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Safety Study of the Potential Use of ACAS II on Helicopters

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Abstract

The Airborne Collision Avoidance System (ACAS) II is mandated for carriage by certain fixed-wing aircraft in European airspace. The mandate does not extend to helicopters. Operational experience and safety studies have demonstrated the benefit to be derived by fixed-wing aircraft that equip with ACAS II but the same benefit would not necessarily be enjoyed by helicopters due to limitations in helicopter performance, and the design of the hardware and software components of ACAS II.

This study has further developed techniques and tools used in previous projects to perform a preliminary safety study of the potential benefits of equipping helicopters with ACAS II.

The conclusion is that those helicopters that have the performance to comply with ACAS Resolution Advisories can benefit from a reduction in the risk of mid-air collision by equipping with ACAS, provided that adequate surveillance performance can be demonstrated.

Keywords

helicopter	ACAS	TCAS	safety
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CONTENTS

EXECUTIVE SUMMARY

Background

The Airborne Collision Avoidance System (ACAS) II is mandated for carriage by fixed-wing aircraft with a maximum take-off mass of over 5,700 kg in European airspace. The mandate does not extend to helicopters.

Safety studies and operational experience have shown that the mandated deployment of ACAS II reduces the risk of mid-air collision. It is natural that the helicopter community should also wish to enjoy this benefit by equipping helicopters with ACAS.

Limitations in the ACAS design of both hardware and software elements (which are optimised for fixed-wing aircraft), and limitations in helicopter performance mean that the benefit enjoyed by fixed-wing aircraft is not necessarily available to helicopters.

This report presents the results of a preliminary study of the potential benefits to helicopters from the deployment of ACAS. Tools developed in a previous EUROCONTROL project have been adapted and used in the present study. As far as possible the limitations mentioned in the previous paragraph have been taken into account.

The study has focussed on helicopter operations in UK airspace, but it is believed that the results are broadly representative of European airspace as a whole.

An extension of the ACAS mandate to include helicopters would require the equippage of about 400 helicopters in Europe. The use of ACAS could approximately halve the risk of collision to which these helicopters are exposed.

Helicopter population

There are about 30,000 civil helicopters in the world of which approximately 3,500 are registered in ECAC member states and 1,159 are registered in UK.

Approximately 400 helicopters in Europe as a whole and 69 helicopters in UK are heavier than the threshold of the ACAS mandate.

Many helicopter types, particularly light helicopters, are unable to climb and descend sufficiently rapidly to comply with routine ACAS resolution advisories. <u>The use of ACAS II on helicopters that cannot achieve these rates should not be permitted.</u>

In extremis ACAS RAs can require an aircraft to climb or descend at 2,500 fpm. Most helicopter types cannot sustain vertical rates of this magnitude. This study has shown that an overall safety benefit is still apparent when helicopter performance is limited to 2,000 fpm, but the benefit in those encounters requiring an increase-rate RA is marginal. The use of the ACAS increase-climb inhibit parameter may mitigate this issue but was not investigated in this study.

Risk of collision

An analysis of recent airproxes occurring in UK involving civil helicopters revealed that current mid-air collision rate for helicopters is about one every 13 years. A value confirmed sadly by experience: the most recent collisions occurred in 1993 and 2004.

From the perspective of an individual helicopter pilot this is a risk of collision of 2.9×10^{-7} per flight-hour. The comparable rate for fixed-wing aircraft required to equip with ACAS is about one tenth of this.

It was observed that all the airproxes involving helicopters occurred below 4,000 ft AGL and in uncontrolled airspace. More than half of the risk of collision was accounted for by encounters with military fast jets.

Tools

A previous project commissioned by EUROCONTROL developed two powerful and flexible tools for analysing the performance of ACAS. These were a safety encounter model and an event tree.

Encounter model

The safety encounter model is a software model of encounters between two aircraft. The characteristics of the encounters are specified by stochastic distributions which can be repeatedly sampled to produce an arbitrarily large number of different encounters. The forms of these distributions can be tailored to produce encounters representative of a particular airspace.

Encounters generated by the model are then used in ACAS simulations and the effects of altimetry error included in an analysis of the risk of collision, both with and without ACAS. These are termed ‘logic risks’ and the ratio of these risks is a measure of the effectiveness of ACAS.

The safety encounter model has been adapted to produce a helicopter safety encounter model for this study.

Event tree

The event tree is a mathematical structure designed to perform a full calculation of the probability of a compound event.

The logic risks, calculated from the encounter model, form one of the inputs to the event tree and are then combined with the probabilities of other factors (such as meteorological conditions, aircraft equippage levels, interaction with ATC, visual acquisition and human factors describing pilot response to ACAS alerts) to obtain ‘full system’ risks.

The event tree has been implemented as an Excel spreadsheet and the event probabilities modified to reflect helicopter operations.

Benefit to helicopters from ACAS

Even without themselves equipping, helicopters will derive some benefit from the ACAS equippage of other aircraft that they encounter. With the full European mandate it is estimated that the risk of collision is reduced to a rate of 2.6×10^{-7} per flight-hour for an individual helicopter: approximately a 10% reduction.

If appropriate helicopters are also equipped with ACAS a further reduction in the risk of mid-air collision can be expected. From the point of view of an individual helicopter pilot the risk will be between 1.2×10^{-7} per flight-hour and 1.6×10^{-7} per flight-hour. A risk ratio of between 43% and 51%.

North Sea operations

Oil and gas rigs in the North Sea are routinely serviced by helicopters operating from shore bases, and travelling to their destinations along the HMR track structure.

The commercial operators of these services may be particularly inclined to equip their helicopters with ACAS if a safety benefit can be demonstrated.

With the full ACAS mandate the risk of collision to individual helicopters operating in the North Sea is estimated to be 1.7×10^{-7} per flight-hour. This is approximately two-thirds the risk experienced by helicopters in UK airspace generally.

If equipped with ACAS individual helicopters can expect this risk of collision to be reduced to a value between 0.5×10^{-7} per flight-hour and 0.8×10^{-7} per flight-hour. A risk ratio of between 29% and 45%.

1. INTRODUCTION

1.1 Preliminary study

The Traffic alert and Collision Avoidance System (TCAS) II, Version 7 is an Airborne Collision Avoidance System (ACAS) that is widely deployed in European airspace as the result of a mandate for the carriage of ACAS. The mandate requires fixed-wing aircraft with a maximum take-off mass in excess of 5,700 kg to be fitted with ACAS, and has been introduced after operational experience and safety studies demonstrated that it will reduce the risk of mid-air collision.

The mandate does not extend to helicopters. Assumptions in the ACAS algorithms and differing aircraft characteristics mean that the safety benefits to fixed-wing aircraft would not automatically apply to helicopters were they to equip with ACAS.

A paper [1] (reproduced here in Appendix B) presented to the ACAS working group of the ICAO Surveillance and Conflict Resolution Systems Panel (SCRSP), reported a short evaluation of the merits of fitting ACAS to helicopters conducted at the request of the EUROCONTROL ACAS Programme Manager. The short evaluation identified five areas in which studies should be carried out before ACAS II is fitted to helicopters:

i) to establish that the helicopters can climb and descend sufficiently rapidly;

ii) to establish that the collision avoidance logic is effective given the particular flight profiles that helicopters might adopt;

iii) to establish that the surveillance is of sufficient quality to support the collision avoidance logic, and remains so during resolution advisory (RA) manoeuvres;

iv) to establish that there will be no systematic tendency to guide the helicopters into surveillance nulls that happen to be occupied by third party aircraft; and

v) to establish that the effect on the ACAS surveillance of fixed wing aircraft operating in close proximity to clusters of ACAS equipped helicopters is acceptable.

The current document reports a preliminary study that has addressed some, but not all, of these areas:

i) this area has been addressed – a review of the performance of some major types has been conducted;

ii) this area has been addressed – the development of a helicopter encounter model has captured the profiles that helicopters might adopt and simulations of the ACAS logic have evaluated the effectiveness of the collision avoidance logic in these circumstances;

iii) this area has been addressed – the inputs to the collision avoidance logic in the simulations have included realistic bearing errors and range measurement noise based on an operational study;

iv) this area has not *been addressed – the surveillance nulls have been modelled but third aircraft are not included in the simulations;*

v) this area has not *been addressed.*

The short evaluation highlighted four reasons that might be advanced for fitting ACAS to helicopters:

- so that collisions may be avoided by following RAs;
- so that collisions may be avoided through improved visual acquisition;
- so that flight crew have an awareness of other traffic in the vicinity;
- so that the efficiency of flight operations may be increased by a knowledge of the presence and relative position of other aircraft.

This preliminary study addresses only the first two of these reasons: the avoidance of collisions by following RAs is addressed through the simulations of the ACAS collision avoidance logic; the avoidance of collisions through improved visual acquisition is one of the factors included in the full system values calculated by an event tree. Reasons for believing that a cockpit display of traffic information (CDTI) might enhance situational awareness are beyond the scope of this preliminary study.

1.2 Risk ratios

The results of ACAS safety analyses are frequently expressed as 'risk ratios'. The risk ratio is a relative measure expressing the risk after equippage[1] with ACAS (or, generally, after any change to a scenario) as a fraction of the risk that existed before equippage with ACAS. A value of the risk ratio that is less than 100% indicates that ACAS decrease the risk of collision and is therefore providing a safety benefit.

There is also the possibility that ACAS will cause a collision (even with the system performing exactly to specification and the pilot responding perfectly to resolution advisories) where a collision would not have occurred if the aircraft had not been ACAS equipped. This generally comes about as the result of a

[1] The term 'equippage' is preferred to the spell-checker's suggestion of 'equipage', which has an entirely different meaning.

late manoeuvre by the threat which thwarts the resolution advisory generated by ACAS. If the number of induced collisions is sufficiently small then it can be tolerated as the price to be paid for the much larger number of collisions that are prevented. The risk of an induced collision can also be expressed as a risk ratio.

Risk ratios can be computed from different perspectives. A regulator will be concerned with the overall risk of collision in a given airspace. In this case the risk ratio is the ratio of the number of collisions in the airspace when aircraft are ACAS equipped to the number of collisions when aircraft are unequipped. An operator or an individual pilot will be concerned with the risk to his own aircraft. In this case the risk ratio is the ratio of the collision risk when own aircraft is ACAS equipped to collision risk when own aircraft is unequipped, the equippage level of other aircraft being unchanged.

It is important to remember that risk ratio is a relative measure and does not directly indicate absolute levels of risk. With two different airspaces the one in which ACAS delivers the smaller risk quite possibly has the larger absolute risk of collision even when ACAS is deployed.

1.3 Layout of report

In chapter 2 a brief background to ACAS is presented including the capabilities of the system, its development and the principles on which it operates. Finally, safety studies of ACAS performance are described, particularly that conducted in the ACASA project.

In chapter 3 the possibility of equipping helicopters with ACAS is considered. The fact that ACAS is designed for fixed-wing aircraft is described and the specific issues that may militate against helicopter equippage are presented. The desire, nevertheless, to fit ACAS to helicopters is discussed.

In chapter 4 a survey of the UK helicopter population is presented including a grouping of the helicopters into three classes based on maximum take-off weight. Numbers of helicopters and the proportion of the time that they are airborne are calculated. Finally the performance specification of typical helicopters in each class is presented.

In chapter 5 an analysis of airprox reports is summarised and the calculated rates of mid-air collision for the UK helicopter population are given.

In chapter 6 the encounter model approach to determining the performance of ACAS is discussed. The encounter model developed in ACASA is described as well as how it has been adapted for this study to produce a helicopter encounter model. The use of the model in ACAS simulations is explained together with the use of an altimetry error model to determine the risk of collision.

In chapter 7 the use of an ‘event tree’ to combine results from ACAS simulations with other environmental and human factors to produce a ‘full system’ risk is discussed.

In chapters 8 and 9 the results of the study are presented. Firstly in chapter 8 the logic risks are presented. These effectively give the best performance that can be expected from ACAS with ideal use of the system.

In chapter 9 the full system risks are presented. These provide more realistic estimates of the expected ACAS performance when other factors are included in the calculation. They also give credit for improved prospects of visual acquisition.

In chapter 10 the results of the study are brought together and conclusions are drawn.

Appendix A presents results limited to a particular theatre of UK helicopter operations, *viz.* helicopters servicing rigs in the North Sea.

2. BACKGROUND TO ACAS

2.1 ACAS capabilities

ACAS is an airborne avionics system that operates independently of air traffic control and aids pilots in avoiding mid-air collisions.

Two types of ACAS systems, with different capabilities, are in operation:

- ACAS I – a system that provides ‘traffic alerts’ (TAs) warning pilots of the presence of traffic that may be a threat to own aircraft; and
- ACAS II – a system that provides TAs and also provides ‘resolution advisories’ (RAs) when the threat from traffic becomes more urgent. An RA provides the pilot with advice on how to regulate or adjust his vertical speed so as to avoid a collision.

This report is concerned solely with ACAS II and henceforth the term ‘ACAS’ shall refer to ACAS II unless otherwise specified.

ACAS is an international equipment standard specified in the ICAO SARPs [2]. There is currently only one implementation of ACAS: the Traffic alert and Collision Avoidance System (TCAS) II Version 7, specified in the RTCA MOPS [3]. Consequently the terms ACAS and TCAS are often used synonymously.

2.2 The development of ACAS

Following a series of mid-air collisions in the USA, TCAS was developed and a phased implementation began in 1989. TCAS was mandated in USA airspace at the end of 1993, an action that resulted in widespread equippage of long-haul aircraft throughout the world.

Operational experience and simulation based studies in many states highlighted issues and led to improvements of the algorithms encoded in the TCAS software (‘the logic’). These ultimately resulted in Version 7 of the TCAS logic, a system which became the basis of the ACAS SARPs.

ECAC has mandated the carriage of ACAS II in European airspace. The mandate is in two phases:

- Phase 1 required aircraft with a maximum take-off mass (MTOM) exceeding 15,000 kg or more than 30 seats to equip with ACAS II by 1st January 2000;[2]

[2] A transition period meant that full Phase 1 equippage level was not necessarily met until the end of March 2001.

- Phase 2 extends the mandate, requiring aircraft with MTOM exceeding 5,700 kg or more than 19 seats to equip with ACAS II by 1st January 2005.[3]

2.3 The principles of ACAS

ACAS uses SSR technology to monitor other aircraft in the vicinity of the equipped aircraft and diagnose any risk of impending collision. The test is of imminence rather than probability of collision.

ACAS interrogates Mode C and Mode S transponder equipped aircraft on a nominal 1 Hz cycle. The altitude of other aircraft is contained in the replies, the time difference of interrogation and reply provides the range, and the use of at least one directional antenna allows the relative bearing of the traffic to be estimated by the ACAS unit.

The altitude, range, and bearing of other aircraft are tracked by ACAS and used to display their relative position on the traffic display using symbols appropriate to the diagnosed level of threat of each aircraft.

In addition, altitude rates and range rates derived from the tracks are used to diagnose the time remaining before any possible collision. ACAS does not have the capability to diagnose a near collision course directly, so these alerts are based on calculations that assume the aircraft to be on collision courses. This necessarily implies a high proportion of alerts in encounters where there is no risk of collision.

The warning times for TAs range from 20 seconds near the ground, through 30 seconds at the highest altitude of helicopter operations, to 48 seconds at high altitude. The warning times for RAs range from 15 seconds at 1,000 ft AGL, through 20 seconds at the highest altitude of helicopter operations, to 35 seconds at high altitude.

ACAS does not provide RAs for aircraft operating at less than 1,000 ft AGL[4] (an important point when considering helicopters which spend a large proportion of their time at such altitudes).

The sense of RAs against other ACAS equipped aircraft is co-ordinated so that the two aircraft choose complementary manoeuvres.

Most ACAS implementations provide the pilot with a permanent display of the traffic in his vicinity (a ‘cockpit display of traffic information’ or CDTI).

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[3] Certain exemptions during a transition period mean that full Phase 2 equippage level will not necessarily be met until the end of March 2006.
[4] Hysteresis on the thresholds means that the altitude is 900 ft AGL for descending aircraft and 1,100 ft AGL for climbing aircraft.

A fuller description of the operation of ACAS can be found in the brochures produced by the FAA [4] and by the EUROCONTROL ACAS Programme Office [5].

2.4 Safety studies

Throughout its development, ACAS has been accompanied by many safety studies quantifying the degree to which the various versions of the logic have been able to achieve their primary aim of reducing the risk of mid-air collision.

One of the most recent safety studies was conducted as part of the ACAS Analysis (ACASA) project. ACASA was a wide ranging set of studies into the performance of ACAS commissioned by the EUROCONTROL ACAS Programme Office in support of the European Mandate. Work Package 1 focussed on safety studies [6] and demonstrated that the deployment of ACAS in European airspace will deliver the anticipated safety benefit.

Within ACASA Work Package 1 two useful tools were developed:

- a European safety encounter model – a software model that captures the characteristics of close encounters as statistical distributions and is then able to select from these distributions to generate an arbitrary large number of encounters which can form the basis of ACAS simulations; and

- an event tree[5] – an Excel spreadsheet that combines the results of ACAS simulations with other external factors (*e.g.* aircraft equippage, meteorological conditions, interaction with controllers, and visual acquisition) to perform a probabilistic calculation of the full system performance.

These tools have been adapted for use in the present study and will be discussed in more detail further on.

2.5 Levels of equippage

Simplified equippage scenarios corresponding to three stages in the ACAS equippage of fixed-wing aircraft are considered in this report:

- pre-mandate – no aircraft equipped with ACAS;

- Phase 1 – only aircraft over 15,000 kg ACAS equipped; and

- full mandate – only aircraft over 5,700 kg ACAS equipped.

In practice changes in equippage levels will not be as abrupt as these scenarios imply and some aircraft outside of the mandate will equip

[5] The term ‘event tree’ has different meanings in different fields. Here it refers to a full calculation of the probability of a compound event.

voluntarily. Nevertheless these scenarios are adequate for the purpose of this study.

Any mandate for the carriage of ACAS by helicopters is likely to employ the same MTOM threshold as the full European mandate (*i.e.* 5,700 kg). The operators of some helicopters outside of this threshold may also wish to equip voluntarily. Equippage of helicopters heavier than the ACAS mandate threshold is considered in this study as well as the equippage of helicopters with MTOM as low as 750 kg.

No account is taken of possible future deployment of collision warning systems (CWS) on military aircraft (principally fast jets).[6]

[6] A CWS for RAF Tornadoes is in development and proprietary systems have been evaluated on the Tucano.

3. POSSIBILITY OF EQUIPPING HELICOPTERS WITH ACAS

3.1 ACAS designed for fixed-wing aircraft

ACAS has been implicitly designed for use on fixed-wing aircraft. Hardware elements such as directional antennae and displays have been optimised for deployment on aeroplanes and software elements in the tracking and collision avoidance algorithms include assumptions that are not necessarily applicable to helicopters.

These potential limitations are recognised in the ACAS mandate which requires equippage with ACAS by fixed-wing aircraft only.

Nevertheless, if it can be demonstrated that these limitations can be overcome or that ACAS performs adequately despite them, then equippage by some helicopters may be desirable or even warrant a mandate [1].

3.2 Desire to equip helicopters with ACAS

At an early stage of the development of ACAS it was realised that a system suitable for deployment on helicopters might be desirable. However, early indications were that the helicopter community themselves (at least in the USA) were ambivalent [7].

As operational experience with the system has increased and studies have shown the safety benefits to be obtained, the desire to equip helicopters with ACAS has grown (see *e.g.* [8] and [9]) (although it is often the traffic display aspect of ACAS that appeals rather than the direct safety net provided by RAs).

Early trials of ACAS II hardware on helicopters [10] and limited installation of ACAS I systems on helicopters (see *e.g.* [9] and [11]) have demonstrated that acceptable solutions to the hardware problems (albeit with some compromises) can be found.

It is therefore an appropriate time to conduct safety studies examining to what extent the software issues may or may not limit the efficacy of ACAS when deployed on helicopters. This study has performed preliminary work in this area.

For this study it was decided to use helicopter operations in UK airspace as the basis for investigation. A number of factors made this an attractive option: the authors and their colleagues are familiar with this area (from having conducted studies applicable to UK airspace, to having worked as controllers); data relating to UK operations is readily available; a wealth of different helicopter operations are conducted in UK airspace (*e.g.* police helicopters, air ambulances, air taxis, news gathering, aerial photography, pipeline and overhead power cable inspection, private flying, and helicopters servicing rigs in the North Sea). In this respect UK airspace is not unusual and it is believed that results from UK airspace will be broadly representative of the results to be expected in western Europe generally.

3.3 Specific issues with equipping helicopters

There are a number of issues, specific to helicopters, that have the potential to degrade ACAS performance.

ACAS antennae are a compromise between surveillance performance, weight constraints and aerodynamic considerations. Antenna performance is susceptible to interference effects caused by other ‘furniture’ on the fuselage (aerials, lights, pitot tubes *etc.*) and multi-path reflections from other parts of the airframe; ACAS antennae perform best when sited well away from other furniture, and on a flat part of the fuselage. Such sites are not generally available on helicopters which tend to be comparatively small and knobbly. In addition, the presence of nearby moving parts (the main rotor, the prop-shaft and the tail rotor) can further degrade the antenna performance.

Nevertheless, studies have shown that acceptable antennae can be designed for helicopters which although not performing as well as their counterparts on fixed-wing aircraft are nevertheless adequate to support ACAS surveillance [10]. The traffic display capability of ACAS, which relies on bearing information, suffers, rather than the RA capability, which can function without bearing information.

ACAS antennae are vertically polarised. This means that the antenna beam pattern has nulls directly above and below. This is not a problem for fixed-wing aircraft which cannot manoeuvre into these ‘blind spots’, but helicopters can. Threats in these areas will not be detected by the ACAS surveillance, and, although the tracks of previously acquired targets will be coasted, the information will necessarily be inaccurate.

The collision avoidance algorithms in ACAS generate RAs that are predicated on the ability of the aircraft to achieve certain vertical rates. Initial RAs may require the aircraft to climb or descend at 1,500 fpm and if the initial RA is not delivering sufficient separation a subsequent ‘increase rate’ RA may require a vertical rate of 2,500 fpm. If an ACAS equipped aircraft (not just helicopters) is unable to achieve these rates then any safety benefit provided by ACAS will be seriously degraded.

4. UK HELICOPTER POPULATION

4.1 UK civil register

The UK civil aircraft register, as it stood at 1st January 2004 [12], was examined to determine the demography of the UK helicopter fleet. In practice some helicopters registered in the UK will be operating overseas and conversely some foreign registered helicopters will be operating in the UK. However, on balance it is believed that a representative profile of the population of helicopters operating in the UK has been obtained.

Helicopters were classified into one of three classes based on their maximum take-off mass (MTOM):[7]

- 'light' helicopters with a MTOM of less than 750 kg – principal types on UK civil register, Robinson R22 and Rotorway Executive;
- 'medium' helicopters with a MTOM in the range 750 kg to 5,700 kg – principal types, Bell 206 (and variants) and Robinson R44; and
- 'heavy' helicopters with a MTOM greater than 5,700 kg – principal types AS332 Puma and Sikorsky S76 Spirit.

The age and total flying hours of each helicopter were noted so that the proportion of the time that each helicopter spent airborne could be calculated.

A total of 1159 helicopters were on the UK register: 277 light; 813 medium; and 69 heavy. There have been no twin rotor helicopters on the UK civil register since 1989.

class	number	total hrs/yr	average hrs/yr per a/c	average hrs/day per a/c	typical number airborne
light	277 (23.9%)	42,246 (16.0%)	152.5	0.42	6
medium	813 (70.1%)	156,630 (59.4%)	192.7	0.53	24
heavy	69 (6.0%)	64,640 (24.5%)	936.8	2.56	10
overall	**1,159 (100%)**	**263,516 (100%)**	**227.4**	**0.62**	**40**

Table 1: Summary statistics of helicopters on the UK civil register

Table 1 summarises the details of helicopters on the UK civil register. In the second column is shown the number of helicopters in each class. In the third

[7] These classes have defined for the purpose of this study and do not necessarily correlate with similarly named classes in other contexts.

column is shown the total flying hours per year accrued by all helicopters in each class. In the fourth and fifth columns are shown the average number of flying hours flown by each helicopter in the relevant class, per year and per day respectively. The final column is illustrative only and shows the typical number of helicopters of each class that can be expected to be airborne in UK airspace at any one time during daylight hours.

The total world population of civil helicopters is around 30,000 of which about 3,500 are registered in ECAC member states (1,159 in UK, 809 in France, 515 in Italy, 371 in Germany, 151 in Norway). It is estimated that the ECAC fleet is comprised of 600 light helicopters, 2,500 medium helicopters and 400 heavy helicopters.

4.2 Helicopter performance

The performance specification of a number of the principal types on the UK civil register were reviewed [13]. The maximum speed, maximum climb rate, and maximum practical descent rate[8] were noted.

The performance of three typical types, the principal type from each weight class, are shown in Table 2: Robinson R22 Beta II, a light helicopter; Bell 206 Jet Ranger, a medium helicopter; and Eurocopter AS332 Puma, a heavy helicopter.

type	MTOM	max speed	max climb	max practical descent	rotor diameter	height
R22 Beta II	622 kg	102 kt	1,000 fpm	1,220 fpm	7.67m	2.72m
Bell 206	1,519 kg	130 kt	1,280 fpm	1,500 fpm	10.16m	2.89m
AS332	9,300 kg	170 kt	1,969 fpm	2,230 fpm	16.20m	4.97m

Table 2: Specification of typical types from each helicopter class

The maximum vertical rates of the Robinson R22 are such that it would be unable to comply with positive ACAS RAs (which require a vertical rate of 1,500 fpm to be achieved). This is also true of the two other types of light helicopter on the UK register (Rotorway Executive and Rotorway Scorpion). As stated in [1] “ACAS II must not be fitted to helicopters that cannot climb or descend sufficiently rapidly”: consequently in this study equippage with ACAS by light helicopters is not considered.

The maximum climb rate of the Bell 206 Jet Ranger is less than the climb rate required by positive RAs. However, the quoted rate is for a sustained climb

[8] A feature unique to rotorcraft is that, at low forward speeds, they can potentially descend into their own downdraft with a consequent loss of lift. In this study, the maximum practical descent rate was taken as 80% of the induced velocity of the air in the downdraft. At higher forward speeds the rotor has a braking effect limiting descent rates to a similar value.

rate and it is possible that for the duration of an RA the required rate might be achievable. Other medium helicopter types such as those manufactured by MD Helicopters and Eurocopter are able to achieve the required rate. Consequently, in this study equippage of medium helicopters is considered, but individual operators and manufacturers would have to satisfy themselves of the appropriateness of equippage before fitting ACAS to specific types in practice.

ACAS can issue ‘increase rate’ RAs, requiring a vertical rate of 2,500 fpm, when the initial RA is diagnosed as not working. This can arise from a deficient response by the pilot of the ACAS aircraft or an unexpected manoeuvre by the threat aircraft. ‘Increase descent’ RAs are inhibited when an aircraft is within 1,450 ft of the ground and ‘increase climb’ RAs can be inhibited on individual aircraft by a setting in the ACAS logic.

In this study it has been assumed that ACAS equipped helicopters can climb and descend at up to only 2,000 fpm (*i.e.* less than the rate required by increase-rate RAs). The setting of the increase-climb inhibit has not been modelled in this study so that incidence of increase-rate RAs and the effect of helicopter performance on their effectiveness can be assessed.

Helicopters can be particularly vulnerable to icing – the formation of ice on the rotor blades with a consequent loss of aerodynamic control. In some weather conditions it may be unsafe for a helicopter to climb above a certain altitude. The ACAS logic can take account of such a limitation by the setting of an internal ‘climb inhibit’ parameter (not to be confused with the separate increase-climb inhibit). Although an important consideration when evaluating the efficacy of ACAS RAs the modelling of climb inhibits is beyond the scope of this preliminary study.

ACAS is an airborne avionics system that operates independently of air traffic control and aids pilots in avoiding mid-air collisions.

5. AIRPROX ANALYSIS

5.1 Introduction

Any investigation of the performance of ACAS in reducing the risk of mid-air collision needs first to determine the characteristics of the airspace being investigated. In particular the pre-existing risk of mid-air collision, before ACAS is deployed, needs to be known.

To determine the risk of mid-air collision to which helicopters are currently exposed an examination of the most recent UK airprox reports, available at the time, [14] was undertaken.

Generally, reported airproxes are a less objective source for these statistics than an analysis of radar data (for example an airprox may go unnoticed and not be reported). However, they are best suited for this study since we are interested only in incidents involving civil helicopters (difficult to determine from radar data) and these may occur in areas without reliable radar coverage (*e.g.* at low level).

The analysis that follows is initially conducted in terms of 'near mid-air collisions' (NMACs) rather than collisions.[9] The use of 'NMAC' rather than 'collision' as the adverse event is common practice and is employed here so that conclusions can be readily compared with other studies, and to increase the number of events available for study. With a separation as small as this the absence of a collision can be assumed purely fortuitous. Consequently figures relating to collisions rather than NMACs can be readily obtained from the ratio of a collision cross-section to the NMAC cross-section. *E.g.* a heavy helicopter is typically 16 m wide (*i.e.* the width of the rotor disc) and 5m high; a fast jet is typically 12 m wide and 5 m; this gives a collision cross-section of $(16m + 12m)\times(5m + 5m) = 280\ m^2$. The NMAC cross-section is $(2\times0.1NM)\times(2\times100ft) = 22{,}580\ m^2$, we therefore expect one collision for every 80 NMACs between a heavy helicopter and a fast jet.

5.2 Method

The airprox reports were examined by an experienced former air traffic controller. Those airproxes involving civil helicopters were identified and summarised. In addition, other airproxes not involving helicopters were also examined. These other airproxes which, in the opinion of the former controller, could equally have involved a civil helicopter were also noted and summarised. The airprox reports were summarised in an Excel spreadsheet, an approach that proved very useful and which provided the inspiration for the development of a database covering all classes of airprox [15].

[9] An NMAC is defined as an incident in which the horizontal separation between two aircraft is less than 0.1 NM and simultaneously the vertical separation is less than 100 ft.

In each airprox the class of helicopter (actual or effective) was noted. Also noted was the type of the other aircraft. These were categorised into one of four classes (the corresponding aircraft performance classes from the ACASA study [6] are given in parentheses):

- class 1 – military fast jets, aircraft not required to equip with ACAS (class G);
- class 2 – aircraft less than 5,700 kg and piston-engined aircraft, aircraft not required to equip with ACAS (classes A and B);
- class 3 – turbo-prop and turbo-jet aircraft between 5,700 kg and 15,000 kg, aircraft required to equip with ACAS under Phase 2 of the mandate (classes C and D); or
- class 4 – turbo-prop and turbo-jet aircraft over 15,000 kg, aircraft required to equip with ACAS under Phase 1 of the mandate (classes E and F).

In each airprox the horizontal miss distance (HMD) and the vertical miss distance (VMD) were noted.

In each airprox the risk category assigned by the UK Airprox Board was noted. This was one of three categories:

- category A – risk of collision ('an actual risk of collision existed');
- category B – safety not assured ('the safety of the aircraft was compromised'); or
- category C – no risk of collision ('no risk of collision existed').[10]

Airproxes in category D (risk not determined) were not included in the analysis.

It was observed that for each risk category the HMD was approximately uniformly distributed. In risk category A HMD was typically between 0 NM and 0.1 NM; in risk category B HMD was typically between 0 NM and 0.5 NM; in risk category C HMD was typically between 0 NM and 2.5 NM. These distributions, combined with the NMAC threshold of 0.1NM, were used to weight the airproxes accordingly. *E.g.* it was considered that for any category C airprox there was a 0.1 NM / 2.5 NM = 0.04 (or 1 in 25) chance that a similar incident, but with an HMD of less than 0.1 NM, could occur. Category A airproxes were assigned a weight of 1.0, category B airproxes were assigned a weight of 0.2, and category C airproxes were assigned a weight of 0.04.

[10] It may seem odd to include incidents categorised as 'no risk of collision existed' in an analysis of collision risk. However, this categorisation by the Airprox Board refers to the specific incident and reflects the actual horizontal and vertical separation that existed. Our analysis treats such incidents as single examples drawn from an underlying population of possible incidents and determines the probability that the separation would happen to be small enough for a collision, were a similar incident to occur again.

The VMD in each airprox was noted. This was treated as the perceived vertical separation that would be measured by comparing the two aircraft's altimeters. The standard altimetry error model (prescribed in the ICAO SARPS [2] and adopted in the ACASA study) was applied to determine the probability that this perceived separation might, in fact, be less than the NMAC threshold of 100 ft.

Finally, the weightings and probabilities were combined to calculate each airprox's contribution to the overall NMAC rate.

The method assumes that any separation that existed in the reported airprox was purely fortuitous and as such will tend to overstate the risk of collision.

5.3 Results

A total of 18 airproxes involving helicopters were noted over a period of 84 days between July and September 2002. A further 22 airproxes which were considered representative of the type of incidents in which helicopters might be involved were also noted. Allowing for seasonal variation the period observed was estimated to effectively correspond to 0.32 years of observation.

In every case the helicopter was operating in a similar manner to a fixed wing aircraft (*i.e.* none of the helicopters were in the hover when the airprox occurred).

The highest altitude of any aircraft involved in an airprox involving a helicopter was 3800 ft. Airproxes were uniformly distributed between the ground and this altitude.

The majority of airproxes involving helicopters occurred in uncontrolled airspace. Only 7.5% of the airproxes analysed occurred in controlled airspace (3 airproxes, all in Class D airspace).

The small number of airproxes in controlled airspace is reflected in the proportion of aircraft types involved in NMACs with helicopters. In only 0.4% of these NMACs do we expect the other aircraft to be a large commercial jet of the type required to equip by Phase 1 of the ACAS mandate.

By contrast, the preponderance of airproxes in uncontrolled airspace is also reflected in the proportions. In the majority of NMACs involving helicopters (64.5%) we expect the other aircraft to be a military fast jet.

None of the airproxes were between two civil helicopters. In the rest of this study it has been assumed that the probability of a collision between two helicopters is negligible.

The proportions of other aircraft types involved in NMACs with helicopters is summarised in Table 3. These proportions have been used in the rest of the study.

class	1	2	3	4
description	military fast jets	aircraft not required to equip with ACAS	aircraft required to equip by Phase 2 of the ACAS mandate	aircraft required to equip by Phase 1 of the ACAS mandate
proportion	64.5%	15.3%	19.8%	0.4%

Table 3: proportion of aircraft types encountered by helicopters in NMACs

Table 4 shows the estimated NMAC and collision rates for the various classes of helicopter. The second column shows the number of NMACs involving helicopters expected each year in UK airspace. In the fourth column we have taken account of the hours flown each year by the appropriate helicopter class (from Table 1) to express the rate as the number of NMACs per flight-hour expected by an individual helicopter of that class. In the third and fifth columns the average collision cross- section for each class has been used to convert the NMAC rates to collision rates.

class	NMAC/yr	collisions/yr	total hrs/yr	NMAC/flt-hr	collisions/flt-hr
light	0.44	0.003	42246	1.03×10^{-5}	0.72×10^{-7}
medium	7.97	0.066	156630	5.09×10^{-5}	4.32×10^{-7}
heavy	0.49	0.006	64640	0.76×10^{-5}	0.98×10^{-7}
overall	**8.90**	**0.076**	**263516**	$\mathbf{3.75 \times 10^{-5}}$	$\mathbf{2.87 \times 10^{-7}}$

Table 4: Estimated collision rate for helicopters during Phase 1 of the ACAS mandate

class	NMAC/yr	collisions/yr	total hrs/yr	NMAC/flt-hr	collisions/flt-hr
light	0.38	0.003	42246	0.89×10^{-5}	0.62×10^{-7}
medium	6.89	0.057	156630	4.40×10^{-5}	3.66×10^{-7}
heavy	0.41	0.005	64640	0.64×10^{-5}	0.83×10^{-7}
overall	**7.68**	**0.065**	**263516**	$\mathbf{2.91 \times 10^{-5}}$	$\mathbf{2.48 \times 10^{-7}}$

Table 5: Estimated collision rate for helicopters with the full ACAS mandate

Table 4 is based on airprox data from 2002 and can be taken to represent the situation where the equippage of other aircraft reflects Phase 1 of the ACAS mandate. Phase 2 of the ACAS mandate comes in to effect from January 2005, and in section 8.2 we calculate figures comparable to those of Table 4 but for the scenario where helicopters are unequipped and other aircraft equippage reflects the full ACAS mandate. For comparison these figures are presented in Table 5.

5.4 Discussion

The figures in Table 4 imply that we can expect, on average, one mid-air collision involving a helicopter every 13 years in UK airspace. When this study was begun the most recent collision had occurred in 1993.[11] Since then another collision has occurred in 2004,[12] regrettably confirming that this estimate is about right.

The average rate of mid-air collision for an individual helicopter in UK airspace is estimated to be 2.87×10^{-7} per flight-hour. This is comparable to the rate of 7.8×10^{-8} per flight-hour,[13] estimated for commercial air traffic receiving a radar advisory service (RAS) in class F/G airspace [16]. The rate averaged over all helicopters operations can be expected to be slightly higher because it includes a proportion of flights not receiving an RAS.

The majority of helicopter operations occur in uncontrolled airspace and so one would expect the mid-air collision rate for helicopters (and other aircraft operating in the same airspace) to be greater than that associated with operations that principally occur in controlled airspace. In this sense the estimated rate of 2.87×10^{-7} per flight-hour is consistent with the rate of 3×10^{-8} per flight-hour adopted in the ACASA study [6].

It is interesting to compare these estimates with the safety record of helicopter operations generally. In addition to the one mid-air collision in 1993 with two fatalities, the CAA Aviation Safety Review [17] reveals that in the 10 year period 1992–2001 there were a total of 32 other fatal airborne accidents to helicopters with a total of 73 fatalities. A helicopter pilot is approximately 40 times less likely to be killed by a mid-air collision than by some other airborne accident.

Table 4 reveals that the majority of mid-air collisions are expected to involve a helicopter from the medium class. This is partly due to the fact that medium class helicopters fly more than half of all helicopter hours in UK airspace, but this is not the full explanation. The collision rates per flight-hour reveal that medium class helicopters are exposed to a collision risk approximately five times greater than that experienced by other helicopters. This probably arises from medium helicopter operations being more concentrated in the areas

[11] 23rd June 1993, Cumbria. A Bell Jet Ranger on pipeline inspection was struck by an RAF Tornado. The two occupants of the helicopter were killed.
[12] 6th July 2004, Hertfordshire. A Robinson R22 and a microlight collided. The two occupants of the microlight were killed.
[13] Due to their rarity, estimates of the rate of mid-air collisions are notoriously difficult to calculate accurately. Two estimates that differ by less than a factor of four are therefore considered close.

where military airproxes occur (the English Midlands and East Anglia, as revealed in general [15]) than other helicopter operations. This explanation is supported by an examination of flying hours throughout UK airspace (Table 1) and flying hours in North Sea operations: 88% of medium helicopter hours are flown outside of North Sea operations whereas the corresponding figure for heavy helicopters is only 12%.

6. ENCOUNTER MODEL

6.1 Introduction

An encounter model is a means by which an arbitrarily large number of close encounters can be generated and subsequently be used in ACAS simulations. In this way the paucity of data from real close encounters (which thankfully are rare events) can, to some extent, be circumvented.

In an encounter model the characteristics of close encounters are parameterised as many statistical distributions (where applicable the distributions of certain parameters are correlated with one another). These distributions can then be sampled as many times as desired and artificial encounters, based on the parameters obtained, can be constructed.

The parameters include such factors as the altitude at which the encounter occurs, the vertical miss distance between the two aircraft at closest approach, the approach angle (the difference in heading between the two aircraft), whether the aircraft turn, the ground-speeds, and the aircraft vertical rates. As part of this last feature the combination of each aircraft's vertical profile (descending, level or climbing noted at the beginning and at end of the encounter) is considered to define an encounter geometry classification (consisting of 90 possibilities).

By observing real encounters in a particular airspace it is possible to derive specific distributions for the parameters, which characterise encounters in that airspace. This is an important point because experience has shown that the safety benefit derived from ACAS is crucially dependent upon the characteristics of the airspace in which it is deployed, especially the level of safety (the collision rate) that exists in the airspace before ACAS is deployed.

6.2 ACASA safety encounter model

The ICAO SARPS [2] specify an encounter model that is not characteristic of any particular airspace. As part of the ACASA project the structure of this encounter model was enhanced and techniques were developed that enabled the distributions of parameters to be tuned to produce an encounter model representing European airspace (see [18] for a detailed description, or [19] for a more accessible summary).

Real encounters with a small HMD were analysed to populate the statistical distributions. Even so there was evidence that the horizontal separations were large enough to distort the distributions of vertical miss distance: more encounters with a small VMD were observed than would be expected given the assumed collision rate in European airspace.

This problem was overcome by adjusting the VMD distributions, using an objective mathematical technique, so that they reproduced the expected collision rate [24].

6.3 Helicopter safety encounter model

To properly assess the performance of ACAS on helicopters we need to produce an encounter model tailored to the type of encounters in which helicopters are involved. To this end the ACASA safety encounter model has been adapted to produce a helicopter safety encounter model.

In section 5.3 the analysis of airproxes found no helicopter incidents above an altitude of 3,800 ft. We therefore use only the lowest altitude layer of the ACASA encounter model, which extends from 1,000 ft AGL to 5,000 ft AGL (below 1,000 ft ACAS issues only TAs, the RA capability of ACAS will consequently have no effect on collision risk below this altitude).

The ACASA model has been adapted so that one of the aircraft in each encounter has a ‘helicopter-like’ profile. This has been achieved by adjusting the thresholds of the minimum and maximum ground-speed, the maximum descent rate and the maximum climb-rate. A single set of thresholds have been used reflecting typical values for medium and heavy helicopters.

Minimum ground-speed was set at 50 kt and maximum ground-speed was set at 160 kt. Maximum descent rate was set at –2,000 fpm and maximum climb rate at 2,000 fpm.

The helicopter safety encounter model produces encounters in which one aircraft is a helicopter and the other aircraft is a fixed-wing aircraft. The proportions of various trajectory profiles among the fixed-wing aircraft were modified to reflect the distribution of aircraft types found in the airprox analysis (see Table 3). This is important because the proportion of fast jets (whose high speed and/or high vertical rate profiles can present problems to ACAS) needs to be much higher in the helicopter safety encounter model (64.5%) than is the case in the ACASA safety encounter model (7.5%).

The weights of the various encounter geometry classes were left unmodified.

The VMD distribution was adjusted separately for each of the three helicopter classes. The standard technique was used to produce the NMAC rates derived in Table 4.

The helicopter safety encounter model was exercised to produce a sample of 90,000 helicopter encounters.

6.4 ACAS simulations

The helicopter encounters were then used as the basis of computer simulations of the behaviour of ACAS.

The simulations include a capability to model measured bearing error and measured range noise on the inputs provided by the surveillance to the ACAS logic. This was used on the inputs to the helicopter's ACAS logic. The model was modified to reproduce bearing errors similar to those observed in operational trials of ACAS surveillance on helicopters [10].

In addition the antenna radiation pattern in the vertical plane was modelled for ACAS equipped helicopters. If the combination of intruder range and angular elevation meant that replies would fall below the detection threshold then these were not supplied to the ACAS logic (which would initially coast the intruder track and, if appropriate, eventually drop it).

Each encounter was simulated with the pilot or pilots of the equipped aircraft responding to RAs with the standard pilot response. However, the response of the helicopter was limited by the same performance limits that were adopted in the helicopter safety encounter model, *viz.* ±2,000 fpm. The consequence is that although the helicopters in the simulation were able to comply with initial positive RAs instructing the pilot to climb or descend at 1,500 fpm, they were unable to fully comply with any subsequent 'increase-rate' RAs instructing the pilot to increase his vertical rate to 2,500 fpm. The effect of this limitation was investigated in a subset of the ACAS simulations.

Each encounter was simulated with first one and then the other aircraft ACAS equipped and also with both aircraft ACAS equipped. In the latter case full account is taken of the co-ordination of RA sense by the two ACAS units.

The vertical separation at closest approach in the original encounter and the vertical separation achieved when aircraft are ACAS equipped is noted in each encounter.

6.5 Altimetry error

The vertical separations, both with and without ACAS, in each encounter are used to assess the risk of collision. These separations are the nominal values that would be perceived from a simple comparison of the altimeters of the two aircraft. However, the presence of altimetry error may negate the perceived separation and there is a finite probability that a collision will occur.

The application of a mathematical model of altimetry error enable the probability of collision in each encounter to be determined. As with the airprox analysis in chapter 5, the standard altimetry error model (prescribed in the ICAO SARPS and adopted in the ACASA study) was used.

6.6 Risk of collision

Finally, the probabilities of collision in each individual encounter are weighted according to the appropriate encounter geometry weighting and the particular equippage scenario under consideration.

The weighted probabilities are combined to provide the overall risk of collision for a specific equippage scenario.

These risks can be used directly to determine the ‘logic’ risk ratio.

Alternatively the risks can be partitioned and various environmental and human factors considerations taken into account before recombining the risks to produce a full system risk ratio.

This latter process is performed by the event tree tool developed in ACASA which is described in the next chapter.

7. EVENT TREE

7.1 Introduction

Simulations of the ACAS logic effectively determine the best performance that can be achieved in ideal circumstances. In practice many other factors will affect the safety benefit that is achieved by the deployment of ACAS.

Pilot response is one of these factors. Pilots may overlook or ignore an ACAS RA, or may respond but with a non standard response – responding slowly or even in some circumstances misinterpreting the RA and responding with the wrong sense.

The interaction of air traffic controllers with the operation of ACAS is another factor.[14] An ACAS TA may prompt the pilot to contact the controller or the controller may provide an avoidance instruction independently. In either case a controller construction will not necessarily be compatible with any ACAS RA, and (despite his training) a pilot may prefer the controller instruction over the advice of ACAS.

ACAS TAs, in conjunction with the traffic display, may allow the pilot to visually acquire the collision threat. Under these circumstances the pilot may use his visual acquisition as the basis of avoiding a collision rather than any ACAS RA.

If these other factors can be captured as distinct events, whose probabilities can be estimated, then the full system safety benefit can be evaluated by combining them with the results of ACAS simulations.

7.2 Excel implementation

The ACASA project developed an event tree to calculate the full system collision risk [21]. This event tree was implemented as an Excel spreadsheet.

Probability values for the basic events were collated from various sources or calculated specifically for the project [22].

These probabilities have been reviewed for the present study and informed judgement used to produce new values relevant to helicopter operations. In this way a helicopter event tree was developed and has been used to calculate full system risks.

[14] This factor is more important for helicopters operating on the HMR track structure (considered in Appendix A) than for general helicopter operations which will not normally be under positive control by ATC.

7.3 Visual acquisition

One important set of probabilities relate to the possibility of the pilot visually acquiring the collision threat (given adequate meteorological conditions and an uninterrupted line of sight).

The pilot may have already acquired the threat before any ACAS alert, or may acquire the threat prompted by an ACAS TA (either aided by the traffic display or not – the latter circumstance most likely arising when the threat cannot be displayed due to unreliable bearing information).

For the ACASA study these probabilities were evaluated by a simple implementation of the visual acquisition model outlined by Lincoln Laboratory [23].

Subsequent analysis revealed that the evaluation of the visual acquisition probabilities was one of the significant areas in which the ACASA event tree could be improved [24]. Consequently for the present study a more sophisticated version of the visual acquisition has been implemented allowing more precise values of the visual acquisition probabilities to be derived taking full account of the geometries generated by the encounter model.

The probabilities calculated from the visual acquisition model are summarised here:

- the probability that the threat will approach from a direction offering no prospect of visual acquisition (due to the limits of the cockpit view) is 0.14;

- the probability that a pilot, given good weather, will visually acquire the threat before a TA is generated (as a result of normal vigilance) is 0.36;

- the probability that the threat will be acquired during a visual search prompted by a TA depends upon whether the pilot has a useful traffic display or not (the latter case most likely arising when poor surveillance prevents an accurate estimate of the threat’s bearing) – with a useful display the probability is 0.77, without a useful display the probability is only 0.28.

8. LOGIC RESULTS

8.1 Introduction

In this chapter we present the risks of mid-air collision calculated directly from ACAS simulations performed on the encounters generated by the helicopter safety encounter model.

Limitations of the ACAS surveillance are modelled in the inputs to the ACAS logic (which is assumed to work precisely as designed).

It is assumed that the pilots of ACAS equipped aircraft respond to any RAs that are issued with the standard pilot response (the response assumed in the ACAS logic).

Consequently, given the limitations of the ACAS surveillance, the logic results effectively represent the best performance that ACAS might achieve. More realistic performance taking into account other factors in the full system, beyond just the operation of the ACAS logic, are presented in the next chapter.

8.2 Benefit to helicopters from ACAS mandate

The ACAS mandate does not require helicopters to equip. However, helicopters will accrue some benefit from the avoidance capability of other ACAS equipped aircraft that they encounter. With helicopters unequipped and assuming threat equippage that reflects the ACAS mandate we can estimate the reduction in the risk of mid-air collisions involving helicopters. The results, when considering only the logic, are shown in Table 6.

	pre-mandate		Phase 1		full mandate	
class	NMACs per year	collisions per year	NMACs per year	collisions per year	NMACs per year	collisions per year
light	0.44	0.003	0.44	0.003	0.38	0.003
medium	7.99	0.066	7.97	0.066	6.89	0.057
heavy	0.49	0.006	0.49	0.006	0.41	0.005
total	**8.92**	**0.076**	**8.90**	**0.076**	**7.68**	**0.065**

Table 6: Helicopter collision rate at various stages of the ACAS mandate (helicopters unequipped) – logic results

The columns under ‘Phase 1’ indicate the situation at the completion of Phase 1 of the ACAS mandate. By comparing these with the columns indicating the situation before the mandate we can be seen that the reduction in the collision rate has been minimal. This is a consequence of the separation of helicopter traffic and those aircraft (over 15,000 kg) required to equip by Phase 1 of the mandate. As we saw in Table 3 these aircraft comprise only 0.4% of the traffic encountered by helicopters.

The columns under ‘full mandate’ indicate the current situation with the last phase of the ACAS mandate complete. Aircraft down to 5,700 kg are required to equip with ACAS so that 20.2% of the traffic encountered by helicopters can be expected to be ACAS equipped. A greater reduction in the collision rate is apparent here with the rate of mid-air collisions involving helicopters being potentially decreased from approximately one every 13 years to one every 15 years: an airspace risk ratio of 86.4%.

8.3 Benefit to helicopters from equipping with ACAS

Having seen the indirect benefit that helicopters gain from the full ACAS mandate we can now determine what further benefit would accrue to individual medium or heavy helicopters if they were to equip with ACAS. The results are presented in Table 7 from the perspective of individual pilots as the risk of collision per hour of flight.

	full ACAS mandate, helicopters unequipped		helicopters ACAS equipped		*induced events*	
class	NMACs per flt-hr	collisions per flt-hr	NMACs per flt-hr	collisions per flt-hr	*NMACs per flt-hr*	*collisions per flt-hr*
medium	4.40×10^{-5}	3.66×10^{-7}	1.77×10^{-5}	1.47×10^{-7}	*0.41×10^{-5}*	*0.34×10^{-7}*
heavy	0.64×10^{-5}	0.83×10^{-7}	0.29×10^{-5}	0.38×10^{-7}	*0.09×10^{-5}*	*0.12×10^{-7}*
average	**3.30×10^{-5}**	**2.83×10^{-7}**	**1.34×10^{-5}**	**1.15×10^{-7}**	***0.32×10^{-5}***	***0.28×10^{-7}***

Table 7: Collision rate for individual helicopters (full ACAS mandate) – logic results

class	risk ratio	*induced risk ratio*
medium	40.1%	*9.3%*
heavy	46.0%	*14.6%*
average	**40.6%**	***9.8%***

Table 8: Risk ratios for individual helicopters that equip with ACAS (full ACAS mandate) – logic results

These results are summarised as risk ratios in Table 8. It can be seen that the risk ratios are less than 50% meaning that an individual helicopter that equips with ACAS could, under ideal circumstances, more than halve its own risk of mid-air collision. However, we can expect a significant proportion of the collisions that do occur to be attributable to the fact that the helicopter has equipped with ACAS. The induced risk ratio is around 10% meaning that if and when a collision does involve an ACAS equipped helicopter there is about a one in four chance that this collision will be attributable to that equippage.

8.4 Increase-rate RAs

Helicopter performance has been limited to vertical rates of no more than 2,000 fpm when modelling the response to RAs. This allows helicopters to respond fully to initial positive RAs (that demand a vertical rate of 1,500 fpm) but means that they cannot fully comply with increase-rate RAs (that demand a vertical rate of 2,500 fpm).

ACAS continually monitors the vertical separation that is expected from following the current RA. If the RA is diagnosed as failing to provide sufficient separation (generally as a result of an adverse manoeuvre by the threat) then the ACAS logic will consider strengthening the RA to an increase-rate RA or reversing the sense of the RA (co-ordination of RA sense with other ACAS equipped aircraft permitting).

ACAS installations can be configured so that an internal ACAS parameter inhibits increase-climb RAs (but not increase-descent RAs). If this inhibit is set, the logic will consider only a reversal in RA sense in the circumstances that might otherwise generate an increase-rate RA. In this study the inhibit has not been set, so that the extent to which the vertical rate limit poses a problem can be determined.

The performance of ACAS against unequipped threats has been evaluated with both a limit of 2000 fpm on the vertical rates in response to RAs and with no limit on the vertical rates. The results are shown in Table 9.

	without ACAS	with ACAS	
		unlimited vertical rate	vertical rate limited 2,000 fpm
‘increase-rate’ encounters	13.0%	8.6%	12.3%
other encounters	87.0%	16.9%	16.9%
all encounters	**100%**	**25.4%**	**29.2%**

Table 9: Proportion of the total risk in various encounter sets

It was found that encounters requiring an increase-rate RA constituted less than 2% of all the RAs generated in encounters from the helicopter safety encounter model. However, these encounters accounted for 13.0% of the pre-existing risk of collision.

Limiting the response to increase-rate RAs increases the risk ratio for all encounters from 25.4% to 29.2%.[15]

Next we consider only those encounters in which an increase-rate RA was generated. When vertical-rates in response to an RA were unlimited it was found that the risk in these encounters was reduced by about one third. When the vertical-rates is limited to 2,000 fpm the risk in these encounters was reduced by only about one twentieth.

[15] These risk ratios differ from those reported in the previous section because we are not considering encounters with ACAS equipped threats, nor encounters below 1,000 ft (where ACAS does not generate RAs).

9. FULL SYSTEM RESULTS

9.1 Introduction

The logic risks from the previous chapter have been used as just one of the inputs to the event tree to calculate full system risks. The results are presented in this chapter.

The effect of considering other factors is generally found to 'dilute' the safety benefit apparent in the logic risks. Consequently the full system risk ratios tend to be larger than the logic risks. The dilution increases the unresolved risk more than the induced risk and so the induced component of the risk ratio tends to decrease.

As well as considering the standard pilot response, the event tree also includes logic risks associated with a slow pilot response, and a pilot response in which the pilot is assumed to misinterpret the sense of any RAs. Limited resources meant that these non standard pilot responses were not simulated. Instead, experience gained from the ACASA study (where these responses were simulated) has been used to infer values for these risks based on the trends observed.

to RAs with a non-standard response. Experience from the ACASA study shows that a conscientious pilot, who always responds to his RAs with the standard response, can significantly reduce the risk of collision to which he is exposed (even though other pilots might still respond with a non-standard response). Conscientious pilots can expect to achieve a risk of collision somewhere between the logic risks and full system risks presented in this report.

The event tree combines many probabilities, estimates of which (particularly in this study) have varying degrees of precision. Consequently the estimates of the full system risk are less precise than the logic risks.

9.2 Benefit to helicopters from ACAS mandate

The ACAS mandate does not require helicopters to equip. However, helicopters will accrue some benefit from the avoidance capability of other ACAS equipped aircraft that they encounter. With helicopters unequipped and assuming threat equippage that reflects the ACAS mandate we can estimate the reduction in the risk of mid-air collisions involving helicopters. The results, for the full system, are shown in Table 10.

The columns under 'Phase 1' indicate the situation at the completion of Phase 1 of the ACAS mandate. By comparing these with the columns indicating the situation before the mandate we can be seen that the reduction in the collision rate has been minimal. This is a consequence of the separation of helicopter traffic and those aircraft (over 15,000 kg) required to equip by

Phase 1 of the mandate. As we saw in Table 3 these aircraft comprise only 0.4% of the traffic encountered by helicopters.

	pre-mandate		Phase 1		full mandate	
class	NMACs per year	collisions per year	NMACs per year	collisions per year	NMACs per year	collisions per year
light	0.44	0.003	0.44	0.003	0.40	0.003
medium	7.99	0.066	7.98	0.066	7.36	0.061
heavy	0.49	0.006	0.49	0.006	0.46	0.006
total	**8.92**	**0.076**	**8.91**	**0.076**	**8.22**	**0.070**

Table 10: Helicopter collision rate at various stages of the ACAS mandate (helicopters unequipped) – full system results

The columns under 'full mandate' indicate the current situation with the last phase of the ACAS mandate complete. Aircraft down to 5,700 kg are required to equip with ACAS so that 20.2% of the traffic encountered by helicopters can be expected to be ACAS equipped. A greater reduction in the collision rate is apparent here with the rate of mid-air collisions involving helicopters being potentially decreased from approximately one every 13 years to one every 14 years: an airspace risk ratio of 86.3%.

9.3 Benefit to helicopters from equipping with ACAS

Having seen the indirect benefit that helicopters gain from the full ACAS mandate we can now determine what further benefit would accrue to individual medium or heavy helicopters if they were to equip with ACAS. The results are presented in Table 11 from the perspective of individual pilots as the risk of collision per hour of flight.

	full ACAS mandate, helicopters unequipped		helicopters ACAS equipped		*induced events*	
class	NMACs per flt-hr	collisions per flt-hr	NMACs per flt-hr	collisions per flt-hr	*NMACs per flt-hr*	*collisions per flt-hr*
medium	4.70×10^{-5}	3.91×10^{-7}	2.39×10^{-5}	1.99×10^{-7}	*0.17×10^{-5}*	*0.14×10^{-7}*
heavy	0.71×10^{-5}	0.92×10^{-7}	0.43×10^{-5}	0.55×10^{-7}	*0.04×10^{-5}*	*0.06×10^{-7}*
average	**3.53×10^{-5}**	**3.04×10^{-7}**	**1.82×10^{-5}**	**1.57×10^{-7}**	***0.13×10^{-5}***	***0.12×10^{-7}***

Table 11: Collision rate for individual helicopters (full ACAS mandate) – full system results

These results are summarised as risk ratios in Table 12. It can be seen that the risk ratios are over 50% meaning that an individual helicopter that equips with ACAS will, with typical pilot behaviour, not quite halve its own risk of mid-air collision. A conscientious pilot, who always follows his own RAs and with the standard response, can expect to achieve a reduction in risk somewhere between these values and the logic values in Table 8 – about 50%.

class	risk ratio	*induced risk ratio*
medium	50.9%	*3.6%*
heavy	60.1%	*6.2%*
average	**51.7%**	***3.8%***

Table 12: Risk ratios for individual helicopters that equip with ACAS (full ACAS mandate) – full system results

10. CONCLUSIONS

10.1 Preliminary study

A study of the potential safety benefits of fitting ACAS to helicopters has been conducted. The study built on established techniques and adapted tools from the ACASA project to produce versions specific to the consideration of helicopter operations.

The resources available and the scope of the project mean that this has been only a preliminary study. However, the techniques and tools used could easily be further refined for use in any subsequent, more comprehensive studies in this field.

10.2 Collision rate

It is estimated that the mid-air collision rate for helicopters in recent years in UK airspace has been an average of one every 13 years – a result sadly confirmed by experience.

From the point of view of an individual helicopter pilot this is a rate of 2.9×10^{-7} per flight-hour.

10.3 Limitations of helicopters

Realistic surveillance limitations, specific to helicopters, have been included in the ACAS simulations conducted in the course of this study. The results suggest that these limitations alone do not militate against general helicopter equippage with ACAS. However, individual installations would need to be comprehensively tested to confirm that their performance was adequate.

ACAS RAs routinely require aircraft to climb or descend at 1,500 fpm. Many helicopter types, particularly light helicopters, are unable to achieve these rates. The use of ACAS II on helicopters that cannot achieve these rates should not be permitted.

In extremis ACAS RAs can require an aircraft to climb or descend at 2,500 fpm. Most helicopter types cannot sustain vertical rates of this magnitude. This study has shown that an overall safety benefit is still apparent when helicopter performance is limited to 2,000 fpm, but the benefit in those encounters requiring an increase-rate RA is marginal. The use of the ACAS increase-climb inhibit parameter may mitigate this issue and warrants further investigation.

10.4 Benefit to helicopters from full ACAS mandate

Helicopters can expect to derive limited benefit from the equippage of other aircraft in compliance with the European ACAS mandate. If helicopters are unequipped the full ACAS mandate can be expected to reduce the collision rate for helicopters to about one every 15 years.

From the point of view of an individual helicopter pilot this is a rate of about 2.6×10^{-7} per flight-hour.

10.5 Benefit to helicopters equipping with ACAS

If, furthermore, helicopters are also equipped with ACAS it is estimated that the rate of collisions will be further reduced to, at best, one every 36 years or, more realistically, one every 28 years.

From the point of view of an individual helicopter pilot this is a rate of between 1.2×10^{-7} per flight-hour and 1.6×10^{-7} per flight-hour. A risk ratio of between 43% and 51%.

A conscientious pilot, who always follows his own RAs with the standard response, can expect to achieve a risk ratio towards the lower these two values.

10.6 Extension of ACAS mandate to helicopters

If the full ACAS mandate were extended to include helicopters with MTOM greater than 5,700 kg (as well as fixed-wing aircraft) then 89 helicopters in the UK (6% of the population) and about 400 helicopters in all ECAC member states (11% of the population) would be required to fit ACAS.

A. NORTH SEA OPERATIONS

A.1 Introduction

One part of the helicopter community has the motivation and resources that may predispose them to equip with ACAS, namely commercial operators servicing rigs in the North Sea [8].

Helicopters ferry workers, equipment and supplies between bases in Scotland (principally Scatsa and Aberdeen) and oil-rigs in the East Shetland basin, and between bases in eastern England (principally Humberside, Norwich and North Denes) and gas-rigs in the southern North Sea. Similar operations are conducted in the Norwegian and Danish sectors from shore bases in those countries.

Operations are general conducted along the Helicopter Main Route (HMR) track structure. In the HMR track structure a limited ATC service is available. Controllers provide separation between participating helicopters, and supply information about the position of helicopters to other traffic that request it. Nevertheless, helicopters using the HMR track structure are still operating in unregulated (class G) airspace, much of it beyond radar coverage.

Concern about the risk of mid-air collision has been heightened by incidents such as the airprox on 5th February 2004 when an RAF Tornado came within an estimated 50 ft of an AS332 Puma *en-route* from the Auk platform to Aberdeen.

With a knowledge of helicopter operations in the North Sea we can adapt the methods that have been applied to the entire UK helicopter population in the body of this report and obtain results specific to the North Sea.

A.2 Risk of collision without helicopter equippage

The two major operators are CHC Scotia Ltd. and Bristow Helicopters Ltd. The UK civil register contains a total of 78 helicopters owned by these operators, averaging 971.6 flight-hours/year. The details are summarised in Table A1, from which it can be seen that the medium helicopters work harder than their counterparts in the rest of the UK population and that the majority of heavy helicopter hours are accounted for by North Sea operations (*cf.* Table 1).

A typical mission starts with the helicopter climbing after take-off, usually at a rate between 500 fpm and 800 fpm (but occasionally as high as 1,500 fpm), to an altitude of 2,000 ft or 3,000 ft. The helicopter will then cruise at a speed usually in the range 130 kt to 145 kt for approximately 30 minutes, before descending at a rate similar in magnitude to the climb rate [25]. The helicopters spend less than 10% of their time at altitudes below 1,000 ft AGL (where ACAS does not issue RAs).

class	number	total hrs/yr	average hrs/yr per a/c	average hrs/day per a/c	typical number airborne
medium	25 (32.1%)	19024 (25.1%)	761.0	2.08	3
heavy	53 (67.9%)	56763 (74.9%)	1071.0	2.93	9
overall	**78 (100%)**	**75788 (100%)**	**971.6**	**2.66**	**12**

Table A1: Summary statistics of North Sea helicopters

The weights of the various encounter geometry classifications in the encounter model can be adjusted to reflect typical missions. Doing this we are able to calculate approximate risks relating to helicopter operations in the North Sea. The results are shown in Table A2 where the risk to unequipped helicopters, with the ACAS mandate, is estimated. On average there will be an NMAC every 11 months and a collision every 78 years. The risk to individual helicopters is less than half of that averaged over the entire UK helicopter population (*cf.* Table 7), reflecting the better controlled environment in which the North Sea fleet operate.

NMAC/yr	collisions/yr	total hrs/yr	NMAC/flt-hr	collisions/flt-hr
1.13	**0.013**	**75788**	$\mathbf{1.49{\times}10^{-5}}$	$\mathbf{1.70{\times}10^{-7}}$

Table A2: Estimated collision rate for North Sea helicopters (full ACAS mandate)

A.3 Logic risk

Applying the adjusted weightings of encounter geometries to the results of the ACAS simulations enables the risk with ACAS equippage of helicopters to be estimated. If North Sea helicopters were to be ACAS equipped then the rate might be reduced to as little as once every 270 years.

In Table A3 we see the logic results presented from the point of view of an individual helicopter that equips with ACAS.

The results presented in Table A3 are summarised as risk ratios in Table A4. With ACAS equippage of North Sea helicopters, under ideal conditions, the risk of collision could be reduced to 29.0% of that existing before.[16]

[16] Readers might expect this risk ratio to be higher than the value averaged over all UK operations because the denominator of the ratio (the risk without ACAS) is smaller for North Sea operations. However, a significant proportion (20%) of operations in the UK are conducted below 1000 ft AGL where ACAS does not issue RAs. In North Sea operations this proportion is less than 10% and so ACAS has the opportunity to reduce the risk of collision in a larger fraction of encounters.

full ACAS mandate, helicopters unequipped		helicopters ACAS equipped		*induced events*	
NMACs per flt-hr	collisions per flt-hr	NMACs per flt-hr	collisions per flt-hr	*NMACs per flt-hr*	*collisions per flt-hr*
1.49×10^{-5}	**1.70×10^{-7}**	**0.43×10^{-5}**	**0.49×10^{-7}**	***0.17×10^{-5}***	***0.19×10^{-7}***

Table A3: Collision rate when individual North Sea helicopters equip(full ACAS mandate) – logic results

risk ratio	*induced risk ratio*
29.0%	***9.9%***

Table A4: Risk ratio for individual North Sea helicopters that equip with ACAS (full ACAS mandate) – logic results

A.4 Full system risk

The logic results have been used in the event tree together with probabilities of other factors appropriate to North Sea operations.

The estimated rate of collisions with the ACAS mandate is still about one every 78 years. If North Sea helicopters were to be ACAS equipped we estimate that this rate would be reduced to one every 170 years.

In Table A5 we see the full system results presented from the point of view of an individual helicopter that equips with ACAS.

full ACAS mandate, helicopters unequipped		helicopters ACAS equipped		*induced events*	
NMACs per flt-hr	collisions per flt-hr	NMACs per flt-hr	collisions per flt-hr	*NMACs per flt-hr*	*collisions per flt-hr*
1.52×10^{-5}	**1.72×10^{-7}**	**0.69×10^{-5}**	**0.78×10^{-7}**	***0.04×10^{-5}***	***0.04×10^{-7}***

Table A5: Collision rate when individual North Sea helicopters equip (full ACAS mandate) – full system results

The results presented in Table A5 are summarised as risk ratios in Table A6. With ACAS equippage of North Sea helicopters the risk of collision is realistically reduced to 45.1% of that existing before.

risk ratio	*induced risk ratio*
45.1%	***2.5%***

Table A6: Risk ratios for individual North Sea helicopters that equip with ACAS (full ACAS mandate) – full system results

A.5 Discussion

With the full ACAS mandate the risk to helicopters operating in the North Sea is estimated to be approximately two-thirds that experienced by helicopters in UK airspace generally.

With the equippage of North Sea helicopters it is estimated that the risk of mid-air collision will be more than halved. In ideal circumstances the risk ratio could be as low 29%, but more realistically a value of about 45% is expected.

A conscientious pilot, who always follows his own RAs with the standard response, can expect to achieve a risk ratio towards the lower of these two values.

This level of reduction indicates that ACAS is expected to perform better in North Sea operations than in UK airspace generally. This reflects the fact that helicopters in North Sea operations spend a smaller proportion of their time below 1,000 ft (where ACAS does not generate RAs) and that in those encounters in which there are RAs the helicopters are more likely to be flying straight and level: circumstances under which ACAS RAs are generally more effective.

B. FITTING ACAS TO HELICOPTERS?

This Appendix reproduces the text of [1]. The paper was prepared by Ken Carpenter of QinetiQ and originally presented to Working Group A of SCRSP at the Stockholm meeting in May 2003. The paper was revised in June 2003.

B.1 Summary

The EUROCONTROL ACAS Programme Manager requested a short evaluation of the merits of fitting ACAS to helicopters, and the resulting paper is presented for information. The paper does not include consideration of whether any particular helicopter type has the performance to respond to ACAS RAs, nor whether ACAS, when installed on helicopters, can provide a useful traffic display.

Four possible reasons for fitting ACAS to helicopters are considered: to avoid collisions by following ACAS II RAs; to avoid collisions through improved visual acquisition; to provide traffic awareness; and to improve the efficiency of flight operations.

A number of studies would be required before fitting ACAS II to helicopters to prove that RAs would be effective for helicopters, and their efficacy cannot be assumed. However, if the results of those studies are positive, the RAs would offer collision avoidance protection to helicopters that have the required performance, and this would then seem to be good reason for fitting ACAS II to helicopters.

There are reasons to suspect that ACAS I might not provide a useful traffic display for helicopters. However, if it is shown that the display is useful, SARPs compliant ACAS I can be encouraged to reduce the risk of collision through improved see-and-avoid.

The use of non-compliant ACAS I (to obtain a better traffic display) involves setting the SARPs to one side, and is a matter for the regulatory authorities. The SARPs place limits on the interference caused by ACAS for safety reasons, and it is not proved that ACAS I offers sufficient safety advantage to outweigh those considerations.

ACAS is not designed specifically to provide situational awareness. Other than improved see-and-avoid, the safety benefits of situational awareness are difficult to identify.

The use of ACAS to modify procedures or improve operations (other than collision avoidance) could erode the established safety of existing practice. The burden of proof that it would be safe would lie with those wishing to use the system in this way. It would undermine the collision avoidance protection otherwise offered by ACAS.

B.2 Introduction

This paper is written at the request of the EUROCONTROL ACAS Programme Manager, who saw a need for a short evaluation of the merits of fitting ACAS to helicopters.

The paper is written from a background of knowledge of how ACAS works, what is was designed to do and how it is reported to perform in general. There are issues that anyone wishing to use an ACAS on a helicopter will need to address that are not resolved here. In particular, these include:

whether any particular helicopter type has sufficient climb (or descend) capability to respond to ACAS II RAs; and

whether ACAS, when installed on helicopters, can provide a traffic display of sufficient clarity and accuracy to be of use as an aid to the visual acquisition of potential threats.

There have been trials of the quality of the traffic display on helicopters, and customers have found the results sufficiently attractive to want to purchase and use ACAS I. However, on its own, this is not sufficient to prove that ACAS I is fit for use on helicopters, still less does it resolve a number of issues of which customers are unlikely to be aware.

B.3 ACAS design and purpose

There are two varieties of ACAS: ACAS II and ACAS I.

ACAS II is highly standardised. It tracks intruders and generates advisories when any possible collision with any of these intruders is imminent. It generates two sorts of advisories:

- Traffic Advisories (TAs), which alert the pilot to the potential collision and advise the pilot where to look for the threat;
- Resolution Advisories (RAs), which advise the pilot what avoiding action to take. The avoiding action is a vertical manoeuvre.

ACAS II is always installed with a traffic display, but international standards (SARPs) do not require this display. As far as the SARPs are concerned, it would be more than sufficient for the display to be activated when there is a TA. The studies that demonstrated that ACAS will reduce the risk of collision, and supported the agreement of SARPs and the eventual international mandate for ACAS, are based solely on the benefits of following RAs accurately; they take no credit for any value from the traffic display, real or imagined.

ACAS I does not generate RAs; we will assume that it provides a traffic display and TAs. The SARPs require that it shall ‘provide indications to the flight crew identifying the approximate position of nearby aircraft as an aid to visual acquisition'. They also place limits on the power of the interrogations made by ACAS I, and make a number of provisions that further limit the interference to the SSR environment caused by ACAS I.

ACAS II is allowed to use more power for its interrogations, and to cause more interference to the SSR environment. This is necessary to support the generation of RAs in sufficient time for them to be effective. The fact that the additional interference is tolerated when it is caused in order to support the RA functionality does not imply that it would be tolerated for any other purpose.

ACAS II is not designed to support 'situational awareness' other than the awareness of potential collision threats when they are diagnosed by ACAS. In particular, there is no attempt to track every intruder, and simple proximity of one aircraft to another is not sufficient grounds to assume that ACAS II will track it. The restrictions on the interference caused by ACAS to the SSR environment have required compromises to be made in the design of ACAS surveillance and not all aircraft are tracked. Flight crews complain when they see or know of aircraft that are not displayed by the ACAS II traffic display. There are enough of these complaints to be sure that the limitations of the ACAS II surveillance are having a significant effect on the quality of the traffic display; this does not matter, because it has no effect on the purpose of ACAS.

ACAS I is required to use lower power than ACAS II, and is more restricted than ACAS II, so one should expect the ACAS I traffic display to be incomplete.

B.4 Non-compliant ACAS I

There are ACAS I that are based on the ACAS II design with the ability to generate RAs removed. It is not surprising that such systems are attractive, because they have the surveillance capability of ACAS II, but they do not comply with the ACAS SARPs. They are antisocial, because they cause more interference to the SSR environment (ground systems and ACAS) than has been accepted as justified.

Whether or not the use of such non-compliant ACAS I be permitted in any State is a matter for the appropriate authorities in that State.

B.5 Why fit ACAS to helicopters?

Reasons that might be advanced for fitting ACAS to helicopters include the following:

- so that collisions may be avoided by following RAs;
- so that collisions may be avoided through improved visual acquisition;
- so that flight crew have an awareness of other traffic in the vicinity;

- so that the efficiency of flight operations may be increased by a knowledge of the presence and relative position of other aircraft.

It might be noticed that the list does not include the use of the traffic display to decide on an avoiding manoeuvre in the event of a collision threat. Even for large aircraft, which provide a relatively clean ground plane for the ACAS antenna, ACAS surveillance does not have the accuracy to support this function, and the surveillance is likely to be less accurate for (small, knobbly) helicopters. Furthermore, ACAS cannot provide the additional information (*i.e.* at least heading information for the intruder) that flight crew would require in order to decide on an appropriate manoeuvre. On the other hand, there have been cases of flight crew deciding, without authority, to manoeuvre on the basis of the traffic display and, consequently, causing a risk of collision that did not otherwise exist.

B.6 RAs

ACAS RAs require climbs or descents at 1,500 fpm routinely, and 2,500 fpm *in extremis*. Many helicopters can achieve these vertical rates, and it is reasonable to consider fitting ACAS II to such helicopters, so that they can benefit from the collision avoidance protection offered by ACAS RAs. However, it is not certain it would work, and there are caveats to be considered.

ACAS II must not be fitted to helicopters that cannot climb or descend sufficiently rapidly.

If ACAS II is fitted to helicopters, the RAs must be followed. Failure to follow the RAs does not merely make the system pointless; it positively increases the risk of collision because it damages the ability of ACAS in the other aircraft to operate correctly. This arises because of the process of RA co-ordination, which can remove the freedom of the ACAS in the other aircraft to adapt to an evolving situation by reversing the sense of its RA. (It is removed in half of the encounters.)

If the RAs are not going to be followed, they should be disabled (*e.g.* by using the system in TA only mode). This would effectively turn the system into a non-compliant ACAS I, and would suggest that ACAS is being used for one of the other reasons listed above.

The efficacy of the ACAS collision avoidance logic has been proved using data for encounters overwhelmingly between fixed wing aircraft. It has not been proved for aircraft with the trajectory and performance characteristics of helicopters, and the ACAS studies that proved the efficacy of RAs would need to be repeated for encounters involving helicopters fitted with ACAS. In particular, helicopters are much more manoeuvrable than fixed wing aircraft; they can hover and then suddenly move. The ACAS collision avoidance logic is based on being able to assume the continuation of the observed relative trajectory of the other aircraft, an assumption that might not be valid for helicopters. This means we cannot be sure that ACAS RAs would be effective for helicopters, even when helicopters are able to execute the manoeuvres demanded.

Helicopters have a different airframe to fixed wing aircraft, and the airframe is more likely to adopt extreme attitudes. This means we cannot assume the ACAS surveillance will work. It would need to be shown that the surveillance continues to work while the helicopter is climbing or descending in response to an RA.

The standard ACAS antenna does not provide surveillance directly above or below the equipped aircraft, because the antenna beam pattern has a null in this direction. Thus ACAS has blind spots directly above and below the aircraft. This is not usually an issue for fixed wing aircraft, for whom the forward speed greatly exceeds the vertical speed, but helicopters could manoeuvre directly into these nulls. It is more likely for helicopters than for fixed wing aircraft that the nulls are occupied by intruders that are not tracked.

The ACAS surveillance protocols contain provisions to limit the interference caused by ACAS interrogations. These are such that clusters of ACAS II have particularly degraded surveillance and cause other, proximate, ACAS II to suffer similar degradation. For the helicopters themselves, which have low ground speed, this does not matter. However, the RA warning time in fixed wing aircraft flying between FL100 and FL180 and close to clusters of ACAS II equipped helicopters might be jeopardised, and this would need to be evaluated and considered.

It has already been noted (section B.3) that the RA functionality does not require a traffic display. It follows that helicopters that are fitted with ACAS II will get the protection offered by RAs whatever the quality of the traffic display. (Section B.6 above refers to the need to verify that the ACAS surveillance would continue to proved the data required for the RA function.)

B.7 Improved visual acquisition

Improved visual acquisition cannot be the sole reason for fitting ACAS II or non-compliant ACAS I, simply because the interference caused to the SSR environment by such systems is not justified by this use. It might be argued that fitting ACAS for this purpose improves the safety of flight (although this point is not conceded), but the interference to the SSR environment potentially damages flight safety by interfering with ground SSR and thus ATC surveillance.

The advantages of ACAS II in terms of improved visual acquisition have never been quantified for the responsible ICAO Panel (formerly SICASP, now SCRSP). Thus we don't know whether ACAS II is of any value in this respect, still less do we know it for ACAS I. In this connection, it is noteworthy that there is no European mandate for ACAS I, and that Phase 2 of the mandate, which extends ACAS to an intermediate category of aircraft, is for ACAS II.

It is possible that the nulls discussed in section B.6 will limit the usefulness of ACAS I as an aid to visual acquisition. This is a function of the probability that the threat is directly above or below the helicopter.

It is possible that the nature of helicopters (small, manoeuvrable, and even more knobbly than small jets) will degrade the surveillance to the point where the traffic display is not useful as an aid to visual acquisition. In this connection, it is noted that it is the bearing of the intruder that is most helpful to visual acquisition, and it is the bearing of the intruder that is most damaged by knobbly bits. Furthermore, the manoeuvrability of helicopters means that the rate of change of bearing may routinely exceed the value considered to be of practical significance (three degrees per second) in the surveillance requirements of the TCAS MOPS. In these circumstances, the bearing estimates could lag behind the true values to an unacceptable degree.

Nevertheless, ACAS I is designed to reduce the risk of collision by improving the prospects for visual acquisition. It has low power and provisions are in place to limit the effect of ACAS I interrogations on the SSR environment. Thus, provided it is demonstrated that each particular design and installation provides a useful display, it seems that the fitting of compliant ACAS I is to be encouraged.

B.8 Traffic situational awareness

Other than for potential collision threats, ACAS is not designed to provide traffic situational awareness, and its ability to do so is limited. Thus it should not be fitted for this purpose alone. Any safety benefits arising from any situational awareness that ACAS does provide are indirect, and difficult to identify and quantify. On the other hand, there is a risk that flight crew will rely too much on a traffic situational awareness that is known to be incomplete.

This is not to say that ACAS provides no situational awareness, still less that flight crew should ignore such information as it provides. The point is that flight crew should not be led to expect situational awareness, because it will be more partial than they will expect, and it should not be installed for this purpose.

There are many claims for the situational awareness provided by ACAS. These come from flight crew, who do not know what they cannot see. Should they see an aircraft at quite long range, it does not follow that other aircraft at closer range are tracked and displayed. Any flight tests designed to test the completeness of the ACAS surveillance (which is designed to be incomplete) would have to do so in the most busy environment that the equipped aircraft will encounter.

B.9 Efficiency of flight operations

The use of ACAS to modify procedures or improve operations (other than collision avoidance) would involve some change in practice. This could potentially erode the established safety of the existing practice, and the burden of proof that the changed procedures would be safe would lie with those wishing to make the change. Additionally, reliance on ACAS in this way would require proof that ACAS is fit for this purpose.

It should not be imagined that ACAS can both provide collision avoidance protection and support changes in practice. To consider a trivial example, using ACAS to manoeuvre two aircraft into close proximity, or an aircraft close to an oil rig on which a transponder has been installed for this purpose, would completely negate its value as a collision avoidance device. This is because, in such a case, ACAS would be used to create a hazard that is avoided only by the advice it gives, and that advice could be in error.

B.10 Conclusion

A number of studies should be carried out before ACAS II is fitted to helicopters:

- to establish that the helicopters can climb and descend sufficiently rapidly;
- to establish that the collision avoidance logic is effective given the particular flight profiles that helicopters might adopt;
- to establish that the surveillance is of sufficient quality to support the collision avoidance logic, and remains so during RA manoeuvres;
- to establish that there will be no systematic tendency to guide the helicopters into surveillance nulls that happen to be occupied by third party aircraft; and
- to establish that the effect on the ACAS surveillance of fixed wing aircraft operating in close proximity to clusters of ACAS-equipped helicopters is acceptable.
- If ACAS II is fitted to helicopters, it must be operated in RA mode and the RAs must be followed.

None the less, ACAS II RAs might offer collision avoidance protection to some helicopters, and it is difficult to see why it should not be encouraged if the studies give favourable results. The training would need to include specific warnings for the helicopter pilots that ACAS II will not track reliably aircraft directly above or below own aircraft (even though flight crew are already trained to clear the airspace into which the RA directs them).

There are reasons to suspect that ICAO SARPs compliant ACAS I might not always provide a useful traffic display for helicopters. However, if the users and the certification authorities are satisfied on this point, the use of ICAO SARPs compliant ACAS I to improve the prospect of collision avoidance through visual acquisition is to be encouraged.

The use of non-complaint ACAS I is a matter for the regulatory authorities. However, it involves setting the ICAO SARPs to one side. The power and interference limiting provisions of the SARPs are there for reasons: to limit interference to ground SSR; and to limit interference with ACAS II. ACAS II can use more power, and create more interference, because of the safety advantage conferred by ACAS RAs. It is not proved, and is almost certainly not true, that ACAS I offers safety advantages of similar magnitude.

Situational awareness should not be advanced, nor accepted, as a reason for fitting ACAS to anything for the reasons given in section B.7. Its use for anything other than collision avoidance is very problematical.

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GLOSSARY

ACAS	Airborne Collision Avoidance System – the generic ICAO term. There are two variants with different capabilities: • ACAS I provides warning of impending collision (traffic alerts) but no resolution advisories; • ACAS II provides traffic alerts and also provides resolution advisories.
ACASA	ACAS Analysis – a project commissioned by EUROCONTROL consisting of a set of ACAS studies. Work Package 1 studied the safety of ACAS.
AGL	above ground level.
airprox	a reported encounter "in which, in the opinion of a pilot or a controller, the distance between aircraft as well as their relative positions and speed have been such that the safety of the aircraft involved was or may have been compromised."
BALPA	British Air Line Pilots Association
CDTI	Cockpit Display of Traffic Information – a CDTI or 'traffic display' is an integral part of most TCAS installations.
CWS	collision warning system.
ECAC	European Civil Aviation Conference.
encounter model	a software model of encounters between two aircraft. The characteristics of the encounters are specified by stochastic distributions which can be repeatedly sampled to produce an arbitrarily large number of different encounters. The forms of these distributions can be tailored to produce encounters typical of a particular airspace.
EUROCONTROL	European organization for the safety of air navigation.
event tree	in this report, a mathematical structure designed to perform a full calculation of the probability of a compound event. The event tree has been implemented as an Excel spreadsheet and calculates full system risk values.
FAA	USA Federal Aviation Administration.
fpm	feet per minute.
full system risk	the risk of collision calculated by an event tree. It includes human and environmental factors as well as the operation of the ACAS logic.
heavy helicopter	in this report, a helicopter with MTOM in excess of 15,000 kg.
HMD	horizontal miss distance – the horizontal separation between two aircraft at the closest point of approach in an encounter.
HMR	helicopter main route – "a Helicopter Main Route is a route indicating where helicopters are operating on a regular and frequent basis, and

	where an Alerting Service, Flight Information Service or other Advisory Services may be provided.”
increase-rate RA	an ACAS RA that can be generated if the initial RA is not providing sufficient separation. Increase-rate RAs require the aircraft to achieve a vertical rate of 2,500 fpm.
intruder	any aircraft tracked by the ACAS logic.
ICAO	International Civil Aviation Organization.
light helicopter	in this report, a helicopter with MTOM less than 750 kg.
logic risk	the risk of collision calculated from an encounter model when the only considerations are the operation of the ACAS logic and the pilot’s response to RAs.
medium helicopter	in this report, a helicopter with MTOM between 5,700 kg and 15,000 kg.
MOPS	Minimum Operational Performance Standards – avionics equipment standards issued by RTCA. DO187A are the MOPS for TCAS II.
MTOM	maximum take-off mass.
NMAC	near mid-air collision – an encounter in which, at some instant, the aircraft are simultaneously separated by less than 0.1 NM horizontally and less than 100 ft vertically.
RA	resolution advisory – an ACAS indication that an intruder may constitute a collision threat. More urgent than a TA and accompanied by advice to the pilot to regulate or modify his vertical rate to avert the threat.
risk ratio	the risk of collision with ACAS expressed as a fraction of the risk of collision without ACAS. Risk ratio is a relative measure and does not indicate absolute levels of safety.
RTCA	an independent USA body including representatives of interested parties from the aviation community. The TCAS II MOPS are prepared under the supervision of RTCA Special Committee 147.
SARPs	standards and recommended practices.
SCRSP	ICAO Surveillance and Conflict Resolution Systems Panel.
TA	traffic alert – an ACAS indication that an intruder may constitute a collision threat.
TCAS	Traffic alert and Collision Avoidance System. TCAS II, Version 7, is a specific implementation of an ACAS II.
VMD	vertical miss distance – the vertical separation between two aircraft at the closest point of approach in an encounter.