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[dstl]

Cost Benefit Analysis:- GR4 Collision Warning System (CWS)

[redacted]

Dstl/CR60910 1.0
03 February 2012

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Executive summary

The Defence Science and Technology Laboratory (DSTL) were tasked to provide Capability Deep Target Attack (Cap DTA) with a Cost Benefit Analysis (CBA) in accordance with Joint Service Publication (JSP) 507[1] and informed by the Military Aviation Authority (MAA) Regulatory Notice (RN) 12/11[2]. This CBA will provide guidance as to whether it is a 'reasonably practicable' safety measure to implement a Collision Warning System (CWS) on the Tornado GR4 aircraft. QinetiQ provided an analysis of the probability per flying hour of collision with other military and civilian aircraft, including commercial air transport, while indicative costs for a CWS were made available by BAE Systems. [U]

The analysis was conducted for two distinct cases. Case 1 assumed an Out of Service Date (OSD) for Tornado in 2018; 1A a total of [redacted] flying hours and 1B a total of [redacted] flying hours. Case 2 assumed an OSD of 2021; 2A, [redacted] flying hours and 2B, [redacted] flying hours. Cases were considered across a range of scenarios proposed by HQ 1Gp and included most likely and worst credible cases. They included collision with general aviation (GA), military aircraft (MIL) and commercial air transport (CAT), with a range of estimated fatalities (for both 1st party i.e. military aircrew and non-aircrew and civilians i.e. 2nd and 3rd party). The total cost for collisions was calculated, taken over the lifetime of the aircraft and included human costs (i.e. fatalities), training, and equipment losses. A multiplier, called the Gross Disproportionate Factor (GDF), was applied to the cost of fatalities, calculated through linear interpolation to be 9.999, as per MAA RN/12/11. The costs of expected collisions can be seen as the 'max spend' to reduce risk from current levels 'to zero', i.e no expected collisions over the period; shown in the below table. [R]

MAX SPEND to ZERO Risk	FATALITY LEVELS (ESTIMATES)		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX F[redacted]	£38,880,000	£90,710,000	£258,050,000
CASE 1B: OSD 2018, MIN FH	£32,940,000	£75,930,000	£214,660,000
CASE 2A: OSD 2021, MAX FH	£43,030,000	£97,660,000	£273,700,000
CASE 2B: OSD 2021, MIN FH	£36,680,000	£82,320,000	£229,320,000

Table 1 Maximum spend to reduce collision risk to zero [R]
(Costs rounded to 4 significant figures)

The figures in Table 1 above represent the maximum spend that would be deemed reasonable to reduce the risk of a mid-air collision to zero for 2018 and 2021 cases for low, medium and high fatality estimates. The figures range between £33M and £274M, the higher figures associated with the longer GR4 remains in service and flying, i.e. the greater exposure to risk. [R]

The analysis examined the tolerability of risk to 1st party aircrew, finding that the annual risk of collision for GR4 crew is approximately 1 in 1166 which reduces to approximately 1 in 5177 given CWS. The MAA (and Health and Safety Executive (HSE)) advise a 1 in 1000 risk of death per annum as the boundary between what is tolerable and intolerable which is illustrated in the figure, known as a 'carrot' diagram, below [R]:

[1] JSP 507, MoD Guide to Investment Appraisal and Evaluation, Version 4.0, December 2010.
[2] (RA) 1210 & RN/12/11 - Risk to Life / CBA principles, Military Aviation Authority, November 2011

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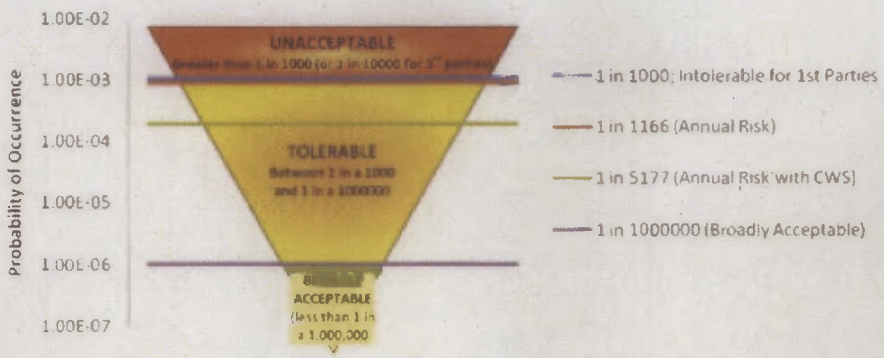

Figure 1 Annual risk of collision: 'Carrot' diagram [R]

Given an effective CWS will not reduce risk to zero; the effect of a CWS was modelled, showing the reduced number of collisions, and therefore costs, as a result. The difference between the cost of collisions without a CWS fit and with a CWS fit represented the benefit offered by CWS, in cost terms, and is summarised below [U]:

MAX SPEND on CWS	FATALITY LEVELS (ESTIMATES)		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	£11,010,000	£25,260,000	£71,310,000
CASE 1B: OSD 2018, MIN FH	£7,230,000	£15,860,000	£43,560,000
CASE 2A: OSD 2021, MAX FH	£14,740,000	£32,030,000	£87,580,000
CASE 2B: OSD 2021, MIN FH	£10,610,000	£22,110,000	£58,830,000

Table 2 Maximum spend to reduce collision risk via use of CWS (or CWS Benefits) [R]
(Costs rounded to 4 significant figures)

The results, including operational flying hours, showed that the greatest benefit offered by CWS was for Case 2A and Cases 1A and 2B (in order of greatest to least benefit), broadly corresponding to remaining flying hours. Simply put, the longer GR4 flies, the greater incentive there is to implement a form of CWS. Indicative costs for CWS however, 50% confidence, are £48.5M for OSD 2021 (Case 2A and 2B) and £54.5M for OSD 2018 (Case 1A and 1B) suggesting that the embodiment of CWS may not be seen as reasonably practicable for all cases (Only for 'high estimates' of fatalities for 2A, 1A, and 2B). [R]

CWS Benefits - Cost of CWS	FATALITY LEVELS (ESTIMATES)		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	-£43,470,000	-£29,220,000	£16,830,000
CASE 1B: OSD 2018, MIN FH	-£47,200,000	-£38,620,000	-£10,920,000
CASE 2A: OSD 2021, MAX FH	-£33,770,000	-£16,480,000	£39,080,000
CASE 2B: OSD 2021, MIN FH	-£37,900,000	-£26,390,000	£10,320,000

Table 3 CWS Benefits – Cost (Most Likely) of CWS [R]
(Costs rounded to 4 significant figures)

However, given the necessarily broad assumptions made in the CBA process it is necessary to examine the results in terms of sensitivities. The Health and Safety

Executive (HSE) recommended testing the robustness of a CBA be examining the impact of changing *'factors by 2 or 3 times'* as much. By increasing estimates of the risk per flying hour by 2, the results change as follows: [U]

CWS Benefits- Cost (x2 Risk)	FATALITY LEVELS (ESTIMATES)		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	-£32,460,000	-£3,950,000	£88,140,000
CASE 1B: OSD 2018, MIN FH	-£40,030,000	-£22,770,000	£32,640,000
CASE 2A: OSD 2021, MAX FH	-£19,030,000	£15,540,000	£126,660,000
CASE 2B: OSD 2021, MIN FH	-£[illegible]290,000	-£[illegible]	£69,160,000

Table 4 CWS Benefits – Cost of CWS (x2 Risk) [R]
(Costs rounded to 4 significant figures)

In this sensitivity case it becomes reasonably practicable to embody CWS in all Cases for higher estimates of fatalities and for some middle estimates of fatalities (in black), with benefits outweighing costs significantly for Case 2A and marginally for Case 1A and 2B (in red). The results of the CBA are subject to sensitivity of the modelling of collision risk and estimates of fatalities caused by collision. The determination therefore if CWS is reasonably practicable is difficult to ascertain but there is a more compelling argument for Case 2A, followed by 2B, then 1A, then 1B, which is to be expected as total flying hours are lower respectively. [R]

In addition this analysis examines '*societal risk*', that is the risk posed to society of a single event causing in excess of 50 fatalities. Research conducted by the HSE in 2001 has suggested that civilian safety targets for non-nuclear hazards should involve effort to ensure that incidents that cause more than 50 fatalities are less frequent than 1 in 5000 per annum. In the case of mid-air collisions, the societal risk is that GR4 will collide with a commercial airliner, perhaps similar to a Boeing 737 or larger aircraft, and so likely to cause in excess of 50 fatalities. Results have shown that, averaged across all cases, the risk of collision with Commercial Air Transport (CAT) is broadly equivalent to 1 in 2918 per annum over the lifetime of the aircraft. The embodiment of a CWS reduces the risk to an average of 1 in 33835 following full embodiment of CWS from 2016. This is illustrated in the figure below: [R]

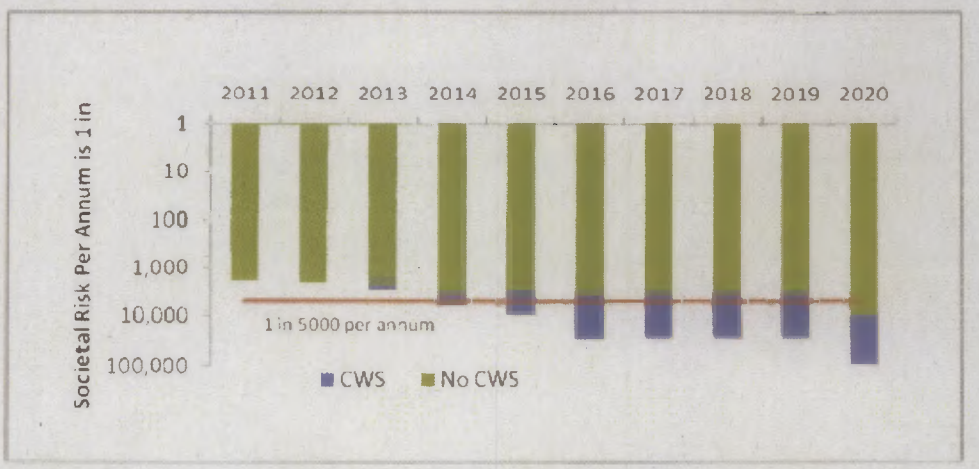

Figure 2 Societal Risk of mid-air collision (1 in 5000 per annum guidance) [R]

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The analysis concludes that, given estimated costs of CWS, the embodiment of this safety measure on a purely cost-benefit basis does not seem a 'reasonably practicable' measure. the benefits are outweighed by costs except for the highest estimates of fatalities, despite being more compelling for Tornado OSD in 2021 as opposed to 2018. However; it is important to note that sensitivity cases (increasing risk by x2 per flying hour) has highlighted that Case 2A, 2B and 1A would present an argument for embodiment and so the results of the CBA are dependent on the confidence in the modelling of mid-air collision events. [R]

Given the nature of mid-air collision and the potential to cause multiple casualties, societal risks cannot be ignored and remain a pressing concern. The risk of collision with CAT aircraft is approximately 1 in 2918 for each year of Tornado flying and this is more frequent than the level that HSE have suggested as a guideline in the past for societal risks. The embodiment of CWS will reduce societal risk considerably, suggesting that there is a case for embodiment for the good of society, regardless of the cost benefit analysis for individual risk. The assessment of the tolerability of societal risk must however ultimately be taken by the duty holder at an appropriate level; according to MAA guidelines, any potential risk to society at large of this magnitude should be notified to the Secretary of State (SoS) as the risk to the public from such events cannot properly be accounted for by the CBA process. [R]

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1 Background

The Defence Science and Technology Laboratory (Dstl) were tasked to provide Capability Deep Target Attack (Cap DTA) and Tornado GR4 stakeholders with a Cost Benefit Analysis (CBA) on the fitting of a Collision Warning System (CWS) to GR4. Data on the risks of mid-air collisions[3] and an analysis of the whole life costs of embodying a CWS on GR4[4] were supplied to MOD via a technical support contract with QinetiQ. [U]

This CBA compares the costs and benefits of embodying a CWS, a safety measure designed to reduce the risk of mid-air collisions, to aid objective decision making as to what is deemed 'reasonably practicable' in accordance with guidelines from the Health and Safety Executive (HSE) and Joint Service Publication (JSP) 507[5], informed by the Military Aviation Authority (MAA) Regulatory Notice (RN): RN/12/11. [U]

[3] 201110314 CWS Analysis Impact V1_3, QinetiQ, (11th Nov 2011).
[4] Tornado CWS Cost Data (NPV 10/50/90% Confidence) – Email (21st Nov 2011)
[5] JSP 507, MoD Guide to Investment Appraisal and Evaluation, Version 4.0, December 2010.

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2 Cost Benefit Analysis and ALARP

CBA is a commonly used tool to guide decision makers on investment decisions. HSE specify that a *"CBA can help a duty holder make judgements on whether further risk reduction measures are reasonably practicable"*[6]. It should be noted that a CBA can help identify practical risk adjustment measures but cannot solely be used to demonstrate risks are As Low as Reasonably Practicable (ALARP). Also it cannot be used to justify risks that are assessed by duty holders to be intolerable or to circumvent any statutory duties. ALARP requires both adherence to *"relevant good practice"* and a CBA to understand what risk reduction measures are reasonable. [U]

The CBA examines safety risks to personnel and is considered in terms of 1st Party and 3rd Party potential casualties. A 1st Party casualty is deemed to be military aircrew and 3rd party casualties are additional non military aircrew and members of the public. Types of 2nd Party personnel include military groundcrew and non-aircrew military staff. However, for the purposes of analysis, they are included in 3rd party casualty estimates and further references to 3rd parties will include any estimates that are not 1st party aircrew. [U]

The CBA uses costs, which have been agreed with the FAST PT Tornado Finance, for a GR4 platform valued at £11.735M at 2011 figures. This value is reduced year on year until the Out of Service Date (OSD) where it has a value of zero. (Two OSDs are considered as part of the analysis, one in 2018 and the other in 2021). Costs for the embodiment of a Collision Warning System is estimated (Most Likely 50% Confidence, rounded to 3 significant figures) at £54.5M for a GR4 OSD of 2018 and £48.5M for 2021, Net Present Value (NPV) 2011 figures. [R]

[6] http://www.hse.gov.uk/risk/theory/alarpcheck.htm, Health and Safety Executive, 2003, accessed Nov 2011.

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3 Methodology

The CBA process can be summarised as follows:

STEP A: The probability of occurrence for a mid-air collision is assessed for a range of representative scenarios which includes both the most likely and worst credible cases. The annual risk per person, for 1st and 3rd parties, is assessed for tolerability, with reference to the relevant MAA regulatory notices.[7] [U]

STEP B: The predicted number of collision events, based on the assessment of risk per flying hour and planned flying hours, is combined with an assessment of costs should a collision occur. From this a 'max spend' figure can be generated which is the most MOD should be willing to pay to reduce the expected number of collisions over the lifetime of GR4 to zero. [U]

STEP C: The assessment of costs is considered with respect to the reduction in collisions should CWS be implemented. The difference between the two values then represents the benefit that CWS offers. The human component of that overall benefit, i.e. the reduced number of casualties, is multiplied by a Gross Disproportionate Factor (GDF) and this total figure (i.e. Health and Safety Benefits * GDF + Non Health and Safety Benefits) is compared to the cost of the CWS. If Benefits prove to be greater, then the CWS must be seen as a 'reasonably practicable' measure. [U]

STEP D: Much of the process is dependent on the robustness of data inputs, especially for estimated risks and costs for event occurrences. A range of sensitivities are examined to determine the robustness of the CBA conclusions. [U]

3.1 Step A – Probability of Occurrence; Scenarios; Tolerability

The types of aircraft considered include; MIL (Military Aircraft), GA (General Aviation), and CAT (Commercial Air Transport). They are described in more detail as scenarios are defined. QinetiQ have modelled the probability of a mid-air collision occurring within UK airspace for these different aircraft types, per GR4 flying hour. A summary of these results, averaged from 2011 to 2020, both with and without CWS, are as follows (CWS figures are averaged from 2016 to 2020 to allow time for full embodiment through the Tornado fleet: [U]

PROBABILITY OF COLLISION PER FLYING HOUR (Without CWS fit)					
Year	MIL	GA	CAT	Overall	CWS
AVERAGE 2011-2021	4.30E-07	3.57E-06	4.32E-08	4.05E-06	NO
PROBABILITY OF COLLISION PER FLYING HOUR (With CWS fit)					
Year	MIL	GA	CAT	Overall	CWS
AVERAGE 2016-2021	1.38E-07	8.92E-07	5.27E-09	9.11E-07	YES

Table 5 Probability of Collision Event per Flight Hour (With/Without CWS) [R]

The probability of collision per flying hour is very small and so is given in scientific notation. In scientific notation, numbers are written in the form of: aE^{B}, where E is equal to 10 and the value of the number is: '**a**' times 10 raised to the power '**b**', where

[7] RA 12/10 & RN/12/11 - Risk to Life / CBA principles - MAA (8th Nov 2011)

'**a**' is a real number and '**b**' is a positive or negative integer. (For example 1.23E-04 = $1.23 * 10^{-4} = 0.000123$, where '**a**' = 1.23 and '**b**' = -4). [U]

3.1.1 Risk Tolerability – 1st Party

The MAA have issued guidance to the tolerability of risk to 1st and 3rd parties. Risk to life is considered 'unacceptable' or intolerable if, for any 1st party individual, there is a greater than a 1 in a 1000 chance of death per annum. A risk is 'broadly acceptable' if it less or as likely to occur as 1 in a 1000000 per annum. The 3rd party boundaries are similar except that a risk is 'unacceptable' if more likely than 1 in 10000, illustrated below: [U]

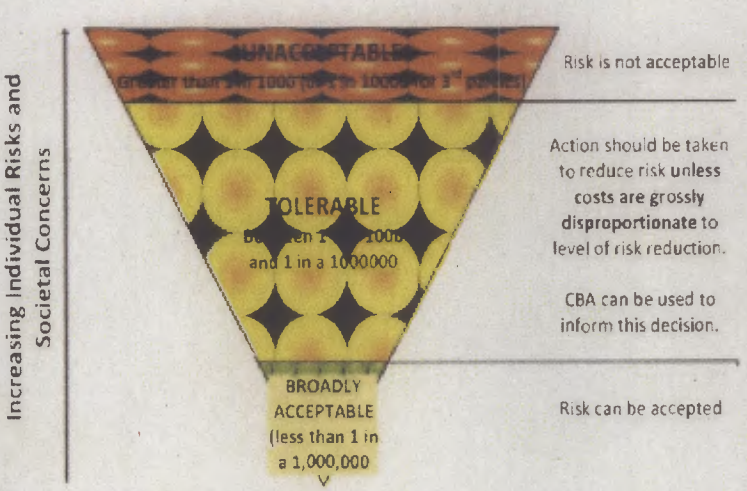

Figure 3 Tolerability of Risk to Life per Annum [U]

To understand the annual risk posed to aircrew one must consider the flying activity of the average GR4 crew (pilot and navigator). Resource planning allows for [redacted] resourced flying hours covering 94 crews (75 FL, 15 OCU, and 4 Test and Evaluation. sqn) in FY11/12. [R]

This gives an approximate annual flying task per crew of [redacted] hours.[8] (Risk to crew is not halved because there are two personnel per crew; both experience the same independent risk). Assuming then that each crew is allocated approximately [redacted] live flying hours per annum; [R]

PROBABILITY OF COLLISION with no CWS				
RISK	**Pr. FH**	**Crew**	**Pr Col. A**	**1 in a...**
1st Party (ALL)	4.05E-06	[redacted]	8.58E-04	**1166**

Table 6 Annual Risk of Collision for 1st Parties [R]

This results in the annual probability of at least one collision at 8.58e-04 per annum[9], per crew, which results in an annual risk of collision for aircrew of approx 1 in 1166. Assuming that a collision event is likely to result in death of at least one 1st Party

[8] Crew requirement, incl. planned uplifts; ratio of [redacted] hours per crew broadly remains true, approx +/- 1.5%.
[9] Given by 1 – Probability of zero collisions = 1 – ((1-Prob (collision per flight hour)$^{No.\ Flight\ Hours}$ i.e. 1-((1-4.05e-6)^{212})

(military aircrew)[10]; then this would be close to the upper end of the tolerable band of Fig 3. [R]

If a CWS was to be fully embodied in GR4 (from 2016 onwards); then the average risk per flight hour is reduced as per Table 6. [U]

PROBABILITY OF COLLISION with CWS				
RISK	Pr. FH	Crew	Pr Col. A	1 in a...
1st Party (ALL)	9.11E-07	[redacted]	1.93E-04	5177

Table 7 Annual Risk of Collision for 1st Parties with full CWS Embodiment [R]

This reduces annual probability of collision considerably; a risk of death of approximately **1 in 5177.** This is illustrated in the Figure below, note that risk is plotted on a logarithmic scale. [R]

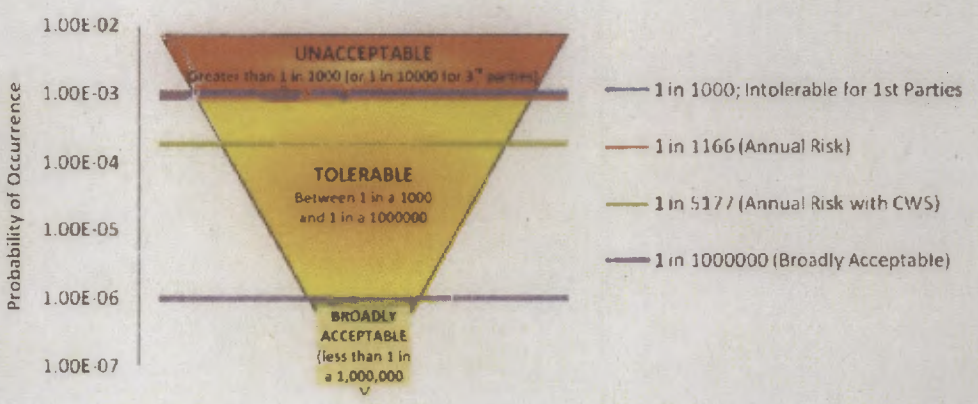

Figure 4 Tolerability of 1st Party Individual Risk; with and without CWS [R]

3.1.2 Risk Tolerability – 3rd Party

Similarly, to understand the individual risk posed to third parties, civilian aircrew and passengers, it is necessary to understand the breadth of risk that they are exposed to per member of the population, it becomes necessary to consider the collision rate with Tornado from a third party perspective and from the average flying activity for both GA and CAT aircrew. [U]

This is considerably more difficult to calculate than that for GR4 aircrew and subject to much more variance. However, to approximate the level of third party risk, estimates of "average" flying are based on some consideration of revalidation status for pilot licensing. (UK National Private Pilot Licence (NPPL), JAR-FCL Private Pilot Licence (PPL), JAR-FCL Commercial Pilot Licence (CPL), JAR-FCL Airline Transport Pilot Licence (ATPL)) and subject matter expert (SME) guidance. [U]

For GA pilots; a PPL typically requires 12 hours of flying over a 24 month period, i.e. approx. 6 hours per year. SME guidance however suggested that this is highly variable and could vary between 0 and 2 hours per month to 50 or more hours per year. A value of 30 hours per annum was used as an estimate of 'average' flying. [U]

[10] Between 1984 and 2009; 9 mid-air collisions, 12 aircrew fatalities, overall fatality rate of 1.3 per collision event.

For CAT pilots, SME guidance suggested anything between 180 hours per year to approximately 900 hours per annum. In light of no more substantiated guidance, a value of 750 hours was given by SME to be used as an estimate. [U]

In a similar manner to 1st party risk excepting probabilities were calculated from the 3rd party perspective and estimates of total civilian flying[11] then:

PROBABILITY OF COLLISION with no CWS				
RISK	Pr. FH	Crew	Pr Col. A	1 in a...
3rd Party (GA)	3.75E-08	30	1.12E-06	889318

Table 8 Annual Risk of Mid-air collision posed to GA aircrew from Tornado GR4 [R]
(Probabilities rounded to 3 significant figures)

PROBABILITY OF COLLISION with no CWS				
RISK	Pr. FH	Crew	Pr Col. A	1 in a...
3rd Party (CAT)	3.30E-09	750	2.47E-06	404640

Table 9 Annual Risk of Mid-air collision posed to CAT aircrew from Tornado GR4 [R]
(Probabilities rounded to 3 significant figures)

It is noted that these assumptions denote the 3rd party risk to GA to be approximately 1 in 1000000, close to the border between tolerable and broadly acceptable. This is sensitive to variance in 'average' flying per GA crew but remains broadly acceptable as long as aircrew are flying less than approximately 30 hours per annum; this is already above the minimum required to maintain a private pilot's license. [R]

For 3rd party risk to CAT, although risk per flight hour is lower, increased average flying hours for CAT aircrew push this figure to approximately 1 in 400000. This is within the tolerable bound but again is sensitive to the assumption on average flying. If a CAT pilot flies approximately 300 hours per annum, this risk becomes broadly acceptable. [R]

[11] Supplementary note on 3rd party risk to 201110314 CWS Analysis Impact V1_3, QinetiQ, November 2011

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If a CWS was to be fully embodied in GR4 (from 2016 onwards); then the average risk per flight hour is reduced considerably: [R]

PROBABILITY OF COLLISION with CWS				
RISK	Pr. FH	Crew	Pr Col. A	1 in a...
3rdParty (GA)	7.29E-09	30	2.19E-07	4571441

Table 10 Annual Risk posed to GA aircrew from Tornado GR4 with CWS [R]
(Probabilities rounded to 3 significant figures)

PROBABILITY OF COLLISION with CWS				
RISK	Pr. FH	Crew	Pr Col. A	1 in a...
3rd Party (CAT)	2.46E-10	750	1.84E-07	5421643

Table 11 Annual Risk posed to CAT aircrew from Tornado GR4 with CWS [R]
(Probabilities rounded to 3 significant figures)

If CWS was to be fully embodied in GR4 (from 2016 onwards) then 3rd party risks are firmly within the 'broadly acceptable' category. from approximately 1 in 4.6 million for GA and 1 in 5.4 million for CAT. This is illustrated in the carrot diagram below: [R]

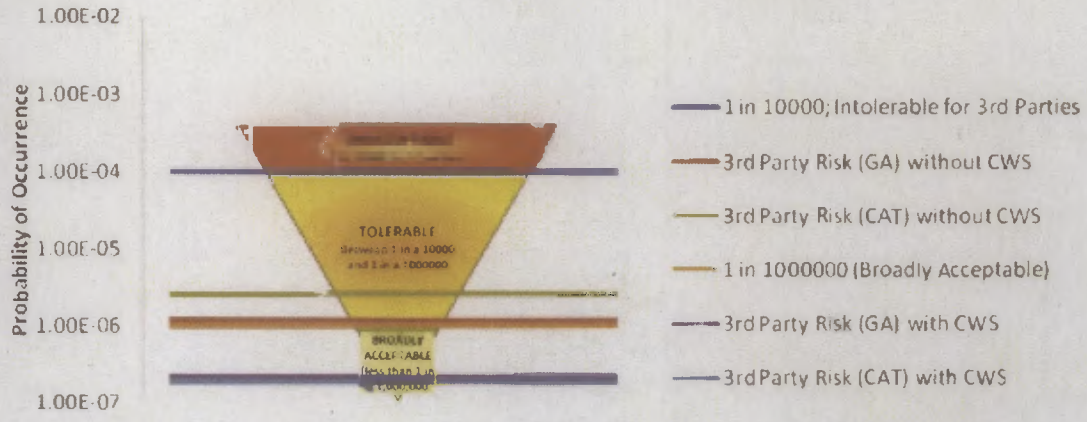

Figure 5 Tolerability of 3rd Party Individual Risk: with and without CWS [R]

It is important to note that these figures represent individual risk per annum that is the risk that an individual GA or CAT aircrew will be involved in a collision event with GR4. These figures do not present the annual risk that any GA or CAT collision will occur; this is considered as part of the wider cost benefit analysis. [U]

The examination of individual risk tolerability is not the equivalent of examining the societal risk to the UK as a whole of any incident occurring. Societal Risk is examined in more detail in a separate section, later in this CBA. [U]

3.1.3 Mid-air Collision Scenarios

A range of credible scenarios to examine the mid-air collision risk for Tornado has been endorsed by HQ 1Gp[12]. Following discussion with QinetiQ and HQ 1Gp, these scenarios have been rationalised for the purposes of modelling, to the following: [U]

ID	DESCRIPTION	LOC	RISK AIRCRAFT		
			MIL	GA	CAT
UK1 (a,b)	Tornado GR4 collides with General Aviation (GA) (Low Level or transiting Low to Medium Level)	UKLFS		X	
UK2 (g,h)	Tornado GR4 collides with Military aircraft (Mil) (Low Level or transiting from Low to Medium Level or in formation, or large ac package).	UKLFS	X		
UK3 (c,d,e ,f)	Tornado GR4 collides with Commercial Air Transport (CAT) through climbing Out From Low-Level – Emergency, or close to CTZ or Class G	Scottish TMA/ or Peak District.			X
O1 (i)	Tornado GR4 collides with CAT while recovering to KAF Afghanistan	Op/Non UK			X
O2 (j)	GR4 collides with MIL in Afghanistan	Op/ Non UK	X		

Table 12 Mid-Air Collision Scenarios (letter ID refers to HQ 1Gp reference) [R]

For the above scenarios, HQ 1Gp has assessed that Scenario UK1 is most likely and Scenario UK3 is the worst credible risk posed to UK airspace. Likewise O2 proves the most likely and O1 the worst credible threats to operational flying from mid-air collision. Some further assumptions are made by the CBA as to parties at risk; [R]

a) Tornado GR4 has a complement of 2 aircrew (1st party) personnel. [U]

b) General Aviation (GA) is a broad category of aircraft including everything from gliders to large, non-scheduled, commercial cargo. "In 2005 the GA [UK] fleet comprised 9,000 fixed-wing aircraft, 4,100 microlights, 1,300 helicopters, 1,800 airships/balloons, 2,500 gliders and some 7,000 hang gliders."[13] It is assumed that GA refers to a fixed-wing aircraft that is similar to a Cessna 172 or even a business jet; assuming a civilian crew of 1 and up to 5 passengers. [U]

c) Other military aircraft (MIL) are deemed to be either Fast-Jet or Rotary Wing platforms. It is assumed that these are encountered in equal proportion.[14] This indicates that crew complements are anywhere between 1 (e.g. single-seat FJ aircraft) to 4 (e.g. Chinook HC1) aircrew (1st party) and typically up to 25 passengers, (2nd or 3rd party).[15] [U]

d) CAT is deemed to be a scheduled commercial airliner, most likely something of similar size and capacity to the Boeing 737 family, the best selling commercial

[12] Mid-Air Collision Scenarios – TORNADO GR4 -AOC1Gp-RM, September 2011
[13] Strategic Review of General Aviation in the UK" (PDF). CAA. 2006-07. pp. iii–iv, paras. 17, 19 & 20
[14] Approximation of number of 1st and 3rd party persons at risk; robustness tested with sensitivity analysis.
[15] June 1994, Chinook HC2 *ZD576* crashed on the Mull of Kintyre, Scotland, killing a25 passengers and 4 crew.

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airliner.[16] For the purposes of analysis, these aircraft are deemed to carry typically between 20 to 200 non military crew and passengers (3rd party).[17] [U]

e) Historical data collated for GR between 1984 and 2009 indicates that the fleet was involved in a total of 9 mid-air collision accidents (out of a total of 18 FJ collisions during this period.) The mid-air collisions involved a total of 12 Tornado GR aircraft, 2 collisions with GA aircraft – 1 x rotary wing, 1 x light fixed wing (and so 7 Mil: Mil collisions) for a total loss of 10 Fast-Jet aircraft, 12 RAF aircrew fatalities and 4 civilian fatalities. [U]

i. **GR4 1st Party**: 9 mid-air collision accidents involving GR4 lead to a total of 12 aircrew fatalities, suggesting an average of 12/9, i.e. 1.33 fatalities (1st party) per accident. [U]

ii. **MIL**: Relatively few actual collisions have occurred and so there is limited data to base assumptions on the average fatality rate associated with a collision between Tornado and RW aircraft. Given an equal weighting given to FJ and RW encounters, an untested approximation, the CBA suggests an average of (1.33 + 4/2)/2 or approx 1.67 aircrew (1st party) and (0 + 25/2)/2 or 6.25 passengers (3rd Party). [U]

iii. **GA**: Between 1995 and 2004 there were 2,630 accidents involving GA aircraft of which 139 were fatal, resulting in the loss of 317 lives. The majority of accidents involved small fixed-wing aircraft engaged in private flights. Given that the likelihood of fatality (100% of two events for GA with Tornado GR4), it is estimated that likely fatality rates are in the region of 317/139, i.e. on average 2.28 fatalities (3rd party) per accident.[18] [U]

iv. **CAT**: The Civilian Aviation Authority (CAA) report that in "the last 10 years (1995-2004) there have been 7 fatal mid-air collision accidents worldwide involving large fixed-wing turbine-powered aero planes, resulting in 451 fatalities. Although there has not been such an accident in UK airspace since 1949, there have been several high profile 'near-misses'." If a mid-air collision accident were to occur, CBA estimates average of 451/7, i.e. 64.4 fatalities per accident. [U]

v. There is limited evidence available where a mid-collision has resulted in zero casualties; a lower bound is assumed therefore that is non-zero and is approximately the same percentage difference, between mid and low as there is between mid and high.[19] [U]

[16] http://www.flightglobal.com/news/articles/boeing-737-aircraft-profile-218496/, Flight Global, 2008
[17] Approximation; sensitivity analysis will address uncertainty in this estimate.
[18] SRG Safety Plan 2008 Update" (PDF). CAA. 2008-06. p. 49. http://www.caa.co.uk/docs/978/GeneralAviation.pdf.
[19] Exception for GA: assumes low estimate of 1.3 and high estimate of 6.0; initially higher estimate was 4 but adjusted due to SME guidance to account for the broad range of aircraft covered by GA and the possibility of business jets.

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ESTIMATES OF POTENTIAL FATALITIES vs. SCENARIO							
ID	AIRCRAFT	1st Party (LOW)	1st Party (MID)	1st Party (HIGH)	3rd Party (LOW)	3rd Party (MID)	3rd Party (HIGH)
UK1	GR4 + GA	0.9	1.3	2.0	1.3	2.3	6.0
[redacted]2	GR4 + MIL	1.5	3.0	6.0	1.6	6.3	25.0
UK3	GR4 + CAT	0.9	1.3	2.0	20.8	64.4	200.0
O1	GR4 + CAT	0.9	1.3	2.0	20.8	64.4	200.0
O2	GR4 + MIL	1.5	3.0	6.0	1.6	6.3	25.0

Table 13 Estimate of potential fatalities; low, mid and high [U]

Scenarios UK3 and O2 both appear to be worst credible cases, allowing for up to 200 civilian fatalities given an occurrence of a collision. Conversely, other scenarios show serious but less catastrophic consequences. Given that each scenario involves a collision between GR4 and one other type of aircraft, it is possible to weight scenarios on their probability of occurrence, i.e. calculating the expected no. of collision events to account for the likelihood of any particular scenario occurring and it's subsequent impact on costs. [U]

For all estimates of fatalities, it is recognised that it is not possible for a 'fraction' of a person to be lost. The figures given are averages per collision for statistical purposes. A value of '1.3' therefore can be considered as, *'on average between one and two but more likely to be one'*. [U]

3.2 Step B – Flying; Expected Collisions; Value of Prevented Fatality

The analysis considered four separate cases for flying hours for Tornado GR4; assumptions on flying hours given an Out of Service Date for GR4 in 2018 were as follows: [U]

2018	UK (MAX)	OP (MAX)	UK (MIN)	OP (MIN)
~~11/12~~	[redacted]			
~~12~~ [redacted]				
~~13~~ [redacted]				
~~14/15~~				
15/16				
16/17				
17/18				
18/19				
19/20				
20/21				

Table 14 Flying Hours for GR4 – assuming an OSD of 2018 [R]

A maximum and minimum flying hour profile, both for UK and Operational Flying, was used. The figures listed as 'Max' were used in the analysis as case 1A, and min as

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case 1B. Likewise for OSD 2021, 'max' and 'min' figures were used for case 2A and 2B respectively. [U]

2021	MAX	MAX	MIN	MIN
FY	UK	OP	UK	OP
11/12	[redacted]			
12/13				
13/14				
14/15				
15/16				
16/17				
17/18				
18/19				
19/20				
20/21				

Table 15 Flying Hours for GR4 – assuming an OSD of 2021 [R]

For the purposed of the QinetiQ modelling, a single set of flying hours was used, broadly corresponding to a % of time (approximately 80%) that GR4 crew would spend flying in airspace (low level (LL) and mid level (ML) flying) where collisions were most likely. These are given below and are used for the calculation of societal risk in the CBA. [U]

2021	UK LL/ML
FY	Low/Mid
11/12	[redacted]
12/13	
13/14	
14/15	
15/16	
16/17	
17/18	
18/19	
19/20	
20/21	

Table 16 Flying hours used to determine probability of collision per flying hour [R]

3.2.1 Expected Number of Collisions – OSD of 2018

QinetiQ have provided a modelled estimate of the risk of collision, per flying hour, for Mil, CAT, and GA aircraft from 2011 to 2021. The expected[20] number of collisions over that time is calculated through the no. flight hours multiplied by the risk of collision per flight hour. [U]

[20] The expected value is the weighted average of all possible values that this could be and calculated by the probability of collision per flying hour * by the no. of flying hours. This is calculated annually, due to modelling variations year, on year and summed.

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QinetiQ have also provided estimates of the risk of collision given the embodiment of a CWS fit over time, the CWS reducing risk over that period. This is illustrated in the tables below: [U]

2018 - UK MAX HOURS - EXPECTED COLLISIONS						
Year / Hours / CWS Profile Fit			Expected No. of Collisions			
Year	UK Flying	CWS Fit	Mil	GA	CAT	Overall
2011	[redacted]	0	5.3E-03	3.9E-02	4.8E-04	4.5E-02
2012		0	6.6E-03	5.0E-02	6.0E-04	5.7E-02
2013		0	6.2E-03	4.8E-02	5.8E-04	5.5E-02
2014		0	5.0E-03	4.0E-02	4.8E-04	4.6E-02
2015		0	4.9E-03	4.0E-02	4.9E-04	4.6E-02
2016		0	4.9E-03	4.1E-02	4.9E-04	4.6E-02
2017		0	3.4E-03	2.9E-02	3.5E-04	3.3E-02
Expected Total No. of Collisions			0.036	0.288	0.004	0.328

Table 17 Number of Collisions (to 3 decimal places) given OSD 2018 Max UK Flying [R]

2018 - UK MIN HOURS - EXPECTED COLLISIONS						
Year / Hours / CWS Profile Fit			Expected No. of Collisions			
Year	UK Flying	CWS Fit	Mil	GA	CAT	Overall
2011	[redacted]	0	5.3E-03	3.9E-02	4.8E-04	4.5E-02
2012		0	6.6E-03	5.0E-02	6.0E-04	5.7E-02
2013		0	6.2E-03	4.8E-02	5.8E-04	5.5E-02
2014		0	3.8E-03	3.0E-02	3.7E-04	3.5E-02
2015		0	4.1E-03	3.4E-02	4.1E-04	3.8E-02
2016		0	3.4E-03	2.9E-02	3.5E-04	3.3E-02
2017		0	2.5E-03	2.2E-02	2.6E-04	2.5E-02
Expected Total No. of Collisions			0.032	0.252	0.003	0.287

Table 18 Number of Collisions (to 3 decimal places) given OSD 2018, Min UK Flying [R]

The total number of collisions ranges from 0.328 to 0.287. It is important to consider the period of analysis; 7 years for the entire fleet and is likely to be heavily weighted in favour with collision with GA (as opposed to CAT or MIL). This figure can be used to consider the impact of collisions and is the weighted average number of collisions over the period. [R]

A different process was applied for Operational Hours to calculate expected collisions; 1Gp SME judgement is that the number of expected collision in operations is "up to twice" that of UK airspace; that is if we expected 2 collisions per year in the UK, we would expect 4 collisions per year on operations given the same amount of flying hours. [R]

For the purposes of the CBA; the expected collision rate, per UK flying hour was calculated; [redacted] to produce 4.7E-02 collisions. (i.e. approximately the same level of collisions given the rate is 'doubled' and the flying hours are approximately halved). [R]

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This process was repeated for all years, with collisions split between MIL and CAT (as there was deemed to be no GA risk on operations) in the same proportions found in UK results (approximately 91% MIL, 9% CAT). Results are show below: [R]

2018 - OP MAX HOURS - EXPECTED COLLISIONS						
Year / Hours / CWS Profile Fit			Expected No. of Collisions			
Year	Op Flying	CWS Fit	Mil	GA	CAT	Overall
2011	[redacted]	0	4.4E-02	0.0E+00	3.9E-03	4.7E-02
2012		0	4.4E-02	0.0E+00	4.1E-03	4.8E-02
2013		0	4.5E-02	0.0E+00	4.3E-03	5.0E-02
2014		0	4.6E-02	0.0E+00	4.5E-03	5.1E-02
2015		0	1.3E-02	0.0E+00	1.3E-03	1.4E-02
2016		0	1.3E-02	0.0E+00	1.4E-03	1.5E-02
2017		0	1.4E-02	0.0E+00	1.4E-03	1.5E-02
Expected Total No. of Collisions			0.219	0.000	0.021	0.240

Table 19 Number of Collisions (to 3 decimal places) given OSD 2018. Max Op Flying [R]

2018 - OP MIN HOURS - EXPECTED COLLISIONS						
Year / Hours / CWS Profile Fit			Expected No. of Collisions			
Year	Op Flying	CWS Fit	Mil	GA	CAT	Overall
2011	[redacted]	0	4.4E-02	0.0E+00	3.9E-03	4.7E-02
2012		0	4.4E-02	0.0E+00	4.1E-03	4.8E-02
2013		0	4.5E-02	0.0E+00	4.3E-03	5.0E-02
2014		0	4.6E-02	0.0E+00	4.5E-03	5.1E-02
2015		0	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2016		0	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2017		0	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Expected Total No. of Collisions			0.179	0.000	0.017	0.196

Table 20 Number of Collisions (to 3 decimal places) given OSD 2018. Min Op Flying [R]

3.2.2 Expected Number of Collisions – Assuming OSD of 2021

2020 - UK MAX HOURS - EXPECTED COLLISIONS						
[redacted]r / Hours / CWS Profile Fit			Expected No. of Collisions			
[redacted]	UK Flying	CWS Fit	Mil	GA	CAT	Overall
[redacted]	[redacted]	0	5.3E-03	3.9E-02	4.8E-04	4.5E-02
[redacted]2		0	6.6E-03	5.0E-02	6.0E-04	5.7E-02
[redacted]3		0	6.2E-03	4.8E-02	5.8E-04	5.5E-02
2014		0	5.0E-03	4.0E-02	4.8E-04	4.6E-02
2015		0	4.9E-03	4.0E-02	4.9E-04	4.6E-02
[redacted]16		0	4.9E-03	4.1E-02	4.9E-04	4.6E-02
[redacted]17		0	4.5E-03	3.9E-02	4.7E-04	4.4E-02
[redacted]18		0	3.8E-03	3.4E-02	4.1E-04	3.8E-02
[redacted]19		0	3.7E-03	3.3E-02	4.0E-04	3.8E-02
[redacted]20		0	1.4E-03	1.3E-02	1.6E-04	1.5E-02
Expected Total No. of Collisions			0.046	0.378	0.005	0.429

Table 21 Number of Collisions (to 3 decimal places) given OSD 2021. Max UK Flying [R]

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2020 - UK MIN HOURS - EXPECTED COLLISIONS						
Year / Hours / CWS Profile Fit			Expected No. of Collisions			
Year	UK Flying	CWS Fit	Mil	GA	CAT	Overall
2011	[redacted]	0	5.3E-03	3.9E-02	4.8E-04	4.5E-02
2012		0	6.6E-03	5.0E-02	6.0E-04	5.7E-02
2013		0	6.2E-03	4.8E-02	5.8E-04	5.5E-02
2014		0	3.8E-03	3.0E-02	3.7E-04	3.5E-02
2015		0	4.1E-03	3.4E-02	4.1E-04	3.8E-02
2016		0	3.6E-03	3.0E-02	3.6E-04	3.4E-02
2017		0	3.6E-03	3.1E-02	3.7E-04	3.5E-02
2018		0	3.6E-03	3.1E-02	3.8E-04	3.5E-02
2019		0	3.4E-03	3.1E-02	3.8E-04	3.5E-02
2020		0	1.1E-03	1.0E-02	1.2E-04	1.1E-02
Expected Total No. of Collisions			0.0412	0.3346	0.0040	0.3798

Table 22 Number of Collisions (to 3 decimal places) given OSD 2021, Min UK Flying [R]

The expected number of collisions; that is GR4 without CWS colliding with any other aircraft from 2011 to 2021, ranges from 0.429 to 0.379. This is broadly comparable to 2018 option, both Max and Min. This is because the probability of an incident per flying hour is very small and does not vary between 2018 and 2021 options; while the variable that is changing is the overall flying hours. [R]

If one was to consider the probability of at least once collision (for GA, CWS, and MIL) over the lifetime of GR4 (considering an OSD of 2018 or 2021 with max and min flying hours for UK and operations), then some alarming observations can be made about the risks of mid-air collision: [R]

PROBABILITY OF MID-AIR COLLISION GIVEN DIFFERENT OPTIONS (no CWS)			
OPTION	Probability (per FH)	UK FLYING	% at least ONE
2020 Max	4.0E-06	[redacted]	35%
2020 Min	4.0E-06		32%
2018 Max	4.0E-06		29%
2018 Min	4.0E-06		26%

Table 23 2018 and 2021 Options vs. Chance of at least ONE collision without CWS [R]

PROBABILITY OF MID-AIR COLLISION GIVEN DIFFERENT OPTIONS (CWS)			
OPTION	Probability (per FH)	UK FLYING	% at least ONE
2020 Max	9.1E-07	[redacted]	9%
2020 Min	9.1E-07		8%
2018 Max	9.1E-07		7%
2018 Min	9.1E-07		7%

Table 24 2018 and 2021 Options vs. Chance of at least ONE collision with CWS [R]

At first glance, the chance of collision seems very high, indeed a 1 in 3 chance that is only mitigated to an approximately 1 in 10 chance by CWS. However this is over a multiple year period (from 2011 to 2018 or 2021 respectively). In addition, this is heavily weighted towards a collision with GA aircraft. One must consider this against

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the expected number of events in total and their expected impact. Impact is calculated through use of a Value of Prevented Fatality and other costs. [R]

VPF is not the value placed on an actual life but on a 'statistical' life. It is more precisely a measure of society's willingness to pay for risk reduction within the tolerable region. For example; if a VPF were considered around £1M – this would reflects society's willingness to pay £10 to reduce a 1 in 100000 risk (within Tolerable region) to a 1 in 1000000 risk (Broadly Acceptable) instead. [U]

3.2.3 Costs of Implementing the CWS Option

MAA principles, to be applied when conducting CBA for aircraft, indicate that the costs associated with risk reduction can include additional through-life costs of: Equipment. Installation, Training, and other Mitigating measures such as lease costs of replacement aircraft/capability during an installation programme. Costs considered by the CBA include, VPF, Cost of Training (for 1st Party Aircrew), Equipment Losses (due to collisions), and embodiment of CWS to GR4. [U]

Costs excluded are estimates of potential damage to property and casualties to 3rd parties due to aircraft debris from a mid-air collision. While this is deemed a credible but un-quantified risk from the duty holder, it has been excluded from analysis due to time constraints and difficulties in obtaining historical evidence that could inform the analysis. It is recognised however that gross estimations of equipment losses are made due to the broad range of aircraft that can constitute GA or CAT or indeed MIL. It is possible then that this estimate will be broad enough to account for any potential losses in this respect. However this remains a potential area of concern and should be considered in more depth given scope to pursue, especially with regard to wider societal risk. [U]

3.2.4 Value of Prevented Fatality (VPF)

JSP 507 states that VPF is £1.58M at 2009 values which can be uplifted to **£1.69M** (from MAA/RN/12/11 (DG) in 2011 values, based upon 6.90% RPIX uplift (obtained using DASA Indigo 'CHMK' (RPIX) Index). [U]

VPF for the CBA is assumed at £1.69M at 2011 value for both 1st and 3rd parties. An additional cost for training 1st party aircrew does not form part of VPF but does form part of overall costs. Guidance from MAA/RN/12/11 suggests that training costs for 1st party aircrew should not be included in VPF calculations but are valid for consideration as part of overall costs. [U]

Given the potential severity of a mid-air collision, this CBA considers the gross risk to personnel only, i.e. the value of prevented fatality as opposed to serious or slight injuries which can also be costed. [U]

3.2.5 Cost of Training

Previous CBAs used for aircrew safety have employed a value of £4M for aircrew but this has included VPF figures of £1.58M at 2009 values. This leaves an estimate of training costs of 4 – 1.58 = £2.42M at 2009 values, or £2.59M in 2011 values. [R]

While this may be accurate; this CBA has not found the evidence to employ this figure. Instead, the CBA uses a figure of £3.1M at 2009 values from selection to OCU, and an addition £3.59M from OCU to Front Line. A total training cost of £6.69M

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at 2008 values or £7.15M at 2011 values.[21] This figure is a broad estimate for Tornado GR4 aircrew but may not be appropriate for other military aircrew. With that caveat, it is used to determine, within a broad error, the expected training cost of 1st party aircrew. [U]

3.2.6 Cost of Embodiment of Collision Warning System

At the time of writing, Most Likely Net Present Value (NPV) costs of CWS fit are given as follows: [U]

NPV Cost	2018 OSD	2021 OSD
10% Conf.	£51,172,000	£46,580,000
50% Conf.	£54,480,000	£48,507,000
90% Conf.	£60,325,000	£52,492,000

Table 25 Indicative costs (NPV) for embodiment of CWS for GR4 (5sf) [R]

3.2.7 Cost of Equipment

Advice from Tornado Finance in the FAST PT (2011); "Value for write off purposes for a GR4 Tornado is £11.735m." This value should be reduced proportionately from 2011 through to OSD (i.e. reduction of approximately 98k month if 2020 OSD is used, approximately 140k month with 2018 option). [U]

Historical analysis suggests that 12 aircraft have been lost in 9 collisions (suggesting a loss rate of 1.33). However, this is higher than 1 due to the prospect of Mil on Mil collisions (where potentially 2 military aircraft can be lost.). In the case of Mil on Mil collision it is assumed that the loss rate of Tornado aircraft is 1.33. For GA collisions it is assumed to be 0.5 (as per historical analysis) and for CAT it is assumed to be 1. All 3rd Party aircraft are assumed to be lost in any collision. [U]

Estimates for 3rd party equipment losses are harder to estimate and subject to a very broad variance given the possible condition, type, and age of aircraft for both GA and CAT and indeed whether MOD would be deemed responsible for covering 3rd party equipment losses. [U]

It is assumed (see previously) that the 'average' GA aircraft can be described as comparable to a Cessna 172. Observing current aircraft classifieds show prices range from as low as £20k for 30 year old aircraft to £172k for new ($274,900 – US 2011 figures[22]). A value of 192/2 = £96k is used as a estimate. Equipment costs for 3rd parties are likely to be liable only in circumstances where MOD is deemed responsible for causing an incident. With no evidence to support likelihood one way or the other, this CBA assumes a 50% chance of MOD being made liable for 3rd party equipment costs reducing estimate to 50% x £96k = £48k [U]

It is assumed (see previously) that the 'average' CAT aircraft is comparable to a Boeing 737. A new Boeing 737-600 is valued approx £37M[23] with a 30 year old aircraft from the Boeing 737 family typically at £0.6M [24] For the purposes of the CBA

[21] http://www.armedforces.co.uk/raf/listings/l0015.html
[22] http://www.cessna.com/single-engine/skyhawk/skyhawk-pricing.html#
[23] http://www.boeing.com/commercial/prices/
[24] http://www.aircraftbargains.com/searchad.asp?avisearch=ok&makes=69

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the value of a CAT aircraft is estimated at £18.8M: an estimate, reduced to £9.4M assuming MOD is liable in 50% of occurrences. [U]

3.2.8 Costing Scenarios

Costing scenarios can now be considered for the following options: [U]

- CASE 1A: Tornado GR4 OSD 2018 – Max UK and Op Flying hours
- CASE 1B: Tornado GR4 OSD 2018 – Min UK and Op Flying hours
- CASE 2A: Tornado GR4 OSD 2021 – Max UK and Op Flying hours
- CASE 2B: Tornado GR4 OSD 2021 – Min UK and Op Flying hours

Each scenario can have a LOW, MID and HIGH cost estimate depending on estimates for casualties in each given scenario (see previous table for estimated fatalities). [U]

3.2.8.1 CASE 1A: Tornado GR4 OSD 2018 – MAX UK and Op Flying hours

The cost of a scenario can be estimated by multiplying expected occurrences by the value of expected fatalities (for 1st and 3rd) party. This human cost is then added to equipment costs (multiplied by estimated equipment losses per scenario per occurring event) and training costs (multiplied by 1st party fatalities). Calculating human costs is done by multiplying expected collisions by estimates of casualties multiplied by VPF which gives the following: [U]

ID	VPF 1st Party			VPF 3rd Party		
CASE 1A	LOW	MID	HIGH	LOW	MID	HIGH
UK1	£437,946	£632,589	£973,214	£632,589	£1,119,196	£2,919,643
UK2	£92,004	£184,008	£368,015	£98,137	£386,416	£1,533,398
UK3	£5,296	£7,650	£11,770	£122,407	£378,990	£1,176,986
O1	£31,575	£45,608	£70,166	£729,726	£2,259,343	£7,016,593
O2	£556,211	£1,112,422	£2,224,843	£593,292	£2,336,085	£9,270,180
TOTALS	£1,123,032	£1,982,277	£3,648,009	£2,176,150	£6,480,030	£21,916,799

Table 26 Human Costs of Case 1A [R]

Equipment Costs are added using expected number of collisions and estimated material costs for GR4 that reduce year on year, illustrated as follows: [U]

COST OF	£M	Loss Rate	UK1 (Collisions)	UK1 (GR4 Costs)
Gr4 in 2011	11.7	0.5	0.039	0.23
Gr4 in 2012	10.1	0.5	0.050	0.25
Gr4 in 2013	8.4	0.5	0.048	0.20
Gr4 in 2014	6.7	0.5	0.040	0.13
Gr4 in 2015	5.0	0.5	0.040	0.10
Gr4 in 2016	3.4	0.5	0.041	0.07
Gr4 in 2017	1.7	0.5	0.029	0.02
TOTALS (Equipment Cost (Gr4) for Scenario UK1				1.01

Table 27 Equipment Costs (GR4 losses) for UK1 assuming loss rate of 0.5 per collision [R]

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Similarly for all equipment costs (GR4) and 3rd party equipment costs: [U]

GR4 Equipment Loss £M				
UK1 (GA)	UK2 (MIL)	UK 3 (CAT)	O1 (CAT)	O2 (MIL)
0.23	0.08	0.01	0.05	0.68
0.25	0.09	0.01	0.04	0.59
0.2	0.07	0	0.04	0.5
0.13	0.04	0	0.03	0.41
0.1	0.03	0	0.01	0.09
0.07	0.02	0	0	0.06
0.02	0.01	0	0	0.03
1.01	**0.35**	**0.02**	**0.17**	**2.37**

Table 28 GR4 Equipment Losses for all Scenarios (OSD 2018, Max Flying Hours) [R]

2018 OSD, Max Flying Hours	3rd Party Costs (£M)				
	UK1 (GA)	UK2 (MIL)	UK 3 (CAT)	O1 (CAT)	O2 (MIL
[illegible]ted Collisions (total)	0.288	0.036	0.003	0.021	0.219
[illegible] Party Aircraft £M	0.048	0	9.4	9.4	0
[illegible]ty COSTS £M	0.014	0	0.033	0.195	0

Table 29 3rd Party Equipment Losses for all Scenarios (OSD 2018, Max Flying Hours) [R]

Training Costs are dependent on 1st party fatalities and so will have LOW, MID, and HIGH estimates, calculated by multiplying training costs by expected scenario occurrences and estimates fatalities per scenario. This gives rise to the following results: [U]

COSTS FOR TRAINING (OSD 2018, UK MAX)		FATALITIES			UK MAX	TRNG	COSTS		
		LOW	MID	HIGH	Collisions	To FL	LOW	MID	HIGH
UK 1	GR4 + GA	0.9	1.3	2	0.288	7.15	1.85	2.68	4.12
UK 2	GR4 + MIL	1.5	3	6	0.036	7.15	0.39	0.78	1.56
UK 3	GR4 + CAT	0.9	1.3	2	0.003	7.15	0.02	0.03	0.05
O1	GR4 + CAT	0.9	1.3	2	0.021	7.15	0.13	0.19	0.30
O2	GR4 + MIL	1.5	3	6	0.219	7.15	2.35	4.71	9.41
TOTALS							4.75	8.39	15.43

Table 30 Training Costs for all Scenarios (OSD 2018 and UK Max Flying Hours) [R]

In summary, the total costs of an incident occurring is the human cost (in VPF), the equipment costs, and the training costs – total expected costs then assuming an OSD of 2018 and the Max Flying Hours profile are as follows: [U]

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SCENARIOS		Total Costs		
OSD 2018 Max FH	UK Flying	LOW	MID	HIGH
UK1	GR4 + GA	£3,950,754	£5,455,493	£9,037,671
UK2	GR4 + MIL	£926,534	£1,696,063	£3,805,547
UK3	GR4 + CAT	£207,351	£476,247	£1,295,792
O1	GR4 + CAT	£1,255,783	£2,858,804	£7,744,512
O2	GR4 + MIL	£5,869,821	£10,522,025	£23,274,940
TOTALS		£12,210,000	£21,010,000	£45,160,000

Table 31 Combined Costs for all Scenarios (OSD 2018, UK Max Flying) [R]

Alternatively costs can be expressed in terms of human (fatalities), training and equipment (for both 1st and 3rd parties): [U]

	Total Costs		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£3,299,183	£8,462,307	£25,564,808
TRAINING COST	£4,751,290	£8,386,556	£15,433,883
EQUIPMENT COST	£4,159,771	£4,159,771	£4,159,771
TOTALS	£12,210,000	£21,010,000	£45,160,000

Table 32 Total Costs for all Scenarios OSD 2018, UK Flying Hours Max [R]

3.2.8.2 Case 1B: Tornado GR4 OSD 2018 – MIN UK and Op flying hours

Applying the same method with a reduced total number of flying hours over the period gives the following results:

SCENARIOS		Total Costs		
OSD 2018 Max FH	UK Flying	LOW	MID	HIGH
UK1	GR4 + GA	£3,510,303	£4,828,161	£7,965,450
UK2	GR4 + MIL	£832,944	£1,510,850	£3,369,168
UK3	GR4 + CAT	£182,802	£418,287	£1,136,003
O1	GR4 + CAT	£1,028,879	£2,317,958	£6,246,829
O2	GR4 + MIL	£5,053,201	£8,856,382	£19,281,901
TOTALS		£10,610,000	£17,930,000	£38,000,000

	Total Costs		
SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£2,768,842	£7,048,026	£21,221,508
TRAINING COST	£4,016,427	£7,060,752	£12,954,983
EQUIPMENT COST	£3,822,860	£3,822,860	£3,822,860
TOTALS	£10,610,000	£17,930,000	£38,000,000

Table 33 Total Costs for all Scenarios OSD 2018, UK Flying Hours Min [R]

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3.2.8.3 Case 2A: Tornado GR4 OSD 2021 – Max UK and Op Flying hours

Similarly for OSD 2021 and Max Flying:

SCENARIOS		Total Costs		
OSD 2020 Max FH	UK Flying	LOW	MID	HIGH
UK1	GR4 + GA	£5,203,004	£7,179,239	£11,883,858
UK2	GR4 + MIL	£1,192,349	£2,176,072	£4,872,715
UK3	GR4 + CAT	£272,705	£625,902	£1,702,377
O1	GR4 + CAT	£1,279,137	£2,882,159	£7,767,866
O2	GR4 + MIL	£6,187,033	£10,839,237	£23,592,152
TOTALS		**£14,130,000**	**£23,700,000**	**£49,820,000**

	Total Costs		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£3,727,585	£9,291,200	£27,686,525
TRAINING COST	£5,447,233	£9,451,998	£17,173,034
EQUIPMENT COST	£4,959,410	£4,959,410	£4,959,410
TOTALS	**£14,130,000**	**£23,700,000**	**£49,820,000**

Table 34 Total Costs for all Scenarios OSD 2021, UK Flying Hours Max [R]

3.2.8.4 Case 2B: Tornado GR4 OSD 2021 – Min UK and Op Flying hours

SCENARIOS		Total Costs		
OSD 2020 Max FH	UK Flying	LOW	MID	HIGH
UK1	GR4 + GA	£4,634,715	£6,383,090	£10,545,268
UK2	GR4 + MIL	£1,069,955	£1,943,803	£4,339,249
UK3	GR4 + CAT	£242,016	£554,476	£1,506,794
O1	GR4 + CAT	£1,041,949	£2,331,029	£6,259,899
O2	GR4 + MIL	£5,236,137	£9,039,317	£19,464,837
TOTALS		**£12,220,000**	**£20,250,000**	**£42,120,000**

	Total Costs		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£3,160,101	£7,805,149	£23,159,724
TRAINING COST	£4,652,068	£8,033,963	£14,543,718
EQUIPMENT COST	£4,412,603	£4,412,603	£4,412,603
TOTALS	**£12,220,000**	**£20,250,000**	**£42,120,000**

Table 35 Total Costs for all Scenarios OSD 2021, UK Flying Hours Min [R]

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3.2.9 Calculating Benefits from CWS

While the figures derived in cost calculations can be used to calculate a 'max spend' to completely mitigate the risk, in practice the embodiment of a CWS system will not reduce the risk to zero. Benefits are determined by examining the reduced risk resulting in implementing a CWS solution; costing the resultant collisions, and then examining the difference in costed scenarios when considered with a CWS system and without. QinetiQ modelling examined an installation of CWS over time with partial embodiment from FY 2013/14 to full embodiment by FY 2016/17. As examined, embodiment of CWS reduces risk per flying hour and has a resultant reduction on the expected number of collisions. Costing the reduced collisions results in the following for the cases we have considered [U]:

	Total Costs		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£1,243,118	£2,633,041	£6,418,102
TRAINING COST	£1,918,593	£3,040,981	£5,126,518
EQUIPMENT COST	£1,685,182	£1,685,182	£1,685,182
TOTALS	**£4,850,000**	**£7,360,000**	**£13,230,000**

Table 36 Costs for All Scenarios (CWS Embodiment) – OSD 2018, MAX Flying [R]

	Total Costs		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£1,152,389	£2,458,483	£6,042,858
TRAINING COST	£1,780,949	£2,836,118	£4,801,301
EQUIPMENT COST	£1,627,004	£1,627,004	£1,627,004
TOTALS	**£4,560,000**	**£6,920,000**	**£12,470,000**

Table 37 Costs for All Scenarios (CWS Embodiment) – OSD 2018, MIN Flying [R]

	Total Costs		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£1,299,835	£2,732,773	£6,606,063
TRAINING COST	£2,010,213	£3,174,058	£5,332,477
EQUIPMENT COST	£1,832,554	£1,832,554	£1,832,554
TOTALS	**£5,140,000**	**£7,740,000**	**£13,770,000**

Table 38 Costs for All Scenarios (CWS Embodiment) – OSD 2021, MAX Flying [R]

	Total Costs		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£1,202,051	£2,545,809	£6,207,444
TRAINING COST	£1,861,180	£2,952,659	£4,981,677
EQUIPMENT COST	£1,748,099	£1,748,099	£1,748,099
TOTALS	**£4,810,000**	**£7,250,000**	**£12,940,000**

Table 39 Costs for All Scenarios (CWS Embodiment) – OSD 2021, MIN Flying [R]

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The resultant (non-discounted) benefit is then calculated by subtracting the costs from expected collisions without CWS embodied from those with CWS embodied over time. [U]

Benefits arise during the period of appraisal. 7 years for considering Tornado between 2011 and 2018, and 10 years for 2011 and 2021. From HSE[25] guidelines it, *"is conventional practice in a CBA…to discount the values of all costs and benefits arising each year to the first year of the appraisal period."* [U]

The HSE (Health & Safety Executive, 2007) states that HMT Treasury recommends a discount rate for both costs and benefits of 3.5%. However, HSE argues that there is a greater value placed on health and safety benefits and, in effect, the discount rate for safety related benefits should be taken to be 1.5%. [U]

Net Present Value is calculated using: [U]

$$NPV = \sum_{i=1}^{n} \frac{values_i}{(1+rate)^i}$$

Equation 1 – NPV (where n is the number of cash flows and i is the 1.5% or 3.5% discount rate)

This CBA therefore uses a discount rate of 1.5% for the Human Costs and Benefits, and a discount rate of 3.5% for Equipment and Training costs. Applying discounting, this gives the following results: [U]

OSD 2021, MAX FH	BENEFITS (Collisions w/out CWS - w CWS)		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£1,201,205	£2,814,154	£8,149,472
TRAINING COST	£1,683,993	£2,843,030	£5,056,115
EQUIPMENT COST	£1,046,473	£1,046,473	£1,046,473
TOTALS	**£3,930,000**	**£6,700,000**	**£14,250,000**

Table 40 Discounted Total Benefits – without CWS vs. CWS [R]

OSD 2021, MIN FH	BENEFITS (Collisions w/out CWS - w CWS)		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£865,756	£1,938,434	£5,463,615
TRAINING COST	£1,213,946	£1,993,592	£3,466,026
EQUIPMENT COST	£739,806	£739,806	£739,806
TOTALS	**£2,820,000**	**£4,670,000**	**£9,670,000**

Table 41 Discounted Total Benefits – without CWS vs. CWS [R]

OSD 2018, MAX FH	BENEFITS (Collisions w/out CWS - w CWS)		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£904,225	£2,234,625	£6,656,382
TRAINING COST	£1,283,806	£2,234,755	£4,070,081

[25] http://www.hse.gov.uk/risk/theory/alarpcba.htm, accessed 16th November 2011

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[illegible] MENT COST	£687,011	£687,011	£687,011
TOTALS	£2,880,000	£5,160,000	£11,410,000

Table 42 Discounted Total Benefits – without CWS vs. CWS [R]

OSD 2018, MIN FH	BENEFITS (Collisions w/out CWS - w CWS)		
ALL SCENARIOS	LOW	MID	HIGH
HUMAN COST (VPF)	£589,399	£1,395,077	£4,055,760
TRAINING COST	£832,098	£1,407,564	£2,507,171
EQUIPMENT COST	£500,194	£500,194	£500,194
TOTALS	**£1,920,000**	**£3,300,000**	**£7,060,000**

Table 43 Discounted Total Benefits – without CWS vs. CWS [R]

In order to understand whether it is practicable to embody a CWS safety measure, it is necessary to consider two additional factors. The first being the Cost of Embodiment of the measure; the second being the multiplication factor that can be applied to Health and Safety Benefits (in this case Human Cost), known as Gross Disproportion. [U]

3.3 Step C - Gross Disproportion Factor (GDF); Reasonably Practicable

UK Case Law suggests that safety measures should be implemented if the risk is within the tolerable boundary unless costs are grossly disproportionate to benefits received. The HSE recommend the use of a Gross Disproportion Factor (GDF), where if total costs of the measure are greater than benefits multiplied by GDF, then the measure's costs are disproportionally high and not reasonable practicable. [U]

The GDF is a multiplication factor then and should be within 1 and 10 assuming the risk is in the tolerable boundary, according to HSE guidelines, and is dependent on whether the annual risk per (1st party) is closer to 1 in 1000 (a GDF of 10) or 1 in 1000000 (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. The MAA further recommend that this is linearly interpolated[26], illustrated in the graph below (Annual Risk is plotted on a logarithmic scale): [U]

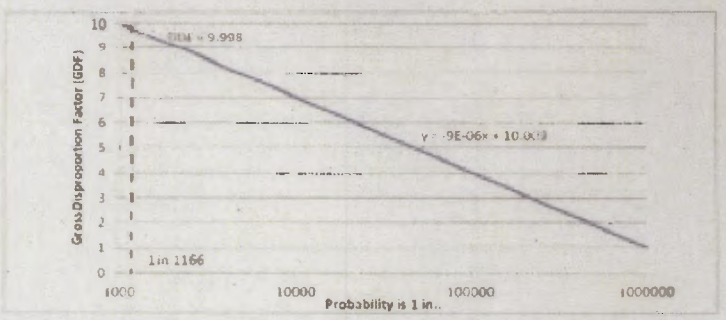

Figure 6 GDF Linear Interpolation [U]

[26] Some discussion with DASA DESA highlighted an economic preference to consider an exponential curve fit to determine GDF. This was not implemented due to MAA guidelines but can be examined in sensitivity testing if deemed appropriate.

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The study has been unable to verify a validated level of 'aggregated risk to life from all causes' to the Tornado GR4 platform although one reference to this was found in a report conducted by Adelard (2002)[27] listing annual risk to GR1/4 aircrew as 1 in 477 from data analysed between 1991 and 2000. It is assumed that subsequent concentration of effort on safety activity has reduced this level of risk to at least the tolerable limit, and hence judgement from the duty holder that it remains 'safe' to fly. [R]

The annual risk posed to 1st party aircrew however has been estimated and is illustrated in table 35 below. The CBA has used this value to calculate an estimated GDF given that the judgement of the stakeholder that mid-air collision proves a credible risk, that it is close to the tolerable boundary, and the duty holder holds that the aggregated risk for the platform as a whole remains tolerable. [R]

RISK	Pr. FH	CFT	Pr Col. A	1 in a...	GDF (Li)
1st Party	4.05E-06	[redacted]	8.58E-04	1166	9.999

Table 44 Overall Results for Case 1A [R]

3.3.1 Determining if Reasonably Practicable

HSE indicates that a measure is reasonable practicable (RP) as long as: Cost of Safety Measure < (Health & Safety Benefits * GDF) + Other Benefits. In this case: RP is True if Costs of CWS < (Human Costs * GDF) + Equipment Costs + Training Costs. [U]

Examining for each case gives the following results (a positive total indicates that Benefits * GDF outweigh Costs and the measure is reasonably practicable. A negative total indicates the opposite and the costs of the safety measure outweigh any potential benefits gained): [U]

CASE 1A: OSD 2018, MAX FH	BENEFITS (Collisions w/out CWS - w CWS)		
COSTS AND BENEFITS	LOW	MID	HIGH
HUMAN (1st and 3rd VPF)	£904,225	£2,234,625	£6,656,382
GDF (Risk is 1 in 1166 approx)	9.998	9.998	9.998
+HUMAN & GDF	£9,040,624	£22,342,227	£66,551,828
+TRAINING	£1,283,806	£2,234,755	£4,070,081
+EQUIPMENT	£687,011	£687,011	£687,011
Most Likely COST OF CWS	£54,479,509	£54,479,509	£54,479,509
TALS	-£43,468,068	-£29,215,517	**£16,829,411**

Table 45 Overall Results for Case 1A [R]

Using only the 50% confidence, most likely, costs for CWS embodiment the combined benefits across all scenarios and estimates for fatalities appear to show that the embodiment of CWS is grossly disproportionate to the benefit gained. [R]

For Case 1B, there is a more compelling case that the measure is not deemed to be reasonably practicable, due to the lower overall flying hours. [R]

[27] Numerical Criteria for Airworthiness (Adelard 2002), produced for ALTG_ADRP1, under contract MAP2b/1351

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CASE 1B: OSD 2017/18, MIN FH	BENEFITS (Collisions w/out CWS - w CWS)		
COSTS AND BENEFITS	LOW	MID	HIGH
HUMAN (1st and 3rd VPF)	£589,399	£1,395,077	£4,055,760
GDF (Risk is 1 in 1166 approx)	9.998	9.998	9.998
+HUMAN & GDF	£5,892,927	£13,948,259	£40,550,294
+TRAINING	£832,098	£1,407,564	£2,507,171
+EQUIPMENT	£500,194	£500,194	£500,194
Most Likely COST OF CWS	£54,479,509	£54,479,509	£54,479,509
TOTALS	-£47,254,290	-£38,623,492	-£10,921,849

Table 46 Overall Results for Case 1B [R]

Examining Case 2A, we would expect to realise the most benefit overall given the most flying hours and the longest period to realise the benefit of reduced expected collisions. [U]

CASE 2A: OSD 2020/21, MAX FH	BENEFITS (Collisions w/out CWS - w CWS)		
COSTS AND BENEFITS	LOW	MID	HIGH
HUMAN (1st and 3rd VPF)	£1,201,205	£2,814,154	£8,149,472
GDF (Risk is 1 in 1166 approx)	9.998	9.998	9.998
+HUMAN & GDF	£12,009,883	£28,136,465	£81,480,036
+TRAINING	£1,683,993	£2,843,030	£5,056,115
+EQUIPMENT	£1,046,473	£1,046,473	£1,046,473
Most Likely COST OF CWS	£48,507,326	£48,507,326	£48,507,326
TOTALS	-£33,766,977	-£16,481,358	£39,075,298

Table 47 Overall Results for Case 2A [R]

Again however, using low, mid, and high estimates for fatalities does not change the overall comparison, the measure appears to be more costly than the benefit that it offers even taking into account a GDF of 9.999, close to the 10 maximum, unless the high estimates of fatalities are used. [R]

Results for 2B are the same, cost of CWS outweigh benefits and GDF.

CASE 2B: OSD 2020/21, MIN FH	BENEFITS (Collisions w/out CWS - w CWS)		
COSTS AND BENEFITS	LOW	MID	HIGH
HUMAN (1st and 3rd VPF)	£865,756	£1,938,434	£5,463,615
GDF (Risk is 1 in 1166 approx)	9.998	9.998	9.998
+HUMAN & GDF	£8,656,004	£19,380,850	£54,626,304
+TRAINING	£1,213,946	£1,993,592	£3,466,026
+EQUIPMENT	£739,806	£739,806	£739,806
Most Likely COST OF CWS	£48,507,326	£48,507,326	£48,507,326
TOTALS	-£37,897,571	-£26,393,078	£10,324,810

Table 48 Overall Results for Case 2B [R]

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A summary of the baseline results, against the 50% confidence costs of the CWS system are shown below.

CWS Benefits - CWS Cost	FATALITY LEVELS (ESTIMATES)		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	-£43,470,000	-£29,210,000	£16,830,000
CASE 1B: OSD 2018, MIN FH	-£47,250,000	-£38,620,000	-£10,920,000
CASE 2A: OSD 2021, MAX FH	-£33,770,000	-£16,480,000	£39,080,000
CASE 2B: OSD 2021, MIN FH	-£37,900,000	-£26,390,000	£10,330,000

Table 49 Summary of Reasonable Practicable Assessment of all Cases [R]

In all cases, saving high fatality level estimates, the costs of embodiment for a CWS outweigh the benefits by a gross margin (applying multiplier GDF of 9.999 to human benefits). [U]

3.4 Step D – Sensitivity Testing: Probability of Collision

It is tempting to draw a conclusion from the above data that in only limited circumstances is the embodiment of CWS a practicable measure. This is not necessarily true because the results have not been subject to sensitivity testing. There are many factors within the CBA that have had the grossest estimates applied given lack of more authoritative data. It is possible to consider each of these variables; flying hours, estimates of fatalities, risk of collision with and without CWS, estimates applied to training costs, equipment, chance of material losses etc. [R]

Given the wide range of variables, it then becomes analytically time consuming to cover the various permutations of variables. The results overall however are more sensitive to some variables than others. The most notable, is the modelling of risk, which is itself subject to an approximate % error (approx +/- 14%) which is discussed in more depth in the QinetiQ paper. [R]

If the risk per flying hour before CWS were increased by 14% (within the accepted error of the estimate) then results change as follows. Case 2A, 2B and 1A becoming 'reasonable' if higher estimates of fatalities occur: [R]

CWS Benefits - CWS Cost	FATALITY LEVELS (ESTIMATES)		
Risk increased by 14%	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	-£41,920,000	-£25,670,000	£26,820,000
CASE 1B: OSD 2018, MIN FH	-£46,240,000	-£36,400,000	-£4,820,000
CASE 2A: OSD 2021, MAX FH	-£31,700,000	-£11,990,000	£51,350,000
CASE 2B: OSD 2021, MIN FH	-£36,410,000	-£23,290,000	£18,570,000

Table 50 Sensitivity Case (risk increased by 14%) [R]

This increase in risk however is relatively modest, indeed still within the error bounds, and reflects the degree to which the results of the CBA are sensitive to small errors or under or over estimates. HSE guidelines recommend testing sensitivities by increasing some factors by 2 or 3 times as much. [R]

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Increasing risk by 200% then reveals that Case 2A (maximum flying hours for an OSD of 2021) becomes reasonably practicable by some margin for 'high' estimates of fatalities and practicable for Case 2A, 'mid' estimate of fatalities. [R]

CWS Benefits - CWS Cost	FATALITY LEVELS (ESTIMATES)		
Risk increased by 200%	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	-£32,150,000	-£3,930,000	£88,210,000
CASE 1B: OSD 2018, MIN FH	-£40,020,000	-£22,750,000	£32,680,000
CASE 2A: OSD 2021, MAX FH	-£19,010,000	£15,580,000	£126,750,000
CASE 2B: OSD 2021, MIN FH	-£27,280,000	-£4,260,000	£69,220,000

Table 51 Sensitivity Case (200% of risk per FH) [R]

Increasing risks further, we are able to determine the robustness of the analysis to underestimating the risk to mid-air collision. Increasing by 3 times, all 'high' cases show that benefits outweigh costs and most 'mid' cases do also. Results show that raising risk between 7 to 8 times baseline shows that all cases and all estimates of fatalities show good cause for CWS embodiment for all cases: [R]

CWS Benefits - CWS Cost	FATALITY LEVELS (ESTIMATES)		
Risk increased by 300%	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	-£21,430,000	£21,360,000	£159,590,000
CASE 1B: OSD 2018, MIN FH	-£32,790,000	£6,880,000	£76,280,000
CASE 2A: OSD 2021, MAX FH	-£4,260,000	£47,630,000	£214,420,000
CASE 2B: OSD 2021, MIN FH	-£18,660,000	£17,880,000	£128,110,000

Table 52 Risk is 3 times higher than Baseline [R]

CWS Benefits - CWS Cost	FATALITY LEVELS (ESTIMATES)		
Risk increased by 800%	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	£33,680,000	£147,800,000	£516,500,000
CASE 1B: OSD 2018, MIN FH	£3,370,000	£72,470,000	£294,290,000
CASE 2A: OSD 2021, MAX FH	£69,510,000	£207,910,000	£652,770,000
CASE 2B: OSD 2021, MIN FH	£36,440,000	£128,550,000	£422,560,000

Table 53 Risk is 8 times higher than Baseline [R]

3.4.1 Societal Risk

The examination of individual risks, to aircrew and third parties, forms the larger part of the CBA. However individual risk alone does not completely describe situations and events where a single accident can have catastrophic consequences, killing or injuring a large number of people. [R]

Risk to individuals is costed by society's willingness to prevent fatalities, however the value applied to a single individual does not easily multiply upwards for single events. To put that in another way, a single accident that causes a single death, occurring 10 times in one year, is more tolerable to society as a whole than a single accident causing 10 deaths in the same year. In context, a train crash might occur once in 10

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years causing a large number of casualties, while in the equivalent time a much greater number might die in many incidents on the UK's roads, but largely unnoticed by the general public. Societal risk is the examination of society's tolerance of low probability events that have the potential to cause a great number of casualties. In this case, the chance of GR4 collision with a CAT aircraft filled with passengers. [R]

There are several methodologies for examining societal risk and HSE have in the past expressed such situations through the relationship between the probability of a catastrophic incident and its consequences. In 2001, the HSE proposed that the risk of 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. [28] This is however an area of much research and ultimately a judgement on tolerability must be taken by the appropriate duty holder. The MAA regulatory notices specify that risks that carry the potential of wider risks to the society should be briefed to the Secretary of State. [R]

For mid-air collisions, the largest societal risk is that of collision with CAT aircraft. QinetiQ used a flying profile to capture an estimate of low and medium level flying for GR4 for all cases (1A, 1B, 2A, and 2B). Examining the risk per annum against flying hours has the following results: [R]

Year	Flying Hours	CAT P(Collision) pFH	CAT P(Collision) pA	1 in...
2011	[redacted]	3.85E-08	5.55E-04	1802
2012		3.96E-08	5.03E-04	1989
2013		4.05E-08	4.65E-04	2152
2014		4.16E-08	2.94E-04	3399
2015		4.26E-08	3.24E-04	3087
2016		4.37E-08	2.89E-04	3457
2017		4.48E-08	2.96E-04	3374
2018		4.59E-08	3.04E-04	3293
2019		4.70E-08	3.00E-04	3331
2020		4.82E-08	9.74E-05	10266

Table 54 Societal Risk (average), given GR4 Low Level and Medium Level Flying. [R]

The above table illustrates that the annual probability of at least one collision with one CAT aircraft (average from 2016) until GR4 OSD is approximately 1 in 3900. This incident does not necessary constitute an event that causes 50 or more people but it is credible to consider it as such given collision with a commercial air liner. [R]

In implementing a collision warning system, the risks change as follows:

Year	Flying Hours	CAT P(Collision) pFH	CAT P(Collision) pA	1 in...
2011	[redacted]	3.85E-08	5.55E-04	1802
2012		3.96E-08	5.03E-04	1989
2013		3.16E-08	3.62E-04	2764

[28] HSE, "Proposals for revised risk policies to address societal risk around onshore non-nuclear major hazard installations", 2007

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2014	[redacted]	2.32E-08	1.64E-04	6098
2015		1.43E-08	1.09E-04	9183
2016		5.01E-09	3.32E-05	30104
2017		5.14E-09	3.40E-05	29383
2018		5.27E-09	3.49E-05	28680
2019		5.40E-09	3.45E-05	29009
2020		5.53E-09	1.12E-05	89413

Table 55 Societal Risk (average) (with CWS) [R]

The overall risks are reduced considerably, CWS fully embodied fully from 2016; risk reduces to 1 in 34000 (average from 2016, to two significant figures) chance of a catastrophic collision, the risk moving to meet previous guidelines of 1 in 5000 per annum. The data in tables 45 and 46 are illustrated below (Risk is displayed on a logarithmic scale): [R]

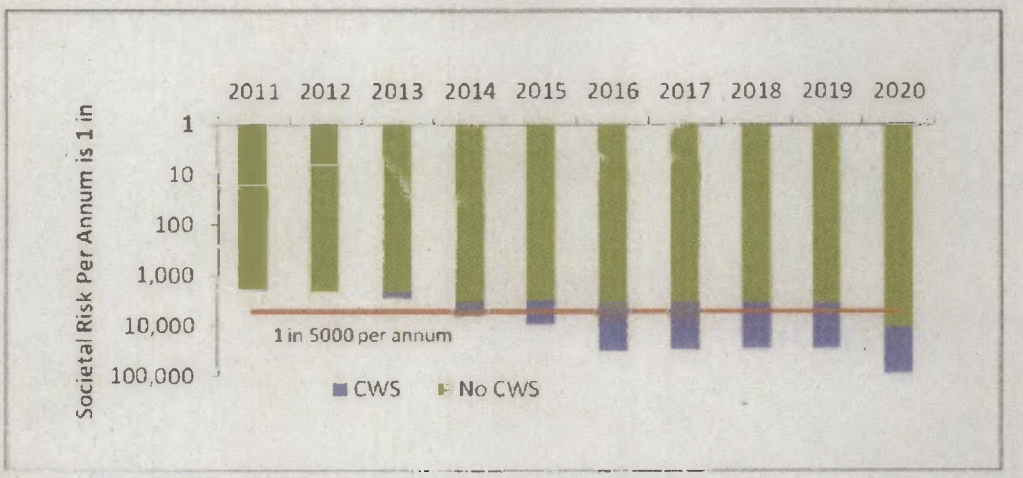

Figure 7 Case 1A: Societal Risk and 'value' of Risk Reduction from CWS [R]

The figure above illustrates annual risk of a catastrophic event, year on year (for Case 2B – interpreted by QQ modelling as 80% of anticipated exposure to risk); the longer the bars, the lower the risk. To meet HSE guidelines, the bar for each year should be lower than the drawn line, marking an annual frequency of 1 in 5000 for societal risk. The embodiment of a CWS system, reduces risk in the remaining life of the aircraft (embodiment begins in 2013/14 and is complete by 2016/17 [R]

The data available suggests that the risk of a mid-air collision that causes multiple casualties, in excess of 50 fatalities from a single incident is more likely than 1 in 5000 year on year for the remaining life of GR4. Results from the flying hour profile used suggests an average risk of 1 in 3900 reducing to 1 in 34000 following CWS embodiment. [R]

4 Conclusions

The total cost of collisions (inc. GDF) can be presented as the 'max spend' as shown in the following table:

MAX SPEND to ZERO Risk	FATALITY LEVELS (ESTIMATES)		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	£38,880,000	£90,710,000	£258,050,000
CASE 1B: OSD 2018, MIN FH	£32,940,000	£75,930,000	£214,660,000
CASE 2A: OSD 2021, MAX FH	£43,030,000	£97,660,000	£273,700,000
CASE 2B: OSD 2021, MIN FH	£36,680,000	£82,320,000	£229,320,000

Table 56 Max Spend given a reduction of risk to zero events [R]

The figures above represent the maximum spend that would be deemed reasonable to reduce the risk of a mid-air collision to zero for 2018 and 2021 cases for low, medium and high casualty estimates. The figures range between £33M and £274M, the highest figure indicating the longer GR4 remains in service and flying, i.e. the risk of collision increases and indicating it is more cost-effective to invest in a range of risk reduction methods. [R]

The CWS considered does not however reduce the overall risk of events to zero. Given an effective CWS is unlikely to reduce risk to zero; the effect of a CWS system was modelled, showing the reduced number of collisions, and therefore max spend on this CWS, as a result. [R]

MAX SPEND on CWS	FATALITY LEVELS (ESTIMATES)		
UK and Op Scenarios	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	£11,010,000	£25,260,000	£71,310,000
CASE 1B: OSD 2018, MIN FH	£7,230,000	£15,860,000	£43,560,000
CASE 2A: OSD 2021, MAX FH	£14,740,000	£32,030,000	£87,590,000
CASE 2B: OSD 2021, MIN FH	£10,610,000	£22,110,000	£58,830,000

Table 57 Max Spend on CWS risk reduction [R]

The results, including operational flying hours, showed that the greatest benefit offered by CWS were for Case 2A and Cases 1A and 2B, and broadly correspond to remaining flying hours. Simply put the longer GR4 flies, the greater incentive there is to implement a form of CWS. Indicative costs for CWS however, 50% confidence, are £48.5M for OSD 2021 (Case 2A and 2B) and £54.5M for OSD 2018 suggesting that the embodiment of CWS could be seen as not reasonably practicable if 'mid' or most likely values for fatality estimates were used. [R]

However, given the necessarily broad assumptions made in the CBA process it is necessary to examine the results in terms of sensitivities, also recommended by HSE guidelines to *'change factors by 2 or 3 times'* as much. By increasing estimates of the risk per flying hour by 2, the results change significantly as follows: [R]

CWS Benefits - CWS Cost	FATALITY LEVELS (ESTIMATES)		
Risk increased by 200%	LOW	MID	HIGH
CASE 1A: OSD 2018, MAX FH	-£32,450,000	-£3,930,000	£88,210,000
CASE 1B: OSD 2018, MIN FH	-£40,020,000	-£22,750,000	£32,680,000
CASE 2A: OSD 2021, MAX FH	-£19,010,000	£15,580,000	£126,750,000
CASE 2B: OSD 2021, MIN FH	-£27,280,000	-£4,260,000	£69,220,000

Table 58 CWS Benefits - CWS Cost (Risk at 200%)

It is evident that the results of the CBA are subject to considerable sensitivity of the modelling of aircraft risk and estimates of fatalities caused by mid-air collision. The determination therefore if a CWS measure is reasonably practicable is difficult to ascertain but there is a more compelling argument for Case 2A, followed by 2B, then 1A, then 1B which is to be expected as total flying hours are reduced respectively. [R]

In addition to the examination of individual risk, this analysis examines societal risk, that is defined here of the risk posed to society of a single event causing in excess of 50 fatalities. The HSE has suggested that civilian safety targets for non-nuclear hazards should involve effort to ensure that incidents that cause more than 50 fatalities are less frequent than 1 in 5000 per annum. In the case of mid-air collisions, the societal risk is that GR4 will collide with a commercial airliner, perhaps similar to a Boeing 737 or larger aircraft, and so likely to cause in excess of 50 fatalities. Modelling results have shown that, for all cases, the risk of collision with commercial air transport (CAT) is broadly equivalent to 1 in 3900 per annum (average from 2016 to OSD). The embodiment of a CWS system reduces societal risk (average from 2016) from the platform to 1 in 34000 per annum. [R]

While additional sensitivities may be investigated, including different GDF values, variations in costs for training and equipment, different assumptions on estimated fatalities; it is suggested that the findings of the CBA are not compelling in determining whether CWS is reasonably practicable for the baseline case (100% risk) and must be complemented with an assessment of risk by the qualified duty holder and supporting subject matter experts. [R]

Determining if CWS is a 'reasonably practicable' measure is more compelling for an OSD for Tornado in 2021 than in 2018 but remains marginal for both overall, and for both flying hour profiles, despite expecting a number of collisions in the remaining life for GR4. [R]

However, societal risks are perhaps the overriding concern. According to MAA guidelines, any potential risk to society at large should be notified to the Secretary of State as the risk to the public from such events cannot properly be accounted for by the CBA process. [R]

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[5] Mid-Air Collision Scenarios – TORNADO GR4 -AOC1Gp-RM, September 2011

[6] Strategic Review of General Aviation in the UK" (PDF). CAA. 2006-07. pp. iii–iv, paras. 17, 19 & 20

[7] SRG Safety Plan 2008 Update" (PDF). CAA. 2008-06. p. 49.

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List of abbreviations

ALARP	As Low As Reasonably Practicable
ATPL	Airline Transport Police Licence
CAA	Civil Aviation Authority
Cap DTA	Capability Deep Target Attack
CAT	Commercial Air Transport
CBA	Cost Benefit Analysis
CPL	Commercial Pilot Licence
CWS	Collision Warning System
Dstl	Defence Science and Technology Laboratories
GA	General Aviation
GDF	Gross Disproportionate Factor
HQ	Headquarters
HSE	Health & Safety Executive
JSP	Joint Service Publication
LL	Low Level
MAA	Military Aviation Authority
MIL	Military
ML	Mid Level
MOD	Ministry Of Defence
NPPL	National Private Pilot Licence
NPV	Net Present Value
OSD	Out of Service Date
PPL	Private Pilot Licence
RN	Regulatory Notice
RP	Reasonable Practicable
SME	Subject Matter Expert
SoS	Secretary Of State
VPF	Value of Prevented Fatality

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16a.	**Abstract:** The Defence Science and Technology Laboratory (DSTL) were tasked to provide Capability Deep Target Attack (Cap DTA) with a Cost Benefit Analysis (CBA) in accordance with Joint Service Publication (JSP) 507 and informed by the Military Aviation Authority (MAA) Regulatory Notice (RN) 12/11. The CBA provides guidance as to whether it is a 'reasonably practicable' safety measure to implement a Collision Warning System (CWS) on the Tornado GR4 aircraft. The analysis was conducted for two distinct cases: Case 1 assumed an Out of Service Date (OSD) for Tornado in 2018; 1A a total of [redacted] flying hours and 1B a total of [redacted] flying hours. Case 2 assumed an OSD of 2021; 2A, [redacted] flying hours and 2B, [redacted] flying hours. Cases were considered across a range of scenarios proposed by HQ 1Gp and included most likely and worst credible cases. They included collision with general aviation (GA), military aircraft (MIL) and commercial air transport (CAT), with a range of estimated fatalities (for both 1st party i.e. military aircrew and non-aircrew and civilians i.e. 2nd and 3rd party). The total cost for collisions was calculated, taken over the lifetime of the aircraft and included human costs (i.e. fatalities), training, and equipment losses. The results showed that the greatest benefit offered by CWS was for Case 2A, Cases 1A, 2B and then 1B (in order of greatest to least benefit), broadly corresponding to remaining flying hours. Indicative costs for CWS embodiment, 50% confidence, are £48.5M for OSD 2021 (Case 2A and 2B) and £54.5M for OSD 2018 (Case 1A and 1B). Results suggested that the embodiment of CWS would not be seen as reasonably practicable for all cases (Only for 'high estimates' of fatalities for 2A, 1A, and 2B). Analysis also examined 'societal risk', defined here as the risk posed to society of a single event causing in excess of 50 fatalities. In the case of mid-air collisions, the societal risk is that GR4 will collide with a CAT aircraft, similar to a Boeing 737, and cause in excess of 50 fatalities. Results have shown that, averaged across all cases, the risk of collision with Commercial Air Transport (CAT) is broadly equivalent to 1 in 2918 per annum over the lifetime of the aircraft. The embodiment of CWS reduces the risk to 1 in 33835 following full embodiment of CWS from 2016. The assessment of the tolerability of societal risk must ultimately be taken by the duty holder at an appropriate level; according to MAA guidelines, any potential risk to society at large of this magnitude should be notified to the Secretary of State (SoS) as the risk to the public from such events cannot properly be accounted for by the CBA process.
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