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ACASA PROJECT

Work Package 4

Final Report
Potential benefits of extension of altitude reporting requirements

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Abstract

WP4 addresses the issue of the tangible safety benefits that a proposed “Mode C reporting” mandate will bring. Mandatory altitude reporting is envisaged for general aviation (GA) aircraft after about January 2006. The benefits to be quantified relate to the expectation that more potential conflicts between TCAS equipped aircraft and GA aircraft will be detected and avoided as a direct consequence of mandatory altitude reporting.

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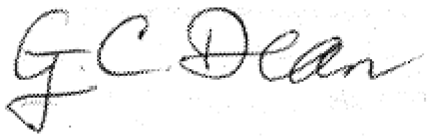
ACASA Project Manager	 Garfield Dean	4 March 2002
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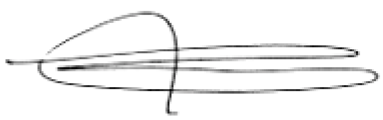
Director Infrastructure, ATC Systems & Support	 Guido Kerkhofs	20 March 2002

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WP-4

Potential benefits of extension of altitude reporting requirements

Prepared by Ted Wilkinson

1 Introduction

1.1 WP4 addresses the issue of the tangible safety benefits that a proposed ‘Mode C reporting’ mandate will bring. Mandatory altitude reporting is envisaged for general aviation (GA) aircraft after about January 2006. The benefits to be quantified relate to the expectation that more potential conflicts between TCAS equipped aircraft[1] and GA aircraft will be detected and avoided as a direct consequence of mandatory altitude reporting.

1.2 In this context there are many aspects of safety benefit which could be of interest. At a general level there is the benefit of reduced risk of loss of separation if more potential conflicts are detected and avoided before they pose a threat. This general benefit may be further classified, according to the class of airspace involved, or according to aircraft activity, *etc.*

1.3 Specific safety benefits include the reduced risk of mid-air collision and the corresponding reduction of casualties both in the air and to third parties on the ground. Reducing casualties has an economic value in that a potential disbenefit, to individuals and to the community as a whole, is thereby reduced. Further economic benefit is derived as the number of aircraft lost or damaged is reduced, and a corresponding reduction in the scale of ground property damage can be expected. Finally, fewer accidents and/or notifiable incidents reduces the costs associated with wreckage recovery and conducting investigations into those occurrences.

1.4 The benefits of mandatory altitude reporting are calculated in two stages. The first stage (reported in Section 4) involves calculating the number of airprox incidents and air accidents that the mandate is expected to prevent. In the second stage (reported in Section 5) the monetary and other benefits associated with the expected reduction of accidents and airprox incidents are calculated.

[1] The mandatory carriage of TCAS in European airspace was introduced in January 2000 for commercial aircraft with a capacity of 30 passengers or more and/or with a max. all up weight of 15,000 kg and above. An extended TCAS mandate is envisaged which will include commercial aircraft with capacity of 19 or more passengers and/or with a max. all up weight of 5,700 kg or above. This report assumes the extended TCAS mandate will be in operation at the time that mandatory altitude reporting is introduced.

2 Background to the study

2.1 This study examines the Mode C reporting mandate safety benefits as they impact on the ECAC area. The safety benefit the mandate is expected to bring can, in principle, be derived from observed differences in appropriate measures of safety as recorded before and again after the mandate is introduced. To be able to calculate the benefit it is therefore necessary to agree what are appropriate measures of safety and then determine their 'before and after' values, by some means.

2.2 The approach adopted in this study has been to assess safety benefit in terms of the expected reduction in air accidents and airprox incidents after mandate introduction, together with the cost benefit that fewer air accidents will represent. Benefit assessment relies on being able to obtain an accurate picture of the air traffic population that is at risk, in the period immediately before the mandate comes into operation and again after its introduction. This population comprises the encounters, *i.e.* airprox incidents and air accidents. Details of the numbers and aircraft types involved are used to assess the number of persons at risk and to estimate air accident costs.

2.3 A mathematical modelling solution was considered as the source of pre- and post-mandate encounter data. Such a model would need to represent all the various types of air traffic including public transport, commercial, military and general aviation (GA) activity. In particular, it would be essential to accurately model Large Aircraft[2] as they make up by far the majority of TCAS carriers, and GA aircraft which, unless already mandate compliant, will be required to upgrade to Mode C and will thus provide the potential for Mode C benefit. On enquiry, however, it became clear that not enough was known about the behaviour of GA traffic, to allow a reliable model to be produced.

2.4 Without a viable mathematical modelling option, contemporary encounter data, provides the best available evidence of the pre-mandate risk to air traffic. It is also possible to use encounter data to estimate the post-mandate risk. This is possible as the numbers of aircraft at risk are not expected to change because of the mandate, but with reduced risk for some aircraft. Risk reduction is calculated probabilistically in terms of the likelihood that, due to equipage changes to meet the mandate, individual encounters will be detected in time to avoid a risk bearing incident.

[2] This study uses the definition of a 'Large Aircraft' that will apply when mandatory altitude reporting is introduced - See Appendix A.

3 Sources and content of encounter data

3.1 The search for contemporary encounter data to support the study focused on the 19 founding ECAC member states, on the grounds that these countries contribute the overwhelming majority of GA traffic within ECAC as a whole. The time period considered was chosen to be the years 1997, 1998 and 1999. This was a compromise between the need to obtain recent data and the need to ensure that encounter reports for the period were published by the states.

3.2 Some of the 19 founding states now place reports on the WWW and this has been a valuable source of data. The web data sources used in the study are summarised below.

country	accident reports	airprox reports
France *	yes	no
Ireland	yes	yes
Sweden *	yes	yes
UK	yes	no

reports written in the language of the issuing country with some reports also available in English.

3.3 Requests for encounter data were sent to the administrations or to the air safety organisations of the founder member states where these could be identified. Favourable responses were received from Finland, Luxembourg and Norway. United Kingdom reports for the 3 year period are in the public domain and were thus available for study.

3.4 Organisations were asked to provide the following baseline parameter set for each encounter:

date of the encounter

time of occurrence

location/class of airspace

altitude, height or F/L

types of the aircraft involved

flight activity for both aircraft (public transport, other commercial, GA, military, *etc.*)

TCAS/transponder equipment fit of both aircraft

equipment usage by both aircraft.

3.5 Additional data was needed for air accidents, to support accident cost analysis. The following data were requested:

number of air fatalities

number of serious air casualties

number of minor air casualties

number of ground fatalities

number of serious ground casualties

number of minor ground casualties

category of damage to each airframe (destroyed, major, minor)

cost estimate for airframe damage

cost estimate for ground property damage

estimate for the cost of wreckage recovery.

3.6 Data from 288 encounters were obtained, comprising airprox incidents and a small number of air accidents. Checks on the sufficiency of the available data resulted in a small number of reports being discarded, due to one or other aircraft type and its flight activity not being specified. Equipment fit and usage data was missing from several reports but it was decided that these reports could still be included in the benefit calculations, subject to using a probabilistic assessment of equipment fit and usage. As a result of preliminary checks 11 reports were discarded. The numbers and country of origin of the remaining 277 encounters used in the study are shown in Figure 1 below. The overall figures include air accidents which are shown alongside in brackets.

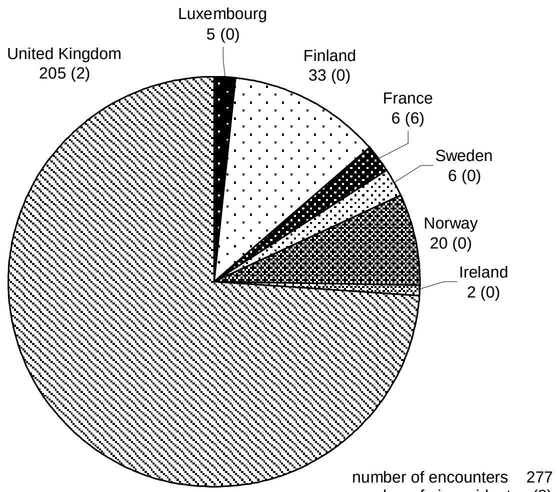

Figure 1. All Encounters - Distribution by country

3.7 Figure 1 shows a clear majority of reports originating from the UK. Two factors contribute to this imbalance. Firstly, the UK report set is extensive as it includes all the GA reports, many of which do not involve commercial aircraft and thus are most unlikely to involve TCAS. Secondly, and in contrast to the UK situation, some other contributing countries may have not have forwarded reports that only involve GA activity. If encounters that do not involve Large Aircraft are excluded the imbalance is much reduced, as indicated below.

Encounters Involving Large Aircraft - Distribution by country						
Finland	France	Ireland	Luxembourg	Norway	Sweden	United Kingdom
29	2	2	5	19	6	48

4 Risk reduction calculations

4.1 The analysis methodology used involves answering the question: “If a representative sample of pre-mandate airprox or accident encounters are examined under post-mandate conditions, *i.e.* with Mode C compliance in force, what is the probability that individual encounters would be detected in time to prevent the incident/accident and, following on from this, what risk reduction can be expected, in terms of fewer airprox incidents and air accidents”.

4.2 Calculating risk reduction in this way makes the following assumptions:

the frequency and distribution of airborne risk bearing encounters will not change with the introduction of a Mode C mandate.

a representative sample drawn from the pre-mandate population of risk bearing encounters is thus also representative of the post-mandate encounter population and consequently post-mandate risk reduction can be estimated from the pre- and post-mandate TCAS and Mode C equipage.

any decrease of post-mandate risk is due solely to the Mode C equipage changes brought about by the mandate.

4.3 Appendix B contains examples that illustrate the principles involved in calculating risk reduction.

4.4 A complete listing and explanation of the terms, reference data and acronyms used in Appendix B, and elsewhere in this paper, is given in Appendix A.

5 Benefit calculations

5.1 A total accident cost was calculated for each encounter that resulted in a mid-air collision. This includes the cost of deaths and injuries in the air and on the ground, and aircraft damage and wreckage recovery costs. Aircraft damage and wreckage recovery costs were estimated from the detailed descriptions given in the accident reports. The cost of deaths and injuries both in the air and to third parties on the ground were calculated on the basis of a unit cost for each of the various categories of casualty. After consultation, agreed values were used for the following unit cost items:

- cost of one death
- cost of one serious injury
- cost of one minor injury

5.2 Each collision was assessed probabilistically to find the likelihood of the collision being detected and avoided under Mode C equipage conditions, in the same way that airprox avoidance probabilities were calculated. The monetary benefit of this calculated probability is the overall cost of the accident scaled according to the calculated probability that it would be avoided under the mandate. Summing the monetary benefits across all collisions gives the total value of the reduction of air accidents attributable to a Mode C mandate. Estimates of the number of deaths and other casualties likely to be saved were made using this same method.

5.3 As the sample of air accidents is small, an estimate of benefit based only on the sample evidence may well be inaccurate. An alternative approach to calculating benefit was therefore also investigated. This used data from those airprox encounters that involved Large Aircraft and where mandate benefit occurred. The following steps were involved:

- calculate the expected number of air accidents involving Large Aircraft from the number of LA encounters that benefit from a Mode C mandate[3].
- estimate the number of air accidents likely to be avoided under the mandate by apportioning the reduction of airprox incidents involving Large Aircraft according to the ratio of encounters to air accidents.
- estimate the airframe values and passenger numbers on board Large Aircraft in airprox incidents where mandate benefit occurred. (A load factor of 70% is used for passenger estimates).
- use these figures to calculate the monetary value of the air accidents that might be avoided.

5.4 Reducing airprox incidents produces a benefit in terms of the number of passengers who are no longer subject to risk. This statistic is calculated by considering the encounters that involve a Large Aircraft and which would be expected to experience a reduced risk under mandate conditions. For a particular encounter the benefit is calculated as the product of the number of passengers involved and the probability that the encounter would be avoided, *i.e.*

Benefit = (prob. of avoiding encounter)   (number of passengers exposed to the risk)

[3] An agreed figure is used for the expected ratio of airprox incidents to air accidents.

5.5 By summing the results across all relevant encounters a figure is derived for the number of passengers expected to avoid exposure to a risk bearing encounter due to the mandate.

5.6 Appendix C explains in more detail how benefit calculations are carried out.

6 Results

6.1 A total of 111 encounters analysed in the study involved Large Aircraft. A breakdown of these encounters by conflicting aircraft category is given in Figure 2. This shows that 22 encounters out of the 111 involved GAP aircraft and a further 5 involved GA Gliders, (GAG). Collectively, these 27 encounters are the principal candidates to show a benefit from the mandate since Large Aircraft will be the dominant group of TCAS carriers and many General Aviation aircraft, which are assumed to be subject to the mandate, may not yet be Mode C equipped.

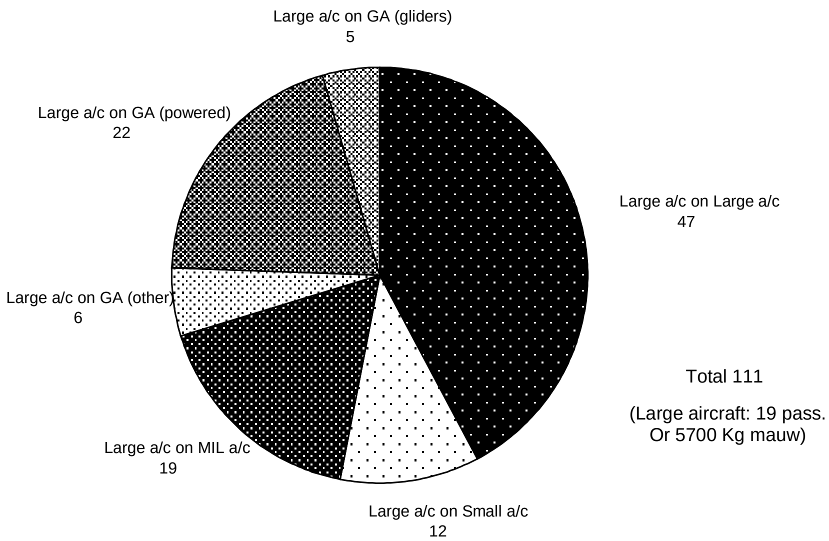

Figure 2. Large Aircraft Encounters - Distribution by Category

6.2 Some encounters between a Large Aircraft and a Small Aircraft could show a benefit under the mandate, as prior to its introduction a small percentage of Small Aircraft may still operate without Mode C selected. There are 22 encounters between a Large Aircraft and a Small Aircraft in the study.

6.3 Military transport aircraft are classified as commercial aircraft for mandate purposes, *i.e.* as Large Aircraft or Small Aircraft according to their max. weight/passenger capacity and using the TCAS mandate threshold that applies to civil aircraft. In 12 of the 111 Large Aircraft encounters the Large Aircraft was a military transport.

6.4 Military operational aircraft (MIL) are assumed to be outside the scope of the mandate. Thus the 19 Large Aircraft encounters with MIL aircraft will not benefit from mandatory altitude reporting.

6.5 Other categories of encounter involving Small Aircraft also have a small probability of benefiting from the mandate. Only a small percentage of the Small Aircraft fleet is expected to fit TCAS, nevertheless the possibility of benefit accruing is considered. Small Aircraft were involved in encounters with GAP aircraft and a further 5 involved gliders.

6.6 Figure 3 shows a percentage breakdown of GAP aircraft equipment usage in the encounters examined. Out of a total of 161 GAP aircraft two were reported to be TCAS equipped, 56 were Mode C compliant, whilst 41 others were reported as not responding to Mode C interrogations. The equipage status of the remaining 62 GAP aircraft was not reported.

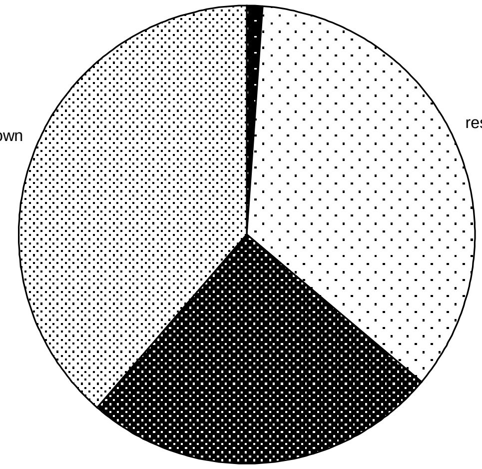

Figure 3. General Aviation Powered Aircraft - Equipage

6.7 Summary data on the encounter population used in the study are given in Table 1. With regard to the 8 air accidents reported, one is the Airbus/glider accident which occurred near to Perpignan in February 1999 and which, fortunately, both aircraft survived. One air accident contributed the majority of the total air accident costs and casualties. This was the collision between a Beech 1900D commuter aircraft and a GAP aircraft over the Baie de Quiberon in July 1998 which resulted in the loss of 15 lives. At the time of the accident the Beech aircraft was classified as a Small Aircraft for TCAS purposes, *i.e.* with no requirement to carry TCAS. By the time mandatory altitude reporting is introduced however, TCAS is expected to be mandated for aircraft carrying 19 passengers, or with a max. weight of 5,700 kg. The Beech with 19 passengrs/7,688 kg max. weight will then be classified as a Large Aircraft. Note also that all the air accidents occurred in class G airspace where a flight information service only is provided.

6.8 The cost figures reported in Table 1 derive from the 8 collision reports, and rely on a subjective assessment of airframe damage and wreckage recovery costs. Casualty costs are calculated using agreed figures for the cost attributable to each death and injury.

6.9 A list of the standard cost factors and other variables used in this study is included in Appendix A.

Encounter totals	(Airprox + AA)	Air accidents
Grand Total	277	8
In class A airspace	25	0
In class B airspace	1	0
In class C airspace	33	0
In class D airspace	33	0
In class E airspace	0	0
In class F airspace	2	0
In class G airspace	183	8
Involving two Large Aircraft	47	0
Involving one Large Aircraft	64	2
Not involving Large Aircraft	166	6
Air accident totals		
Number of air accidents with fatalities		3
Number of Large Aircraft incurring loss of life		1
Total air fatalities (including aircrew)		21
Fatalities (fare paying passengers only)		12
Sum of all accident air costs		29,081,0(
Sum of accident air costs involving two Large Aircraft		0 €
Sum of accident air costs involving one Large Aircraft		20,985,0(
Sum of accident air costs not involving Large Aircraft		8,096,0(
Proportion of air accident costs involving two Large Aircraft		0.00%
Proportion of air accident costs involving one Large Aircraft		72.16%
Proportion of air accident costs not involving Large Aircraft		27.84%

Table 1. Summary of encounter data

6.10 The results of the mandate expected benefit calculations are reported in Table 2. The figures given relate only to the 277 encounters that were studied. The results are calculated using the following assumptions:

The definition of a Large Aircraft is as given in Appendix A.

All Large Aircraft are TCAS compliant when the altitude reporting mandate is introduced

Small Aircraft are not required to be TCAS compliant

All GAP aircraft and gliders will comply with an altitude reporting mandate

Operational aircraft, except for military transport aircraft, are not subject to the mandate

Military transport aircraft are classified as commercial aircraft i.e. as Large Aircraft or Small Aircraft according to their max. weight/passenger capacity and the TCAS mandate threshold.

6.11 The results from Table 2 suggest that approximately 7.43 risk bearing encounters out of the 277 encounters studied could be averted when aircraft are equipped to meet the proposed Mode C mandate. The corresponding reduction in air collisions is expected to be 0.5 over the three year period, albeit this figure is based on very few accident events.

6.12 A Mode C mandate does not assuredly eliminate risk from any encounter but will reduce the level of risk for many encounters. In the sample studied some 31 encounters benefited from a reduced level of risk to produce the overall expectation of 7.43 avoided incidents. This figure includes the reduction in airprox incidents and the reduced mid-air collision risk.

6.13 Some 27 of the 31 benefiting encounters involved a Large Aircraft. Summing the individual benefits across all encounters produces the expectation of 6.76 fewer Large Aircraft incidents. Eliminating these encounters is expected to result in 486 fewer passengers being involved in a risk related incident over the period. This figure is based on the expected passenger load averaged across the Large Aircraft in encounters where benefit occurred. A residual benefit, of 0.67 incidents avoided, occurs without Large Aircraft involvement This is the result of encounters between Small Aircraft and GAP/GAG aircraft and one encounter involving two GAP aircraft, one of which was TCAS equipped.

6.14 Considering only the evidence from the sample of European encounters, Table 2 suggests that the monetary benefit of fewer mid-air collisions is a very modest 17,500 €. This figure comes from one encounter; between the Airbus and a glider, when only superficial damage occurred and thus only modest benefit could be expected. The glider in this accident was not Mode C compliant and the analysis applies the 50% probability that, under the mandate, this accident would have been avoided. Accident cost benefits are then scaled accordingly.

6.15 One other mid-air collision involved a Large Aircraft; the accident between the Beech 1900D commuter aircraft and a GAP aircraft. All 15 persons on board the two aircraft lost their lives and both aircraft were destroyed. However, both aircraft were fully compliant; the commuter aircraft was TCAS equipped whilst the GAP aircraft was Mode C compliant. Thus no benefit would have been derived from a Mode C mandate as no equipage changes would be required and the probability of detecting and avoiding the encounter would not change under the mandate.

6.16 A Small Aircraft was involved in one of the remaining accidents, but again, both conflicting aircraft were already Mode C compliant and the mandate would not have provided benefit. The remaining five collisions involved GA aircraft and one military aircraft and they too would not have benefited from a Mode C mandate.

6.17 The outcome of the Airbus on glider accident is clearly less than commonplace and unrepresentative of the overall air accident population. The expected outcome of such an accident must tend towards the destruction of both aircraft and the loss of all persons on board. A potentially more reliable way of obtaining collision cost estimates is therefore to base the analysis on ‘average’ airprox conflict data.

Overall risk reduction	
Overall reduction of air collisions and risk bearing airprox incidents	7.43
Air collision and airprox reduction (incidents involving two Large Aircraft)	0
Air collision and airprox reduction (incidents involving one Large Aircraft)	6.76
Air collision and airprox reduction (incidents not involving Large Aircraft)	0.67
Number of Large Aircraft experiencing some degree of risk reduction	27
Reduction in number of Large Aircraft involved in airprox incidents	6.26
Average passenger load of Large Aircraft experiencing some degree of risk reduction (70% load factor assumed)	64.9
Expected reduction in passenger numbers involved in airprox incidents (assuming a 70% load factor)	486
Air collision and airprox incident reduction in class A airspace	0
Air collision and airprox incident reduction in class B airspace	0
Air collision and airprox incident reduction in class C airspace	1.03
Air collision and airprox incident reduction in class D airspace	3.59
Air collision and airprox incident reduction in class E airspace	0
Air collision and airprox incident reduction in class F airspace	0
Air collision and airprox incident reduction in class G airspace	2.81
Air collision risk reduction	
Air collision reduction	0.50
Air deaths reduction	0.00
Air serious casualty reduction	0.00
Air minor casualty reduction	0.00
Ground death reduction	0.00
Ground serious casualty reduction	0.00
Ground minor casualty reduction	0.00
Expected monetary benefits	
Accident air cost reduction	17,500
Accident ground cost reduction	0 €
Accident total cost reduction	17,500

Table 2. Mandate expected benefits
(based on the study sample of 277 encounter reports)

6.18 The first part of Table 3 contains average data from the 27 airprox incidents where an altitude reporting mandate would have benefited a Large Aircraft. In this ‘average conflict’ the number of persons at risk is shown to be 74.7 with 66.7 passengers and 8 aircrew and cabin staff. Some of the incidents with benefit potential involved a Small Aircraft conflicting with the Large Aircraft and they produce the expectation that, on average, 1.8 of the fare paying passengers will be carried on the second aircraft. The combined value of the two aircraft involved in the ‘average conflict’ is 58.1 M€.

6.19 The overall cost of a mid-air collision involving this ‘average conflict’ can now be calculated. Human costs are estimated using cost benefit assumptions from Appendix A, and a total loss scenario is assumed. The results are reported in the second part of Table 3. Additional and inevitable costs such as emergency services involvement, wreckage recovery and post-accident investigations have not been researched, however they might be expected to add another 10 M€ to the average cost.

6.20 It was not possible to estimate ground damage and ground casualty costs from the scant information in the European incident reports. A brief check for more evidence was therefore carried out on two other databases (see references [1] and [2]) both of which report accidents world-wide. One database reports 22 mid-air collisions that occurred between 1976 and 1997 and involved passenger transport aircraft. Of these 22 collision reports 2 only, or almost 10%, resulted in ground casualties. The average ground death rate from these two accidents was equivalent to approximately 1 fatality per collision. The second database reported 31 mid-air collisions over the same 21 year period, including the same two fatal accident reports but without further fatal reports. From this, albeit scant, evidence it seems probable that the death rate on the ground when averaged across all mid-air accidents may not exceed one fatality per mid-air collision.

6.21 Property damage, regrettably, was not reported in detail in either of the databases although minimal comments were sometimes given. Both instances of ground casualties, for example, were reported as occurring when the aircraft “crashed into a residential area”. In two further collisions the reports respectively observe that “two residences and two vehicles were destroyed” and “wreckage was scattered over 2 square miles in a residential area”. Domestic residences would thus appear to be the main category of ground damage. Estimating the scale of damage involved however is difficult but it seems probable that, on average, no more than one residence would be destroyed per ground death.

6.22 From this limited evidence it would seem that airborne costs exceed ground-related air collision costs by more than one and possibly nearer to two orders of magnitude. Ground costs are thus probably smaller than the margin of error associated with the major cost factor estimates. Accordingly, it is suggested that ground costs are not a significant part of the overall cost of mid-air collisions and can therefore be ignored in mandate benefit calculations.

6.23 The overall cost of a total loss mid-air collision, involving the average conflict, is thus estimated in Table 3 to be 122.8 M€. Finally, the last section of Table 3 reports the benefits that these average values represent in terms of the collision losses that the mandate is expected to prevent.

Averages of 27 airprox incidents involving LA where mandate benefit occurred	
average number of passengers on board (70% load factor)	66.7
estimated number of aircrew and cabin staff (2 + 1) + (5)	8
average airframe value (Large Aircraft)	35.5 M€
average airframe value (second aircraft)	2.6 M€
Cost components of total loss mid-air collision	
human cost	74.7 M€
value of two aircraft destroyed	38.1 M€
emergency services involvement, wreckage recovery and post-accident investigations	10.0 M€
Total cost estimate for a single total-loss mid-air collision	**122.8 M€**
Benefit from a reduction of 0.5 in the number of mid-air collisions	
air deaths reduction	37.35
air serious casualty reduction	-
air minor casualty reduction	-
ground death reduction	~0.5
ground serious casualty reduction	-
ground minor casualty reduction	-
accident air cost reduction	61,400,000 €
accident ground cost reduction	insignificant
Accident total cost reduction	61,400,000 €

Table 3. Air accident costs and benefits (based on airprox averages)

7 Discussion

7.1 It is likely, and almost inevitable that, within the states that contributed the incident reports, further aircraft were at risk of collision within the time frame considered, but that those incidents were not reported. Incidents are not reported for a variety of reasons. It is possible, for example, that both crews fail to see the other aircraft and so are unaware of the danger. It is also possible for a pilot or a controller not to file a report due to misjudging the severity of the risk. The number of encounters within the reporting countries, and the potential for benefit, may therefore exceed the levels suggested by this study. The unrecorded potential for benefit however, is likely to be small. This is due to the fact that encounters with benefit potential, *i.e.* involving commercial aircraft, are usually subject to controller monitoring and few can be expected to go unreported. Unreported incidents are most likely to involve two GA aircraft or military aircraft where little or no potential for benefit exists.

7.2 It is clear that only a small part of the overall encounter population from the ECAC area was made available to this study. Many countries with a significant level of GA traffic either failed to respond to the request for incident data or were unable to contribute for internal legal reasons. Data obtained for one country was limited to air accident reports only, and several other ECAC states were not approached due to resource limitations. Consequently, the benefits identified by the study must understate the ECAC wide benefits of the mandate by a considerable margin, possibly by a factor of three or four. This factor of three or four is, admittedly, little more than a guess[4].

7.3 On the other hand, the study assumes that Mode C equipage and usage in Small Aircraft and in GA aircraft will remain at its current level until the mandate requirements oblige operators to re-equip. In fact, routine end-of-life equipment replacement is likely to result in some additional aircraft having a Mode C capability regardless of the mandate's introduction. This trend will tend to reduce the scale of benefit that calculations in this report attribute to a Mode C mandate.

[4] When arriving at this figure, consideration was given to the population ratios of the founding ECAC states that did not provide data and those founding states that did (2000 data). The ratios of collective GDP were also noted as a possible indicator to the level of GA activity. In the case of air accident data sources, the respective populations are in the ratio of about 2.2. In the case of airprox data sources the population ratio is approximately 4.5. (The difference between the two figures is due to the fact that accident data, but not airprox data, was available from France.) Corresponding ratios based on GDP are 1.8 and 3.9 (1999 data).

8 Summary and Conclusions

8.1 This study has examined a sample of 277 airprox and air accident reports drawn from six ECAC states. The reports relate to encounters which, with one exception, occurred within a contiguous 36 month period aligned with the calendar years 1997 through 1999. (One state provided data for a 36 month period starting six months later than the others.)

8.2 These reports of recent risk bearing encounters are the best evidence available of the risk of collision in the period before the introduction of mandatory altitude reporting.

8.3 The sample size used is drawn from only 6 of the ECAC states and is thought to understate the number of risk bearing encounters across the ECAC area over the three year period, by a factor of about 4.

8.4 It is assumed that introducing a Mode C mandate will not affect the distribution of aircraft and therefore the potential for encounters to occur. *i.e.* it is assumed that encounter numbers will remain sensibly constant before and after the mandate's introduction, albeit the degree of risk involved is expected to be reduced by mandatory altitude reporting.

8.5 On the basis that encounter numbers will remain unchanged in the short term after the mandate is applied, this study considers this same encounter sample to be representative of the post mandate population of aircraft at risk. Equipage changes needed to comply with the mandate are deduced from the encounter reports, and these are used to calculate the probability that, where mandate compliance involves equipage changes, then those incidents might be detected and averted. The corresponding risk reduction is calculated and the associated benefits are then quantified.

8.6 Benefit estimates relate only to interactions between TCAS systems and aircraft that upgrade to Mode C. Better height awareness may produce further benefit by helping Controllers and STCA systems to recognise potential conflicts and to suggest conflict avoidance manoeuvres, but this possibility has not been studied.

8.7 The calculated benefits attributable to mandatory altitude reporting are as follows:

Expected number of risk bearing incidents avoided under the mandate (both airprox and air accidents)	Within the study sample of 277 encounters	In one year[5] within the ECAC area
total number	7.42	9.9
incidents in Class A airspace	0	0
incidents in Class C airspace	1.03	1.4
incidents in Class D airspace	3.59	4.8
incidents in Class G airspace	2.81	3.7
airprox incidents involving one Large Aircraft	6.26	8.3
airprox incidents not involving Large Aircraft	0.67	0.9
number of Large Aircraft expected to experience some degree of risk reduction	27	36
reduction in passenger numbers involved in airprox incidents (70% load factor is assumed)	486	648
number of mid-air collisions avoided	0.5	0.7
number of lives saved[6]	37.35	52.39
monetary benefit from the mid-air collisions avoided.[6]	61,400,000 €	85,960,000 €

9 References

[1] *The University of Warwick Air Accident Database*: http://www.air-accidents.warwick.ac.uk

[2] *Aviation Safety Network*: http://www.aviation-safety.net

[5] These figures are scaled up from the results of the sample analysis, and assume that the sample of encounters understates the total number across the whole of the ECAC area by a factor of four. This assumption probably slightly overstates the potential benefit of the mandate.

[6] Figures are calculated from average data from the 27 airprox incidents where an altitude reporting mandate would have benefited a Large Aircraft.

Appendix A: Definitions, assumptions and acronyms

A1 This report makes use of the following distinct groups of definitions and assumptions. They are:

Assumptions about the TCAS/Mode C capability and equipment use of one or both conflicting aircraft, where this information is not included in the incident report;

Parameters that define the scenario for TCAS and Mode C equipment use when mandatory altitude reporting is introduced. These include the definition of certain aircraft categories and the requirement for the carriage and use of TCAS as well as the scope of the Mode C mandate and its assumed application;

Incident detection and avoidance probabilities relating to specific combinations of aircraft category and equipage levels where a Mode C mandate is expected to produce benefit;

Assumed cost benefit values for each death, serious injury and minor injury that mandatory altitude reporting may prevent.

A2 Definitions:

A2.1 *Large Aircraft*: An aircraft engaged in commercial activity with a max. all up weight of not less than 5,700 kg. and/or with a passenger capacity of not less than 19 persons.

A2.2 *Small Aircraft*: Any aircraft engaged in commercial activity that is not a Large Aircraft.

A3 Equipment use assumptions:

A3.1 When an incident report fails to state the TCAS/Mode C equipment use of a conflicting aircraft the following usage probabilities are used in benefit calculations:

probability that a GAP aircraft (equipment use unknown) will be Mode C compliant	0.5
probability that a commercial aircraft (equipment use unknown) with max. weight of 15,000 kg and above, or with passenger capacity of 31 persons or more will be TCAS compliant	0.1
probability that a commercial aircraft (equipment use unknown) with max. weight of less than 15,000 kg, and with passenger capacity of less than 31 persons will be TCAS compliant	0.05
probability that a commercial aircraft (equipment use unknown) with max. weight of less than 15,000 kg, and with passenger capacity of less than 31 persons will be Mode C compliant but not TCAS compliant	0.9
probability that a military operational aircraft (equipment use unknown) will be Mode C compliant	0.8

A3.2 No figure is given for the expected level of Mode C compliance for aircraft weighing more than 15,000 kg *etc.* as these aircraft are assumed to be Mode C compliant if they are not TCAS compliant.

A3.3 TCAS equipage in GAP aircraft and MIL aircraft, and Mode C compliance in gliders is expected to be very low in the encounters that are examined. Consequently, all three probabilities are assumed to be zero unless reported otherwise.

A3.4 Note that thresholds of 15,000 kg max weight and 31 passengers separate the two levels of TCAS usage that are assumed to exist within the commercial fleet. This division reflects the fact that, at the time when the reported incidents occurred, (January 1997 to June 2000), aircraft operators were preparing to meet a TCAS mandate that will affect aircraft above these threshold values, from January 2001.

A3.5 Note also the low value of 0.1 given for the probability that the heavier commercial category will be TCAS compliant. This figure assumes that an incident report which does not specifically state the equipment in use during the encounter is a strong indicator that the aircraft in question was not TCAS equipped.

A4 Assumed incident detection and avoidance probabilities:

A4.1 The following values correspond to the probability that, for the given combination of equipment use, an encounter will be detected and avoided before it can develop into a risk bearing incident.

two TCAS compliant aircraft	0.8
TCAS compliant aircraft / commercial Mode C compliant aircraft	0.65
TCAS compliant aircraft / Mode C compliant GAP aircraft	0.6
TCAS compliant aircraft / Mode C compliant GAG	0.5
TCAS compliant aircraft / Mode C compliant military (operational) aircraft	0.35

A5 Cost benefit assumptions:

Cost benefit of each death that is avoided by mandatory altitude reporting	1,000,
Cost benefit of each serious casualty prevented by mandatory altitude reporting	5,000,
Cost benefit of each minor casualty prevented by mandatory altitude reporting	10,000

A6 Assumed scope and operation of a Mode C mandate:

A6.1 The mandate is assumed to apply to the following categories of aircraft:

Aircraft engaged in commercial activity

GAP aircraft except for those classed as microlights

GA (gliders and motor-gliders)

Military aircraft except for operational aircraft. (*i.e.* the mandate will apply to troop transports, freighters, communications aircraft and training aircraft but will not apply to aircraft with an offensive capability.)

A6.2 Full compliance with the mandate is assumed, *i.e.* all aircraft covered by the mandate will be Mode C operational at the time it comes into effect.

A7 Assumed TCAS equipage when the Mode C Mandate is introduced:

All Large Aircraft will be TCAS compliant

Small Aircraft and GA aircraft will not be required to carry TCAS

The proportion of TCAS equipped Small Aircraft and GA aircraft will remain at today's level (*i.e.* the benefit of mandatory altitude reporting for TCAS equipped Small Aircraft and GA aircraft when in conflict with Mode C compliant aircraft can be assessed from the evidence of the sample of contemporary conflicts).

Military aircraft, other than operational aircraft, will comply with a TCAS mandate according to their max. all up weight and passenger capacities using the same Large Aircraft thresholds that apply to civil aircraft

A8 Acronyms:

ac1probC	Generic expression for the calculated probability that the first aircraft of a conflicting pair is Mode C compliant
ac1probT	Generic expression for the calculated probability that the first aircraft of a conflicting pair is TCAS compliant
ac2probC	Generic expression for the calculated probability that the second aircraft of a conflicting pair is Mode C compliant
ac2probT	Generic expression for the calculated probability that the second aircraft of a conflicting pair is TCAS compliant
ECAC	European Civil Aviation Conference
F/L	Flight Level
GA	General Aviation
GAG	GA (Glider)
GAGprobC	The calculated probability that a given GA (Glider) is Mode C compliant
GAP	GA (Powered)
GAPprobC	The calculated probability that a given GAP aircraft is Mode C compliant
GDP	Gross Domestic Product (sometimes used as an indicator of a country's wealth and used in this report as a potential pointer to the level of GA activity)
LA	Large Aircraft (defined according to the applicable TCAS mandate)
MIL	Military Operational Aircraft
MILprobC	The calculated probability that a given Military Operational Aircraft is Mode C compliant
MILprobT	The calculated probability that a given Military Operational Aircraft is TCAS compliant

n/a	Not Applicable
PIA	**P**robability of **I**ncident **A**voidance – the probability that a given encounter would be detected and an incident avoided if both aircraft were operating to applicable Mode C and TCAS mandates
SA	Small Aircraft (defined according to the applicable TCAS mandate)
SAprobC	The calculated probability that a given Small Aircraft is Mode C compliant
SAprobT	The calculated probability that a given Small Aircraft is TCAS compliant
TC	(**T**CAS on **C**ommercial**)** – the detection and avoidance probability for a TCAS equipped aircraft against a Commercial Mode C compliant aircraft
TP	(**T**CAS on GA**P)** – the probability that an encounter between a TCAS equipped aircraft and a GAP aircraft will be detected in time to avert a risk bearing incident
UK	United Kingdom
WWW	World Wide Web

Appendix B: Outline examples of risk reduction calculations

B1 Example 1
An airprox incident involving a Large Aircraft operating TCAS and a General Aviation/Powered (GAP) aircraft responding only to Mode A interrogations.

B1.1 Under the mandate the GAP aircraft will become Mode C compliant and thus 'visible' to the TCAS aircraft. The encounter will then have a probabilistic outcome based on:

the detection and advisory performance of the TCAS equipment

the crew response from the Large Aircraft

the circumstances of the encounter (airspeeds, relative headings, relative levels, vertical rates, aircraft manoeuvrability, *etc.*).

B1.2 Encounter data does not usually include detailed circumstances of the event and so a general detection and avoidance statistic is used in the analysis (this is agreed after consultation); namely the probability that a potential airprox/air accident encounter between a TCAS equipped Large Aircraft and a GAP Mode C aircraft will be detected and avoided. This probability will be referred to again in the next example as **TP**, (*i.e.* **T**CAS on GA**P**).

B2 Example 2
An airprox incident involving a Large Aircraft that is not TCAS equipped and a GAP aircraft whose equipment fit and usage is not reported.

B2.1 The Large Aircraft, although not currently TCAS equipped, should be TCAS equipped when a Mode C mandate is introduced. Mode C mandate benefit calculations will therefore assume a TCAS equipped Large Aircraft.

B2.2 The unknown GAP equipment usage is expressed probabilistically to support benefit calculations. Assume that (GAPprobC) is the probability of the GAP being Mode C compliant and (1 – GAPprobC) is the probability that it is not Mode C compliant. (The probability of a GAP aircraft being TCAS equipped is assumed to be very low and is ignored unless specifically stated).

B2.3 The detection and avoidance probability for this encounter under mandate conditions is then given by:

$$(1 - \mathbf{GAPprobC}) \quad (\mathbf{TP})$$

where (**TP**) is the detection and avoidance probability for TCAS equipped aircraft against a GAP Mode C compliant aircraft. No benefit will occur under mandate conditions if the GAP in the original encounter is already Mode C compliant.

B3 Example 3
An airprox incident involving two commercially operated C525 Citation jets (max. pass. 7, max weight 4,700 kg). Equipage details for both aircraft are unknown.

B3.1 In the absence of reliable equipage information a probabilistic assessment of equipment usage is needed for both aircraft. In a commercial role the C525 is classified as a 'Small Aircraft'[7] according to current TCAS requirements, *i.e.* it falls below the 30 pass./15,000 kg threshold for 'Large' aircraft and is not required to carry TCAS. It will

[7] This study uses the TCAS mandate definition of 'Small Aircraft' as it will apply when mandatory altitude reporting is introduced - See Appendix A.

retain this classification when the TCAS mandate is extended to aircraft with 19 passengers or a max. weight of 5,700 kg. Without an obligation to equip with TCAS the majority of Small Aircraft are expected to be Mode C compliant. However a few may be TCAS equipped, and it is assumed that a few may even operate without Mode C.

B3.2 The acronyms used in the probabilistic equipage statement for a Small Aircraft are as follows:

SAprobT: Probability that a given Small Aircraft is TCAS compliant

SAprobC: Probability that a given Small Aircraft is Mode C compliant

B3.3 The probability of the third equipage state; that of not responding to Mode C is therefore:

(1 – **SAprobT** – **SAprobC**)

B3.4 Mode C benefit calculations are more complex, as more equipage combinations must be considered. The combinations that will provide Mode C benefit are those with one aircraft TCAS equipped and the other not Mode C compliant. By relating equipage probabilities to the individual aircraft, *i.e.* (**ac1probT**), (**ac1probC**), (**ac2probT**), (**ac2probC**), *etc.* the expression of Mode C benefit in terms of detection and avoidance probability then becomes:

(**TC**) [(**ac1probT**) (1 – **ac2probC** – **ac2probT**)]
+ (**TC**) [(**ac2probT**) (1 – **ac1probC** – **ac1probT**)]

(**TC**) *i.e.* **T**CAS on **C**ommercial, is a general detection and avoidance performance statistic (agreed after consultation) for TCAS against a commercial aircraft.

B3.7 A table setting out the probabilities of detecting and avoiding encounters for the various combinations of aircraft category and equipage is included in Appendix A.

Appendix C: Steps in calculating the benefit of mandatory altitude reporting

C1 Overview

C1.1 Mode C benefit calculations assume that the distribution of air traffic will not be affected by introducing mandatory altitude reporting, and therefore the number and distribution of encounters with a potential for risk will also be unaffected by the mandate. It follows that if the population of risk bearing encounters does not change after the mandate is introduced then any benefit must be due to a reduced risk posed by at least some of the encounters.

C1.2 Contemporary encounters are therefore examined as being representative of the post-mandate encounter population. The analysis assumes that any benefit from the mandate will be due to the opportunities for TCAS equipped aircraft to detect and safely avoid what would otherwise be risk bearing encounters due to more aircraft becoming Mode C compliant.

C1.3 Successfully detecting and avoiding any encounter can not be assured and so the analysis probabilistically calculates the likelihood of individual encounters being avoided. These calculated probabilities are further examined to assess the benefit they represent. In the case of an encounter that originally produced an airprox incident the passengers and crew were exposed to risk. The probability that, under the mandate, the encounter might be detected and avoided means this result will contribute to an expected reduction in the number of airprox incidents. It is also likely to reduce the number of passengers that are exposed to risk.

C1.4 An encounter that originally resulted in a mid-air collision and which showed a probability of being avoided under the mandate will contribute to an expected drop in the number of accidents. In addition, the number of lives lost, any other casualties incurred and the associated human costs and airframe damage etc. can be scaled according to the probability of avoiding the accident to produce benefit figures in terms of reduced loss of life, fewer aircraft lost and the cost savings that these represent to the community.

C2 Specific calculations

C2.1 The steps involved in calculating possible Mode C benefit for a given encounter are as follows:

Determine the category of the two aircraft; LA, SA, GAP, GAG, MIL, *etc.*

Determine the equipment usage for the two conflicting aircraft in the original incident; from the incident report if possible. If the report is deficient in this regard a probabilistic assessment will be necessary using appropriate assumptions for equipment use as described in Appendix A.

Express each aircraft's equipment usage in terms of probabilities. *e.g.* the probability that the first aircraft/second aircraft is TCAS compliant, Mode C compliant only, or neither of these. *i.e.* values are calculated for (**ac1probT**), (**ac2probT**), (**ac1probC**), and (**ac2probC**), whilst the probabilities of non-compliance with mode C are given by:

[1 – (**ac1probT**) – (**ac1probC**)]

and

[1 – (**ac2probT**) – (**ac2probC**)]

Calculate the PIA value for the encounter. i.e. the scale of benefit expressed as the probability that Mode C compliance will allow the encounter to be detected and avoided. Expressions for the PIA benefit to be expected from the mandate are set out in Table C1**Error! Reference source not found.** below, for all relevant combinations of conflicting aircraft category and equipment usage.

Use the calculated PIA value as a scaling factor to estimate the various numerical and monetary benefits that the mandate would be expected to produce for this encounter.

Finally, sum the numerical and monetary benefits across all encounters to produce the overall benefit summary as set out in Table 2 in the body of this report.

Categories of conflicting aircraft and equipment in use during the reported incident		PIA benefit from Mode C Mandate	PIA generalised probabilistic statement of benefit from Mode C Mandate
LA	**LA**		
n/a	n/a	nil	
LA	**SA**		
n/a	TCAS	nil	
n/a	Mode C	nil	
n/a	< Mode C	TC	TC (1 – SAprobT – SAprobC)
LA	**MIL**		
n/a	TCAS	nil	
n/a	Mode C	nil	
n/a	< Mode C	nil	
LA	**GAP**		
n/a	TCAS	nil	
n/a	Mode C	nil	
n/a	< Mode C	TP	TP (1 – GAPprobT – GAPprobC)
LA	**GAG**		
n/a	Mode C	nil	
n/a	< Mode C	TG	TG (1 – GAGprobT – GAGprobC)
SA_1	**SA_2**		
TCAS	TCAS	nil	
Mode C	TCAS	nil	
< Mode C	TCAS	TC	Σ TC $(1 - SA_1probT - SA_1probC)$ (SA_2probT)
TCAS	Mode C	nil	
Mode C	Mode C	nil	
< Mode C	Mode C	nil	
TCAS	< Mode C	TC	TC $(1 - SA_2probT - SA_2probC)$ (SA_1probT)
Mode C	< Mode C	nil	
< Mode C	< Mode C	nil	

Table C1: Mandate expected benefit - PIAs for various combinations of aircraft category and equipment use.

Categories of conflicting aircraft and equipment in use during the reported incident		PIA benefit from Mode C Mandate	PIA generalised probabilistic statement of benefit from Mode C Mandate
SA	**MIL**		
TCAS	TCAS	nil	
Mode C	TCAS	nil	
< Mode C	TCAS	TM	TM (1 – SAprobT – SAprobC) (MILprobT)
TCAS	Mode C	nil	
Mode C	Mode C	nil	
< Mode C	Mode C	nil	
TCAS	< Mode C	nil	
Mode C	< Mode C	nil	
< Mode C	< Mode C	nil	
SA	**GAP**		
TCAS	TCAS	nil	
Mode C	TCAS	nil	
< Mode C	TCAS	TC	TC (1 – SAprobT – SAprobC) (GAPprobT)
TCAS	Mode C	nil	
Mode C	Mode C	nil	Σ
< Mode C	Mode C	nil	
TCAS	< Mode C	TP	TP (SAprobT) (1 – GAPprobT – GAPprobC)
Mode C	< Mode C	nil	
< Mode C	< Mode C	nil	
SA	**GAG**		
TCAS			
Mode C			
< Mode C			
TCAS	Mode C	nil	
Mode C	Mode C	nil	
< Mode C	Mode C	nil	
TCAS	< Mode C	TG	TG (SAprobT) (1 – GAGprobT – GAGprobC)
Mode C	< Mode C	nil	
< Mode C	< Mode C	nil	

Table C1(continued): Mandate expected benefit - PIAs for various combinations of aircraft category and equipment use.

Categories of conflicting aircraft and equipment in use during the reported incident		PIA benefit from Mode C Mandate	PIA generalised probabilistic statement of benefit from Mode C Mandate
MIL	**GAP**		
TCAS	TCAS	nil	
Mode C	TCAS	nil	
< Mode C	TCAS	nil	
TCAS	Mode C	nil	
Mode C	Mode C	nil	
< Mode C	Mode C	nil	
TCAS	< Mode C	TM	TM (MILprobT) (1 – GAPprobT – GAPprobC)
Mode C	< Mode C	nil	
< Mode C	< Mode C	nil	
GAP_1	**GAP_2**		
TCAS	TCAS	nil	
Mode C	TCAS	nil	
< Mode C	TCAS	TP	TP $(1 - GAP_1probT - GAP_1probC)$ (GAP_2probT)
TCAS	Mode C	nil	
Mode C	Mode C	nil	Σ
< Mode C	Mode C	nil	
TCAS	< Mode C	TP	TP $(1 - GAP_2probT - GAP_2probC)$ (GAP_1probT)
Mode C	< Mode C	nil	
< Mode C	< Mode C	nil	
GAP	**GAG**		
TCAS	Mode C	nil	
Mode C	Mode C	nil	
< Mode C	Mode C	nil	
TCAS	< Mode C	TG	TG (GAPprobT) (1 – GAGprobT – GAGprobC)
Mode C	< Mode C	nil	
< Mode C	< Mode C	nil	

Table C1(continued): Mandate expected benefit - PIAs for various combinations of aircraft category and equipment use.