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The Risk of Mid-Air Collision to Commercial Air Transport Aircraft Receiving a Radar Advisory Service in Class F/G Airspace

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This paper discusses the quantification of the risk of mid-air collision to commercial air transport aircraft receiving a Radar Advisory Service in UK Class F/G airspace. The aim is to produce the best estimate, given published data, and then to indicate what extra studies and data would be needed to improve the estimate. A study of typical flight routeings by certain aircraft types, e.g. Sikorsky S76, Saab SF340, Short SD3-60 and Aeritalia ATR42-300, could provide useful additional information. The fitment and use of ACAS could be crucial in delivering the required protection against collision.

1. INTRODUCTION. There are seven different classes of airspace in the UK, denoted by the letters A to G. Apart from some very specific exceptions, Classes A to E are all controlled airspace, in that pilots must get clearance to enter the airspace and must then follow controllers' instructions. Classes F and G, combined here as Class F/G, are not controlled in this sense; they are usually known as the Open Flight Information Region. Air traffic services (ATS) provide various kinds of information and advisory to pilots operating in Class F/G. One of them is a Radar Advisory Service (RAS). This paper discusses the quantification of the current risk of mid-air collision to commercial air transport (CAT) aircraft receiving a RAS in Class F/G airspace. The aim is to produce the best estimate given published data, taking a generally cautious approach and clearly setting out modelling assumptions, and then to indicate what extra studies and data would be needed to improve the quality of the estimate.

Section 2 briefly explains what a RAS is. Section 3 addresses safety targets for CAT aircraft receiving a RAS. Section 4 is a statistical analysis of Airproxes and flying hours for CAT aircraft receiving a RAS in Class F/G airspace. Section 5 then discusses the quantification of the risk of mid-air collision for these aircraft. The final section summarises the results and tries to identify data collections, studies and analyses that might help to improve the risk estimate.

All references to collision risk, Airproxes, flying hours, etc in this paper are for CAT aircraft receiving a RAS in Class F/G airspace unless explicitly stated otherwise. Calculations are carried out to two decimal places, but this does not indicate anything about the actual precision involved. Risk rates given are historical estimates rather than predictions of long term averages.

2. RADAR ADVISORY SERVICE.

The formal definitions of RAS and Classes F/G are as set out in CAP 493, the Civil Aviation Authority (CAA) Manual of Air Traffic Services (MATS) Part 1 – referred to here as MATS Part 1. With a RAS, the controller provides information, based on a radar picture, of the bearing, distance and, if known, the flight level of other aircraft in the vicinity, and provides advice on action necessary to resolve potential conflicts and erosions of separation. The other conflicting traffic can be non-participating in the RAS. For example, as will be described later, the flight path of a CAT aircraft receiving a RAS can come into conflict with a military aircraft receiving a service from another air traffic services unit (ATSU).

Some edited extracts from MATS Part 1 complete the picture:

- RAS is advisory, but controllers pass the advice in the form of instructions.
- RAS is only provided to flights under Instrument Flight Rules (IFR).
- Should a pilot choose not to comply with advisory avoiding action then that pilot becomes responsible for his own separation and any subsequent avoiding action.
- Controllers' avoiding action instructions seek, wherever possible, to achieve separation which is not less than 5 nm or 3000 ft.

3. SAFETY TARGETS.

Calculating collision risk without any context of what would be acceptable would be a flawed exercise, so some definitions of safety terms and benchmarks are required. The key concept is that of a Target Level of Safety (TLS). This is actually a design hurdle. It is a quantified risk level (measured as an accident rate) that a system should (i.e. be designed to) deliver, usually as a proportion of fatal accidents per so many flying hours (or airport movements when that is more appropriate). It is not in any way a model of collision risk, nor is it a statement of the actual level of safety achieved in practice. Most of the practical problems are not actually with the TLS but with the proper estimation of the safety level that is or would be achieved. There is an Actual Level of Safety (ALS) being achieved in the system under examination. The key question is how is this to be calculated with sufficient accuracy to be confident that the $ALS < TLS$?

TLSs appropriate for accidents arising from mid-air collisions in controlled airspace have been developed since the 1970s. They are usually derived by taking historical accident rates, which show a progressive reduction over time, and extrapolating forward. The original focus was on commercial passenger jet flights in North Atlantic airspace, but the TLS has been used for en route controlled airspace generally and so will be referred to here as the ATC TLS. Calculations of separation standards in oceanic and domestic airspace use this TLS.

The ATC TLS measures the rate of fatal aircraft accidents, i.e. accidents in which at least one person in the aircraft was killed, per so many aircraft flying hours. The current International Civil Aviation Organisation ICAO (RGCSP, 1995) figure of $1{\cdot}5 \times 10^{-8}$ fatal aircraft accidents per flying hour is the rate corresponding to mid-air collisions, for any reason and in any spatial dimension, in en route flight in controlled airspace. As noted already, the ATC TLS was derived by examining accident statistics trends for passenger jet aircraft in controlled airspace. Would the same risk target be an appropriate TLS for CAT aircraft receiving a RAS in Class F/G airspace? This question is not addressed here, although it is obviously an important one. The ATC TLS is taken as an initial benchmark for RAS.

4. STATISTICAL ANALYSIS OF AIRPROXES AND FLYING HOURS FOR CAT AIRCRAFT RECEIVING A RAS IN CLASS F/G AIRSPACE.

This section examines recent statistics on Airproxes and flying hours for CAT aircraft. Airprox data has been abstracted from the Airprox Reports (1999 -) with the help of Airprox Board staff. Airproxes are the only fully publicly available data on UK ATC safety (Brooker (2002) comments on the merits of Airproxes versus (e.g.) Mandatory Occurrence Reports). They are useful indicators of relative risk, and they help towards quantifying accident risk (NB: Airprox here covers risk category A, B and C unless stated otherwise). The flying hours data used later is derived from CAA UK Airline statistics (CAA, 2001). Year 2000 figures are used here because this is the latest full year available with undistorted traffic. CAT as used here is the Airprox Board definition (there are others) for commercial flights. It covers scheduled/non-scheduled passenger flights in airliners and helicopters, and cargo flights.

Table 1 lists the Airproxes involving CAT aircraft receiving a RAS during the period 1999 to 2001 inclusive. [The three years data are used because they increase the statistical sample. The Airprox Board started in 1998. In some calculations here, the Airprox data is divided by 3 to give a yearly average: this assumes constant traffic levels and patterns over the 3 years.]

The information in Table 1 is derived from the Airprox Board database: see the Airprox Board Report for full explanations of the abbreviations used. Class 1 and Class 2 are the first and second reporting aircraft respectively: note that almost invariably the CAT aircraft crew reports first and that all the conflicting aircraft bar one are military. Table 1 also shows that the ATSUs controlling the CAT aircraft tend to be away from the main areas of controlled airspace, as would be expected.

Of considerable interest is the type of CAT aircraft involved. Table 2 shows the breakdown by Vortex Wake category – Heavy, Medium, Small and Light (see Appendix B of MATS Part 1). The data is from the Airprox Board database. These proportions are very different from those for total flying hours in the UK. Calculations of flying hours from movement statistics are not simple, Light aircraft generally fly more slowly than Heavy ones, but the latter (particularly oceanic flights) spend longer in UK airspace. However, it does seem that the proportion of Light CAT aircraft involved in Airproxes is much greater than for other weight categories. This is hardly unexpected given the nature of typical flights by CAT aircraft at the smaller airports and in, for example, oil-related operations by helicopters.

The predominance of Light category aircraft in the Airprox statistics, with some types occurring more frequently than others in this weight band, suggests that a more detailed examination of their operations might yield some worthwhile results. To do this, it is necessary to try to construct some estimates of the flying hours of the different types. The CAA Airline statistics for 2000, Tables 1.111 and 1.13 are used. These set out the flying hours by aircraft type for UK airlines and air taxis (NB: Note these statistics do not cover foreign airlines). Table 3 compares the hours flown with the Airproxes recorded for each type (NB: The name of the type here is as stated in MATS Part 1, although in several cases the current manufacturer/name is somewhat different). It is assumed in the following that all the Airproxes involve UK aircraft: the Airprox Board does not retain this information in its database, but most Light aircraft Airproxes are UK-operated – although some are certainly not UK-registered.

Table 1. Airproxes involving commercial air transport receiving a RAS: 1999 to 2001 inclusive.

Serial No.	risk	Class 1	Class 2	ATSU 1	ATSU 2
015/99	C	CATP	MILF	London Mil. Radar	London Mil. Radar
017/99	C	CATP	MILF	Pennine Radar	Neatishead ADRS
059/99	C	CATQ	MILF	London ATCC	*None*
081/99	C	CATP	MILF	Bristol Lulsgate	Lyneham
114/99	C	CATP	MILF	Scottish Mil. Radar	*None*
146/99	B	CATP	MILF	Scottish ATCC	*None*
164/99	C	MILF	CATP	Neatishead ADRS	Pennine Radar
189/99	C	CATP	MILF	Anglia Radar	*None*
210/99	C	CATP	MILF	Scottish Mil. Radar	Buchan ADRS
215/99	C	CATP	MILF	Scottish Mil. Radar	*None*
217/99	C	CATP	MILF	Aberdeen Dyce	Buchan ADRS
224/99	C	CATP	MILF	Scottish ATCC	Scottish Mil. Radar
005/00	C	CATP	MILF	Aberdeen Dyce	*None*
017/00	C	CATP	MILF	Bristol Lulsgate	*None*
039/00	A	CATP	MILF	Newcastle Woolsington	AEW Aircraft
042/00	C	CATP	MILF	Newcastle Woolsington	AEW Aircraft
043/00	C	CATP	CIVP	Birmingham	*None*
044/00	C	CATP	MILX	Pennine Radar	Leeming
048/00	C	CATP	MILF	Prestwick Airport	*None*
057/00	C	MILF	CATP	Cardiff	Cardiff
062/00	C	CATP	MILF	Scottish ATCC	Lossiemouth
068/00	C	CATP	MILF	Glasgow Airport	Scottish Mil. Radar
077/00	C	CATP	MILF	Norwich	London Mil. Radar
080/00	C	CATP	MILF	Anglia Radar	Marham
094/00	A	CATP	MILF	Scottish ATCC	*None*
138/00	C	CATP	MILF	Anglia Radar	Neatishead ADRS
195/00	C	CATP	MILF	Pennine Radar	London Mil. Radar
014/01	C	CATP	MILF	Newcastle Woolsington	Scottish Mil. Radar
033/01	C	CATP	MILF	Scottish ATCC	Scottish Mil. Radar
038/01	C	CATQ	MILF	Scottish ATCC	*None*
051/01	C	CATQ	MILF	Anglia Radar	London Mil. Radar
062/01	C	CATQ	MILF	Norwich	Lakenheath
105/01	C	CATP	MILF	Scottish ATCC	*None*
138/01	C	CATH	MILF	Anglia Radar	Humberside
139/01	B	CATP	MILF	Pennine Radar	London Mil. Radar
144/01	B	CATH	MILF	Anglia Radar	London Mil. Radar

Source: Airprox Board Reports
CAT = Commercial Air Transport, MIL/Mil = Military

The flying hours for those types not recorded in Airproxes are combined into a residual class, and the Annual Rate figures are put in descending order.

The results shown in Table 3 are extremely interesting, as only a few types were recorded in Airproxes. To try to make some sense of this data, one key assumption is needed:

> The number of Airproxes involving a particular CAT type receiving a RAS in Class F/G airspace is directly proportional to its flying hours in Class F/G airspace.

This appears to be a reasonable starting premise about flying hour rates, but it may be too crude to use the same constant of proportionality for all types. For example, fixed wing and helicopters may use dissimilar zones of Class F/G airspace, with the level of

Table 2. Breakdown of CAT in Airproxes by vortex wake category.

	Heavy	Medium	Small	Light
Number	1	7	9	19
Percentage	2·8	19·4	25·0	52·7

Table 3. CAT Types in Airproxes and Flying Hours.

Type	Hours	Annual Rate per 100,000 flying hours	Airproxes	Expected Airproxes
Sikorsky S76	12,373	16·16	6	1·38
Saab SF340	22,883	10·20	7	2·54
Short SD3-60	20,708	4·83	3	2·30
Aeritalia ATR42-300	15,549	4·29	2	1·73
Handley Page Jetstream	35,436	0·94	1	3·94
All other types	63,964	—	0	7·11
Totals/averages	*170,913*	*3·71*	*19*	*19*

military operations in these zones being very different. The third column of Table 3 shows the Airprox rate per 100,000 hours, remembering that the Airproxes actually cover a three-year period.

Table 3's right hand column shows the number of Expected Airproxes. It is calculated by taking the total number of Airproxes and multiplying by the corresponding proportion of flying hours. In essence, the assumption in the previous paragraph is being combined with an assumption that all the flying hours are in Class F/G airspace. When these figures are coupled with some crude statistical testing (just using Poisson distribution confidence bands), the conclusions are:

(a) The lack of any Airproxes in the 'All other types' grouping is not very likely to be just a statistical fluctuation.
(b) The one Airprox involving a Handley Page Jetstream is not that likely to have been a statistical fluctuation from the expected number.
(c) The observed numbers for the Sikorsky S76 helicopter and the Saab SF340 are markedly larger than might be expected from statistical fluctuations.

The simplest explanations for the data set are:

1. The aircraft in the 'All other types' grouping and the Handley Page Jetstream spend comparatively few flying hours receiving a RAS in Class F/G.
2. The four types with the highest number of Airproxes are likely to be operated by airlines/air taxi firms from airports that are not closely tied into the airway system, and hence spend a large proportion of time receiving a RAS in Class F/G.
3. Helicopters may be operating in dissimilar Class F/G airspace from fixed wing aircraft.

Table 4 is essentially a sub-table of Table 3; it covers just the four aircraft types noted in (2) immediately above. The Expected Number of Airproxes has changed markedly, because the flying hours over which they are distributed have reduced considerably.

Table 4. Most Common CAT Types in Airproxes and Flying Hours.

Type	Hours	Annual Rate per 100,000 flying hours	Airproxes	Expected Airproxes
Sikorsky S76	12,373	16·16	6	3·11
Saab SF340	22,883	10·20	7	5·75
Short SD3-60	20,708	4·83	3	5·21
Aeritalia ATR42-300	15,549	4·29	2	3·92
Totals/averages	*71,513*	*8·39*	*18*	*17·99*

The two right hand columns are now much more alike – the differences between expected and actual could very easily be the product of statistical fluctuations.

The analysis of activity is not complete. It cannot be assumed that all the hours flown are in Class F/G airspace, for the simple reason that flights operate from airports embedded in various types of control zone. Most Light CAT aircraft flights are of comparatively short duration. From the CAA airline statistics, the average flight times (using stage flights because most of the Sikorsky flights could be offshore between rigs and platforms) for the relevant types are:

Sikorsky S76 – 14 minutes
Saab SF340 – 62 minutes
Short SD3-60 – 49 minutes
Aeritalia ATR42-300 – 78 minutes.

On the available data, it is not possible to estimate how much time is spent on average outside Class F/G airspace. A figure of 25% is assumed in the following (this is probably a rather cautious figure – i.e. tends to overestimate risk). Using the rate of 8·39 from Table 4 and the 75% assumption on the time in Class F/G gives the result:

> Airprox rate for Light CAT aircraft receiving a RAS in Class F/G is estimated as 11·2 Airproxes per 100,000 flying hours exposure.
>
> Annual Hours exposed for Light CAT aircraft receiving a RAS in Class F/G are $71{,}513 \times 0{\cdot}75 = 53{,}635$.

If it can be assumed that the rate of these Airproxes is the same for all weight categories of aircraft, then the total flying hours for CAT aircraft receiving a RAS in Class F/G can be estimated by scaling up in proportion to the number of Airproxes; i.e. the rate of Airproxes is the same for all the weight categories. In this case, the sum is simple as there were 36 in total:

> Annual Hours exposed for all CAT aircraft receiving a RAS in Class F/G are 107,000. (Note that, because hours are inferred from Airproxes, flights by foreign aircraft would now be included.)

Taking the figures at face value, the Airprox rate for this type of service, 11·2 per 100,000 flying hours exposure, is about 50% greater than that for CAT aircraft generally (7·13 in 2000 from Airprox Board Report statistics). Obviously, the preceding paragraphs have set out a rather synthetic and inferential calculation. It contains several simplifying assumptions, so the degree of confidence in the final answers cannot be great. For example, the Airprox rate could be much higher if the proportion of time out of controlled airspace were markedly lower, which could well be the case (e.g. taking 50% rather than 75% in Class F/G would produce an Airprox rate of 16·6). As already noted, it might also be that the rates for helicopters and fixed wing are different, and there might be marked difference in risks between aircraft types that tend to operate in different geographical areas.

Caution is needed here. Under-reporting of Airproxes by pilots and controllers might also be more likely for CAT aircraft receiving a RAS. CAT/CAT Airproxes are reported in an environment that usually has ACAS and STCA operational, and so would be much less likely to go undetected. Thus, the risks for CAT aircraft receiving a RAS could be significantly higher than estimated above.

5. QUANTIFICATION OF THE RISK OF MID-AIR COLLISION.

What does the Airprox rate for CAT aircraft receiving RAS indicate about the risk of mid-air collision, the ALS? A slightly different safety question might be asked by an aircraft passenger: '*How do the risks to me with this type of operation compare with those occurring in controlled airspace?*' A key point is that the system safety layers are not the same in the two cases, as will be made evident in the following.

In the (fortunate) absence of historical accident rates, risk calculations about CAT aircraft receiving RAS in Class F/G have to be extrapolations, but these have to be firmly based on what actually happens in hazardous incidents. This is a necessary ingredient but not a sufficient one. Extrapolation from safety incidents generally assume that the causal factors producing them are the same as those that would, over the long term, produce accidents. It is easy to find counterexamples to this, e.g. the Titanic was the first ship with safety compartments to strike icebergs. But that does not alter the fact that there are usually many safety incidents of a particular type detected before an accident. It would just be a great misfortune not to get one of these free safety lessons before an accident.

Put another way, one necessary ingredient of accident rate estimation is that the mechanisms and factors involved should be traceable to what happens in the real world. The assumptions made in modelling must match what is known from serious incidents. To illustrate this point in the present context, Annex A summarises the five hazardous (A or B category) Airproxes that have occurred in 1999–2001, all with military aircraft. Some observations:

- The military crew tend to see the CAT aircraft late.
- The military aircraft is engaged in manoeuvres, turns or climbs.
- Where ACAS is operational, it does provide a RA before the closest point of approach.
- Only on some occasions does the RAS controller detect the potential conflict and provide instructions. Sometimes the controller is not aware of the incident until the conflict is in progress.
- Conflicts are either with crossing traffic or near to the opposite direction.
- Avoiding action does not always take place, because military aircraft manoeuvres are too rapid.

These simple observations start to indicate the difficulty involved in attempting to estimate risk by means of some kind of causal chain analysis (often termed

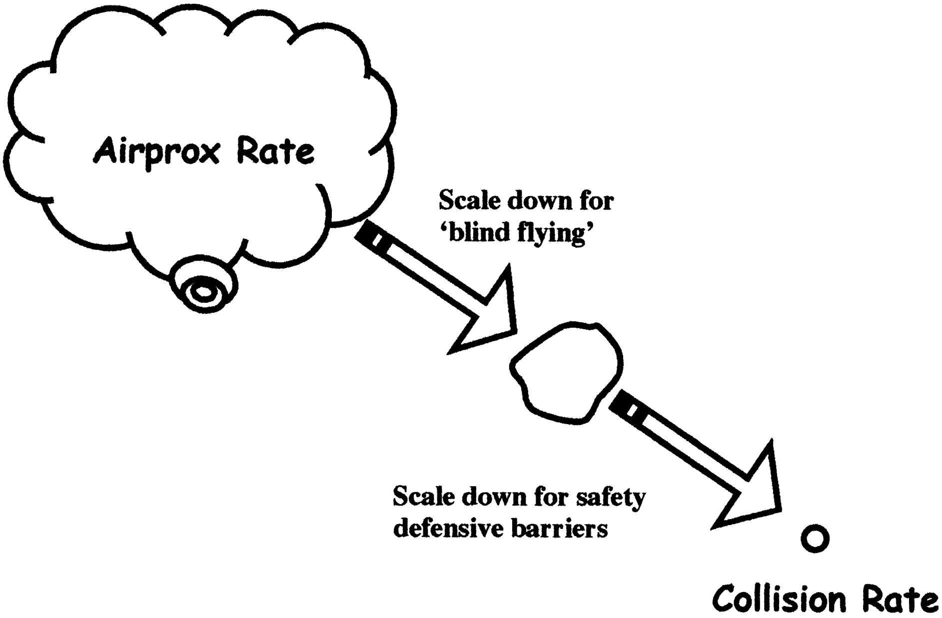

Figure 1. The Calculation Process.

Probabilistic Risk Analysis (PRA)). These methods assume that accidents are produced by causal chains of errors or natural variations from normal operations. To get to the accident rate, the probabilities of the wrong combinations of circumstances have to be multiplied together appropriately. Thus, for example, a mid-air collision in controlled airspace could occur in bad visibility because of a navigational error in manoeuvring plus an orientation of the aircraft flightpaths that produced very late ACAS and STCA alerts.

In the present case, finding all these causal chains and all the associated probabilities of occurrence are intrinsically very difficult, as there are so many different potential combinations to examine and insufficient statistical data in the Airproxes to estimate what are very small probabilities. Probabilities would need to be estimated for such risk components as controller perceptual or judgement error, attention failure, memory lapse, etc. The models may well be appropriate but the difficulty is in populating them with relevant data, given that the error-types are rare events.

The method adopted here is to attempt to estimate risks by using extrapolations from Airprox data. The calculation does not guarantee high accuracy but no other known method is necessarily assured of delivering better precision. A general method for CAT/CAT collision risk is set out in Brooker (2002): the simplified analysis here is self-contained, albeit rather terse. The process is sketched in Figure 1, which will be explained as the steps are followed.

May (1971) derives the statistical expectation of a collision for an 'intruder' aircraft, represented by a disc of radius R and height H, that spends a time period T in an airspace volume A filled with N similar-sized aircraft. N divided by A is the density D of aircraft. The safety defensive barrier effects of automatic warning systems and controller/pilot action are for the moment ignored. The statistical expectation of a collision is:

$$2H \times 4R \times T \times (N/A) \times (Average\ V_r).$$

Here, *Average* V_r is the magnitude of the average relative velocity between the intruder aircraft and the N aircraft. Were all the N aircraft to be flying in the opposite direction to the intruder, then V_r would equal the sum of the intruder and typical aircraft speeds.

Cautious CAT aircraft dimensions used to reflect operations in en route controlled airspace are:

$$H = 0{\cdot}010\,\text{nm} = \text{about } 60\,\text{ft};$$
$$R = 0{\cdot}017\,\text{nm} = \text{about } 100\,\text{ft}.$$

However, these figures correspond to large jets. For RAS, the two aircraft would pose much smaller collision targets, given that the typical CAT aircraft would be in the Light/Small category and the non-RAS aircraft might be a Tornado.

Light/Small category and military aircraft dimensions are typically 30 ft high and 80 ft length/wingspan, so for CAT/military collisions appropriate sizes might be:

$$H = 0{\cdot}005\,\text{nm} = \text{about } 30\,\text{ft};$$
$$R = 0{\cdot}007\,\text{nm} = \text{about } 40\,\text{ft}.$$

Note that vortex wake effects on the disk's effective size are not included.

An initial assumption for CAT/military conflicts under RAS is that the positions of air traffic in the intruded flight volume are essentially random as far as the intruding aircraft is concerned, its crew has no knowledge of the CAT aircraft flightpaths. On this basis, the likelihood of a collision compared to an Airprox will be in proportion to their relative dimensions. This is because the calculations follow through exactly in the same way for an Airprox as they do for a collision – the values of T, N, A and (*Average* V_r) would be the same. This assumes that a separation infringement corresponding to an Airprox has consistent effective dimensions, having a similar disk shape to the aircraft.

Airprox numbers are used here as indicating the frequency of proximate incidents, albeit not always hazardous in nature (i.e. not necessarily of Category A or B). They are prima facie instances of some degree of unexpected separation loss or need for action by pilots or controllers; they can be thought of as potential precursor events. However, Airproxes do not have defined closest approach distances associated with them although presumably these would generally be somewhat less that the appropriate separation minima. UK National Air Traffic Services (NATS) studies (see Brooker, 2002 for references) have used standard Airprox dimensions H_a and R_a, analogous to H and R respectively, of:

$$H_a = 0{\cdot}050\,\text{nm} = \text{about } 300\,\text{ft}$$
$$R_a = 1\,\text{nm}.$$

Thus the statistically expected ratio of Airproxes to collisions is:

$$(H_a \times R_a)/(H \times R) = (0{\cdot}050 \times 1)/(0{\cdot}005 \times 0{\cdot}007) = 1429$$

On this basis, the statistically expected rate of a mid-air collision for a RAS CAT aircraft, using the Airprox rate derived in the previous section, would be

$11{\cdot}2 \times 10^{-5}/1429 = 7{\cdot}8 \times 10^{-8}$. If this is compared with the current RGCSP (1995) figure of $1{\cdot}5 \times 10^{-8}$ fatal aircraft accidents per flying hour there is about a factor of 5 difference.

As already noted, this calculation (blind flying in the fullest sense) does not include the safety defensive barrier effects of automatic warning systems and controller/pilot action, including the effectiveness of See-and-Avoid. There is limited statistical evidence to help in estimating what safety gain there actually is from the combination of warning systems and human intervention. For CAT/CAT conflicts, Brooker (2002) notes:

> 'It is certainly better than a factor of 10; the data from Airprox reports could be consistent with a factor of 100 – and it could be even higher'.

In the present case, such a large improvement factor would seem very unlikely, for reasons such as:

- The non-RAS aircraft might be engaging in rapid manoeuvres rather than fly the smooth flight plan of CAT aircraft.
- Only one aircraft might have ACAS rather than both. The RAS aircraft might not be equipped or be using ACAS.
- Given that military aircraft tend to fly at greater speeds than CAT aircraft, the closing speed in a typical incident would be higher and hence the ACAS/STCA warning time would be less (for CAT/CAT conflicts the warning time is typically 25 to 40 seconds (Hale and Law, 1989)).
- The same controller would not be handling the two aircraft; indeed the non-CAT aircraft might not be receiving a service.
- 'See-and-Avoid' is unlikely to offer marked added protection in these circumstances. Visual acquisition of the other aircraft would be less likely because of the smaller dimensions and relative speeds.

Given these factors, is a factor of five improvement likely? Only if it were assured would the TLS be achieved. Coincidentally, there are five hazardous Airproxes listed in Annex A. Had there been comparatively small variations in the parameters involved, such as to produce a negligible miss-distance, would no more than one of these incidents have led to a collision? The evidence does not offer strong support for such a proposition. For example, in Airprox 094/00 the controller was not monitoring the incident, nor was the STCA alert noticed. While in Airprox 139/01 the military jet pilot did not sight the F50, and when the ATSU perceived the conflict it was too late for effective avoiding action.

One important element in reducing risk in Class F/G airspace is the carriage of ACAS by commercial aircraft. The current European ACAS II Implementation Schedule (Eurocontrol, 2002) requires the mandatory carriage and operation of ACAS II. Its first phase covers aircraft above 15,000 kg, and its second phase states:

> Phase 2: With effect from 1 Jan 2005, all civil fixed-wing turbine-engined aircraft having a maximum take-off mass exceeding 5,700 kg, or a maximum approved passenger seating configuration of more than 19 will be required to be equipped with ACAS II.

Of the types involved in the UK Airproxes in Table 1, the Short SD3-60 is 12,200 kg, the Saab SF340 is 13,000 kg, and the Sikorsky S76 is well below the limit, with only the ATR42-300 being above. Some of these types are no longer in production, so refits during maintenance periods would presumably be needed. In three of the hazardous Airproxes, ACAS (= TCAS II here) was not operational/fitted on the civil aircraft. To quote the Airprox report 039/00:

> 'The Board went on to discuss what more could be done to avoid such incidents in the future. The most obvious point was that the SD3-60 in the Airprox had no TCAS. The Chairman advised the Board that another Airprox (152/00) … contained almost exactly the same ingredients (a DHC-8 descending into Newcastle which was not seen by the crew of a passing Tornado not under a radar service) but which had a very different outcome because of TCAS in the CAT [aircraft]'.

Hence the incident might have had a very different outcome had ACAS been fitted. For Airprox 094/00, STCA alerted when the aircraft were about 5 nm apart, so it is reasonable to assume that ACAS would have provided a RA, perhaps 15 to 20 seconds before closest point of approach. From the diagram in the 144/01 Airprox Report [NB: the civil aircraft was a helicopter], the aircraft were flying towards each other for much of the incident, so, on the geometry, ACAS would have produced a RA.

On the basis on this very limited sample, if all the CAT aircraft had had operational ACAS then perhaps half of the incidents would not have been judged hazardous. This does not provide the factor of five safety improvement desired but it is a significant step towards it.

6. SUMMARY AND DISCUSSION.

6.1. *Summary.* Airproxes analysed by the Vortex Wake categories of CAT aircraft receiving a RAS in Class F/G airspace show that smaller aircraft are much more likely to be involved than heavier ones. A detailed analysis of Light category CAT Airproxes leads to inferences that:

- Airprox rate for CAT aircraft receiving a RAS in Class F/G is 11·2 Airproxes per 100,000 flying hours exposure.
- Annual Hours exposed for all CAT aircraft receiving a RAS in Class F/G are 107,000.
- The Airprox for this type of service is about 50% greater than that for CAT aircraft generally (7·13 in 2000), and CAT Airproxes in controlled airspace are probably more likely to be reported.

There are two key assumptions made in deriving these figures:

- *The number of Airproxes involving a particular CAT type receiving a RAS in Class F/G airspace is directly proportional to its flying hours in Class F/G airspace, with the same constant of proportionality for all types.*
- *Light category aircraft types having the highest rate of Airproxes spend the bulk of their en route time in Class F/G airspace.*

Estimates can be made of collision risk from the Airprox rate by scaling down to blind flying (taking account of the much larger dimensions of an Airprox compared with a collision) and the safety defensive barrier effects of automatic warning systems and controller/pilot action, including the effectiveness of see-and-avoid. The achievement of the TLS depends critically on the safety improvements offered by the latter, which are likely to be markedly less effective than the case of CAT/CAT conflicts. The indications are that the risk level for CAT aircraft receiving a RAS is somewhat higher than the TLS.

6.2. *Discussion*. How valid are the assumptions made? A key one is the estimated proportion of time that Light category aircraft spend in Class F/G airspace. A statistical study of typical flight routeings by such aircraft types (Sikorsky S76, Saab SF340, Short SD3-60 and Aeritalia ATR42-300) could provide evidence to improve the estimate. It is likely that only a few airlines operating at a limited number of aerodromes in particular geographical areas (compare the Airprox locations in Table 1) would need to be surveyed. If the proportion is lower than presently estimated then the Airprox rate for these types could be much higher than for CAT aircraft generally. While a general census of UK air traffic might be useful for other reasons, it would not be a very cost effective means of estimating flying hours in UK Class F/G airspace. Census data would not of course be of any help in collision modelling.

The fitment and use of ACAS could be crucial in delivering the required protection against collision. Light category aircraft are less likely to have ACAS than other CAT aircraft, and manufacturing exemptions mean that fitment could take some years. ACAS is the key conflict tool and is important because of the extra time required for instructions following STCA alerts to be conveyed from the controller to the crew.

It is not obvious that more detailed collision risk modelling could help in improving the quality of the estimates here. However, despite the comparatively small number of incidents and the number of causal sequences that could lead to an accident (each of which would require an estimated probability with a reasonable statistical confidence), it might be that Probabilistic Risk Analysis would produce better estimates than those above, or would produce insights into important operational risk factors.

It might well be worthwhile examining the efficacy of safety defensive barrier effects of automatic warning systems and controller/pilot action in Class F/G airspace, including the effectiveness of see-and-avoid. This could be done through flight deck simulation. It could for example lead to improvements in training.

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ANNEX A:

SOME FEATURES OF A & B CATEGORY RAS/CLASS F & G AIRSPACE AIRPROXES. The following summary notes (edited quotes) use data of 'Airprox involving CAT aircraft' (NB: CAT here includes air taxis) from the Airprox Board Reports in 1999–2001. Refer to the original reports for abbreviations, etc.

146/99 – **B**. B767 receiving RAS from ScOACC in Class F/G airspace on ADR. TCAS RA. Tornados flew directly through the flightpath. RAS controller passed traffic information and avoiding action to the B767. Issues about ATC squawk selection and civil/military views on RAS separations. Recorded separation 0·85 nm laterally.

039/00 – **A**. Shorts 360 receiving RAS from Newcastle in IMC. Tornado turned into conflict with SD3-60, which they did not see. Recorded separation 0·3 nm lateral. TCAS not fitted to SD360. RAS controller issued traffic information and avoiding action, but Tornado climbed when lateral separation was about 1 nm. AAIB observed inter alia that separation under a RAS cannot always be achieved when fast aircraft not under service makes unpredictable manoeuvres.

094/00 – **A**. SAAB 340 receiving RAS from ScACC in Class F airspace. TCAS not operational. Tornado crew realised late they were about to cross the ADR and hence saw the RAS aircraft late. Recorded separation 500 ft vertical. 'All the safeguards to prevent a collision had failed and the safe outcome [was] a matter of chance.' Controller did not monitor the SAAB 340's progress – he was bandboxing and had been concentrating on traffic situation elsewhere – and did not notice the developing confliction. STCA alerted when aircraft about 5 nm apart, but this was not noticed by the controller.

139/01 – **B**. F50 receiving RAS from Pennine Radar in Class F/G airspace. Climbing F15 crossed in front, not far from opposite direction, and pilot did not sight F50. Reported separation 300 ft vertical. TCAS RA issued. By the time confliction perceived by Pennine Radar, too late to provide effective avoiding action.

144/01 – **B**. S76 receiving modified RAS in Class F/G airspace and warned by ATSU of two contacts at 5 nm and 2 o'clock. Tornado formation was late sighting the S76 when turning towards it. Recorded separation 0·3 nm. No mention of TCAS in incident report [note the S76 is a helicopter]. Both aircraft took avoiding action, with both pilots unsighted for a period. Operations were close to or below the limit of radar cover.

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