THE GUILD OF AIR PILOTS AND AIR NAVIGATORS

Discussion Paper on Sense and Avoid Safety Level Requirements for Unmanned and Remotely Piloted Aircraft

Introduction

For the sake of simplicity, unmanned aerial vehicles (UAVs), unmanned aerial systems (UAS), remotely piloted aircraft (RPA) and remotely piloted air systems (RPAS) both singular and plural are referred to as RPAS in this paper.

UK CAA policy dictates that RPAS will not be permitted to fly in non-segregated airspace unless they have shown that they can match the demonstrated level of safety of manned aircraft. The policy does not specify numerical targets to define what the target level of safety (TLOS) is. GAPAN commissioned a study which analysed the 32 million hours of flying carried out by British registered aircraft in the 10 year period 1st January 1999 – 31st December 2008 in order to assess the actual risk of an aircraft being involved in a mid-air collision (MAC) in UK airspace. The Study is set out in full as a Schedule to this paper.

1 UK Data

1.1 The average level, across all airspace types and types of operation, was one MAC in a million hours. This rate is usually represented as a ‘risk’, often termed a ‘level of safety’ (LOS), of $1x10^{-6}$ MACs per flying hour.

1.2 This risk was not equal across the different types of flying. Day VFR flying was much more risky than night, IMC and procedural aviation. General aviation (GA) was over twice as risky as military aviation which itself reflected the average. In this study, the actual MAC risk in commercial air transport (CAT) aviation was not positively determined because it was so small; however, it was less than $7x10^{-8}$ MACs per flying hour.

1.3 The volumes of airspace that carried the highest risk of mid-air collision were Class G airspace, especially below 3000ft, and around airfields, both inside and particularly outside controlled airspace.

1.4 Actual collisions were infrequent, but formally reported Category A ‘Airprox’ events, where an ‘actual risk of collision existed,’ occurred 10 times more often than MACs. These Airprox Reports were assessed as being the tip of an iceberg. The results of a separate survey of GAPAN members showed that ‘very near misses’ (subjectively assessed by the respondents as Category A events) occurred, on average, 40 times as often as they were reported and 400 times as often as MACs actually happened. The study found that under-reporting exists and therefore the collated reports understate the risk.

1.5 MAC risks are mitigated in different ways in the different operational environments. At the ‘uncontrolled’ end of the airspace spectrum, in Class G airspace, the primary mechanism of avoiding a MAC is through the pilot’s lookout and subsequent decision-making. At the other end of the airspace spectrum, in controlled airspace, the air traffic management (ATM) system is used to reduce the risk over and above what pilots can achieve using their on board sensors. Operations in controlled airspace were found to be 400 times less risky than the operations in uncontrolled airspace.

2 Indications from the UK Data

2.1 Rather than having a one size fits all solution, RPAS sense and avoid mechanisms should reflect the operational scenarios in which the aircraft will be flown. Assuming that the platform can comply with the necessary Air Traffic Management (ATM) requirements, in order to operate exclusively in controlled airspace an RPAS would need only to be equipped like an airliner; it would not need a bespoke sense and avoid system. However, if it were to operate in uncontrolled airspace, the platform itself would need to be capable of sensing other (potentially passive) airspace users in order to avoid them. As the technical solutions for the former already exist, it is assessed that uncontrolled airspace is the more challenging scenario for RPAS to be policy compliant.

2.2 Outside controlled airspace, a RPAS exhibiting a MAC risk of less than one accident in 500,000 hours would match the existing demonstrated LOS in manned aviation. Inside controlled airspace they will have to better a risk level of $5x10^{-9}$ MACs per flying hour to comply with the internationally agreed TLOS but, they will be able to rely on the ATM system to do so. Any additional on-board sense and avoid systems that may be installed and used must not increase the risk of a MAC.

3 NATO Naval Armaments Group TLOS Recommendation Compared

3.1 In 2008, the NATO Naval Armaments Group agreed and recommended a numerical TLOS that RPAS should demonstrate before being granted access to non-segregated airspace. For unmanned aerial systems this target was $5x10^{-9}$ MAC per flying hour (or one MAC event in 200million flying hours).

3.2 This target was derived from the TLOS for Reduced Vertical Separation Minima (RVSM) operations. As a sense and avoid driver, this TLOS should be contested because, while it may be a valid TLOS for operations in managed airspace, it is not actually achieved by all types of manned aircraft, carrying out all types of operation, in all types of airspace.

Conclusion

At $1x10^{-6}$ MAC per flying hour, the average actual MAC risk demonstrated in the UK over the past decade is 200 times higher than NATO's recommended MAC TLOS for RPAS. RPAS must match the performance demonstrated by manned aviation in order not to increase the risk in aviation. As a single, overarching number, NATO's MAC TLOS is set too high. Separate targets are required for each different operational scenario.

SCHEDULE

GAPAN – TASC – RPAS Team – Study Findings
Sense and Avoid Safety Level Requirements for Unmanned and Remotely Piloted Aircraft

Introduction to Study

RPAS are not permitted to fly in the UK in non-segregated airspace. Cascading down from ICAO agreements, CAA policy[1] dictates that unmanned aircraft must meet the same level of safety (LOS) and operational standards as equivalent manned aircraft. So far, it has not been demonstrated that they can 'sense and avoid' other aircraft. Consequently, the military rarely trains to use RPAS outside theatres of operation and the potential civilian and commercial users do not benefit from the operational capabilities that RPAS can provide.

While the word 'unmanned' is moot, because very few RPAS are actually fully autonomous (there is usually a man in the loop), for the purposes of this paper, the definition of 'unmanned' is that the pilot of the aircraft is not on board.

S1 Purpose of the Study

S1.1 Rather than define the risk level targets for RPAS as absolutes, CAA policy stipulates comparative targets that reflect the extant level of safety in the relevant field of manned aviation.[1] This means the rule need not be changed as the relevant benchmarks change. However, the lack of a quantitative definition of risk levels inherent in manned aviation creates a vacuum which begs to be filled. Without numerical performance requirements, RPAS designers have found it hard to invent sense and avoid solutions. Therefore, in 2008, the NATO Naval Armaments Group's Joint Capability Group On Unmanned Aerial Vehicles sought to define a target LOS that a RPAS must exhibit.[2]

S1.2 The Group's conclusion was that an acceptable LOS, across all types of operation in all types of airspace, was one mid-air collision (MAC) occurrence every 200 million flying hours; a risk level of $5x10^{-9}$ MAC per aircraft flight hour. This has become accepted wisdom but it is not supported by the actual MAC statistics for manned aircraft. ICAO introduced this number as a target level of safety (TLOS) to define the risk within RVSM airspace resulting from a loss of vertical separation due to any cause[3 and 4]. This TLOS was adopted for, and has been used in, the British and North Atlantic air traffic region since 1997 and it is the agreed, and indeed mandated, TLOS for the European Air Traffic Management System. However, outside controlled airspace the arguments and the mathematical models that support the defining safety case are not valid. This TLOS is not a valid number for all types of aircraft across all types of airspace.

S1.3 This paper does not set out to dissect the NATO paper itself; readers may wish to critically assess its assumptions, arguments and conclusions for themselves. Instead, because there was a perception that the overall risk of MAC in manned aviation was actually much greater than this TLOS, the RPAS Team of the GAPAN's Technical and Air Safety Committee was tasked to find out what the actual MAC risk levels in UK manned aviation really were. With those results, GAPAN could inform the RPAS debate and, in particular, establish its position concerning sense and avoid performance requirements for RPAS flight in non-segregated airspace in the UK.

[1] CAP 722.
[2] NATO Naval Armaments Group's Joint Capability Group On Unmanned Aerial Vehicles paper dated 23 April 2008 titled "Sense And Avoid Requirements For Unmanned Aerial Vehicle Systems Operating In Non-Segregated Airspace" signed by G Romani.
[3] ICAO Doc. 9574 (2nd Edition). Manual on the Implementation of a 300M (1000ft) Vertical Separation Minimum between FL 290 and FL 410 inclusive.
[4] The EUR RVSM Pre-Implementation Safety Case - RVSM 691 – Version 2.0 dated 14 August 2001.

S2 Method

S2.1 In addition to a search of relevant papers[5], the RPAS Team conducted research in 3 specific areas to generate its findings:

S2.1.1 Firstly, to determine the probability of one aircraft actually hitting another in the UK, the Team analysed the CAA's Mandatory Occurrence Reporting Scheme database for MACs involving British registered aircraft and the equivalent military MAC accident database held by the Directorate of Aviation Regulation and Safety (DARS).[6] Close formation flying occurrences were removed from both sets of results because such events were not germane to the sense and avoid argument. The Team derived the statistical MAC risks for GA, CAT and military flying in the UK in the 10 years between 1999 and 2008 inclusive, terming them the 'Actual Risks.'

S2.1.2 Secondly, the Team analysed the UK Airprox Board's Reports from the past 15 years with particular reference to reported Category A events (those where 'an actual risk of collision existed') in the 10 years between 1999-2008 inclusive[7]. This comprised over 32 million flying hours in UK airspace, the breakdown of which was: 14.75 million hours of commercial air transport (CAT); 12.71 million hours of general aviation (GA) which included gliding and micro-light flying; and 4.6 million hours of military flying.[8] While these (Category A) events did not entail collisions, they were very near misses and had been formally reported. The findings in this area are termed 'Reported Risks.'

S2.1.3 The Airprox Board relied largely on the Mandatory Occurrence Reporting (MOR) Scheme for its data. However, anecdotal evidence indicated that the MORs might be just the tip of an iceberg. Therefore, the RPAS Team polled the GAPAN's 680 strong UK membership to discern how many Category A occurrences might have gone unreported.[9] Of those polled, 16% responded. They submitted returns that covered the breadth of aviation disciplines over the length of their flying careers. This created a database comprising over 720,000 flying hours of which 55% was CAT, 26% was military and 19% was GA. Analysis of this database allowed the Team to assess what we have phrased the 'Un-reported Risk.' It is accepted that the data gathered includes some reported events and that, strictly, the phrase 'un-reported' is a misnomer; nevertheless, the term underlines the point. The GAPAN survey was also able to elicit which types of airspace and environmental conditions were perceived as most dangerous and how pilots knew they had had a near miss. The results of those lines of questioning were intended to provide signposts for industry to use to solve the 'sense' challenges of sense and avoid.

S3 Results

Table 1. Statistical MAC Risk of Types of Flying in the UK in the Period January 1999 to December 2008

	Actual Risk		**Reported Risk**		**Un-reported Risk**		
Type of Flying	Likelihood of Having a MAC	Risk Level	Likelihood of Having a Category A Event	Risk Level	Likelihood of Having a Category A Event	Risk Level	Fraction of Survey
CAT	Less than 6.7×10^{-8}		One in a million hrs	1×10^{-6}	One in 7000 hours	1.4×10^{-4}	55%
Military	One in a million hrs	1×10^{-6}	One in 50,000 hrs	2×10^{-5}	One in 1700 hours	6×10^{-4}	26%
GA	One in 400,000 hrs	2.6×10^{-6}	One in 100,000 hrs	1×10^{-5}	One in 1000 hours	1×10^{-3}	19%
Average of All Aviation	One in a million hrs	1×10^{-6}	One in 100,000 hrs	1×10^{-5}	One in 2,300 hrs	4×10^{-4}	100%

[5] All other footnoted references and "Decision Support For Risk Assessment Of Mid Air Collisions Via Population Based Measures" by N Fulton M Westcott and S Emery published in Transportation Research Part A43 (2009) pp 150-169.
[6] The MAC data from these 2 databases is appended at Annex A.
[7] UK Airprox Board - Analysis of Airprox in UK Airspace Report Number 21.
[8] From Tables 2, 5, 8 and 9 at UK Airprox Board - Analysis of Airprox in UK Airspace Report Number 21, summarised at Annex A.
[9] GAPAN TASC Risk of Collision Survey – conducted in March 2010.

S3.1 Actual Risk. In the 32 million hours of flying in UK airspace during the 10 year period 1999-2008, there were 19 MACs; 38 aircraft actually hit each other. Therefore, the headline risk of a pilot having a MAC in the UK was greater than once in every million flying hours. The 38 aircraft involved comprised 5 military aircraft (2 helicopters and 3 fast jets) and 33 GA aircraft (of which 12 were gliders). Not one CAT aircraft was involved. GA, which included gliding and microlight flying, accounted for 86% of the MAC accidents but there was 2.7 times as much GA flying as military flying during the period. Therefore, hour for hour, GA flying was 2.4 times more likely to involve a random MAC than military flying. Even though CAT operations comprised 14.75 million flying hours, this database was too small to positively determine the Actual Risk of a MAC in CAT.

S3.2 Reported Risk. The Airprox database had already been extensively analysed by the Airprox Board. The Team focussed on Category A events, where an actual risk of collision existed; these generally numbered less than 20 per year (or one every 100,000 flying hours). Reportedly, military flying carried the most risk - one event in every 50,000 flying hours. This was 20 times the Actual Risk in the military MAC data. Interestingly, within the same database, GA flying produced Category A reports at only 4 times their MAC rate. In stark contrast, CAT operators reported incidents where an actual risk of collision existed only 13 times during the 10 year period. While this equated to a likelihood of one event per 100,000hrs, 10 of those events occurred in the first 2 years of the period and none were in the last 3. The trend showed a significant reduction in the MAC risk in CAT operations towards the end of the period.

S3.3 The Airprox Board's database also indicated in which types of airspace events occurred. Acknowledging that the following assessment was generated using all Airprox Reports, not just Category A events, over 70% of the events reported each year occurred in Class G airspace, particularly below 3000ft, and in areas around aerodromes (whether they were ATZ, MATZ, Class A or D Terminal Control Areas and Zones).[10] This finding was supported by a similar study carried out in the US in 2001[11] which found that a majority of MACs occurred within 3nm of airfields.

S3.4.1 Un-reported Risk. The Un-reported Risk results, while they cut across all flying disciplines, were not constrained to a particular period and, therefore, could not be used for trend analysis. However, respondents remained anonymous and the questionnaires were completed by serious people who understood the survey's purpose. It was noted that, in comparison to statistical break down of flying reported by the Airprox Board, the survey sample was skewed (by the respondents) towards professional flying hours (both CAT and military); the GA world was under-represented in the survey. Importantly, the survey questions were designed to elicit the number of total number of Category A incidents that respondents thought that they had had, not just the ones that they had reported.

S3.4.2 In the 720,000 flying hour sample there were 313 reported Category A events and one MAC. Of the incidents, 45% occurred in GA, 36% in military flying and 18% of them occurred during CAT. Notwithstanding that there had not been an actual MAC in CAT, respondents did not view CAT as risk free. In this database, GA was found to be nearly twice as risky as military flying and over 7 times as risky as CAT. These results were in line with the Actual Risk relationships but not the Reported Risk numbers (which indicated that military aviation was the most risky). The number of unreported events was 40 times the reported level. The perception that the MORs were only highlighting the tip of an iceberg seemed to be borne out.

S3.4.3 In line with the Airprox database, 76% of the 'un-reported' incidents occurred in Class G airspace (usually by day and in VMC). In 90% of cases, respondents stated that the other aircraft was sighted visually; on-board electronic means made up the over half the remainder. Of the 21 incidents that happened at night, 9 were identified by electronic means, 9 were assessed visually and 2 were only realised when the pilot heard the other aircraft!

S4 Error Bars

S4.1 Stress testing revealed that the fidelity of the results was good. The sample sizes in both the Actual and Reported Risk databases were large and, even induced errors of 100% in the occurrence levels did not make material differences to the results. For example, if we were to define a MAC as a single event (even though it must involve at

[10] From analysis of Airprox Board - Analysis of Airprox in UK Airspace Reports for the period 1999-2008.

[11] Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomics Society. Santa Monica, CA: Human Factors & Ergonomics Society. 2001. ANALYSIS OF MID-AIR COLLISIONS IN CIVIL AVIATION by Narinder Taneja and Douglas A. Wiegmann

least 2 aircraft) then the number of MACs and the risk would be halved but the results would still be the same order of magnitude. The GAPAN survey had the smallest sample size and relied on respondents' (notoriously unreliable) long-term memories so the 'un-reported risk results' had the least fidelity. However, by constraining the questions to interrogate only Category A events, which were 'shocking' and, therefore, memorable, most respondents were dealing with single figures for their flying careers. It was judged that this survey gave credible results.

S4.2 The relationships between Actual, Reported and Un-reported Risks in military and GA flying were contradictory so the Team studied why. It was thought that the results might have been skewed by the small number of events in both databases. Therefore, the sample periods were increased. Military collisions between 1971 and 2008 were assessed, although the available Airprox Board data only stretched back 15 years. In military flying, in the 9 years from 1990 to 1998 inclusive, 21 military aircraft were involved in random MACs and 3 more were lost to MAC in 2009. This implied that, in terms of MACs, the military may just have had a very good period between 1999 and 2008. With 29 relevant collisions during the 20 years between 1990 and 2009, the 20-year military MAC rate was actually double that of the last 10 years and was roughly the same as the GA rate. However, especially in the military fast jet community, the MAC rate had dropped markedly towards the end of the period. It was assessed that the 10-year rate was a more accurate indicator of the current military risk level and that there might be other reasons for the low Airprox reporting rate in GA. These are discussed in the analysis below.

S5 Analysis

S5.1 Overall, the major results speak for themselves. During the period, the overall Actual Risk in UK airspace of an aircraft colliding with another aircraft was once in a million flying hours. Military flying was roughly as risky as GA but CAT was at least an order of magnitude safer than both (and probably more). While the risk of collision was 'one in a million,' statistically, a pilot will report he has 'just missed' ten times as often as he 'hits.' This was not common across the board; in CAT, such an event was significantly less likely and the trend was improving. Nevertheless, the risk level results were at odds with the accepted wisdom. The average Actual MAC Risk for manned aircraft was 200 times higher than NATO's proposed overarching MAC target level of safety for RPAS.

S5.2 <u>CAT</u>. In spite of the excellent level of safety demonstrated recently in British CAT operations, the CAA's 2009 Partnership in Safety Symposium identified airborne conflict as the greatest single risk to CAT operations. Twenty nine airborne conflict events were listed in British CAT operations during the 3 years from 2005-8. While the specific Airprox categories were not defined for these events, the statistic added weight to the CAT Reported Risk level and the 'Un-reported' results and warned against too much reliance on the demonstrated level of safety in CAT. A single MAC event in UK CAT would have considerable impact on the statistics. Moreover, MACs do happen in CAT: In 1996 at New Delhi a Saudi Boeing 747-100 and a Kazakhstan Air Lines Ilyushin 76 cargo aircraft collided, killing 349 people; in 2002 a DHL Boeing 757 and a Bashkirian Tu 154 collided over Germany, killing 71; and in 2006 an Embraer Legacy 600 corporate jet collided with a Brazilian Gol Airlines Boeing 737-800, killing all 155 on board the latter.

S5.2 <u>Military</u>. Military aircrew reported Category A events at 20 times their actual MAC rate while GA pilots only filed reports at 4 times their MAC rate. Military (and commercial) pilots seemed much more likely to report an Airprox than GA pilots. Albeit that the 20 year military MAC rate was double what it was between 1999 and 2008, any statistical errors were assessed as having much less influence on the results than did differences in 'culture' and 'training:'

S5.3 <u>Under-reporting</u>. The Team believed there were systemic and human reasons that military aircrew would be more likely to file an Airprox than their GA counterparts. Arguably, it is human nature not to report a near miss, particularly when one might assess it as being one's own fault. If the other pilot does not file an Airprox, a natural reaction might be 'I learned about flying from that, but no-one else needs to know how close I (we) came; the other crew might not even have realised.' While 'open and honest reporting' and professional aviation reporting systems promoted reporting, all pilots were subject to this temptation and it was believed that there were many more near misses than had been reported. The GAPAN study supported this assertion, which the data indicated was particularly true of GA. However, the document search (referred to at footnote 5 above) indicated that even in managed airspace the under-reporting level was one report for every five occurrences.

S5.4 Lookout. Secondly, and crucially for the arguments that follow, military aircrew were trained, particularly, in lookout. Operating for much of the time as they did in non-segregated airspace, flying machines which afforded relatively good visibility (compared with many civilian aircraft) and having the situational awareness afforded by tactical formation, airborne early warning aircraft and radar services, it was thought likely that military pilots saw more potential conflicts than the GA community did. In some military aircraft, pilots had other sensors to enhance their lookout but, air-to-air radars were not that widespread, nor were electronic anti-collision aids and, much of the threat in uncontrolled airspace was electronically non-cooperative anyway. Good visual lookout was assessed as being key to averting MAC in 'open,' unmanaged airspace and, thereby, to reducing the Actual MAC risk.

S5.5 In contrast, the CAT community had invested hugely in airways design and control procedures and electronic anti-MAC technology to achieve, and better, the TLOS mandated by ICAO. Cooperative electronic sensors for the aircraft themselves, ground-based radars and electronic aids, flight-path prediction tools, scheduling, deconfliction and conflict-resolution procedures and, of course, high levels of training, all mitigated the MAC risk in CAT. Of these, perhaps the most important was the Air Traffic Management (ATM) system itself. Indeed, cooperative collision avoidance tools such as TCAS II were not pre-requisites for operations in controlled airspace. In Europe, TCAS II was only mandated for civilian turbine aircraft carrying over 19 passengers or with a maximum take-off mass of over 5,700kg. Effectively, the ATM system has made CAT as safe as it is today; pilots, and collision warning technology may augment safety, but the ATM system needs to achieve the target anyway.

S5.6 Furthermore, cooperative electronic collision avoidance tools were not assessed as being the panacea. By far the most common warning mechanism in the GAPAN survey's results was the pilots' eyes, particularly in GA and military respondents, but also in 77% of the CAT events. Using provocation to illustrate the point, notwithstanding all the electronic aids with which a wide-bodied airliner is equipped, it would not take too many hours of flying one by day, under VFR, in the Class G airspace around London and south-east of England, to make the CAT MAC statistics significantly worse! The ATM system, in which CAT operates, is the most significant input to achieving the CAT TLOS, not the platforms themselves.

S5.7 Flying in VMC around aerodromes and glider sites in Class G airspace below 3000ft was much more risky than flying at night, in IMC and in controlled airspace. It was not difficult to see why. The sky at night was much less crowded than it was by day; and GA aircraft, gliders and micro-lights were rarely flown then. Even in the military, those pilots flying at night did so more procedurally, more sedately, using a visual-instrument flying mix even when flying under VFR. Through both regulation and sensible practice, in general, pilots flying at night, and in controlled airspace, and in IMC, tended to be more experienced, and tended to fly more extensively equipped aircraft, more predictably and often more procedurally, to tighter tolerances, under higher levels of radar service, with better self-illumination (both by lights and by electronic means) than pilots operating under VFR by day.

S6 Potential Solutions

S6.1 RPAS need to demonstrate an equivalent level of safety to equivalent aircraft in equivalent operational conditions. This study showed there were considerable differences in the risks inherent in the different operational scenarios. The required anti-collision solutions were very different too.

S6.2 Simple RPAS operating in non-segregated airspace should be able to sense and avoid as well as, but only as well as, simple manned aircraft flown by appropriately qualified pilots in similar conditions. CAP 722 was clear that RPAS were only required to match manned aircraft; they should not be penalized by extraordinary performance requirements just because better capabilities might be technologically possible. Electronically non-cooperative gliders, microlights and light aircraft abound in British Class G airspace. As 'passive' aircraft, they rely on seeing and avoiding, or being seen and avoided. Therefore, to be flown in such airspace, being able to sense and avoid as well as a man can see and avoid has to be a basic driving requirement for RPAS sensor suites. To be equivalent to current manned aviation in Class G airspace, this would have to be achieved without the benefit of an air traffic service or cooperative collision-warning sensors.

S6.3 Towards the other end of the spectrum, to match manned aircraft, RPAS will have to be able to demonstrate increasing levels of safety as they operate in progressively more controlled airspace. For RPAS to operate in Class A, the overall collision avoidance performance requirement would be much higher than that required for it to operate in Class G. However, just as manned aircraft operating in controlled airspace rely on electronic aids and procedural control to achieve this, RPAS should be able to rely on the same systems to the same degree. The sense and avoid performance would only have to increase in higher classes of airspace if it was an integral part of the collision avoidance function in that airspace. Procedural segregation, flight planning and notification, procedural flying, lights, transponders, TCAS, radars and other sensors, air traffic services and, of course, other users, all play their part in the systemic equation. Those capabilities are not all on board the RPAS.

S6.4 The equipment and sensor suites required by RPAS to enable them to meet any sense and avoid requirements should be appropriate to the operational scenarios in which the platform will be used.

S6.5 Even when the RPAS has the sensor suite to realize that there is a threat and where it is, it must also be able to avoid it. This paper does not deal with the 'avoidance' challenge save to say that, enough reaction time (taking into account communications latency), correct decision making capabilities, and sufficient physical agility are all required (as well the sensors of course), to allow RPAS to comply with the Rules of the Air.

S6.6 It will be up to industry to develop the technical solutions for RPAS to meet the relevant levels of safety for each type of RPAS in each scenario. It is likely that all the MAC avoidance techniques that exist in manned aviation will need to be used as part of a 'system of systems' approach to reproduce equivalent levels of safety to each type of manned operation. Therefore, in addition to the sensors and communications equipment, training will be important too.

S6.7 Although, relatively speaking, it was the safest environment, it was judged that controlled airspace would not be the most testing sense and avoid scenario for RPAS. Most of the required system safety will be provided by the procedural nature of operations therein, and the electronic and off-board aid to the operators that abounds there. Instead, it was thought that sensing non-cooperative threats in the busiest volumes of uncontrolled airspace would prove the hardest challenge to overcome, since to match manned aviation, the RPAS sensors and their controlling computers will need to provide most of the 'sense' solution themselves.

S6.8 It was assessed that the major gap in the 'sense' armoury was the visual spectrum. What was not commonly fielded amongst sense and avoid suites was an optically cued system that could match human 'see and decide' to provide avoidance capabilities. Alternative sensors might be able to match or out-perform man's primary sense but, for overall equivalence, mimicry might be a good place to start searching for a non-cooperative 'sense' solution. It was envisaged that a sensor (or a system of sensors, processors and algorithms) could equal (or better) the capabilities of the human eye. Such a system would need to sense a threat sufficiently early to enable a timely avoidance reaction by the RPAS operator (or by any autonomous control systems). Being able to search and scan intelligently would help enormously in this (in the same way that the experienced human mind guides a pilot where to look). That being said, 'staring' sensors or sensor arrays (such as a fixed camera suite) might be able to demonstrate even better performance than 'scanning' ones (like a man's eyes).

S6.9 Once a potential threat has been sensed and identified, the next challenge would be to mimic (or better) human decision making skills so that the RPAS could react to avoid a collision in the huge variety of situations that could exist. The easy solution would be to put a man in the loop (catering, of course, for failure in communication links to the platform). For autonomous systems, or even automatic systems, matching the human brain in terms of decision making will take significant computing power. TCAS has shown that the concept already exists (albeit it is not yet necessarily providing a perfect solution). Of course, the RPAS must be able to physically perform the avoidance manoeuvres too.

S6.10 Even with both 'sense' and 'avoid' resolved, and while outside the scope of this paper, RPAS would still need to demonstrate equivalent levels of safety as a manned aircraft when things go wrong, not just in their sense and avoid systems, but in their performance, mean time between failure and accident rates too. Only then will RPAS exhibit an equivalent level of safety to equivalent manned aircraft in equivalent scenarios.

S7 Conclusions

S7.1 The aim of this study was to derive a position for the Guild about what levels of risk actually exist in various manned aviation scenarios and, therefore, should be matched by unmanned aviation in equivalent scenarios, in order to inform the RPAS 'sense and avoid' debate.

S7.2 The findings showed that the currently accepted wisdom of a TLOS of $5x10^{-9}$ MAC per flight hour by all RPAS in all classes of airspace should be contested. The Team found that the Actual Risk levels in manned aviation were much higher. The overall Actual Risk level for all aircraft in the UK combined was $1x10^{-6}$ MAC per flight hour and, for GA aircraft, it was at least twice that. The TLOS of $5x10^{-9}$ MAC per flight hour did not bear scrutiny as an overarching design driver for RPAS operation in non-segregated airspace. While this TLOS was accepted for operations in RVSM airspace and better, it was at least 2 orders of magnitude too demanding for other scenarios.

S7.3 In uncontrolled airspace, RPAS would only need to match a rate of one MAC in 500,000 hours to equal GA performance. To be operationally equivalent, RPAS would need to be able to sense other aircraft as well as a manned aircraft pilot could see them. In uncontrolled airspace, the ability to 'sense and avoid' uncooperative MAC threats is a requirement and RPAS should be able to achieve this without resorting to off-board sensors or cooperative electronics.

S7.4 Similarly, for RPAS to operate in controlled airspace they must match the performance of manned aircraft in that environment. The target level of safety for RVSM airspace was defined by international agreement at $5x10^{-9}$, although this study's 14.75million CAT flying hours sample was far too small to prove it by example. Even though there may be a collision waiting to happen to a CAT aircraft operating in both the uncontrolled and/or procedurally managed airspaces around the UK's many commercial airports, CAT is believed to be beating the TLOS.

S7.5 Aircraft operating in controlled airspace have to meet many requirements, which RPAS will have to meet as well in order for them to be a normal part of the ATM system and indistinguishable from manned aircraft. However, manned aircraft do not have to demonstrate any particular level of safety due to see and avoid because see and avoid is not part of the safety case in the ATM system. Consequently, RPAS operating in the ATM system should not be required to demonstrate any particular level of safety due to sense and avoid either. CAT achieves its TLOS by dint of the ATM system. Theoretically, albeit not necessarily emotionally, as long as they can show ATM system compliance capabilities equivalent to CAT, RPAS should be able to demonstrate CAT levels of 'anti-collision safety' too. 'Sense and avoid' *per se* is not a requirement, although it may help.

S7.6 In the RPAS sense and avoid debate, the defining level of safety for sense and avoid technology to meet is that necessary to meet the requirements of Class G airspace, which is to match the 'see and avoid' capabilities of a man.

S8 Assertions

The GAPAN TASC UAS Team's assertions are:

A The accepted wisdom on generic MAC risk and the equivalent TLOS (which is widely held as being $5x10^{-9}$ MAC per flight-hour) is overstated.

A1 At one MAC per million flight hours, the average level of safety actually demonstrated by manned aviation in the UK between 1999 and 2008 was 200 times worse than this currently accepted wisdom.

A2 By stipulating the RVSM TLOS for all operational scenarios, the performance requirement for RPAS sense and avoid in non-segregated airspace has been overstated by up to 400 times.

A3 Different levels of safety already exist in different operational scenarios; these only need to be matched by RPAS.

B The technical anti-collision solutions for each operational scenario should be relevant to its nature.

B1 Controlled airspace requires technical solutions, provided by systems other than 'on board sense and avoid', that meet the requirements of air traffic management in controlled airspace.

B2 Uncontrolled airspace requires 'sense and avoid' systems that match the capabilities of a man.

Annex A to
GAPAN TASC UAS Team Study
Sense and Avoid Requirements for RPAS
Summary of Data Analysed

Table A-1. Mid-Air Collision Accidents in UK Airspace From 1-01-1999 and 31-12-2008 Drawn From The UK CAA's Mandatory Occurrence Reporting Scheme (MORS) Database and The Directorate of Aviation Regulation and Safety (DARS) Accident and Selected Incident Database

Note. Close-formation MACs are excluded.

Date	Aircraft Involved	Operation Type	Fatal?	No. of Fatalities	Location
21/01/1999	Cessna 152 vs Tornado	GA vs Mil	Yes	4	Mattersey
31/05/1999	Glider vs Glider	GA vs GA	Yes	3	Great Hucklow
19/04/2000	Cessna 150 vs Yak 50	GA vs GA	Yes	3	North Weald
31/05/2000	Piper PA28 vs Piper PA28	GA vs GA	No	0	Oxford
31/05/2000	Jaguar vs Jaguar	Mil vs Mil	No	0	Galloway
30/06/2000	Piper PA18 vs Glider	GA vs GA	No	0	Lasham
08/10/2000	Piper L21 vs Glider	GA vs GA	No	0	Bembridge
15/07/2001	Piper PA18 vs Glider	GA vs GA	Yes	1	Bidford on Avon
14/09/2001	Piper PA25 vs Glider	GA vs GA	Yes	2	Aston Down
21/06/2002	Piper PA28 vs Thruster T600	GA vs GA	No	0	Manchester Barton
26/07/2002	Socata TB9 vs Flight Design CT2K	GA vs GA	No	0	Cambridge
26/04/2004	Glider vs Glider	GA vs GA	Yes	1	Lasham
06/07/2004	Hybred 44XLR vs Robinson R22	GA vs GA	Yes	2	Welham Green
18/12/2005	Cessna 152 vs EV-97	GA vs GA	Yes	1	Moreton-in-Marsh
02/10/2006	Glider vs Glider	GA vs GA	Yes	1	Sutton Bank
10/01/2007	Squirrel SA350 vs Squirrel SA350	Mil vs Mil	Yes	1	Tern Hill
14/07/2007	Glider vs Glider	GA vs GA	No	0	Southam
16/12/2007	Luscombe 8 vs PAC 750	GA vs GA	Yes	2	Rugeley
17/08/2008	Cessna 402 vs Rand KR2	GA vs GA	Yes	5	Coventry

Table A-2. Number of Category A Airprox Reports by Year Drawn From The UK Airprox Board's Analysis of Airprox in UK Airspace Report No 21

Category A Reports	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Period Total
CAT	4	6	0	1	0	1	1	0	0	0	13
GA	17	19	24	9	10	13	16	10	8	8	134
Military	7	16	27	14	8	5	10	7	2	7	103
Total	28	41	51	24	18	19	27	17	10	15	250

Table A-3. Hours Flown by Operational Activity (Type of Flying) Drawn From The UK Airprox Board's Analysis of Airprox in UK Airspace Report No 21

Hours Flown (x1000 hrs)	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Period Total
CAT	1,332	1,389	1,395	1,366	1,398	1,485	1,546	1,602	1,620	1,615	14,748
GA	1,268	1,226	1,209	1,240	1,254	1,266	1,249	1,305	1,346	1,351	12,714
Military	491	458	502	495	492	456	446	431	434	401	4,606
Annual Total	3,091	3,073	3,106	3,101	3,144	3,207	3,241	3,338	3,400	3,367	32,068

Note. Hours flown are computed from data provided by the UK CAA using long-established formulae.