Forward Available Fleet (FAF) + 3 aircraft (total of 40 aircraft based on current Force-level assumptions) 'fitted with' CWS.

20 Assessed as potentially preventable accidents had a collision avoidance system been fitted.

11. The analysis delivered results derived from the expected Tornado UK flying hours profile (adjusted for realism) and a progressive fleet CWS embodiment, starting in 2013 and completed by 2016. Flying profile variations from predictions of operational flying (producing min and max flying profiles) were examined in the subsequent CBA. The main insights drawn from the modelling were:

a. Between now and the <u>2021 OSD</u>, the expected rate of Tornado random mid-air collision accidents in UK uncontrolled airspace would be reduced from 1 in 32 years[21] to 1 in 59 years by the introduction of CWS. **Within this calculation there is a 90% chance that any collision will be with GA traffic, 8.7% with a mil aircraft and 1.3% against CAT.**

b. Between now and the <u>2018 OSD</u>, the expected rate of Tornado random mid-air collision accidents in UK uncontrolled airspace would be reduced from 1 in 30 years to 1 in 44 years by the introduction of CWS. **Within this calculation there is a 90% chance that any collision will be with GA traffic, 8.7% with a mil aircraft and 1.3% against CAT.**

c. The probability of a collision between a Tornado and CAT in UK Class F/G (uncontrolled) airspace is reduced from a mean of 1 in 3,900 years to 1 in 34,000 years after the full introduction of CWS.

d. The implementation of CWS reduces the modelled random overall expected collision rate for the Tornado from 4.04 collisions per million flying hours to a residual rate of 0.9 collisions per million flying hours; for comparison, the observed historical collision rate for UK GA, the closest comparator, is 1.3 collisions per million flying hours.[22]

<u>RISK AND COST BENEFIT ANALYSIS</u>

12. At Reference B, DSTL have taken the output of the QQ model along with a range of further agreed assumptions and conducted a comprehensive Risk and Cost-Benefit Analysis (CBA). The CBA sought to determine the individual RtL to 1st and 3rd parties and, if *Tolerable*, assist the ALARP assessment. **It should be stressed that the CBA cannot be used to justify risks that the Duty Holder assesses to be intolerable (unacceptable), circumvent any statutory duties or to solely demonstrate that risks are ALARP. The CBA contributes to the quantitative assessment and, as it is based on assumptions and modelling, its results are indicative rather than absolute. It provides, in conjunction with other factors that may be more important, an aid to decision making.** Finally, the analysis also considered the specific case of a Tornado collision with CAT in the context of a societal risk. For societal risks, the examination of individual RtL tolerability is not appropriate and comparisons have been made to HSE literature.

13. The CBA compared evaluated risks against the MAA risk boundary table, illustrated at Figure 1 below (and graphically as Figures 1 and 2 in Annex B). The risk of collision to 1st party[23] was 1 in 1166 per annum, therefore *Tolerable*, but close to the 1 in 1000 per annum boundary. The fitting of CWS would reduce the 1st party risk of collision to 1 in 5177 per annum, still within the *Tolerable* region but well short of the 1 in 1,000,000 *Broadly Acceptable* level. The relevant 3rd party risks were all assessed to be in the *Tolerable* region but lie much closer to the *Broadly Acceptable* boundary; fitting CWS moves the 3rd party risk beyond the *Broadly Acceptable* boundary.

Boundary	Aircraft Types	Risk Of Death Per Annum for Population at Risk		
		1st Party	2nd Party	3rd Party
Intolerable	All	> 1 in 1000	> 1 in 1000	> 1 in 10000

[21] In this context, accepted to correspond to 'per annum' values used by HSE.
[22] The Tornado GR fleet achieved the 1,000,000 flying hours milestone in 2011.
[23] Not all Tornado collisions have resulted in 100% crew fatalities; some aircraft have landed safely and a number of crews have successfully ejected. Thus, the actual risk to 1st party lives is theoretically 'safer' than the *risk of collision* figures.

Tolerable	All	≤1 in 1000	≤1 in 1000	≤1 in 10000
Broadly Acceptable	All	≤1 in 1,000,000	≤1 in 1,000,000	≤1 in 1,000,000

Figure 1: MAA Risk Boundaries

14. The CBA assessed two distinct OSD cases (2018 and 2021) with an expected and enhanced flying profile for each. Tornado mid-air collision scenarios for assessing most likely and worst-credible events were provided by the ODH at Annex C. Importantly, the main CBA results (Tables 1 to 3 in Annex B) included hours flown in operational theatres. For all these hours, whether or not they were flown in the anticipated Op HERRICK period, the risk of collision was based on what is currently observed in Afghanistan where the risk is judged by HQ 1 Gp to be 'double the UK.' However, there is a considerable difference between the composition of air traffic in the UK and Afghanistan (and any other potential operational theatre). In particular, where there is a 90% chance in the UK that any collision will be with GA, there is little, if any, GA present in the Afghanistan. Therefore, this risk was distributed and mathematically factored across the mil aircraft and CAT risk to produce an outcome in overall risk terms that was equivalent to doubling the UK risk. This broad estimate of operational theatre risk, based entirely on the current Afghanistan assessment, has a significant, arguably driving, impact on the overall results which is open to challenge.

15. The results (including Benefit tables shown in Annex B) indicate that, from a CBA perspective only, embodiment of CWS is reasonably practicable only in certain cases where maximum fatality levels are assumed. Risk would need to be multiplied by 4 times for benefit to outweigh costs in all cases at the mid fatality level and by approximately 8 times at the low fatality level. A key judgement is whether the modelled risk per flying hour is optimistic (underplays the actual risk) or pessimistic (overplays the actual risk). The model does not take into account a number of mitigating factors and it predicts a rate of collisions and conflicts that is statistically plausible, but beyond the current rate of Airprox incidents particularly where CAT is concerned. If the Duty Holder considers the modelled risk to be pessimistic, this calls into question the validity of multiplying the risk beyond the +14%, assessed as the model accuracy.[24] Given the care taken not to underestimate risk, the effects of operational theatre assumptions and the application of worst case casualty values, it could be deemed reasonable to limit the multiplication of risk to +14%. Should this be accepted, **the cost-benefit case to fit Tornado CWS on an individual RtL basis is not compelling for either 2018 or 2021 OSD.**

16. In addition to the examination of individual RtL, DSTL also analysed the societal risk of a collision involving Tornado and CAT. The HSE has *proposed* that, as a basic criterion for the limit of tolerability, '*the risk of such an accident causing the death of 50 or more people in a single event should be regarded as intolerable if the frequency is estimated to be more than 1 in 5000 per annum*[25]. In the modelled case of Tornado collision with CAT, including the equivalent in operational theatres, risk of a societal event is averaged to a frequency of 1 in 2918 per annum over the lifetime of Tornado (and 1 in 3900 per annum for the period post 2015 - the potential CWS FOC point). Clearly, these frequencies are higher than the level that HSE *suggest* as the limit of tolerability. The embodiment of a CWS system reduces the risk of a societal event over the lifetime of the platform to a frequency of 1 in 33835 per annum. If the risk of a Tornado collision with CAT is judged intolerable under the HSE criterion, this **provides justification for CWS regardless of OSD and indeed cost, if Tornado operations are to continue**. MAA regulations require that where societal concerns are identified, the SofS must be informed for consideration of the wider implications.

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24 In Reference A, the risk per fg hour calculation accuracies are estimated as +/- 14.1% with a 95% confidence level.

25 HSE publication Reducing Risks, Protecting People para 136 dated 2001.

ODH JUDGEMENT

17. In judging whether a risk is ALARP, the MAA advises[26] Duty Holders to consider three areas when making his overall risk assessment: *Good practice,* comprising areas such as policy[27], regulations[28] and relevant best practice[29]; *quantitative assessment*, the CBA, which the ODH accepts; *Qualitative Judgement,* for which the ODH states:

a. *The operating environment of any aircraft poses an ever present possibility of a mid-air collision. As part of the air operating environment in which the Tornado GR4 flies, it should be noted that it is not possible to remove the risk of collision with another aircraft completely, regardless of the controls and mitigations put in place. A mid-air collision may result in no loss of life. However, Risk to Life (RtL) is always present and that the spectrum of outcome varies widely. Therefore, it is necessary to consider the worst credible outcome along with a range of more likely outcomes.*

b. *Taking into account all the factors presented to the ODH on the risk of mid-air collision for the Tornado GR4, he accepts the quantitative arguments and conclusions and agrees that the case for embodiment of CWS on the Tornado GR4 is marginal. The ODH is also content that all mitigating activity within his control has been and continues to be taken to minimise the risk of a mid-air collision. The RtL of continuing Tornado GR4 operations without a CWS is, therefore, considered to be Tolerable and ALARP. However, owing to societal concerns and the reputational damage should a collision occur, in accordance with Regulatory Article 1210, it is inappropriate for the ODH to hold this risk which must remain with the SDH.*[30]

PRESENTATION AND HANDLING

18. This is a complex and contentious safety issue that potentially affects the wider public. Should the IAC decide not to proceed with the CWS programme, special presentation measures may be required to avoid any misunderstanding of the risk complexities.

M L ROBERTS
Air Cdre
HoC DTA

Annexes:

A. Tornado Collision Charts
B. Headline Results of the Tornado CWS Cost-Benefit Analysis
C. Mid-air Collision Scenarios – Tornado GR4 – HQ 1 Gp

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[26] MAA Regulatory Article 1210 Annex E.
[27] SofS Policy Statement contained within JSP 815 Annex A (Pt 1).
[28] ICAO TCAS mandate and the Air Navigation Order 2009 under which the UK military has TCAS exemption.
[29] The RAF has already fitted forms of CWS to many in-Service types however, there are no known foreign fast-jet users. Specifically, the USAF has deleted a programme to fit its F-series and A-series FJ aircraft with a CWS as it was deemed unaffordable. The French L'Armee de L'Air does not have such a system embodied in its fast jets. However, JSF is currently mandated to be fitted with a CWS (ADS-B) from Block 4 (~2020) onwards.
[30] In accordance with Para 5, Annex C, Regulatory Article 1210, MAA Regulatory Publications.

ANNEX A TO
EC-41-06-02-02
DATED 9 Jan 12

TORNADO COLLISION CHARTS

1. Historic charts for Tornado losses:

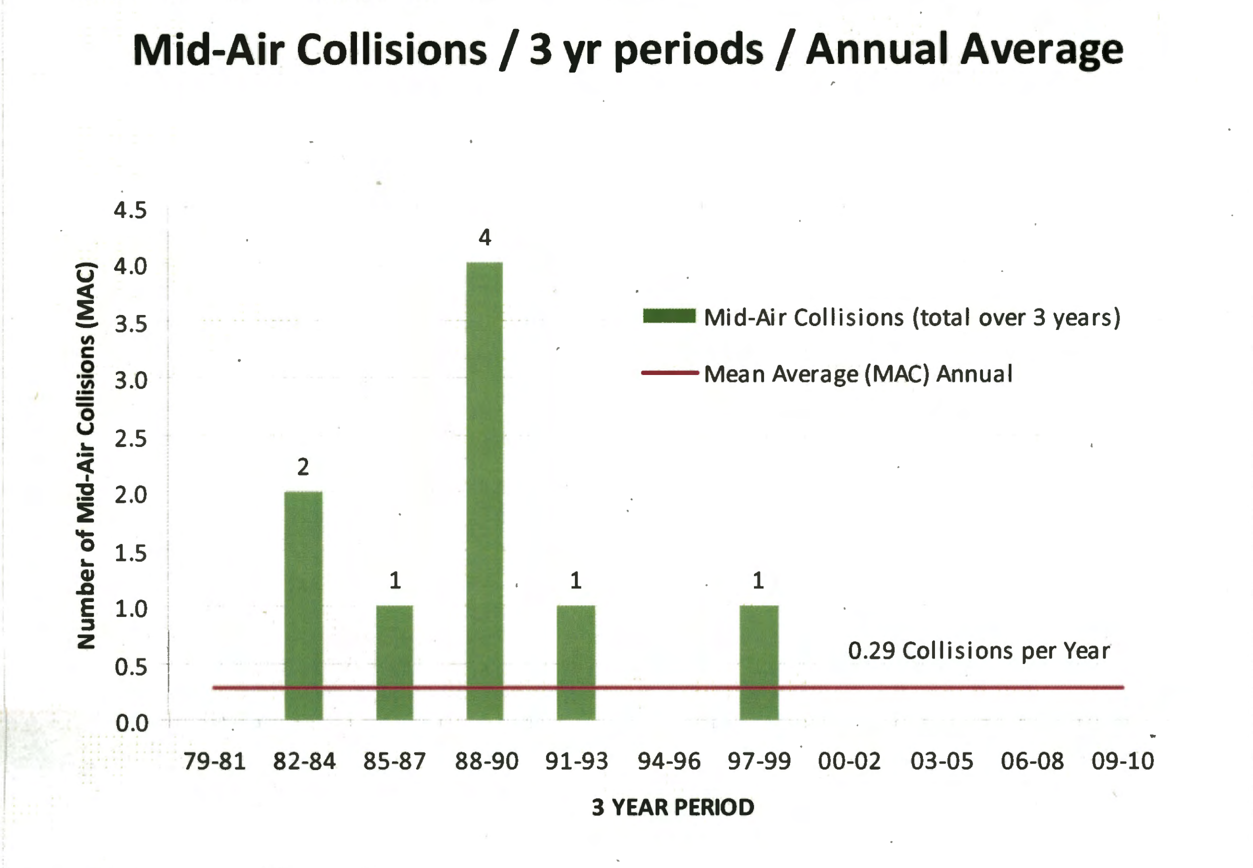

Figure 1 – UK Tornado Collision Rate[31]

[31] Source – QinetiQ analysis data (v2) compiled through DARS. The collisions calculated were those considered potentially benefiting from CWS.

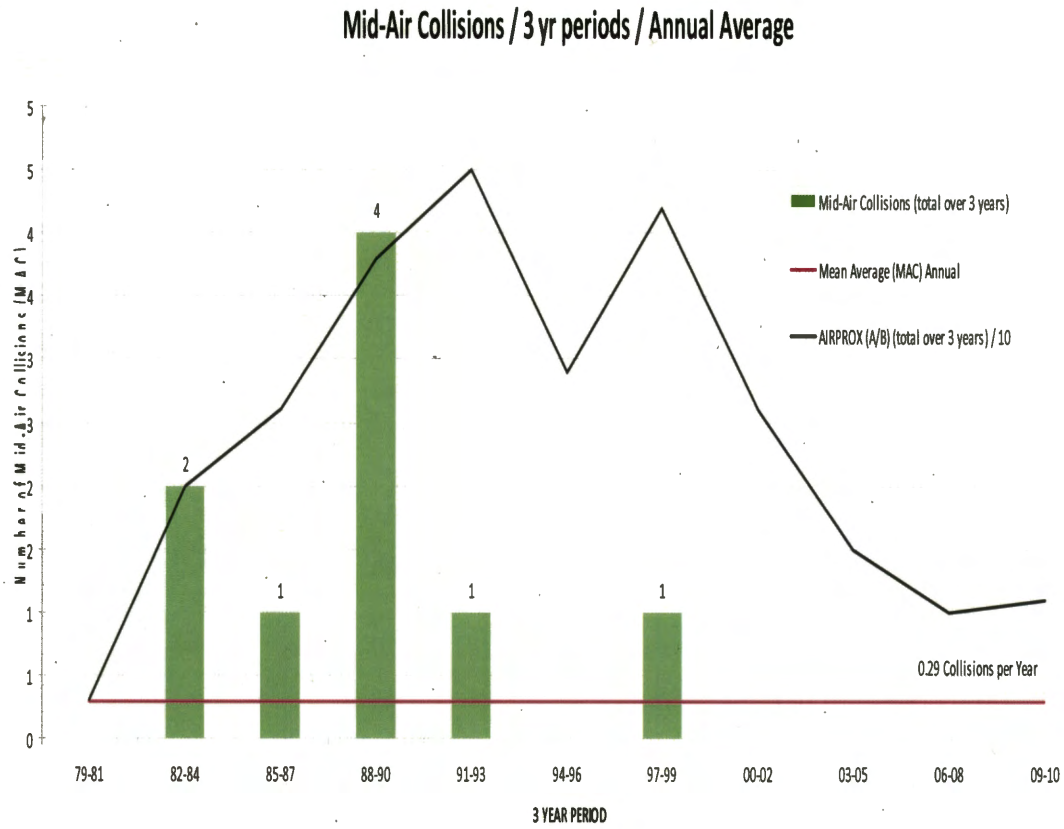

Figure 2 – UK Tornado Rate Collision with UK Category A&B Airprox overlay[32]

[32] Source – QinetiQ analysis data (v2) compiled through DARS, UK Airprox Board and HQ1Gp. The collisions calculated were those considered potentially benefiting from CWS.

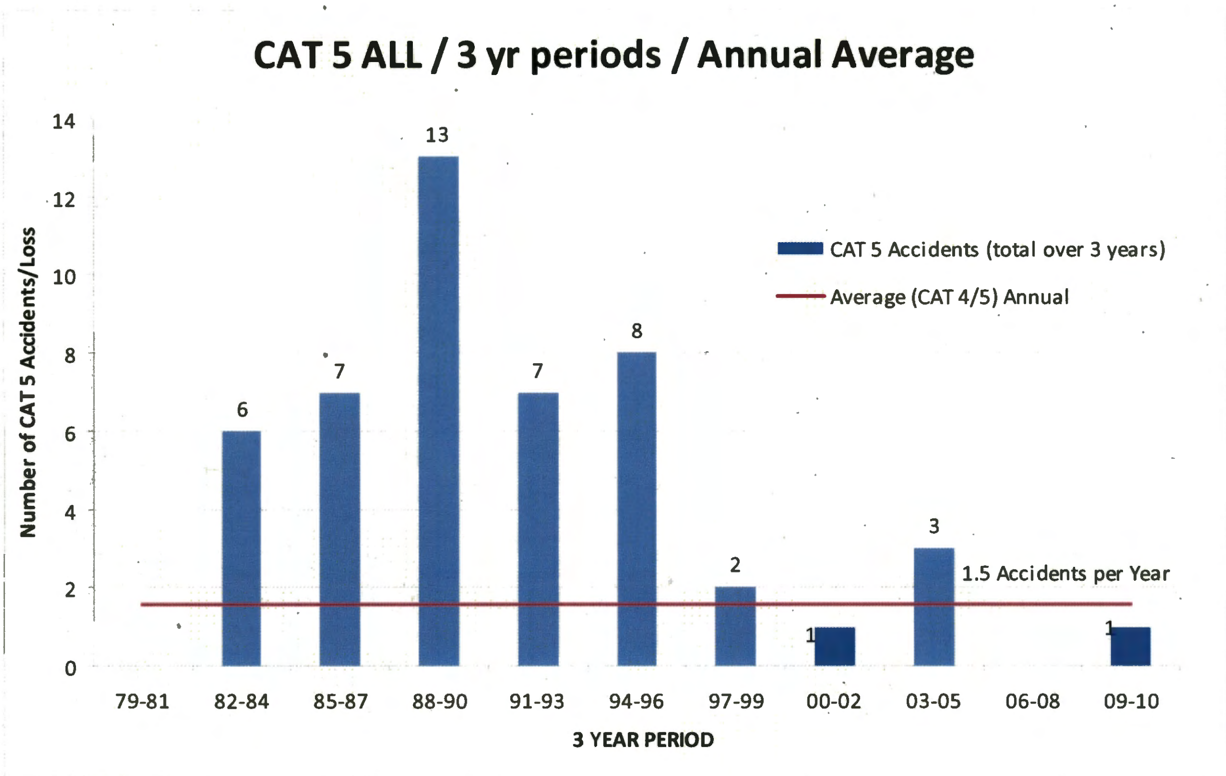

Figure 3 – UK Tornado All Category 5 Losses

ANNEX B TO
EC-41-06-02-02
DATED 9 Jan 12

HEADLINE RESULTS OF THE TORNADO CWS COST- BENEFIT ANALYSIS

1. Graphic representations of Tornado related RtL against the MAA Tolerability 'carrot' are shown below:

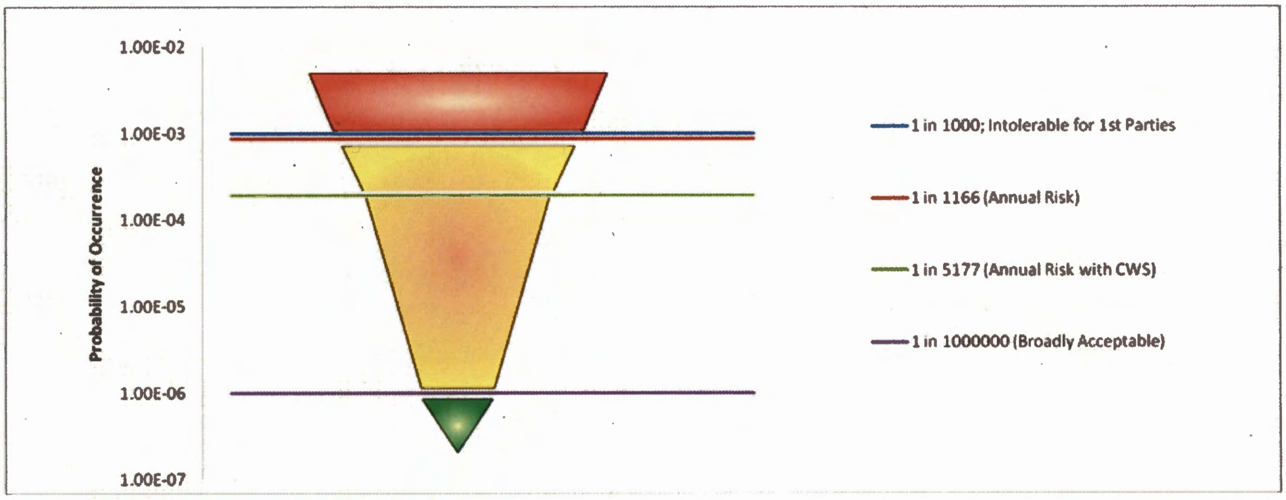

Figure 1: Tolerability of Individual RtL per Annum – 1st Party

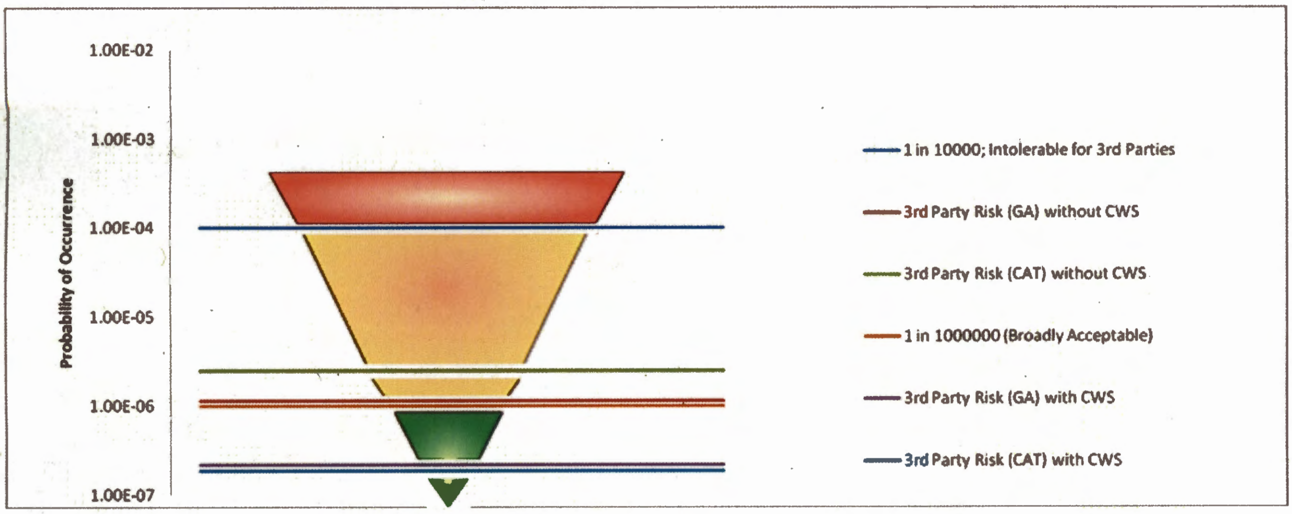

Figure 2: Tolerability of Individual RtL per Annum – 3rd Party

2. The CBA was conducted for two distinct cases, each with 2 sub-cases::

a. Case 1 assumed a Tornado OSD of 2018.

i. Case 1A assumed a total of [redacted] flying hours (enhanced flying hours).

ii. Case 1B assumed a total of [redacted] flying hours (anticipated flying hours - consistent with the 2018 OSD Option profile for Tornado).

b. Case 2 assumed a Tornado OSD of 2021.

i. Case 2A assumed a total of [redacted] flying hours (enhanced flying hours).

ii. Case 2B assumed a total of [redacted] flying hours (anticipated flying hours – consistent with the 2011 RAF Management Plan, corrected for realism).

4. Scenarios for mid-air collision events provided by HQ 1Gp included possible collisions with a range of aircraft resulting in a range of 1st and 3rd party fatality figures, from 1 to in excess of 200. These were used to produce Low, Medium and High (worst credible case) fatality scenarios. The analysis, which is consistent with the principles outlined by the MAA[33], determined the net benefit of fitting CWS. Importantly, the results included hours flown in operational theatres. For all these hours, whether or not they were flown in the anticipated Op HERRICK period, the risk of collision was based on what is currently observed in Afghanistan where the risk is assessed by HQ 1 Gp to be 'double the UK.'

5. The results indicate that the greatest benefit offered by CWS is for Case 2A (2021, enhanced flying hours), then Cases 1A (2018, enhanced flying hours) and 2B (2021, anticipated flying hours), broadly corresponding to remaining flying hours. Case 1B (2018, anticipated flying hours) is the only case where the benefit does not outweigh cost regardless of fatality level. Using mid fatality levels, which are based on historic statistical averages, the CBA suggests that benefits are outweighed by costs in all cases.

6. The figures in the tables below indicate the net positive or negative benefit of fitting CWS. From a CBA perspective only, a negative benefit indicates that the cost could be considered grossly disproportionate to the benefit gained; alternatively, a positive benefit (bold) indicates where fitting CWS could be considered proportionate to the benefit gained. Given the nature of this risk, iaw MAA guidelines, a calculated **Gross Disproportionality Figure (GDF) of 9.998 has been used in all benefit calculations.**[34]

Baseline (100%) Risk	FATALITY LEVELS		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, ENHANCED FH	-£43.5M	-£29.2M	**+£16.8M**
CASE 1B: OSD 2018, ANTICIPATED FH	-£47.3M	-£38.6M	-£10.9M
CASE 2A: OSD 2021, ENHANCED FH	-£33.8M	-£16.5M	**+£39.1M**
CASE 2B: OSD 2021, ANTICIPATED FH	-£37.9M	-£26.4M	**+£10.3M**

Table 1: Net Benefit - Baseline 100% Risk

7. Given the broad assumptions made in the CBA process, sensitivities must be applied. The modelling suggests that the figures for risk per flying hour can be assumed to be +/- 14% and HSE guidelines suggest that such key assumptions on risk should be factored by 2 or 3 times to properly

[33] MAA/RN/12/11 (DG) – Cost Benefit Analysis of Potential Air Safety Measures – Principles dated 08 Nov 11. In addition to this notice, MAA (Tech) provided guidance and feedback throughout the analysis process.
[34] The HSE discuss the use of a Gross Disproportion Factor (GDF) where if total costs of the safety measure are greater than benefits multiplied by GDF, then the measure's costs are disproportionally higher and it is not reasonable practicable to implement. The GDF is a multiplication factor between 1 and 10, assuming the risk is in the tolerable boundary, and is dependent on the annual risk per 1st party; a 1 in 1000 risk would have a GDF of 10, a 1 in 1,000,000 risk would have a GDF of 1. MAA guidance specifies that the risk considered for determining GDF should be the overall aggregated risk to the activity that is the annual risk of death, per pilot or navigator in flying Tornado GR4, and recommend that this is linearly interpolated.

understand the sensitivities. Increasing the risk per flying hour by 14% produces a similar pattern to the baseline evaluation. Although benefits are increased across the board, costs still outweigh benefits for Case 1B (2018, anticipated flying hours) at all fatality levels. If the risk per flying hour is increased by 200% the benefit always outweighs cost at the high fatality level. However, at the mid fatality level, benefits only outweigh costs in Case 2A (2021, enhanced FH) where the level of flying hours is significantly beyond the currently resourced position.

Sensitivity (114%) Risk	FATALITY LEVELS		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, ENHANCED FH	-£41.9M	-£25.7M	**+£26.8M**
CASE 1B: OSD 2018, ANTICIPATED FH	-£46.2M	-£36.4M	-£4.8M
CASE 2A: OSD 2021, ENHANCED FH	-£31.7M	-£12.0M	**+£51.4M**
CASE 2B: OSD 2021, ANTICIPATED FH	-£36.4M	-£23.3M	**+£18.6M**

Table 2: Net Benefit - 114% Risk

Sensitivity (200%) Risk	FATALITY LEVELS		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, ENHANCED FH	-£32.5M	-£4.0M	**+£88.2M**
CASE 1B: OSD 2018, ANTICIPATED FH	-£40.0M	-£22.8M	**+£32.7M**
CASE 2A: OSD 2021, ENHANCED FH	-£19.0M	**+£15.6M**	**+£126.8M**
CASE 2B: OSD 2021, ANTICIPATED FH	-£27.3M	-£4.3M	**+£69.2M**

Table 3: Net Benefit - 200% Risk

Sensitivity (300%) Risk	FATALITY LEVELS		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, ENHANCED FH	-£21.4M	**+£21.4M**	**+£159.6M**
CASE 1B: OSD 2018, ANTICIPATED FH	-£32.8M	-£6.9M	**+£76.3M**
CASE 2A: OSD 2021, ENHANCED FH	-£4.3M	**+£47.6M**	**+£214.4M**
CASE 2B: OSD 2021, ANTICIPATED FH	-£16.7M	**+£17.9M**	**+£128.1M**

Table 4: Net Benefit - 300% Risk

Sensitivity (800%) Risk	FATALITY LEVELS		
UK and Op Scenarios	LOW	MID	HIGH

CASE 1A: OSD 2018, ENHANCED FH	+£33.7M	+£147.8M	+£516.5M
CASE 1B: OSD 2018, ANTICIPATED FH	+£3.4M	+£72.5M	+£294.3M
CASE 2A: OSD 2021, ENHANCED FH	+£69.5M	+£207.9M	+£652.8M
CASE 2B: OSD 2021, ANTICIPATED FH	+£36.4M	+£128.6M	+£422.6M

Table 5: Net Benefit - 800% Risk

ANNEX C TO
EC-41-06-02-02
DATED 9 Jan 12

20110919-GR4CollisionScenarios-AOC1Gp-RM

19 Sep 11 (Revised 24 Nov 11)

Cap DTA - HOC

MID-AIR COLLISION SCENARIOS – TORNADO GR4

1. **Issue**. Mid-air collision scenarios that inform analysis in creating a MGBC for fitting CWS to Tornado GR4.

2. **Key Points**:

a. I offer 10 scenarios for mid-air collisions involving Tornado GR4.

b. I assess the Most Likely mid-air collision scenarios to be:

(1) **Op**. Collision between a Tornado GR4 and another air platform in the vicinity of KAF.

(2) **UK**. Collision between a Tornado GR4 and a GA platform in the UKLFS.

c. I assess the Worst Credible mid-air collision scenarios to be:

(1) **Op**. Collision between a Tornado GR4 and an airliner in the vicinity of KAF.

(2) **UK**. Collision between a Tornado GR4 and a commercial airliner when the GR4 conducts an emergency climb-out from low-level into UK Controlled Airspace (CAS).

3. **Recommendation**. That the 10 scenarios be considered when assessing the probability of mid-air collision involving Tornado GR4 aircraft.

BACKGROUND

4. Cap DTA asked for advice in my capacity as the Tornado GR4 ODH to inform analysis of the requirement to fit CWS to the Tornado GR4 fleet. I have identified a comprehensive, but not exhaustive, list of factors that affect Likelihood and Severity of a mid-air collision scenario, together with the platforms that could be in collision with a Tornado GR4 (detailed at Annex A). I have also cross-referred to Airprox data, where possible, to support my analysis. To address aggregated risk simply, and in terms of Human Factors, I have based this upon trained, competent and supervised aircrew, but who are susceptible to HF errors. I therefore offer you a series of credible mid-air collision scenarios, primarily based upon informed judgement, on which you can base elements of your analysis as you progress the Tornado GR4 CWS BC towards MG. I have judged where I believe the Most Likely and Worst Credible scenarios sit, and would appreciate feedback from the mathematical analysis used within the BC to reinforce, or allow me to redefine, my judgements. CONOPS advice was sought from TCAS2 users on the Hawk T Mk2 at RAF Valley as the sole users of TCAS2 within the low-level fast jet community. The Hawk TMk2 has only been in service a limited time so the colloquial evidence gathered so far is limited and should not be treated as authoritative.

ASSESSMENT

5. I assess the following mid-air collision scenarios to be credible:

a. **Tornado GR4 in the UKLFS.** There were 9 mid-air collisions involving Tornado aircraft between 1984 and 2009 involving 12 Tornado airframes and 2 GA platforms.[35] In addition, DARS report that there have been 378 reported Airproxes from 2001 to 2008, of which 94 involved Tornado GR4, of which 48 were Cat A or B. Of those 48, 31 were with GA and 2 with commercial AT.[36] With the reduction in UK military low-flying in recent years, I believe that the probability of a mid-air collision with another Defence platform, although entirely credible, is not as high as is the risk of collision with a GA platform. I, therefore, consider the Most Likely UK mid-air collision scenario is between a Tornado GR4 and a GA platform at low-level. Discussions with crews from the Hawk TMk2 showed the main limitation of TCAS at low level was the Line-of-Sight (LOS) nature of the system. Warnings were generated against other low level fast jet aircraft but were invariably late in nature an nearly always after any confliction had been picked up visually. Warnings against GA traffic were generated slightly earlier but we also subject to LOS limitations. From this limited evidence it is safe to assume that installation of a TCAS2 system on GR4 would reduce the risk of collision but the system does have major limitations in this environment.

b. **Tornado GR4 Climbing Out From Low-Level – Routine.** A climb-out from low-level is a dynamic manoeuvre, often without full radio contact with an ATC agency, and when lookout arcs can be subject to airframe blanking. The rapid change in altitude also leaves little time for Area ATC agencies to co-ordinate other traffic around the GR4's radar return. Such a collision scenario could happen anywhere in the UKLFS. User evidence shows that TCAS2 is very useful during the initial stages of a controlled climb-out before 2-way communication has been established with a radar agency. There is a limitation with the system in that if the host aircraft's rate of climb exceeds 6000 fpm the system, effectively, 'shuts down'. Even during a relatively gentle fast jet climbing profile this is exceeded thereby negating the warnings that could be generated by TCAS2. A mitigation could be introduced by ensuring crews reduce their rate of climb to maintain TCAS functionality. Assuming this mitigation was adopted TCAS2 could provide good deconfliction from traffic in the initial stages of a controlled climb-out.

c. **Tornado GR4 Climbing Out From Low-Level – Emergency.** Based upon the previous scenario, but when under emergency conditions or deteriorating weather, a crew will have less time to plan the location of a climb-out, more focus in-cockpit, and therefore less Situational Awareness (SA) of other air traffic. Moreover, an emergency entry into CAS is likely to increase proximity to a commercial airliner (increasing severity). I view the scenario of a GR4 colliding with an airliner in CAS when the GR4 is conducting an emergency climb from low-level as the Worst Credible UK scenario. Examples are when operating under the Scottish TMA or under the airways above the Peak District. However, in a continuation from the scenario in para b above, the TCAS2 system would be rendered useless by the rate of climb during a low level abort manoeuvre. No mitigation would be possible in this scenario as the safety of the aircraft and crew would be paramount and reducing rate of climb would not be a viable option. Once established in a safe flight regime the system could be used for deconfliction.

d. **Tor GR4 Operating Close to a CTZ.** Air traffic density increases near CTZs. To mitigate the risk of collision described in sub-para 4a, crews give due berth to CTZs, backed up by 2-way contact with the controlling agencies when possible. Notwithstanding this, GA operating ivo CTZs and commercial platforms operating into remote CTZs do not always

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[35] QINETIC Report 10/00702 dated 23 Mar 10.
[36] QINETIC Report 10/00702 dated 23 Mar 10.

follow predictable flight-paths (before entering the CTZ), both of which provide a credible opportunity for mid-air collision. Examples are the Stornaway region and the numerous 2nm / 2,000' Zones on the west coast of Scotland. As GA traffic operating closer to airfields tend to be at or above 2000' AGL the TCAS2 system should give more than adequate warning of any potential confliction as the LOS limitation should be minimised, regardless of the height of the military aircraft. Having said this, military crews tend to be more alert and focussed on deconfliction when close to known areas of higher traffic density such as around ATZ / CTZs so while the TCAS2 would increase awareness its effect may not be as marked.

e. **Tornado GR4 Operating in Class G Airspace**. Military aircraft are permitted to transit in Class G airspace without an ATC service, although airmanship dictates that this should not be undertaken unless necessary. There are increasing numbers of commercial airliners operating outside of airways whose flight-paths could conflict with a transiting GR4. An example of this is commercial aircraft transiting N-S on the east coast of the UK to Newcastle. RAF Valley users state that this scenario is where the TCAS system is at its most useful. Once the aircraft is established in the transit at ML the system is within its ideal operating environment and will provide excellent warning of any confliction. Military aircraft recovering to base (but not transiting far enough to make the establishment of a radar service worthwhile) would benefit most from TCAS2 installation as it would greatly reduce chance of collision. It is also worth noting that the instances of GA or CAT operating in Class G airspace is increasing (Eastern Airways over the North Sea, for example); installation of TCAS2 to GR4 aircraft would significantly reduce the chance of a collision on this scenario.

f. **Tornado GR4 Operating Within Controlled Airspace**. A Tornado GR4 operating within a TMA or CTZ will be in closer proximity to civilian platforms, in particular commercial airliners. However, the Tornado will be under a full radar service and subject to specific deconfliction. This would be a credible mid-air collision scenario, of which an example is a Tornado GR4 on practice diversion to Edinburgh. There is little user evidence within this scenario although it is assumed that as all aircraft will be under full radar control the chance of collision would be minimal, although credible. Installation of TCAS2 would reduce the chance of collision on the very rare occasion that ATC make a critical error during controlling.

g. **Tornado GR4 Operating Within a Large Ac Package**. There is a significant degree of co-ordination when operating within large packages, time and space deconflicted by airspace coordination measures (eg ATO). Similar to the above scenario, although there is greater co-ordination, the nature of the task brings aircraft close together in a dynamic and pressured environment, thus creating a credible mid-air collision risk. There are 2 differing scenarios that must be considered in this case; low level and medium level. At low level the LOS limitations outlined in para a above would apply significantly reducing the effectiveness of TCAS2. At medium level, the system would be more effective at giving warning of any potential collision but no data is available on the credibility of the system when operating in a large aircraft, dynamic formation. Further analysis would be required as to the level of spurious warnings that may be generated due to the proximity of a large number of aircraft in a limited area.

h. **Tornado GR4s in Formation**. Significant levels of training are invested in aircrew for formation flying, be that In close formations or tactical formations. It is of note that work in AWRs and medium level CAS orbits force aircrew to divide their focus between formation deconfliction in a small, dynamic portion of airspace and the task itself. I assess this, therefore, as being a credible in-formation mid-air collision scenario. Again, the low level vs medium level scenario and spurious warning limitation may well apply as outlined in para g. Hawk users report that very few warnings are generated from 'within the formation'.

i. **Tornado GR4 Recovering to KAF.** The arising rate for Airprox in AFG is 0.88 per 1000 FH vice the UK rate of 0.45.[37] While there is not necessarily a direct correlation between Airprox reporting and mid-air collision, it would be reasonable to offer that a doubled incidence of Airprox, in simple terms, would double the risk of mid-air collision. Based upon feedback from the TGRF, I assess the risk to be at its highest ivo KAF. I, therefore, assess this to be the Most Likely Op theatre mid-air collision scenario. I assess the Worst Credible to be such a collision that involves a commercial airliner. There has already been one reported Airprox between a GR4 and a PAMIR Airways B737 on 1 Mar 2011.[38]

j. **Tornado GR4 Operating in Afghanistan**. Although I assess the mid-air collision risk at KAF to be the Most Likely Op theatre scenario, I cannot ignore the potential for mid-air collision when in Afghanistan airspace on task. This ranges from holding in a CAS-stack awaiting tasking, to transiting through areas that have less than optimal ATC cover, to rapid descents for a SOF, to the SOF itself. Although difficult to quantify, the risk of collision increases when in large op COMAOs at night. From the evidence provided by users on the Hawk TMk2 it is in the 2 scenarios outlined in paras i and j that TCAS2 would provide most benefit. The airspace is busy and the Air Traffic service available cannot always provide guaranteed separation of all aircraft but the LOS limitations outlined earlier in this paper would not apply as the vast majority of operations within Afg are conducted at medium level. The installation of TCAS2 would provide significant mitigation from both the Worst Credible and Most Likely scenarios outlined in this and the previous paragraphs.

6. **3rd Party RtL**. There is a small but credible likelihood of debris from a mid-air collision causing 3rd Party RtL when conducting low-flying operations. This likelihood would increase for those scenarios occurring over populated areas. Furthermore, collisions involving civilian platforms would, by definition, cause 3rd Party RtL.

{Signed Electronically}

N E Wharmby
Air Cdre
For AOC

Annex:

A. Tornado GR4 Mid-Air Collisions – Contributory Factors.

[37] ASIMS search 20 Jun 09 – 01 Mar 11. 9 Airprox were recorded in 10 199 FH in theatre vice 16 Airprox in 35 407 FH in the UK.
[38] ASIMS report fsor\OOA Kandahar\TorDet - KAF\Tornado\11\1651

ANNEX A TO
20110919-GR4COLLISIONSCENARIOS-AOC1GP-RM
DATED 19 SEP 11

TORNADO GR4 MID-AIR COLLISIONS – CONTRIBUTORY FACTORS

Factors / Environment

- Location
  - Op
  - UK Trg
  - Overseas Trg
- Altitude
  - ML
  - LL
- Airspace
  - Controlled airspace
  - Under ATC radar service
  - Uncontrolled airspace near CTZ
  - Uncontrolled airspace away from CTZ
- Activity
  - Transit
  - Navigation
  - Evasion
  - CAS / FAC
- Human Factors
  - Fatigue
  - Weather
  - Pressure of task
  - Op focus
- Bespoke scenarios
  - Emergency climb-out from low-level
  - Rapid descent to low-level

Aircraft in Collision

- Tornado GR4 in formation
- Other military ac (co-ordinated)
- Other military aircraft (unco-ordinated)
- Civilian FW (GA)
- Civilian FW (Glider)
- Civilian RW (GA)
- Civilian other (hang-glider, balloon)
- Commercial airliner
- UAV