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Airborne Collision Avoidance System (ACAS) Manual

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and published under his authority

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International Civil Aviation Organization

AMENDMENTS

The issue of amendments is announced regularly in the *ICAO Journal* and in the supplements to the *Catalogue of ICAO Publications and Audio-visual Training Aids*, which holders of this publication should consult. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA		
No.	Date	Entered by

FOREWORD

This manual has been developed by the Surveillance and Conflict Resolution Systems Panel (SCRSP) (now known as the Aeronautical Surveillance Panel (ASP)). On 2 June 2005, the Air Navigation Commission approved Recommendations 1/2 of the first meeting of the SCRSP relating to the publication of this manual which is a compendium of information on various technical and operational aspects of the airborne collision avoidance system (ACAS).

The material contained in this manual supplements ACAS Standards and Recommended Practices (SARPs) and procedures contained in Annex 10 — *Aeronautical Telecommunications,* Volume IV — *Surveillance Radar and Collision Avoidance Systems*, *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444) and *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168). Guidance provided in this manual includes a detailed description of ACAS and associated technical and operational issues in order to facilitate correct operation and operational monitoring, as well as training of personnel.

Like other manuals, this document will be amended as and when deemed necessary. In that respect, comments from States and other parties concerned with ACAS would be appreciated. Such comments should be addressed to:

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GLOSSARY

ACAS I	Airborne collision avoidance system I (does not provide RAs)
ACAS II	Airborne collision avoidance system II
AD	Airworthiness directive
ADS	Automatic dependent surveillance
AGL	Above ground level
AHRS	Attitude and heading reference system
AIC	Aeronautical information circular
Alerting Volume	Airspace around an ACAS-equipped aircraft, shaped by TAU and DMOD
ANSP	Air navigation service provider
ASP	Aeronautical Surveillance Panel
ASR	Airborne surveillance radar
ATC	Air traffic control
ATCRBS	Air traffic control radar beacon system
CAA	Civil aviation authority
CAS	Collision avoidance system (generic term)
CBT	Computer-based training
CPA	Closest point of approach
CRM	Cockpit resource management or crew resource management
DF	Mode S downlink format
DME	Distance measuring equipment
DMOD	Distance modification, adjustment to TAU at close range
DR	Downlink request
EFIS	Electronic flight information systems
EICAS	Engine indication and caution alerting system
EMI	Electromagnetic interference
ERP	Effective radiated power
fpm	Feet per minute
FRUIT	Undesired transponder replies elicited by ground interrogators or other ACAS interrogators
Garble, nonsynchronous	Garble (i.e. the overlapping of replies) caused by FRUIT
Garble, synchronous	An overlap of reply pulses received from two or more transponders answering the same interrogation
GNSS	Global navigation satellite system
GPWS	Ground proximity warning system
HUD	Heads up display
IFR	Instrument flight rules
II	Interrogation identification (code)
Image Track	Tracks that could be formed by replies specularly reflected from the ground

IL	Interference limiting, self-limiting of interrogation power by ACAS to minimize FRUIT caused by ACAS and limit transponder unavailability from ACAS activity. The combined effects should not occupy a victim transponder more than 2 per cent.
ILP	Interference limiting procedure
INS	Inertial navigation system
IoI	Interrogators of Interest
IRS	Inertial reference system
IVSI	Instantaneous vertical speed indicator
KIAS	Knots indicated air speed
Kt	Nautical miles per hour
MEL	Minimum equipment list
MHz	Megahertz
MMEL	Master minimum equipment list
Mode S	Mode select, evolutionary replacement for ATCRBS
MODEST	Mode S transponder tester
MOPS	Minimum operational performance standards
MSL	Mean sea level
MSSR	Monopulse secondary surveillance radar
MTL	Minimum triggering level (of the TCAS receiver)
NM	Nautical mile
NMAC	Near mid-air collision
NTA	Number of TCAS aircraft, used in interference limiting
PARROTS	Position adjustable range reference orientation transponders
PF	Pilot flying
PFD	Primary flight display
PI Code	Parity/Interrogator code
PNF	Pilot not flying
RA	Resolution advisory: an indication given to the flight crew recommending a manoeuvre or a manoeuvre restriction to avoid collision
RAC	Resolution advisory complement
Resolution Manoeuvre	Manoeuvre in the vertical direction resulting from compliance with an RA
RF	Radio frequency
Risk Ratio	The ratio between the risk of collision with ACAS and the risk of collision without ACAS
RITA	Replay Interface for TCAS Alerts
RNAV	Area navigation
ROA	Remotely operated aircraft
RSS	Root sum square
RVSM	Reduced vertical separation minimum
SARPs	Standards and Recommended Practices
SCRSP	Surveillance and Conflict Resolution Systems Panel
SL	Sensitivity level, which controls the warning time given by ACAS advisories

SLC	Sensitivity level control
SSR	Secondary surveillance radar
Sense	The direction of an RA, i.e. either up or down
Sense Reversal	A change in the sense of an RA. *Note.— In some encounters, it is necessary to reverse sense of the original RA to avoid a collision.*
Squitters	Unsolicited transmissions generated by Mode S transponders
STC	Supplemental type certificate
STCA	Short-term conflict alert
TA	Traffic advisory: an indication given to the flight crew that a certain intruder is a potential threat
TAS	Traffic advisory system
TAS	True airspeed
TAWS	Terrain avoidance warning system
TCAS	Traffic alert and collision avoidance system
TFC	Traffic
TMA	Traffic management area
TO	Technical order
TOC	Top of climb
TRP	Total radiated power
TSO	Technical standards order
Target	A Mode S or Mode A/C-equipped aircraft which is being tracked by an ACAS-equipped aircraft
TAU	Time to go to closest point of approach, or estimated time to collision
Threat	An intruder that has satisfied the threat detection criteria and requires an RA
ToI	Transponder of interest
UAV	Unmanned aerial vehicles. (This includes ROAs.)
UF	Mode S uplink format
VFR	Visual flight rules
VSI	Vertical speed indicator
VTT	Vertical threshold test
Whisper-Shout	A method of controlling synchronous garble from Mode A/C transponders through the combined use of variable power levels and suppression pulses

Chapter 1

INTRODUCTION

1.1 PURPOSE

1.1.1 The purpose of this manual is to provide guidance on technical and operational issues applicable to the Airborne Collision Avoidance System (ACAS), as specified in Annex 10 — *Aeronautical Telecommunications*, Volume IV — *Surveillance Radar and Collision Avoidance Systems*, Chapter 4. Unless otherwise stated in the manual, the use of the term “ACAS” refers to ACAS II.

1.1.2 The material provided in this manual has generally been effective in addressing ACAS implementation issues. Nevertheless, individual administrations may find modified or alternative methods more appropriate due to local situations or available resources.

1.2 SCOPE AND CONTENT

1.2.1 Scope and target audience

This manual aims to describe all the important aspects of ACAS and the implications for:

a) aviation regulators;

b) aircraft operating agencies;

c) flight crew;

d) maintenance engineers;

e) air navigation service providers;

f) air traffic controllers; and

g) persons conducting safety studies.

1.2.2 Content

This chapter provides an overview of the purpose, scope and content of the document as well as a brief description of ACAS and its objectives.

- Chapter 2 outlines major implementation aspects of the ACAS;
- Chapter 3 describes in detail the ACAS equipment, functions and capabilities;

- Chapter 4 outlines the relationship between ACAS performance, safety and airspace configuration;

- Chapter 5 stresses the importance of the proper operation of the ACAS system by flight crews and provides pilot training guidelines;

- Chapter 6 recommends that controllers follow an ACAS training programme and provides recommendations for the content of that training;

- Chapter 7 discusses the issues related to the adaptation of ACAS to situations that go beyond its original intended use. In particular the use of ACAS by the military, helicopters and unmanned aerial vehicles are addressed;

- Chapter 8 provides an overview of the safety and electromagnetic assessments required for ACAS;

- Chapter 9 explains the need for ACAS monitoring and then describes practical ways of conducting it;

- Chapter 10 explains the need for transponder monitoring and then describes ACAS-related problems that should be detected;

- Chapter 11 provides details of how ACAS certification and operational approvals are to be granted. Also guidelines are given for military systems that have an ACAS function.

1.3 OBJECTIVE OF ACAS

1.3.1 The objective of ACAS is to provide advice to pilots for the purpose of avoiding potential collisions. This is achieved through resolution advisories (RAs), which recommend actions (including manoeuvres), and through traffic advisories (TAs), which are intended to prompt visual acquisition and to act as a precursor to RAs.

1.3.2 ACAS has been designed to provide a back-up collision avoidance service for the existing conventional air traffic control system while minimizing unwanted alarms in encounters for which the collision risk does not warrant escape manoeuvres. The operation of ACAS is not dependent upon any ground-based systems.

1.4 SYSTEM OVERVIEW

1.4.1 ACAS equipment in the aircraft interrogates Mode A/C and Mode S transponders on aircraft in its vicinity and listens for their replies. By processing these replies, ACAS determines which aircraft represent potential collision threats and provides appropriate display indications (or advisories) to the flight crew to avoid collisions.

1.4.2 The ACAS equipment described in this document is capable of providing two classes of advisories. RAs indicate vertical manoeuvres or vertical manoeuvre restrictions that are predicted to either increase or maintain the existing vertical separation from threatening aircraft. TAs indicate the positions of potential threats, i.e. aircraft that may later cause RAs to be displayed.

1.4.3 ACAS II RAs do not indicate horizontal escape manoeuvres.

1.4.4 TAs indicate the position of the intruding aircraft relative to own aircraft. TAs without altitude information are also provided against non-altitude-reporting, transponder-equipped aircraft.

1.4.5 ACAS operation

1.4.5.1 ACAS equipment periodically transmits interrogation signals. These interrogations are replied to by transponders installed on nearby aircraft. A Mode C transponder replies with its altitude. A Mode S transponder replies with its altitude and unique aircraft address.

Note.— Transponder-equipped aircraft may temporarily not report altitude, but will reply.

1.4.5.2 ACAS then computes the range of the intruding aircraft by using the round-trip time between the transmission of the interrogation and the receipt of the reply. Altitude, range and bearing (using a directional antenna) are estimated from the reply information and used to determine whether the intruding aircraft is a threat.

1.4.5.3 If the threat detection logic in the ACAS computer determines that a nearby aircraft represents a potential, imminent collision, the computer threat resolution logic determines the appropriate vertical manoeuvre or vertical manoeuvre restriction to reduce the risk of collision. Each threat aircraft is processed individually to permit selection of an RA based on track data. The appropriate manoeuvre is one that avoids all threat aircraft, assuming that the threat aircraft do not manoeuvre to thwart the RA and that own aircraft complies with the RA.

1.4.5.4 If a threat aircraft is equipped with ACAS that is capable of generating RAs, a coordination procedure via the air-to-air Mode S data link is performed. This procedure assures that the RAs are compatible.

1.4.5.5 TAs are intended to alert the flight crew to the presence of potential threat aircraft with a longer warning time than that provided by RAs.

1.4.6 System components

1.4.6.1 The equipped aircraft carries ACAS surveillance electronics that interrogates and receives replies from Mode S and Mode A/C transponders on other aircraft. The components of ACAS are shown in Figure 1-1.

1.4.6.2 The ACAS-equipped aircraft also carries a Mode S transponder that performs the functions of existing Mode A/C transponders and provides Mode S air-to-air communications for coordinating the resolution of encounters between ACAS-equipped aircraft. The Mode S transponder may also be used for communications with a ground-based Mode S sensor for surveillance and data link purposes.

1.5 DESIGN INTENTION OF ACAS II

1.5.1 ACAS II was designed for use on turbine-powered, fixed-wing aircraft flying in accordance with civil operating procedures.

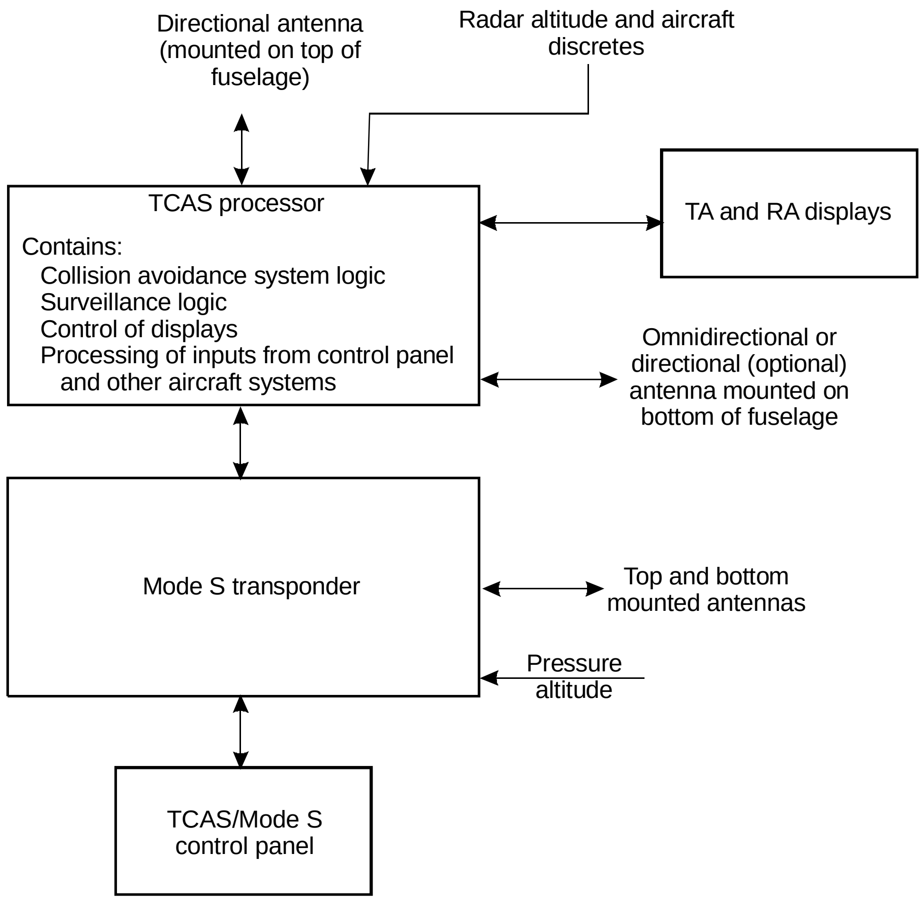


Figure 1-1. ACAS Components

1.5.2 ACAS II was not designed for use by closely spaced formation aircraft, rotary wing aircraft or aircraft operating in clusters. Additional design requirements and assumptions to be taken into account for some specific types of operation are contained in Chapter 3.

1.5.3 ACAS II was not designed with the intent of being installed on tactical military (e.g. fighter aircraft) or unmanned aircraft. As such, there are technical and operational issues that must be addressed and resolved prior to installing ACAS II on these types of aircraft.

Note.— When a fighter aircraft, with altitude reporting enabled, intercepts an ACAS II-equipped aircraft, there is a risk that the ACAS aircraft will generate an undesirable RA. Guidance for avoiding such RAs is provided in Appendix 7.

1.6 ACAS I AND ACAS III

1.6.1 ACAS I is a system that provides information as an aid to “see and avoid”. It uses the same principles of operation as ACAS II, but does not provide RAs.

Note.— ACAS I may or may not provide TAs.

1.6.2 The surveillance function of ACAS I is addressed by Annex 10 to provide compatibility with ground and airborne SSR systems. ACAS I is typically installed on rotary wing aircraft and smaller, turbine-powered, fixed-wing aircraft.

1.6.3 ACAS I is not designed for use by closely spaced formation aircraft or aircraft operating in clusters.

1.6.4 ACAS III was envisioned as a system that would provide RAs in both the vertical and horizontal planes. Some provisions for ACAS III are contained in Annex 10, but no ACAS III systems have been developed yet.

Chapter 2

IMPLEMENTATION OF ACAS

2.1 ICAO IMPLEMENTATION REQUIREMENTS

Annex 6 — *Operation of Aircraft*, Part I — *International Commercial Air Transport — Aeroplanes*, includes the following ACAS equipage requirements:

a) from 1 January 2003, all turbine-engined aeroplanes of a maximum certificated take-off mass in excess of 15 000 kg, or authorized to carry more than 30 passengers shall be equipped with ACAS II;

b) from 1 January 2005, all turbine-engined aeroplanes of a maximum certificated take-off mass in excess of 5 700 kg, or authorized to carry more than 19 passengers shall be equipped with ACAS II;

c) all aeroplanes should be equipped with an airborne collision avoidance system (ACAS II). (A Recommendation); and

d) an airborne collision avoidance system shall operate in accordance with the relevant provisions of Annex 10, Volume IV.

2.2 RESPONSIBILITIES

2.2.1 Civil Aviation Authority (CAA) responsibilities

2.2.1.1 The CAA publishes aviation regulations and ensures compliance therewith. It is the responsibility of the CAA to ensure that ACAS is as effective as possible in its airspace. The CAA should ensure that:

a) Aeronautical Information Circulars (AICs) are published to ensure appropriate operation of ACAS in their airspace — e.g. for aircraft to climb and descend at less than 1 500 ft/minute (depending on performance characteristics of the aircraft) in the last 1 000 ft before leveling off at a cleared flight level;

b) controllers receive appropriate ACAS training;

c) the effect of ACAS is analysed and understood during any formal safety investigations (e.g. airprox/near miss);

d) ACAS-related safety indicators are regularly monitored. In particular the number and distribution of RAs and the percentage of RAs followed by pilots should be known;

e) information regarding ACAS is coordinated with other CAAs and organizations; and

f) changes in airspace structure and procedures take into account the presence of ACAS.

2.2.1.2 The CAA is also responsible for regulation of aircraft equipage and aircraft operations. In this role, the CAA is responsible for ensuring there is:

a) an ACAS mandate in national regulations relating to relevant Annex 6 requirements. Any differences between the national regulations and Annex 6 requirements should be notified to ICAO;

b) an ACAS installed in all relevant aircraft according to the mandate. Installations can be verified by proof of purchase and installation, Mode S monitoring (where available) and ramp check;

c) a strict exemptions policy that allows operations by non-ACAS-equipped aircraft only in well defined and justified circumstances;

d) a Minimum Equipment List (MEL) requirement;

e) verification of correct Mode A/C, Mode S and ACAS operation through monitoring; and

f) approved initial and recurrent training for air traffic controllers, flight crew and maintenance personnel.

2.2.2 Air Navigation Service Provider (ANSP) responsibilities

The ANSP, which has the delegated responsibility of providing air traffic services, should:

a) maintain awareness of ACAS operational monitoring activities conducted by States and international organizations;

b) train ATC specialists on ACAS and expected flight crew responses to ACAS advisories and provide familiarization flights for specialists on ACAS-equipped aircraft whenever possible;

c) provide pertinent CAA offices with data and information about ACAS ATC compatibility issues, e.g. airspace or airports where excessive numbers of RAs occur, hazardous conditions, situations or events which may be related to ACAS. Information on such issues should also be coordinated with other ANSPs and organizations; and

d) ensure that procedures are in place that implement the requirements of PANS-ATM especially those related to the discontinuance of Mode C reports when erroneous Mode C reports in excess of 60 m (200 ft) are detected. In addition, the ANSP should implement a means of following up with the operators of aircraft observed with erroneous altitude reporting to ensure they take the necessary actions to correct the anomalous performance of the transponder.

2.2.3 Responsibilities of operator of ACAS-equipped aircraft

Operators should comply with all appropriate ACAS legislation. Operators should ensure that:

a) aircraft are properly equipped with ACAS and that the equipment is properly maintained;

b) approved pilot training programmes are implemented for initial and recurrent training;

c) approved maintenance training programmes are implemented for initial and recurrent training;

d) procedures are in place for pilots and maintenance personnel to report problems with ACAS performance; and

e) procedures are in place to analyse any reported problems and then provide feedback to the CAA and other involved parties.

2.3 RELATED DOCUMENTS

- ACAS II Safety Bulletin 1, *Follow the RA!*, Eurocontrol, www.eurocontrol.int/acas/, July 2002.
- ACAS II Safety Bulletin 2, *RAs and 1 000 ft level-off manoeuvres*, Eurocontrol, www.eurocontrol.int/acas/, March 2003.
- ACAS II Safety Bulletin 3, *Wrong reaction to "Adjust Vertical Speed" RAs*, Eurocontrol, www.eurocontrol.int/acas/, October 2003.
- Advisory Circular (AC) 120-55B, *Air Carrier Operational Approval and Use of TCAS II*, Federal Aviation Administration, United States, 2001.
- Advisory Circular (AC) 20-131A, *Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders*, Federal Aviation Administration, United States, 1993.
- Annex 6 to the *Convention on International Civil Aviation — Operation of Aircraft*; Part I —*International Commercial Air Transport — Aeroplanes*, 2001, and Part II — *International General Aviation — Aeroplanes,* 1998, ICAO.
- Annex 10 to the *Convention on International Civil Aviation — Aeronautical Telecommunications*, Volume IV — *Surveillance Radar and Collision Avoidance Systems*, 2002, ICAO.
- Annex 11 to the *Convention on International Civil Aviation — Air Traffic Services*, 2001, ICAO.
- *ED-73B MOPS [minimum operational performance standards] for SSR Mode S Transponders*, EUROCAE, January 2003.

- *Introduction to TCAS II Version 7*, Federal Aviation Administration, United States, October 2000.
- *Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment, DO-181C*, RTCA, Incorporated, June 2001.
- *Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment, DO-185A*, RTCA, Incorporated, April 1997.
- *Procedures for Air Navigation Services — Air Traffic Management*, (Doc 4444), 2001, ICAO.
- *Procedures for Air Navigation Services — Aircraft Operations*, Volume I — *Flight Procedures*, (Doc 8168), 1993, ICAO.

2.4 ACAS MANUFACTURERS

The following manufacturers produce ACAS II equipment:

a) Aviation Communication and Surveillance Systems (ACSS), 19810 North 7th Avenue, Phoenix, AZ 85027-4400, USA;

b) Honeywell Aerospace, 15001 NE 36th Street, Redmond, WA 98073, USA; and

c) Rockwell Collins Inc., 400 Collins Road, NE, Cedar Rapids, IA 52498, USA.

Chapter 3

FUNCTIONS AND CAPABILITIES

3.1 GENERAL

The following material is intended to provide guidance concerning the technical characteristics of the airborne collision avoidance system (ACAS) having vertical resolution capability (ACAS II). ACAS SARPs are contained in Annex 10, Volume IV, Chapter 4.

Note.— Non-SI alternative units are used as permitted by Annex 5 — Units of Measurement to be Used in Air and Ground Operations*. In limited cases, to ensure consistency at the level of the logic calculations, units such as ft/s, NM/s and kt/s are used.*

3.2 ADVISORIES PROVIDED

3.2.1 Traffic advisories (TAs)

TAs alert the flight crew to potential resolution advisories (RAs) and may indicate the range, range rate, altitude, altitude rate and bearing of the intruding aircraft relative to own aircraft. TAs without altitude information may also be provided on Mode C- or Mode S-equipped aircraft that have temporarily lost their automatic altitude-reporting capability. The information conveyed in TAs is intended to assist the flight crew in sighting nearby traffic.

3.2.2 Resolution advisories

3.2.2.1 If the threat detection logic in the ACAS computer determines that an encounter with a nearby aircraft could soon lead to a near-collision or collision, the computer threat resolution logic determines an appropriate vertical manoeuvre that will ensure the safe vertical separation of the two aircraft. The selected manoeuvre ensures adequate vertical separation within constraints imposed by the climb rate capability and proximity to the ground of the two aircraft.

3.2.2.2 The RAs provided to the pilot can be divided into two categories: corrective advisories, which instruct the pilot to deviate from the current flight path (e.g. “CLIMB” when the aircraft is in level flight); and preventive advisories, which advise the pilot to maintain or avoid certain vertical speeds (e.g. “DON’T CLIMB” when the aircraft is in level flight).

3.2.3 Warning times

In any potential collision, ACAS generates an RA nominally 15 to 35 seconds before the closest point of approach (CPA) of the aircraft. The ACAS equipment may generate a TA up to 20 seconds in advance of an RA. Warning times depend on sensitivity levels of RAs (see 3.10.12).

3.2.4 Air-air coordination of RAs

3.2.4.1 When the pilot of an ACAS aircraft receives an RA and manoeuvres as advised, the ACAS aircraft will normally be able to avoid the intruding aircraft provided the intruder does not accelerate or manoeuvre so as to defeat the RA response of the ACAS aircraft.

3.2.4.2 If the intruding aircraft is equipped with ACAS, a coordination procedure is performed via the air-to-air Mode S data link to ensure that the ACAS RAs are compatible.

3.2.5 Air-ground communication

3.2.5.1 ACAS may communicate with ground stations using the Mode S air-ground data link.

3.2.5.2 Mode S ground stations can transmit sensitivity level control commands to ACAS equipment, and thus reduce the RA warning time for the local traffic environment as an ACAS aircraft moves through the region of coverage of the station. An effective trade-off between collision warning time and alert rate might thereby be ensured. However, there are no internationally agreed operational procedures for use of this capability and it is not used in practice.

3.2.5.3 The Mode S air-ground data link may also be used to transmit ACAS RAs to Mode S ground stations. This information can then be used by air traffic services to monitor ACAS RAs within an airspace of interest.

3.2.6 Functions performed by ACAS

3.2.6.1 The functions executed by ACAS are illustrated in Figure 3-1. To keep the illustration simple, the functions “own aircraft tracking” and “intruder aircraft tracking” have been represented once in Figure 3-1, under “surveillance”.

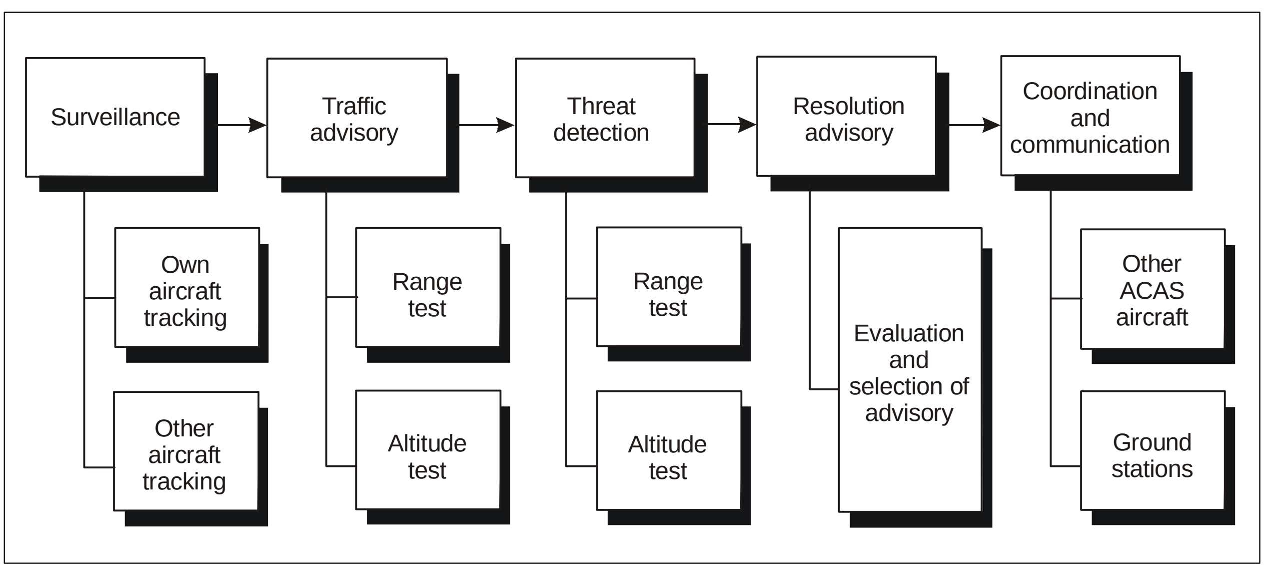


Figure 3-1. Illustration of ACAS Functions

3.2.6.2 Surveillance is normally executed once per cycle; however, it may be executed more frequently or less frequently for some intruders. For example, surveillance is executed less frequently, or not at all, for some non-threatening intruders to respect interference-limiting constraints, or it may be executed more frequently for some intruders to improve the azimuth estimate.

3.3 INTRUDER CHARACTERISTICS

3.3.1 Transponder equipage of intruder

ACAS provides RAs against aircraft equipped with altitude reporting Mode A/C or Mode S transponders. Some aircraft are equipped with Secondary Surveillance Radar (SSR) transponders but may have temporarily lost their altitude-reporting capability. ACAS cannot generate RAs in conflicts with such aircraft because, without altitude information, a vertical avoidance manoeuvre cannot be calculated. ACAS equipment can generate only TAs on such aircraft, describing their ranges, range rates and bearings. Aircraft not equipped with or not operating Mode A/C or Mode S transponders cannot be tracked by ACAS.

3.3.2 Intruder closing speeds and traffic densities

3.3.2.1 ACAS II equipment is designed for operation in high-density airspace and is capable of providing overall surveillance performance of intruders as defined in Annex 10, Volume IV, Chapter 4, 4.3.2 and Table 3-1 of this manual.

Note.— Table 3-1 was used in the design validation for earlier versions of traffic alert and collision avoidance systems (TCAS). Operational experience and simulation show that ACAS continues to provide adequate surveillance for collision avoidance even when the “Maximum number of other ACAS within 56 km (30 NM)” is somewhat higher than shown in Table 3-1. Future ACAS designs will take account of current and expected ACAS densities.

Table 3-1. Closing speeds and traffic densities

Conditions									*Performance*
Quadrant						*Maximum Traffic Density*		*Maximum number of other ACAS within 56 km (30 NM)*	*Probability of success*
Forward		*Side*		*Back*					
Maximum Closing Speed									
m/s	*kt*	*m/s*	*kt*	*m/s*	*kt*	*aircraft/ km²*	*aircraft/ NM²*		
260	500	150	300	93	180	0.087	0.30	30	0.90
620	1 200	390	750	220	430	0.017	0.06	30	0.90

3.3.2.2 The conditions enumerated in Table 3-1, which define two distinct density regions in the multi-dimensional condition space that affects ACAS performance, were extrapolated from airborne measurements of the performance of a typical ACAS. The airborne measurement data indicated that the track establishment probability will not drop abruptly when any of the condition bounds are exceeded.

3.3.2.3 The performance is stated in terms of probability of tracking a target of interest at least 30 seconds before CPA, at a maximum closing speed in a given traffic density. The maximum traffic density associated with each density region is defined as:

$$\rho = n(r)/\Pi r^2$$

where $n(r)$ is the maximum 30-second time average of the count of SSR transponder-equipped aircraft (not counting own aircraft) above a circular area of radius r about the ACAS aircraft ground position. In the airborne measurements, the radii were different for the two density regions. In the high-density measurements the radius was 9.3 km (5 NM). In the low-density measurements the radius was 19 km (10 NM). Traffic density outside the limits of the circular area of constant density may be assumed to decrease inversely proportional to range so that the number of aircraft is given by:

$$n(r) = n(r_o)r/r_o$$

where r_o is the radius of the constant density region.

3.3.2.4 When the density is greater than 0.017 aircraft/km^2 (0.06 aircraft/NM^2), the nominal radius of uniform density r_o is taken to be 9.3 km (5 NM). When the density is equal to or less than 0.017 aircraft/km^2, r_o is nominally 18.5 km (10 NM).

3.3.2.5 Table 3-1 is based on an additional assumption that at least 25 per cent of the total transponder-equipped aircraft in the highest density 0.087 aircraft/km^2 (0.3 aircraft/NM^2) airspace are Mode S-equipped. If fewer than 25 per cent are Mode S-equipped, the track probability for Mode A/C aircraft may be less than 0.90 because of increased synchronous garble. If the traffic density within r_o exceeds the limits given in the table or if the traffic count outside of r_o continues increasing faster than r, the actual track establishment probability for Mode A/C aircraft may also be less than 0.90 because of increased synchronous garble. If the closing speed exceeds the given limits, the tracks for Mode A/C and Mode S aircraft may be established late. However, the track probability is expected to degrade gradually as any of these limits is exceeded.

3.3.2.6 Table 3-1 reflects the fact that the ACAS tracking performance involves a compromise between closing speed and traffic density. It may not be possible to maintain a high probability of tracking an intruder when the traffic density and the intruder closing speed are both simultaneously large. However, the ACAS design is capable of reliable track establishment in the following circumstances:

a) when operating in en-route airspace (typically characterized by densities of less than 0.017 aircraft/km^2, i.e. 0.06 aircraft/NM^2) where the maximum closing speeds are below 620 m/s (1 200 kt); or

b) when operating in low-altitude terminal airspace (typically characterized by densities up to 0.085 aircraft/km^2, i.e. 0.30 aircraft/NM^2) where the closing speeds are below 260 m/s (500 kt) for operational reasons.

3.3.2.7 Table 3-1 also accounts for the fact that higher closing speeds are associated with the forward direction rather than with the side or back directions, so that the ACAS surveillance design is not required to provide reliable detection for the highest closing speeds in the side or back directions.

3.3.3 System range limitations

The required nominal tracking range of the ACAS is 26 km (14 NM). However, when operating in high density, the interference limiting feature may reduce system range to approximately 8.4 km (4.5 NM). An 8.4 km (4.5 NM) range is adequate to provide protection for a 260 m/s (500 kt) encounter.

3.4 CONTROL OF INTERFERENCE TO THE ELECTROMAGNETIC ENVIRONMENT

3.4.1 ACAS is capable of operating in all traffic densities without unacceptably degrading the electromagnetic environment. Each ACAS knows the number of other ACAS units operating in the local airspace. This knowledge is used in an attempt to ensure that no transponder is suppressed by ACAS activity for more than 2 per cent of the time and that ACAS does not contribute to an unacceptably high FRUIT rate (i.e. undesired transponder replies elicited by ground interrogators or other ACAS interrogators) that would degrade ground SSR surveillance performance. Multiple ACAS units in the vicinity cooperatively limit their own transmissions. As the number of such ACAS units increases, the interrogation allocation for each of them decreases. Thus, every ACAS unit monitors the number of other ACAS units within detection range. This information is then used to limit its own interrogation rate and power as necessary. When this limiting is in full effect, the effective range of the ACAS units may not be adequate to provide acceptable warning times in encounters in excess of 260 m/s (500 kt). This condition is normally encountered at low altitude.

3.4.2 Whenever the ACAS aircraft is on the ground, ACAS automatically limits the power of its interrogations. This limiting is done by setting the ACAS count (n_a) in the interference limiting inequalities to a value three times the measured value. This value is selected to ensure that an ACAS unit on the ground does not contribute any more interference to the electromagnetic environment than is unavoidable. This value will provide an approximate surveillance range of 5.6 km (3 NM) in the highest-density terminal areas to support reliable ground ACAS surveillance of local airborne traffic and a 26 km (14 NM) range in very low-density airspace to provide wide-area surveillance in the absence of an SSR.

3.4.3 The presence of an ACAS unit is announced to other ACAS units by the periodic transmission of an ACAS interrogation containing a message that gives the address of the ACAS aircraft. This transmission is sent nominally every 8 to 10 seconds and uses a broadcast format. Mode S transponders are designed to accept message data from a broadcast interrogation without replying. The announcement messages received by the ACAS aircraft's Mode S transponder are monitored by the interference limiting algorithms to develop an estimate of the number of ACAS units in the vicinity.

3.5 FACTORS AFFECTING SYSTEM PERFORMANCE

3.5.1 Synchronous garble

When a Mode C interrogation is transmitted, all the Mode C transponders that detect it reply. Since the reply duration is 21 microseconds, aircraft whose ranges from ACAS are within about 3.2 km (1.7 NM) of each other generate replies that persistently and synchronously overlap each other when received at the interrogating aircraft. The number of overlapping replies is proportional to the density of aircraft and their range from ACAS. Ten or more overlapping replies might be received in moderate-density terminal areas. It is possible to decode reliably only about three overlapping replies. Hence, there is a need to reduce the number of transponders that reply to each interrogation. Whisper-shout and directional transmit techniques are available for controlling such synchronous garble (see 3.6.2). They are both needed in ACAS equipment operating in the high-traffic densities.

3.5.2 Multipath from terrain reflections

3.5.2.1 SSR transponders use quarter-wave monopole antennas mounted on the bottom of the aircraft. A stub antenna of this sort has a peak elevation gain at an angle of 20 to 30 degrees below the horizontal plane. This is suitable for ground-air surveillance, but the direct air-air surveillance path may operate at a disadvantage relative to the ground reflection path, particularly over water.

3.5.2.2 If the ACAS unit uses a bottom-mounted antenna, there are geometries for which the reflected signal is consistently stronger than the direct signal. However, when a top-mounted antenna is used for interrogation, its peak gain occurs at a positive elevation angle and the signal-to-multipath ratio is improved. Thus, when ACAS transmits from the top-mounted antenna, the effects of multipath are reduced significantly. Even when a top-mounted antenna is used, the multipath will still occasionally exceed the receiver threshold. Thus, there is need to reject low-level multipath. ACAS can achieve this rejection through the use of variable receiver thresholds (see 3.9.2.2).

3.5.3 Transponders installed on other aircraft can also affect the performance of ACAS. These affects are addressed in Chapter 10 of this manual.

3.6 SYSTEM OPERATION

3.6.1 Surveillance of intruders

3.6.1.1 The main purposes of the surveillance processes described below are to obtain position reports and to correlate these to form tracks. This involves the use of trackers and requires the estimation of rates.

3.6.1.2 The ACAS unit transmits an interrogation sequence nominally once per second. The interrogations are transmitted at a nominal effective radiated power (ERP) level of +54 ±2 dBm as measured at zero degree elevation relative to the longitudinal axis of the aircraft. When these interrogations are received by Mode A/C and Mode S altitude-reporting transponders, the transponders transmit replies that report their altitude. The ACAS unit computes the range of each intruding aircraft by using the round-trip time between the transmission of the interrogation and the receipt of the reply. Altitude rate and range rate are determined by tracking the reply information.

3.6.1.3 In the absence of interference, overload, interference-limiting conditions, or other degrading effects, the equipment will nominally be capable of providing surveillance for Mode A/C and Mode S targets, i.e. transponder-equipped aircraft, out to a range of 26 km (14 NM). However, because the surveillance reliability degrades as the range increases, the equipment should assess as possible collision threats only those targets within a maximum range of 22 km (12 NM). No target outside this range should be eligible to generate an RA. However, ACAS is able to detect ACAS broadcast interrogations from ACAS-equipped aircraft out to a nominal range of 56 km (30 NM).

3.6.1.4 The equipment should have the capacity for surveillance of any mix of Mode A/C or Mode S targets up to at least 30 aircraft. ACAS equipment is nominally capable of reliable surveillance of high-closing-speed targets in a peak traffic density of up to 0.017 aircraft per square km (0.06 aircraft per square NM) or approximately 27 aircraft in a 26 km (14 NM) radius. When the average traffic density exceeds the above value, the reliable surveillance range decreases.

3.6.1.5 ACAS equipment is capable of providing reliable surveillance of targets closing only up to 260 m/s (500 kt) in an average traffic density as high as 0.087 aircraft per square km (0.3 aircraft per square NM). The surveillance range required for 260 m/s (500 kt) targets is about 9.3 km (5 NM). It is possible to provide 9.3 km (5 NM) surveillance in a short-term peak traffic density of 0.087 aircraft/km^2 (0.3 aircraft/NM^2) or more without exceeding a total target capacity of 30.

3.6.1.6 If the overall target count ever exceeds the surveillance capacity at any range up to 26 km (14 NM), the long-range targets may be dropped without compromising the ability to provide reliable surveillance of lower-speed targets. If the number of Mode A/C plus Mode S targets under surveillance exceeds the surveillance capacity, excess targets are to be deleted in order of decreasing range without regard to target type.

3.6.2 Surveillance of intruders with Mode A/C transponders

3.6.2.1 Surveillance of Mode A/C transponders is accomplished by the periodic transmission of a Mode C-only all-call (intermode) interrogation (Annex 10, Volume IV, Chapter 3). This elicits replies from Mode A/C transponders, but not from Mode S transponders, thus preventing the replies of Mode S transponders from synchronously garbling the replies of Mode A/C transponders. Other techniques for reducing synchronous garble are: 1) the use of directional antennas to interrogate only those aircraft in an azimuth wedge; and 2) the use of a sequence of variable power suppressions and interrogations (known as "whisper-shout") that interrogates only aircraft that have similar link margins (see 3.7.2). The use of both of these techniques together provides a powerful tool for overcoming the effects of synchronous garble.

3.6.2.2 Whisper-shout employs a sequence of interrogations at different power levels transmitted during each surveillance update period (see 3.7.2 and Figure 3-3). Each of the interrogations in the sequence, other than the one at lowest power, is preceded by a suppression transmission, where the first pulse of the interrogation serves as the second pulse of the suppression transmission. The suppression transmission pulse begins at a time 2 microseconds before the first pulse of the interrogation. The suppression pulse is transmitted at a power level lower than the accompanying interrogation so that the transponders that reply are only those that detect the interrogation but not the suppression. To guard against the possibility that some transponders do not reply to any interrogation in the sequence, the suppression pulse is transmitted at a power level somewhat lower than that of the next lower interrogation. The time interval between successive interrogations should be at least 1 millisecond. This ensures that replies from transponders at long range are not mistaken for replies to the subsequent interrogation. All interrogations in the sequence are transmitted within a single surveillance update interval.

3.6.2.3 Responses to each Mode C-only all-call interrogation are processed to determine the range and altitude code of each reply. It is possible to determine the altitude codes for up to three overlapping replies if care is taken to identify the location of each of the received pulses.

3.6.2.4 After all of the replies are received in response to the whisper/shout sequence, duplicate replies should be merged so that only one "report" is produced for each detected aircraft. Reports may be correlated in range and altitude with the predicted positions of known intruders (i.e. with existing tracks). Since intruding aircraft are interrogated at a high rate (nominally once per second), good correlation performance is achieved using range and altitude. Mode A code is not needed for correlation. Reports that correlate are used to extend the associated tracks. Reports that do not correlate with existing tracks may be compared to previously uncorrelated reports to start new tracks. Before a new track is started, the replies that lead to its initiation may be tested to ensure that they agree in all of the most significant altitude code bits. A geometric calculation may be performed to identify and suppress specular false targets caused by multipath reflections from the terrain.

3.6.2.5 Tracks being initiated may be tested against track validity criteria prior to being passed to the collision avoidance algorithms. The purpose of these tests is to reject spurious tracks caused by garble and multipath, i.e. image tracks as defined in 3.6.2.9.6. Spurious tracks are generally characterized by short track life.

3.6.2.6 Aircraft for any reason not reporting altitude in Mode C replies are detected using the Mode C reply framing pulses. These aircraft are tracked using range as the correlation criterion. The additional use of bearing for correlation will help to reduce the number of false non-Mode C tracks.

3.6.2.7 *Reply merging.* Multiple replies may be generated by a Mode A/C target during each whisper-shout sequence or by a target that responds to interrogations from both the top and bottom antennas. The equipment is expected to generate no more than one position report for any target even though that target may respond to more than one interrogation during each surveillance update interval.

3.6.2.8 *Mode A/C surveillance initiation.* The equipment will pass the initial position reports to the collision avoidance algorithms only if the conditions in a) and b) below are satisfied:

a) initially, a Mode C reply is received from the target in each of three consecutive surveillance update periods, and:

   1) the replies do not correlate with surveillance replies associated with other tracks;

   2) the range rate indicated by the two most recent replies is less than 620 m/s (1 200 kt);

   3) the oldest reply is consistent with the above range rate in the sense that its range lies within 95.3 m (312.5 ft) of a straight line passing through the two most recent replies;

   4) the replies correlate with each other in their altitude code bits;

b) a fourth correlating reply is received within five surveillance update intervals following the third reply of the three consecutive replies in a) above and is within ±60 m (±200 ft) of the predicted altitude code estimate determined in a) 4).

3.6.2.8.1 As an example, rules for assessing correlation of reply code bits (Annex 10, Volume IV, Chapter 3) and determining the initial altitude track code estimate for a target may depend on which of the D, A, B and C code pulses agree.

3.6.2.8.2 The test for code agreement among the three replies is made individually for each of the reply pulse positions. This test is based on the presence of code pulses alone; agreement occurs for a given reply pulse position if all three replies are detected with a ONE in the position or all three replies are detected with a ZERO in that position. The confidence associated with those pulse detections does not affect agreement.

3.6.2.8.3 However, the confidence associated with pulse detections does affect the determination of the initial altitude of new tracks. The confidence flag for a reply pulse position is set “low” whenever there exists another received reply (either real or phantom) that could have had a pulse within ±0.121 microsecond of the same position. Otherwise, the confidence flag is set “high”.

3.6.2.8.4 When agreement among the three replies does not occur for a given reply pulse position, the initial track pulse code estimate for that position is based on the values of the individual pulse codes and the confidence flags associated with those pulse codes in three replies.

3.6.2.8.5 When agreement fails for a given pulse position, the rules for estimating the initial track code for that position are based on the principle that "low" confidence ONES are suspect. The rules are as follows:

a) if in the most recent (third) reply the detected code for a given pulse position is "high" confidence or a ZERO, the initial track pulse code estimate for that position is the same as the code detected in that position in the most recent reply; and

b) if in the most recent reply the detected code for a given pulse position is a "low" confidence ONE, the initial track pulse code estimate for the position is the same as the code detected in that position in the second reply provided that was not also a "low" confidence ONE. If the second was also a "low" confidence ONE, the initial track pulse code estimate is the same as the code detected in that position in the first reply.

3.6.2.9 *Mode A/C surveillance extension*

3.6.2.9.1 *General.* The equipment should pass position reports for a target to the collision avoidance algorithms only if:

a) the track has not been identified as an image (see 3.6.2.9.6);

b) the reply altitudes occur within an altitude window of ±60 m (200 ft) centred on the altitude predicted from previous reply history; and

c) all replies used for threat assessment after the initiation procedure occur within a range window centred on the range predicted from previous reply history.

3.6.2.9.2 *Range correlation.* The following is an example of an acceptable set of rules for determining the size of the range window:

a) the tracks are processed individually in increasing range order with input range precision of at least 15 m (50 ft) and retained computational accuracy of at least 1.8 m (6 ft). Range is estimated and predicted by a recursive (alpha-beta) tracker with alpha of 0.67 and beta of 0.25;

b) after each surveillance update a new range measurement is available for each target. Since the measurement includes errors, it must be smoothed based on previous measurements to obtain improved estimates of the current target position and velocity. The range and range rate estimation equations are as follows:

$$r(t) \text{ estimate} = r(t) \text{ prediction} + [\text{alpha} \times (r(t) \text{ measurement} - r(t) \text{ prediction})]$$

$$\dot{r}(t) \text{ estimate} = \dot{r}(t - T_p) \text{ estimate} + [(\text{beta}/T_p) \times (r(t) \text{ measurement} - r(t) \text{ prediction})],$$

where T_p is the time difference between the current and previous measurements;

c) the gains, alpha and beta determine the relative degree of reliance on current and previous measurements; gains of unity would place complete reliance on the current measurement and result in no smoothing;

d) the estimates obtained from the above equations are subsequently used to predict the range at the time of the next measurement as follows:

$r(t + T_n)$ prediction = $r(t)$ estimate + [$\dot{r}(t)$ estimate $\times$ T_n]

where T_n is the time difference between the next measurement and the current measurement;

e) the range correlation window is centred at the predicted range and has a half-window width as follows:

760 ft if coasted last interval 570 ft if updated last interval	+	**if track is not established:** 0 **if track is established**: 2 000 ft, if 0.00 NM ≤ r < 0.17 NM 1 000 ft, if 0.17 NM ≤ r < 0.33 NM 600 ft, if 0.33 NM ≤ r < 1.00 NM 240 ft, if 1.00 NM ≤ r < 1.50 NM 0 ft, if 1.50 NM ≤r

f) if the track is above 3 050 m (10 000 ft), the term contained within the second pair of brackets is multiplied by four to account for higher speeds and accelerations.

3.6.2.9.3 *Altitude correlation.* For the purposes of altitude correlation, altitude is estimated and predicted by an alpha-beta tracker with alpha of 0.28 and beta of 0.06. The tracker has computational accuracy of 30 m (100 ft) divided by 16. The altitude prediction is rounded to the nearest 30 m (100 ft) increment and converted to grey code (Annex 10, Volume IV, Appendix to Chapter 3). The grey codes of the predicted altitude are also computed. The longer-term altitude predictions performed by the threat detection logic require a more accurate altitude tracking procedure (see 3.15.2). The reply (or replies) that lies in the range correlation window is tested for altitude correlation in increasing range order. The track is updated with the first reply that has exact agreement (in all bits) with any of the three grey codes computed above. If no reply matches, two additional grey codes ±60 m (200 ft) are computed and the process is repeated.

3.6.2.9.4 *Track updating — establishment.* The updating reply (if any) is eliminated from further consideration in updating other tracks, or in the track initiation process. If there is no updating reply, the range and altitude estimates are set equal to the corresponding predicted values. If this is the sixth consecutive interval having no updating reply, the track is dropped. If there is an updating reply, and if the track is not identified as an image (see 3.6.2.9.6), the track is flagged as established, that is, it is now available for use by the threat detection logic. Once established, a track remains established until it is dropped, even if it subsequently satisfies the conditions for an image track.

3.6.2.9.5 *Test for track splits.* When all tracks have been processed, they are combined with the tracks that are newly initiated during the current scan, and then all the tracks are examined pairwise to determine if a given pair of tracks is likely to represent the same intruder. That would be the case if:

a) the ranges differ by at most 150 m (500 ft);

b) the range rates differ by at most 4.6 m/s (8.9 kt); and

c) either:

1) the altitudes differ by at most 30 m (100 ft); or

2) the altitude rates differ by at most 3 m/s (10 ft/s) and both tracks were initiated during the same scan.

In such cases, only one of the tracks is retained, preference being given to the track showing the larger number of replies since initiation.

3.6.2.9.6 *Image track processing.* Those tracks that could have been formed by replies specularly reflected from the ground are referred to as image tracks. A track is identified as an image if there exists a track at shorter range (referred to as the real track) such that:

a) the difference between the real altitude and the image altitude is less than or equal to 60 m (200 ft) for altitude-reporting targets, or both the image track and the real track are non-altitude-reporting; and

b) the difference between the measured image range rate and the calculated image range rate is less than or equal to 21 m/s (40 kt), where the calculated image range rate is either (for the single-reflection case):

$$\dot{r}_i = \left(\frac{1}{2}\right)[\dot{r} + (\frac{1}{2r_i - r})\,[\,(\,(2r_i - r)^2 - r^2 + (Z_0 - Z)^2)^{\frac{1}{2}}\,(\dot{Z}_0 + \dot{Z}) + r\dot{r} - (Z_0 - Z)\,(\dot{Z}_0 - \dot{Z})\,]\,]$$

or (for the double-reflection case):

$$\dot{r}_i = \left(\frac{1}{r_i}\right)[(r_i^2 - r^2 + (Z_0 - Z)^2)^{\frac{1}{2}}\,(\dot{Z}_0 + \dot{Z}) + r\dot{r} - (Z_0 - Z)\,(\dot{Z}_0 - \dot{Z})]$$

where:

r_i is the image range,

r is the real range,

Z is the real altitude, for altitude-reporting targets (set to own altitude for non-altitude reporting targets), and

Z_0 is own altitude.

If a track is identified as an image, it may be retained, but it cannot be flagged as established for use by the threat detection logic.

3.6.2.10 *Missing Mode A/C reports.* The equipment continues to pass to the collision avoidance algorithms predicted position reports for Mode A/C targets for six surveillance update intervals following the receipt of the last valid correlating reply. The equipment does not pass position reports for more than six surveillance update intervals following the receipt of the last valid correlating reply unless the target again satisfies the surveillance initiation criteria of 3.6.2.8.

3.6.3 Surveillance of intruders with Mode S transponders

3.6.3.1 Efficient air-air surveillance techniques have been developed for intruders equipped with Mode S transponders. Because of Mode S selective address, there is no synchronous garble associated with surveillance of Mode S transponders. However, multipath must be dealt with and the surveillance of Mode S transponders should be accomplished with as few interrogations as possible to minimize interference.

3.6.3.2 The Mode S modulation formats are inherently more resistant to multipath than are the Mode A/C modulation formats. However, the greater length of the Mode S transmission makes it more likely to be overlapped by multipath. The use of top-mounted antennas and variable receiver thresholds (to protect the Mode S reply preamble) increases the multipath resistance to an acceptable level for reliable air-air surveillance. The use of antenna diversity transponders on ACAS aircraft provides an additional reliability margin for coordination between pairs of conflicting ACAS aircraft.

3.6.3.3 Mode S interrogation rates are kept low by passive detection of transponder transmissions and by interrogating once per second only those intruders that could become immediate threats as defined in 3.6.3.8.5. Intruders that are not likely to become immediate threats should be interrogated less frequently (i.e. once every 5 seconds). Passive address acquisition prevents unnecessary interference with other elements of the SSR and ACAS system. ACAS listens to Mode S all-call replies (DF = 11, acquisition squitter transmissions, Annex 10, Volume IV, Chapter 3). These may occur in response to Mode S ground station all-call interrogations or as spontaneous replies (called acquisition squitters) at intervals ranging from 0.8 to 1.2 seconds. Reception of squitters may be alternated between the top and bottom antennas. If reception is switched, it will be necessary to control the switching times to avoid undesirable synchronism with the squitters transmitted by Mode S antenna diversity transponders. The same applies if DF=17 (extended squitter) is used.

3.6.3.4 The 24-bit aircraft address in the squitter is protected by error coding to ensure a high probability of obtaining a correct address. Since the squitter transmission does not contain altitude information, ACAS attempts to obtain altitude passively from Mode S replies generated in response to ground interrogations or interrogations from other ACAS aircraft. If altitude is not received shortly after address detection, the Mode S aircraft is actively interrogated to obtain altitude.

3.6.3.5 After ACAS has determined the altitude of a detected Mode S aircraft, it compares the altitude of this aircraft to its own altitude to determine whether or not the target can be ignored or should be interrogated to determine its range and range rate. If the measured range and the estimated range rate indicate that it is (or could soon be) a collision threat, the intruder should be interrogated once per second and the resulting track data fed to the collision avoidance algorithms. Other aircraft within the surveillance range should be interrogated only as often as necessary to maintain track and ensure that it will be interrogated once per second before it becomes a collision threat (see Annex 10, Volume IV, Chapter 4).

3.6.3.6 The use of passive detection in combination with altitude comparison and a less frequent interrogation of non-threat intruders reduces the Mode S interrogation rate automatically when the local densities of other ACAS aircraft are very high. Therefore, a higher interrogation power level is available to improve surveillance performance.

3.6.3.7 *Mode S surveillance initiation*

3.6.3.7.1 The equipment is intended to provide Mode S surveillance with a minimum of Mode S interrogations. The identity of Mode S targets is determined by passively monitoring transmissions received with DF = 11 of DF = 17. Error detection is applied to the received squitters to reduce the number of addresses to be processed. The altitude of the Mode S targets from which a squitter has been received is determined by monitoring transmissions received with DF = 0 (short air-air surveillance replies, Annex 10, Volume IV, Chapter 3) or DF = 4 (surveillance altitude replies, Annex 10, Volume IV, Chapter 3). The equipment monitors squitter and altitude replies whenever it is not transmitting, or receiving replies to, Mode S or Mode C interrogations. Each received reply is examined to determine what further action should be taken.

3.6.3.7.2 To reduce the number of unnecessary interrogations, a squitter target is not interrogated if so few squitters and altitude replies are received from it that no threat is indicated (see 3.6.3.7.3). Targets that might be a threat are called valid targets. The equipment is not intended to interrogate a target unless the altitude information indicates that it is within 3 050 m (10 000 ft) of own altitude. The ACAS aircraft interrogates targets from which it does not receive altitude information but does continue to receive error-free squitters. In order to establish timely acquisition of targets that cross the 3 050 m (10 000 ft) relative altitude boundary, the altitude of targets that are beyond 3 050 m (10 000 ft) of own altitude are monitored using unsolicited DF = 0 or DF = 4 replies, or in the absence of such replies, by periodically interrogating with low frequency to elicit a DF = 0 reply.

3.6.3.7.3 The following is an example of one acceptable means of processing squitters and altitude replies to reduce unneeded interrogations:

a) when a valid squitter is first received, a running sum initialized at 0 is associated with it. During each succeeding surveillance update interval the sum is decremented by 1 if no squitters or altitude replies with a particular address are received, and the sum is incremented by 16 for each reception of either a squitter or an altitude reply. The process continues until the sum equals or exceeds 20. When the sum becomes less than or equal to –20, the address is removed from the system. When it equals or exceeds +20, the target is declared to be valid;

b) when a target has been declared to be valid, it is interrogated unless its altitude differed from the ACAS altitude by more than 3 050 m (10 000 ft). Otherwise, its altitude is monitored using DF = 0 or DF = 4 replies, or in the absence of such replies, by interrogating once every 10 seconds to elicit a DF = 0 reply; and

c) when any of these conditions are satisfied, the running sum continues to be incremented and decremented even though its value may exceed 20.

3.6.3.8 *Mode S range acquisition*

3.6.3.8.1 The equipment should transmit an air-to-air acquisition interrogation (UF = 0, 16, AQ = 1, Annex 10, Volume IV, Chapter 3) to determine the range of each valid target with relative altitude as defined above or from which inadequate altitude information has been received.

3.6.3.8.2 If an acquisition interrogation fails to elicit a valid reply, additional interrogations should be transmitted. The total number of acquisition interrogations addressed to a single target must not exceed three within a single surveillance update period. The first acquisition interrogation is to be transmitted using the top antenna. If two acquisition interrogations to a target fail to elicit valid replies, the next two acquisition interrogations to that target are to be transmitted using the bottom antenna. If in the acquisition attempt in the first surveillance update period, valid replies are not received, ACAS transmits a total of nine acquisition interrogations distributed over the first six successive surveillance update periods. If acquisition interrogations fail to elicit replies within six surveillance update intervals, the acquisition process is to cease until enough additional squitters/FRUIT are received to indicate that a successful acquisition is likely. One means of accomplishing this is to process subsequent squitters/FRUIT as described in 3.6.3.7.3, but with the increment 16 replaced by 8. If a second failure to acquire occurs, the process is repeated with an increment of 4. After any subsequent failure, an increment of 2 is used.

3.6.3.8.3 If additional attempts are made to acquire the target, they conform to the pattern described above except that:

a) on the second and third attempts, only one interrogation is to be made during a single surveillance update interval; and in the absence of valid replies, six interrogations are to be transmitted during the first six surveillance update intervals; and

b) any further attempts consist of a single interrogation during the entire six update intervals.

3.6.3.8.4 When a valid acquisition reply is received, the VS field in the reply is examined to determine the vertical status of a target. If a Mode S target is determined to be on the ground, its vertical status is periodically monitored by interrogating as often as necessary to ensure timely acquisition when airborne. If an ACAS target is determined to be on the ground, its range is measured by active interrogations once every five seconds for use in interference limiting. Tracks of targets that are determined to be on the ground should not be passed to the collision avoidance logic. When a valid acquisition reply is received from an airborne target, one or more interrogations are to be transmitted to the target within two surveillance update intervals in order to confirm the reliability of the altitude data and the altitude quantization bit. When two replies have been received from an airborne target that have altitude values within 150 m (500 ft) of each other and within 3 050 m (10 000 ft) of own altitude and have identical quantization bit values, periodic surveillance interrogations (designated as “tracking” interrogations) are to be initiated for that target.

3.6.3.8.5 The range of the target is used with its calculated range rate to estimate the immediacy of any collision. If collision with the target is not immediate, the target can be interrogated less frequently than if it might soon be a potential threat for which an advisory would have to be issued. Each 1-second surveillance update interval, an estimated time to collision (TAU) for the target is calculated as follows:

$$TAU = -\left(r - SMOD^2 / r\right) / \dot{r}$$

where r is the tracked range, $\dot{r}$ is the estimated relative range rate and SMOD is a surveillance distance modifier which is equivalent to 5.6 km (3 NM). If the estimated relative range rate is either a negative value of less than –6 kt or positive (either a slow convergence or the aircraft are diverging), the $\dot{r}$ value used to calculate *TAU* is –6 kt. An *SMOD* value of 5.6 km ensures that ACAS will always use the nominal 1-second interrogation cycle in situations where the value of *TAU* can change rapidly, such as in a parallel approach. A target with a *TAU* value of equal to or less than 60 seconds is interrogated at the nominal rate of once every second. A target with a *TAU* value greater than 60 seconds is interrogated at a rate of once every five seconds if the altitude of the target and own aircraft are both less than 5 490 m (18 000 ft) and at a rate of at least once every five seconds if the altitude of the target or own aircraft is greater than 5 490 m (18 000 ft).

3.6.3.9 *Mode S surveillance extension*

3.6.3.9.1 The equipment passes position reports for a Mode S target to the collision avoidance algorithms only if:

- all replies used for threat assessment after the initial range acquisition occur within range and altitude windows centred on range and altitude predicted from previous reply history;
- the altitude quantization bit matches the previous value; and
- the VS field in the short special surveillance reply indicates the target to be airborne at least once during the previous three surveillance update cycles.

The range and altitude windows are the same as those used for Mode A/C tracking in 3.6.2.9.2 and 3.6.2.9.3, respectively.

3.6.3.9.2 If a tracking interrogation fails to elicit a valid reply, additional interrogations are transmitted. The total number of tracking interrogations addressed to a single target is not expected to exceed five during a single surveillance update period or sixteen distributed over six successive surveillance update periods. The first tracking interrogation is transmitted using the antenna that was used in the last successful interrogation of that target. If two successive tracking interrogations fail to elicit valid replies from a target, the next two interrogations to that target are transmitted using the other antenna.

3.6.3.10 *Missing Mode S replies.* The equipment continues to pass to the collision avoidance algorithms predicted position reports for Mode S targets for six surveillance update intervals following the receipt of the last valid reply to a tracking interrogation if the target is interrogated once every second, or for eleven 1-second surveillance update intervals following receipt of the last valid reply to a tracking interrogation if the target is interrogated once every five seconds. The equipment does not pass position reports for Mode S targets for more than six surveillance update intervals following the receipt of the last reply to a tracking interrogation whose rate is once every second or for more than ten 1-second surveillance update intervals following receipt of the last reply to a tracking interrogation whose rate is once every five seconds unless the target again satisfies the range acquisition criteria of 3.6.3.8. The Mode S address of a dropped track is retained for four additional seconds to shorten the reacquisition process if squitters are received.

3.6.3.11 *Mode S overload.* The equipment passes position reports for all Mode S targets regardless of the distribution of targets in range, provided the total peak target count does not exceed 30.

3.6.3.12 *Mode S power programming.* The transmit power level of Mode S tracking interrogations to targets (but not air-to-air coordination interrogations) is to be automatically reduced as a function of range for targets within 18.5 km (10 NM) as follows:

$$P_T = P_{\max} + 20 \log \frac{r}{10}$$

where P_T is the adjusted power level, P_{max} is the nominal power level (typically 250 W), which is transmitted to targets at ranges of 18.5 km (10 NM) or more, and r is the predicted range of the target. The actual transmitted power is the lesser of P_T and the limit imposed by the interference limiting inequalities of Annex 10, Volume IV, Chapter 4, 4.3.2.2.2.2.

3.6.3.13 *Mode S track capacity*. When the aircraft density is nominally 0.087 Mode S aircraft per km^2 (0.3 aircraft per NM^2) in the vicinity of the ACAS aircraft, there will be about 24 aircraft within 9.3 km (5 NM) and about 142 aircraft within 56 km (30 NM) of the ACAS aircraft. Thus, the ACAS equipment is expected to have capacity for at least 150 aircraft addresses.

3.6.3.14 *Use of bearing estimates for Mode S surveillance.* Bearing estimation capability is not required for high-density Mode S surveillance. However, if bearing estimates are available, it is seen that the use of directional Mode S interrogations significantly reduces the transmitter power requirement of the equipment. Directional Mode S interrogations may also be used in the absence of bearing information, provided the interference limits are not exceeded.

3.7 TRANSMITTER

3.7.1 Power levels

3.7.1.1 In the absence of interference and when using an antenna whose pattern is identical to that of a quarter-wave monopole above a ground plane, it is possible to provide reliable air-to-air surveillance of transponders at ranges of 26 km (14 NM) by using a nominal effective radiated power of 54 dBm (250 W).

3.7.1.2 The transmitter output power is to be carefully limited between transmissions because any leakage may severely affect the performance of the Mode S transponder on board the ACAS aircraft. The leakage power into the transponder at 1 030 MHz is generally to be kept at a level below –90 dBm. If the physical separation between the transponder antenna and the ACAS antenna is no less than 50 cm, the coupling loss between the two antennas will exceed 20 dB. Thus, if the radio frequency (RF) power at 1 030 MHz at the ACAS antenna terminal does not exceed –70 dBm in the inactive state, and if a minimum antenna spacing of 50 cm is adhered to, the direct interference from the ACAS antenna to the transponder antenna will not exceed –90 dBm. This requirement is to ensure that, when not transmitting an interrogation, ACAS does not radiate RF energy that could interfere with, or reduce the sensitivity of, the SSR transponder or other radio equipment in nearby aircraft or ground facilities.

3.7.1.3 Measures must also be taken to ensure that direct 1 030 MHz leakage from the ACAS enclosure to the transponder enclosure is below –110 dBm when the two units are mounted side-by-side in a typical aircraft installation.

3.7.1.4 It is expected that the ACAS equipment be tested side-by-side with Mode S transponders of equivalent classification to ensure that each unit meets its sensitivity requirements in the presence of transmitter leakage from the other.

3.7.2 Control of synchronous interference by whisper-shout

3.7.2.1 To control Mode A/C synchronous interference and facilitate ACAS operation in airspace with higher traffic densities, a sequence of interrogations at different power levels may be transmitted during each surveillance update period. Each of the interrogations in the sequence, other than the one at lowest power, is preceded by a suppression pulse (designated S_1) two microseconds preceding the P_1 pulse. The combination of S_1 and P_1 serves as a suppression transmission. S_1 is transmitted at a power level lower than that of P_1. The minimum time between successive interrogations is to be 1 millisecond. All interrogations in the sequence should be transmitted within a single surveillance update interval.

3.7.2.2 Because the suppression transmission in each step is always at a lower power level than the following interrogation, this technique is referred to as whisper-shout. The intended mechanism is that each aircraft replies to only one or two of the interrogations in a sequence. A typical population of Mode A/C transponders at any given range may have a large spread in effective sensitivity due to variation in receivers, cable losses and antenna shielding. Ideally, each transponder in the population will respond to two interrogations in the sequence and will be turned off by the higher power suppression transmissions accompanying higher-power interrogations in the sequence. Given a situation in which several aircraft are near enough to each other in range for their replies to synchronously interfere, it is unlikely they would all reply to the same interrogation and, as a result, the severity of synchronous interference is reduced. Use of whisper-shout also reduces the severity of the effects of multipath on the interrogation link.

3.7.2.3 Figure 3-2a defines a whisper-shout sequence that is matched to the requirements for high-density Mode A/C surveillance, and Figure 3-2b defines a whisper-shout sequence that is matched to the requirements for low-density Mode A/C surveillance. Five distinct subsequences are defined; one for each of the four beams of the top-mounted antenna and one for the bottom-mounted omnidirectional antenna. The interrogations may be transmitted in any order. When the high-density sequence of Figure 3-2a is truncated to limit interference, the steps are dropped in the order shown in the column “Interference Limiting Priority”. When the low-density sequence of Figure 3-2b is reduced in power to limit interference, each interrogation and its related minimum triggering level (MTL) value, as indicated in the last column, is reduced by 1 dB in the order shown in the column “Interference Limiting Priority”. The lowest numbered steps in the sequence are dropped or reduced first. The timing of individual pulses or steps in either sequence is defined in Figure 3-3 which illustrates the three lowest-power steps in the top-forward antenna sequence. The first pulse of the interrogation serves as the second pulse of the suppression.

3.7.2.4 The MTL values tabulated in Figure 3-2a and Figure 3-2b are based on the assumption that replies to all interrogations are received omnidirectionally. If a directional-receive antenna is used, the MTL values must be adjusted to account for the antenna gain. For example, for a net antenna gain of 3 dB, all MTL values in the table would be raised by 3 dB; and the MTL for step number 1 would be –71 dBm rather than –74 dBm.

3.7.2.5 The power is defined as the effective radiated power for the interrogation. All power levels are to be within ±2 dB of nominal. The tolerance of the step increments is to be ±1/2 dB, and the increments are to be monotonic throughout the entire power range of the sequence.

3.7.2.6 Most of the interrogations are transmitted from the top antenna because it is less susceptible to multipath interference from the ground.

3.7.2.7 Selection of the appropriate whisper-shout sub-sequence for a particular antenna beam is performed each interrogation cycle based on the current or anticipated level of Mode A/C synchronous garble in that beam as determined by ACAS surveillance. The high-density whisper-shout sub-sequence is selected for an antenna beam whenever synchronous garble is present in that beam as evident from the existence of at least one low-confidence altitude code bit in two consecutive Mode C replies. The 6-level whisper-shout sequence is selected for an antenna beam if either:

a) a single Mode A/C aircraft exists within the surveillance range of that beam and synchronous garble is not present; or

b) synchronous garble is not present, Mode A/C targets are not within garble range of each other, and the Mode A/C aircraft density within the reliable surveillance range is equal to or less than 0.23 aircraft/km (0.43 aircraft/NM). Whenever a TA is generated on a threat within a particular antenna beam, the high-level sequence is used for that beam for the duration of the advisory. Whenever an RA is generated, the high-level sequence is used for all antenna beams for the duration of the advisory.

Step number	Sequence	Minimum effective radiated interrogation power (dBm)	Interference limiting priority	MTL (-dBm)
1	S··I	52	1	74
2	S·I	51	5	74
3	S··I	50	9	74
4	S·I	49	13	74
5	S··I	48	17	74
6	S·I	47	21	74
7	S··I	46	25	74
8	S·I	45	29	73
9	S··I	44	33	72
10	S·I	43	37	71
11	S··I	42	41	70
12	S·I	41	45	69
13	S··I	40	49	68
14	S·I	39	53	67
15	S··I	38	57	66
16	S·I	37	61	65
17	S··I	36	64	64
18	S·I	35	67	63
19	S··I	34	70	62
20	S·I	33	73	61
21	S··I	32	76	60
22	S·I	31	77	59
23	S··I	30	78	58
24	···I	29	79	57
25, 26	S··I	48	2, 3	74
27, 28	S·I	47	6, 7	74
29, 30	S··I	46	10, 11	74
31, 32	S·I	45	14, 15	73
33, 34	S··I	44	18, 19	72
35, 36	S·I	43	22, 23	71
37, 38	S··I	42	26, 27	70
39, 40	S·I	41	30, 31	69
41, 42	S··I	40	34, 35	68
43, 44	S·I	39	38, 39	67
45, 46	S··I	38	42, 43	66
47, 48	S·I	37	46, 47	65
49, 50	S··I	36	50, 51	64
51, 52	S·I	35	54, 55	63
53, 54	S··I	34	58, 59	62
55, 56	S·I	33	62, 63	61
57, 58	S··I	32	65, 66	60
59, 60	S·I	31	68, 69	59
61, 62	S··I	30	71, 72	58
63, 64	···I	29	74, 75	57

Steps 1–24: Top antenna, Forward direction

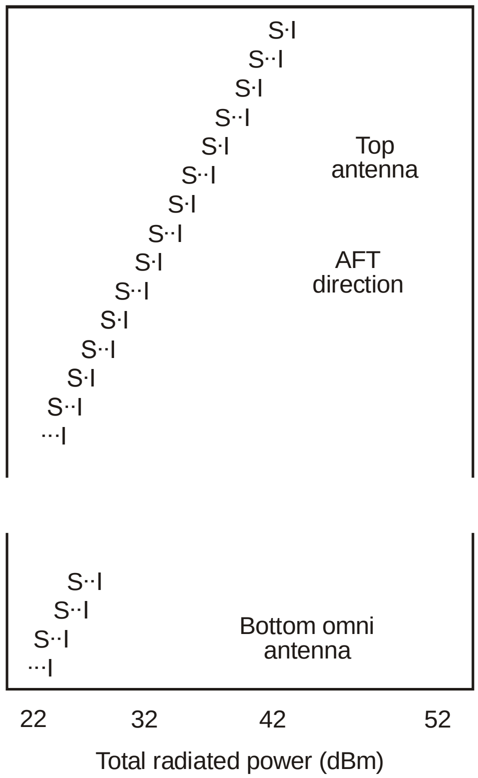
Steps 25–64: Top antenna, Left and right directions

22 32 42 52

Effective Radiated Power (dBm)

Figure 3-2a. Example of high-density whisper-shout sequence

Step number	Minimum effective radiated interrogation power (dBm)	Interference limiting priority	MTL (-dBm)
	43	4	71
65	42	8	70
66	41	12	69
67	40	16	68
68	39	20	67
69	38	24	66
70	37	28	65
71	36	32	64
72	35	36	63
73	34	40	62
74	33	44	61
75	32	48	60
76	31	52	59
77	30	56	58
78	29	60	57
79			
80	34	80	62
81	32	81	60
82	30	82	58
83	28	83	56



Notes:

"I" indicates ERP of P_1, P_3 and P_4 interrogation pulses.

"S" indicates ERPof S_1 suppression pulse.

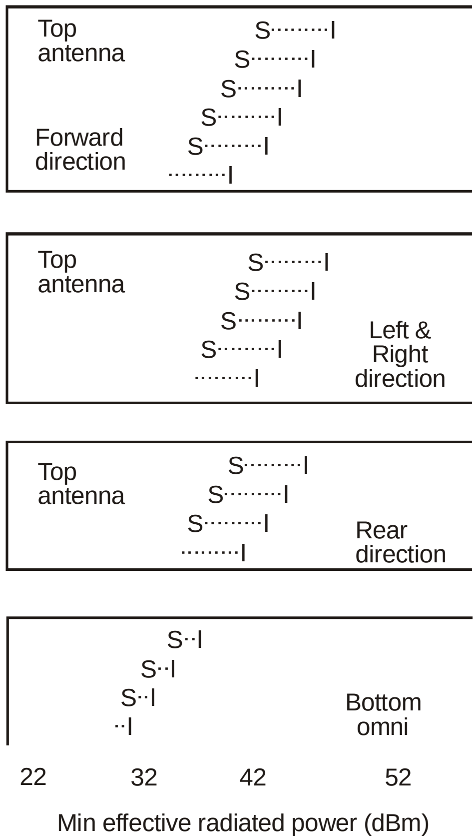
"S·I" means that the S_1 ERP is 2 dB less than the interrogation ERP.

"S··I" means that the S_1 ERP is 3 dB less than the interrogation ERP.

All transmissions are from the top antenna, unless labelled "bottom".

In steps 24, 63, 64, 79 and 83 no S_1 pulses are transmitted.

Figure 3-2a. Example of high-density whisper-shout sequence (cont.)



Step number	Minimum effective radiated interrogation power (dBm)	Interference limiting priority	MTL (-dBm)
1	52	Note: Each 1 dB reduction in the sequence follows the priority for the forward beam in Figure A-2a.	74
2	48		74
3	44		72
4	40		68
5	36		64
6	32		60
7, 8	52	Note: Each 1 dB reduction in the sequence follows the priority for the forward beam in Figure A-2a.	74
9, 10	48		74
11, 12	44		72
13, 14	40		68
15, 16	36		64
	32		60
17	43	Note: Each 1 dB reduction in the sequence follows the priority for the rear beam in Figure A-2a.	71
18	39		67
19	35		63
20	31		59
16	34	Note: Each 1 dB reduction in the sequence follows the priority for the bottom beam in Figure A-2a.	62
17	32		60
18	30		58
19	28		56

Notes:

"I" indicates ERP of P_1, P_3 and P_4 interrogation pulses.

"S" indicates ERPof S_1 suppression pulse.

"S··I" means that the S_1 ERP is 3 dB less than the interrogation ERP.

"S·········I" means that the S_1 ERP is 10 dB less than the interrogation ERP.

In the last steps of each quadrant no S_1 pulses are transmitted.

Figure 3-2b. Example of low-density whisper-shout sequence

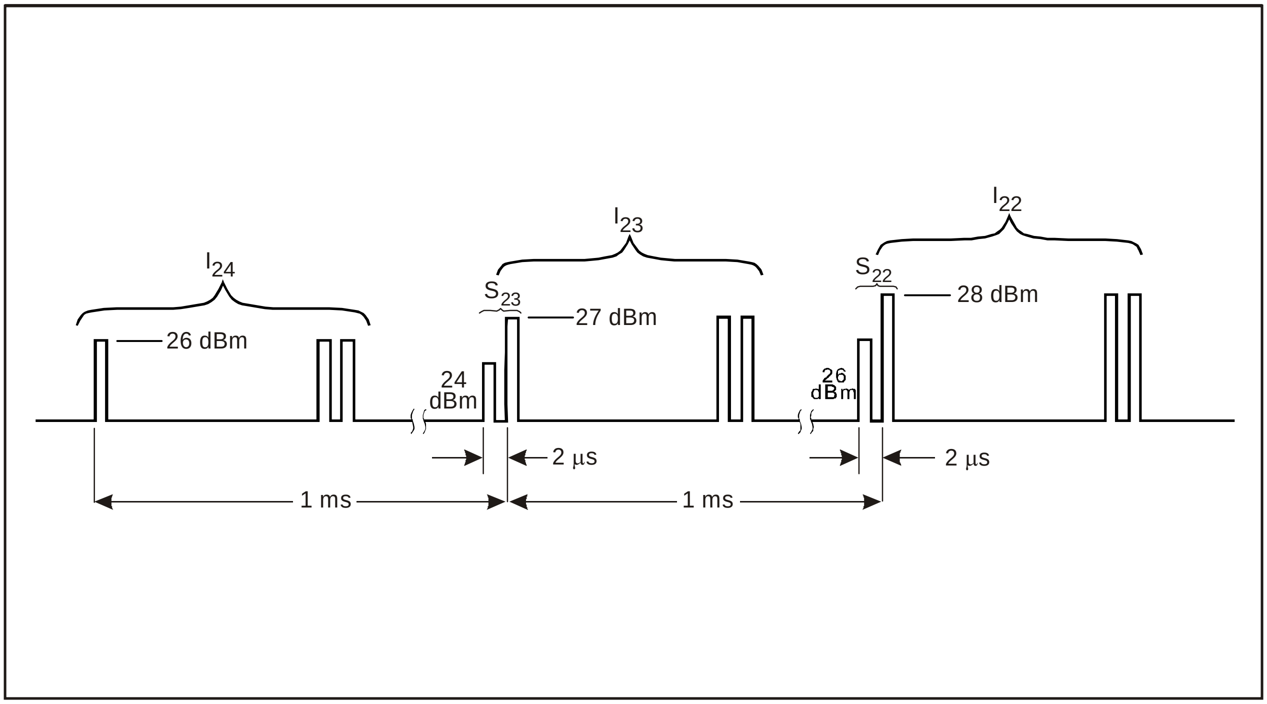


Figure 3-3. Example of timing for lowest power steps in omnidirectional whisper-shout sequence for top antenna

3.7.2.8 If no established Mode A/C surveillance track nor any candidate track, consisting of three correlating Mode C acquisition replies, exists within the surveillance range of an antenna beam, degarbling is unnecessary and ACAS transmits a single Mode C interrogation in that beam. The power level of the single interrogation and its associated MTL in each beam is equivalent to the highest allowable power level of the corresponding low-level whisper-shout sub-sequence as determined by interference limiting. Single Mode C interrogations are susceptible to uplink Mode conversion due to multipath and may result in a mixture of Mode A and Mode C replies from an intruder that are separated by 13 microseconds. ACAS, therefore, selects the low-level whisper-shout sub-sequence for a beam for reliable surveillance acquisition and tracking whenever:

a) a single interrogation in that beam results in a Mode A/C reply that occurs within a 1 525 m (5 000 ft) range window centred either at the measured range of a Mode A/C reply received in the previous surveillance update interval or at a range offset from the previous reply range by ±13 microseconds; or

b) an established Mode C track or a Mode C track in the process of being acquired traverses into that beam from another beam. ACAS switches back to the single interrogation after ten surveillance update intervals in which two correlating acquisition replies were not received.

3.7.3 Interference limiting

3.7.3.1 ACAS equipment conforms to a set of three specific inequalities for controlling interference effects. These three inequalities, shown below, apply to ACAS operating below a pressure altitude of 5 490 m (18 000 ft) and are associated with the following physical mechanisms: 1) reduction in "on" time of other transponders caused by ACAS interrogations; 2) reduction in "on" time of own transponder caused by mutual suppression during transmission of interrogations; and 3) Mode A/C FRUIT caused by ACAS Mode A/C interrogations. Setting n_a to 1 in inequalities 1) and 3) for ACAS operating above pressure altitude of 5 490 m (18 000 ft) prevents a single ACAS from transmitting unlimited power by providing an upper limit on the ACAS one-second interrogation power/rate product.

$$\left\{ \sum_{i=1}^{i_t} \left[\frac{p(i)}{250} \right]^{\alpha} \right\} < \min \left[\frac{280}{1+n_a}, \frac{11}{\alpha^2} \right] \qquad (1)$$

$$\left\{ \sum_{i=1}^{i_t} m(i) \right\} < 0.01 \qquad (2)$$

$$\left\{ \frac{1}{B} \sum_{k=1}^{k_t} \left[\frac{P_a(k)}{250} \right] \right\} < \min \left[\frac{80}{1+n_a}, 3 \right] \qquad (3)$$

The variables in these inequalities shall be defined as follows:

i_t = number of interrogations (Mode A/C and Mode S) transmitted in a 1 s interrogation cycle;

i = index number for Mode A/C and Mode S interrogations, $i = 1, 2, ..., i_t$;

= the minimum of α_1 calculated as 1/4 [n_b /n_c] subject to the special conditions given below and α_2 calculated as Log_{10} [n_a / n_b] / Log_{10} 25, where n_b and n_c are defined as the number of operating ACAS II- and ACAS III-equipped aircraft (airborne or on the ground) within 11.2 km (6 NM) and 5.6 km (3 NM), respectively, of own ACAS (based on ACAS surveillance). ACAS aircraft operating at or below a radio altitude of 610 m (2 000 ft) AGL shall include both airborne and on-ground ACAS II and ACAS III aircraft in the value for n_b and n_c. Otherwise, ACAS shall include only airborne ACAS II and ACAS III aircraft in the value for n_b and n_c. The value of α is further constrained to a minimum of 0.5 and a maximum of 1.0.

In addition:

IF [($n_b \le 1$) OR ($n_b > 4n_c$) OR ($n_b \le 4$ AND $n_c \le 2$ AND $n_a > 25$)] THEN $\alpha_1 = 1.0$,
IF [($n_c > 2$) AND ($n_b > 2n_c$) AND ($n_a < 40$)] THEN $\alpha_1 = 0.5$;

p(i) = peak power radiated from the antenna in all directions of the pulse having the largest amplitude in the group of pulses comprising a single interrogation during the i^{th} interrogation in a 1 s interrogation cycle, W;

m(i) = duration of the mutual suppression interval for own transponder associated with the i^{th} interrogation in a 1 s interrogation cycle, s;

B = beam sharpening factor (ratio of 3 dB beamwidth-to-beamwidth resulting from interrogation side-lobe suppression). For ACAS interrogators that employ transmitter side-lobe suppression (SLS), the appropriate beamwidth shall be the extent in azimuth angle of the Mode A/C replies from one transponder as limited by SLS, averaged over the transponder population;

{ } see Annex 10, Volume IV, Chapter 4, 4.2.3.3.3
$P_a (k)$ see Annex 10, Volume IV, Chapter 4, 4.2.3.3.3
k see Annex 10, Volume IV, Chapter 4, 4.2.3.3.3
k_t see Annex 10, Volume IV, Chapter 4, 4.2.3.3.3
n_a see Annex 10, Volume IV, Chapter 4, 4.2.3.3.3

3.7.3.2 Inequality (1) ensures that a “victim” transponder will never detect more than 280 ACAS interrogations in a one-second period from all the ACAS interrogators within 56 km (30 NM) for any ACAS distribution, surrounding the “victim” transponder, within the limits of uniform-in-range to uniform-in-area. The left-hand side of the inequality allows an ACAS unit to increase its interrogation rate if it transmits at less than 250 W since low-power transmissions are detected by fewer transponders. Each normalized power value within the summation in the left-hand side of this inequality contains an exponent α, which serves to match the inequality to the localized ACAS distribution. The value of α defines the local ACAS aircraft distribution curve and is derived from own ACAS measurement of the distribution and number of other ACAS within 56 km (30 NM) range. As the ACAS distribution varies from uniform-in-area (α = 1) to uniform-in-range (α = 0.5), the density, and therefore the electromagnetic impact, of ACAS aircraft in the vicinity of a “victim” transponder becomes greater. This increased potential for ACAS interference is offset by the greater degree of interference limiting that results from using an exponent of less than one in the normalized power values of the inequality. The denominator of the first term on the right-hand side of this inequality accounts for other ACAS interrogators in the vicinity and the fact that all ACAS units must limit their interrogation rate and power in a similar manner so that, as the number of ACAS units in a region increases, the interrogation rate and power from each of them decreases, and the total ACAS interrogation rate for any transponder remains less than 280 per second.

3.7.3.3 Within an airspace in which ACAS aircraft are distributed between the limits of uniform-in-range to uniform-in-area, and provided that the “victim” is taken off the air for 35 microseconds by suppression or reply dead time whenever it receives an ACAS interrogation, the total “off” time caused by ACAS interrogations will then never exceed 1 per cent. Measurements and simulations indicate that the total “off” time can be higher than 1 per cent in high-density terminal areas because of ACAS aircraft distributions that are beyond the region defined by uniform-in-area to uniform-in-range and because of a Mode S transponder recovery time to certain interrogations that is expected to be greater than 35 microseconds. The second term on the right-hand side of this inequality limits the maximum value of the interrogation power-rate product for ACAS II, regardless of n_a, in order to allow a portion of the total interference limiting allocation to be used by ACAS I. The term, which is matched to the ACAS distribution by the value of α in the denominator, ensures that an individual ACAS II unit never transmits more average power than it would if there were approximately 26 other ACAS II nearby distributed uniformly-in-area or approximately 6 other ACAS II nearby distributed uniformly-in-range.

3.7.3.4 Inequality (2) ensures that the transponder on board the ACAS aircraft will not be turned off by mutual suppression signals from the ACAS unit on the same aircraft more than 1 per cent of the time.

3.7.3.5 Inequality (3) ensures that a “victim” Mode A/C transponder will not generate more than 40 Mode A/C replies in a one-second period in response to interrogations from all the ACAS interrogators within its detection range. Like inequality (1) it includes terms to account for reduced transmit power, to account for the other ACAS interrogators in the vicinity, and to limit the power of a single ACAS unit. Forty Mode A/C replies per second is approximately 20 per cent of the reply rate for a transponder operating without ACAS in a busy area of multiple Mode A/C ground sensor coverage.

3.7.3.6 *Example of interference limiting*

3.7.3.6.1 As an example, when interrogation limiting is not invoked, the overall Mode A/C and Mode S interrogation rates of a directional ACAS unit would typically be as follows: the Mode A/C interrogation rate k_t is typically constant at 83 whisper-shout interrogations per second. Assume that the sum of the normalized whisper-shout powers, i.e. the Mode A/C contribution to the left-hand side of inequality (1), is approximately 3. The Mode S interrogation rate depends on the number of Mode S aircraft in the vicinity. In en-route airspace it is typically an average of about 0.08 interrogations per second for each Mode S aircraft within 56 km (30 NM). In a uniform aircraft density of 0.006 aircraft per square km (0.02 aircraft per square NM), the number of aircraft within 56 km (30 NM) is 57. If 20 per cent of these are ACAS-equipped, n_a = 12 and the variable term on the right-hand side of inequality (1) is 21.5. If the number of ACAS aircraft in the area does not exceed 26, the fixed term continues to govern and no limiting occurs until there are approximately 100 Mode S aircraft within 56 km (30 NM).

3.7.3.6.2 Similar considerations hold for inequalities (2) and (3). In inequality (2) the mutual suppression interval associated with each top antenna interrogation is 70 microseconds. The bottom antenna mutual suppression interval is 90 microseconds. Thus the Mode A/C contribution to the left-hand side of inequality (2) is 0.0059 and the Mode S interrogation rate can be as high as 59 top antenna interrogations per second before violating the limit. With a typical whisper-shout sequence, the left-hand side of inequality (3) is approximately 3. The number of ACAS aircraft within 56 km (30 NM) can be as high as 26 without violating inequality (3).

3.7.3.6.3 When the interrogation rate or density increases to the point at which one of the limits is violated, either the Mode A/C or Mode S normalized interrogation rate or both must be reduced to satisfy the inequality. If the density were to reach 0.029 aircraft per km^2 (0.1 aircraft per NM^2) uniformly out to 56 km (30 NM), there would be 283 aircraft within a 56 km (30 NM) radius. If 10 per cent of these were equipped with ACAS, n_a = 28. The right-hand limits in inequalities (1) and (3) would then be 9.66 and 2.76, respectively. To satisfy these lower limits, the Mode A/C and Mode S contributions to the left-hand side of inequality (1) would both have to be reduced. As a result, the surveillance range of both Mode A/C and Mode S targets would be less.

3.7.3.6.4 Inequality (1) contains an exponent α which serves to match the inequalities to the specific local ACAS aircraft density such that a “victim” transponder operating in the vicinity of ACAS that are distributed within the limits of uniform-in-area to uniform-in-range will never detect more than 280 ACAS interrogations in a one-second period.

3.7.3.6.5 The value of α defines the local ACAS distribution characteristic within the vicinity of own ACAS.

It is based on the relative numbers of ACAS within 56 km (30 NM), within 11.2 km (6 NM) and within 5.6 km (3 NM) as derived from ACAS broadcast interrogations and from ACAS surveillance. The value of α is the minimum of:

a) the logarithm of the ratio of the number of ACAS aircraft, n_a, within 56 km (30 NM) to the number of ACAS aircraft, n_b, within 11.2 km (6 NM) divided by the logarithm of 25; and

b) one fourth of the ratio of the number of ACAS aircraft, n_b, within 11.2 km (6 NM) to the number of ACAS aircraft, n_c, within 5.6 km (3 NM).

A uniform-in-area distribution of ACAS aircraft within 56 km results in an α value of 1.0 and a uniform-in-range distribution results in a value of 0.5. Since decreasing values of α result in greater power reduction and therefore shorter surveillance ranges, the minimum value of α is constrained to 0.5 in order to preserve adequate surveillance range for collision avoidance in the highest-density terminal areas. Additional constraints are imposed on the value of α_1 to account for special situations in which the measured local ACAS distribution is:

1) based on numbers so small as to be inconclusive (n_b = 1), in which case α_1 is constrained to 1;

2) inconsistent with a relatively high overall ACAS count ($n_b \le 4$, $n_c \le 2$, $n_a > 25$), in which case α_1 is constrained to 1; or

3) inconsistent with a relatively low overall ACAS count,($n_c > 2$, $n_b > 2n_c$, $n_a < 40$), in which case α_1 is constrained to 0.5.

3.7.3.7 *Interference limiting procedures*

3.7.3.7.1 At the beginning of each surveillance update interval, n_a, n_b and n_c are to be determined as indicated above. n_a is then used to evaluate the current right-hand limits in inequalities (1) and (3). Smoothed values of the Mode S variables in the inequalities are also to be calculated.

n_b and n_c are used to compute the value of α_1 according to the following expression:

$$\alpha_1 = 1/4\ [n_b/n_c].$$

n_a and n_b are used to compute the value of a α_2 according to the following expression:

$$\alpha_2 = \frac{\text{Log}_{10}\left[n_a / n_b\right]}{\text{Log}_{10}\ 25}$$

In addition:

IF [($n_b \le 1$) OR ($n_b > 4n_c$) OR ($n_b \le 4$ AND $n_c \le 2$ AND $n_a > 25$)] THEN $\alpha_1 = 1.0$;
IF [($n_c > 2$) AND ($n_b > 2n_c$) AND ($n_a < 40$)] THEN $\alpha_1 = 0.5$;
IF ($n_a > 25n_b$) THEN $\alpha_2 = 1.0$;
IF ($n_a < 5n_b$) THEN $\alpha_2 = 0.5$;
the value of α is the minimum of α_1 and α_2.

3.7.3.7.2 All air-to-air coordination interrogations and RA and ACAS broadcast interrogations are transmitted at full power. Air-to-air coordination interrogations and RA and ACAS broadcast interrogations are not included in the summations of Mode S interrogations in the left-hand terms of these inequalities. Whenever an RA is posted, surveillance interrogations to that intruder may be transmitted at full power to allow for maximum link reliability. Because the frequency of RAs is very low, these transmissions do not result in a measurable increase in interference.

3.7.3.7.3 If the smoothed value of the left-hand side of either inequality (1) or (2) equals or exceeds the current limit and own ACAS aircraft are operating below a pressure altitude of 5 490 m (18 000 ft), both the Mode S and Mode A/C surveillance parameters are to be modified to satisfy the inequalities. If the left-hand side of inequality (3) exceeds the current limit and own ACAS aircraft are operating below a pressure altitude of 5 490 m (18 000 ft), Mode A/C surveillance parameters are modified to satisfy the inequalities.

3.7.3.7.4 Mode A/C surveillance can be modified by sequentially eliminating steps from the whisper-shout sequence described in 3.7.2. Each whisper-shout step is uniquely associated with a receiver MTL setting. Thus, the receiver sensitivity in Mode A/C surveillance periods will be automatically tailored to match these power reductions.

3.7.3.7.5 The overall surveillance sensitivity for Mode S targets can be reduced by reducing the interrogation power and by increasing the receiver MTL during all Mode S squitter listening periods. This will indirectly reduce the Mode S interrogation rate by reducing the target count. Many Mode S interrogations are acquisition interrogations transmitted to targets of unknown range. It is thus not effective to directly control the Mode S interrogation rate simply by dropping long-range targets from the track file.

3.7.3.7.6 For airborne ACAS, the Mode A/C and Mode S surveillance power and sensitivity reductions are to be accomplished such that equality between the surveillance ranges for Mode S and Mode A/C targets exists in the forward beam. In order to provide a reliable 11.2 km (6 NM) surveillance range in all directions for n_b, the maximum allowed interference limiting power reduction in any beam for an airborne ACAS unit is 10 dB for Mode S and 7 dB for Mode A/C. Mode A/C surveillance power and sensitivity reductions for ACAS on the ground are to be accomplished such as to achieve equal whisper-shout capability in each beam. This requires that Mode A/C power and sensitivity reduction be accomplished in the forward beam until it is equivalent to the side beams and then in the forward and side beams until they are equivalent to the rear beam. In order to provide a reliable 5.6 km (3 NM) surveillance range in all directions for surveillance prior to departure, the maximum allowed interference limiting power reduction for an ACAS unit on the ground is as follows:

a) forward beam: 13 dB for Mode S and 10 dB for Mode A/C;

b) side beam: 13 dB for Mode S and 6 dB for Mode A/C; and

c) rear beam: 13 dB for Mode S and 1 dB for Mode A/C.

In addition, the Mode A/C and Mode S surveillance power and sensitivity reductions for ACASs that are airborne or on the ground are to be accomplished such that the ACAS equipment is not prematurely limited and has the capability of using at least 75 per cent of the allowance specified in the three limiting equations for all mixes of target types and for all densities up to the maximum density capability of the system. When the value of any of the smoothed limits is exceeded, the appropriate action is required to limit interference within one surveillance update interval. Means are to be provided for gradually restoring the surveillance sensitivity when the environment subsequently improves enough to allow the interference limits to be relaxed.

3.7.3.7.7 ACAS cross-link interrogations are included in the summation of Mode S interrogations in the left-hand terms of the interference limiting inequalities.

3.7.3.8 *Implementation of a typical interference-limiting procedure*

3.7.3.8.1 The following describes one possible implementation of an interference-limiting procedure. It varies the system parameters appearing in inequalities (1), (2) and (3) to maximize and maintain approximate equality between the estimated surveillance ranges for Mode S and Mode A/C targets. In evaluating these inequalities, 8-second averages of the Mode S parameters are used, and current or anticipated values of the Mode A/C parameters are used. The procedure is illustrated in the flow chart of Figure 3-4.

3.7.3.8.2 *Step 1.* The first step in the control process is to reduce the number of whisper-shout steps tentatively scheduled for use during the present scan if either:

a) inequality (3) is violated; or

b) inequality (1) or (2) is violated and the Mode S surveillance range of the last scan does not exceed the Mode A/C surveillance range that would result from use of the scheduled whisper-shout sequence.

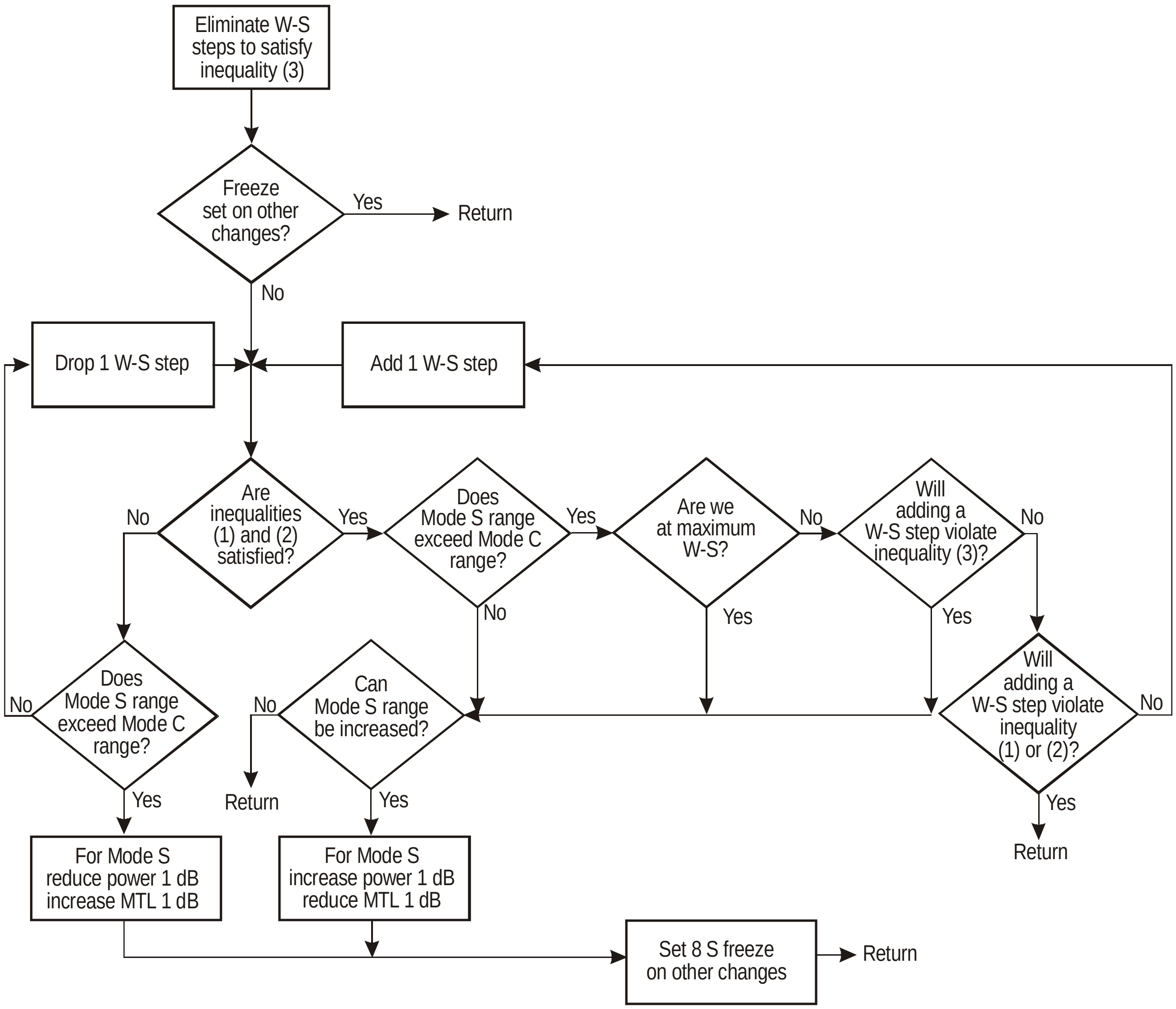


Figure 3-4. Interference limiting flow diagram

Whisper-shout steps are eliminated in the order dictated by the design of the Mode A/C processor, and the number of steps eliminated is just large enough to ensure that neither of the above conditions is satisfied. The value of the number of whisper-shout steps tentatively scheduled for use is initialized at the number used on the last scan.

The relative magnitudes of the Mode S and Mode A/C surveillance ranges are determined from the estimated effective radiated power (ERP) seen by targets with Mode S and Mode A/C transponders located directly ahead of the ACAS aircraft. The ERP in a given direction is determined by the product of the power input to the antenna, and the antenna pattern gain in that direction. If the transponder sensitivities were identical, the Mode S range would be more or less than the Mode A/C range according to whether the Mode S transmitted power was more or less than the Mode A/C transmitted power. Since Mode A/C transponders may have somewhat lower sensitivities than Mode S transponders, the Mode A/C range is assumed to be greater than the Mode S range if, and only if, the Mode A/C power exceeds the Mode S power by 3 dB.

3.7.3.8.3 *Step 2.* The second step in the controlling process is to reduce the Mode S interrogation power for acquisition by 1 dB, and to increase the MTL for Mode S squitter listening by 1 dB from the values last used, if inequality (1) or (2) is violated and the Mode S surveillance range of the last scan exceeds the Mode A/C surveillance range that would result from use of the scheduled whisper-shout sequence.

Once such a change has been made, the only change allowed during the ensuing 8 seconds is a reduction in the number of whisper-shout steps if needed to satisfy inequality (3). This 8-second freeze allows the effect of the Mode S changes to become apparent since the 8-second averages used in inequalities (1) and (2) then will be determined by the behaviour of the system since the change.

3.7.3.8.4 *Step 3.* The third step is to add a whisper-shout step to those tentatively scheduled, when it is not prevented by an 8-second freeze, and the following conditions are satisfied:

a) inequalities (1), (2) and (3) are satisfied and will continue to be satisfied after the step is added; and

b) the Mode S surveillance range of the last scan exceeds the Mode A/C surveillance range that would result from use of the scheduled sequence; and

c) as many steps are added as possible without violating a) or b) above.

3.7.3.8.5 *Step 4.* Finally, if condition a) of 3.7.3.8.4 is satisfied, but condition b) is not, an estimate is made of the effects of increasing the Mode S interrogation power for acquisition by 1 dB and reducing the MTL for Mode S squitters/FRUIT by 1 dB. If the estimate indicates that inequalities (1) and (2) will not continue to be satisfied, the 1 dB change is not made. If the estimate indicates that they will continue to be satisfied, the 1 dB change is made and no further changes in either the Mode A/C or Mode S parameters are made for the ensuing 8 seconds, except as described in 3.7.3.8.3.

3.7.4 Interrogation jitter

Mode A/C interrogations from ACAS equipment are intentionally jittered to avoid chance synchronous interference with other ground-based and airborne interrogators. It is not necessary to jitter the Mode S surveillance interrogations because of the inherently random nature of the Mode S interrogation scheduling process for ACAS.

3.8 ANTENNAS

3.8.1 Use of directional interrogations

3.8.1.1 A directional antenna is recommended for reliable surveillance of Mode A/C targets in aircraft densities up to 0.087 aircraft per square km (0.3 aircraft per square NM). The recommended antenna system consists of a four-beam antenna mounted on top of the aircraft and an omnidirectional antenna on the bottom. A directional antenna may also be used instead of the omnidirectional antenna on the bottom of the aircraft. The directional antenna sequentially generates beams that point in the forward, aft, left and right directions. Together these provide surveillance coverage for targets at all azimuth angles without the need for intermediate pointing angles.

3.8.1.2 The directional antenna typically has a 3-dB beamwidth (BW) in azimuth of 90 ±10 degrees for all elevation angles between +20 and –15 degrees. The interrogation beamwidth is to be limited by transmission of a P_2 side-lobe suppression pulse following each P_1 interrogation pulse by 2 microseconds. The P_2 pulse is transmitted on a separate control pattern (which may be omnidirectional).

3.8.1.3 There is need for timely detection of aircraft approaching with low closing speeds from above and below. Detection of such aircraft suggests a need for sufficient antenna gain within a ±10 degree elevation angle relative to the ACAS aircraft pitch plane. An ACAS directional antenna typically has a nominal 3 dB vertical beamwidth of 30 degrees.

3.8.1.4 The shape of the directional antenna patterns and the relative amplitude of the P_2 transmissions is controlled such that: a) a maximum suppression transponder located at any azimuth angle between 0 and 360 degrees and at any elevation angle between +20 and –15 degrees would reply to interrogations from at least one of the four directional beams; and b) a minimum suppression transponder would reply to interrogations from no more than two adjacent directional beams. A maximum suppression transponder is defined as one that replies only when the received ratio of P_1 to P_2 exceeds 3 dB. A minimum suppression transponder is defined as one that replies when the received ratio of P_1 to P_2 exceeds 0 dB.

3.8.1.5 The effective radiated power (ERP) from each antenna beam (forward, left, right, aft, omni) is expected to be within ±2 dB of its respective nominal value as given in Figure 3-2a.

3.8.1.6 A forward directional transmission, for which Total Radiated Power (TRP) = 49 dBm and BW = 90° has a power gain (PG) product at beam centre of approximately:

$$PG = TRP + 10 \log \left(\frac{360°}{BW}\right) = 55 \text{ dBm}$$

This is 1 dB greater than the nominal and allows for adequate coverage at the crossover points of the directional beams. The TRP of the side and aft beams is reduced relative to the front beam to account for the lower closing speeds that occur when aircraft approach from these directions. Mode A/C surveillance performance will generally improve as the directivity (and hence the number of beams) is increased for the top-mounted antenna. However, the use of a directional antenna on the bottom would provide only marginal improvement in detectability and would, if used at full power, degrade the overall performance of the equipment by increasing the false track rate due to ground-bounce multipath.

3.8.2 Direction finding

The angle-of-arrival of the transmissions from the replying transponders can be determined with better than 10-degree RMS accuracy by means of several simple and practical direction-finding techniques. These techniques typically employ a set of four or five monopole radiating elements mounted on the aircraft surface in a square array with quarter-wave spacing. The signals from these elements may be combined so as to generate from two to four distinct beams, which may be compared in phase or amplitude to provide an estimate of the direction of arrival of the received signal. This level of direction-finding accuracy is adequate to provide the pilot with TAs to effectively aid the visual acquisition of intruding aircraft.

3.8.3 Directional transmission for control of synchronous garble

3.8.3.1 The use of directional interrogation is one technique for reducing synchronous garble. The directional interrogation can reduce the size of the interrogation region. Coverage must be provided in all directions. Hence, multiple beams are used to elicit replies from all aircraft in the vicinity of the ACAS-equipped aircraft. Care must be taken to overlap the beams so that gaps in coverage do not exist between beams.

3.8.3.2 The antenna may be a relatively simple array capable of switching among typically four or eight discrete beam positions. For four beam positions, the antenna beamwidth is expected to be on the order of 100°. The effective antenna beamwidth for interrogating Mode A/C transponders can be made narrower than the 3dB beamwidth by means of transmitter side-lobe suppression.

3.8.4 Antenna location

The top-mounted directional antenna is to be located on the aircraft centre line and as far forward as possible. The ACAS antennas and the Mode S transponder antennas are to be mounted as far apart as possible on the airframe to minimize coupling of leakage energy from unit to unit. The spacing must never be less than 0.5 m (1.5 ft), as this spacing results in a coupling loss of at least 20 dB.

3.9 RECEIVER AND PROCESSOR

3.9.1 Sensitivity

A sensitivity equivalent to that of a Mode S transponder (minimum triggering level of –74 dBm) will provide adequate link margin to provide reliable detection of near co-altitude aircraft in level flight at a range of 26 km (14 NM) provided those aircraft are themselves equipped with transponders of nominal transmit power.

3.9.2 Control of receiver threshold

3.9.2.1 ACAS receivers use a variable (dynamic) threshold to control the effects of multipath. When the first pulse of a reply is received, the variable receiver threshold technique raises the receiver threshold from the minimum triggering level (MTL) to a level at a fixed amount (e.g. 9 dB) below the peak level of the received pulse. The receiver threshold is maintained at this level for the duration of a Mode A/C reply, at which time it returns to the MTL. When multipath returns are weak compared to the direct-path reply, the first pulse of the direct-path reply raises the receiver threshold sufficiently so that the multipath returns are not detected.

3.9.2.2 Variable receiver thresholds have historically been avoided in Mode A/C reply processors because such thresholding tends to discriminate against weak replies. However, when used in conjunction with whisper-shout interrogations, this disadvantage is largely overcome. On any given step of the interrogation sequence it is possible for a strong reply to raise the threshold and cause the rejection of a weaker overlapping reply. However, with whisper-shout interrogations, the overlapping replies received in response to each interrogation are of approximately equal amplitudes since the whisper-shout process sorts the targets into groups by signal strength.

3.9.2.3 The ACAS receiver MTL used in the reply listening period following each whisper-shout interrogation relates to the interrogation power in a prescribed manner. In particular, less sensitive MTLs are used with the lower interrogation powers in order to control the Mode A/C FRUIT rate in the ACAS receiver while still maintaining a balance between the interrogation link and the reply link so that all elicited replies are detected.

3.9.3 Pulse processing

3.9.3.1 A relatively wide dynamic range receiver faithfully reproduces the received pulses. Provisions may be included for locating the edges of received pulses with accuracy, and logic may be provided for eliminating false framing pulses that are synthesized by code pulses from real replies. The processor is capable of resolving pulses in situations where overlapped pulse edges are clearly distinguishable. It is also capable of reconstructing the positions of hidden pulses when overlapping pulses of nearly the same amplitude cause the following pulses to be obscured. The reply processor has the capacity for handling and correctly decoding at least three overlapping replies. Means are also provided for rejecting out-of-band signals and for rejecting pulses with rise times exceeding 0.5 microsecond (typically, distance measuring equipment (DME) pulses).

3.9.3.2 If a Mode S reply is received during a Mode C listening period, a string of false Mode C FRUIT replies may be generated. The ACAS equipment is expected to reject these false replies.

3.9.4 Error detection and correction

3.9.4.1 ACAS avionics intended for use in airspace characterized by closing speeds greater than 260 m/s (500 kt) and densities greater than 0.009 aircraft per km^2 (0.03 aircraft per NM^2), or closing speeds less than 260 m/s (500 kt) and densities greater than 0.04 aircraft per km^2 (0.14 aircraft per NM^2), requires a capability for Mode S reply error correction. In these high densities, error correction is necessary to overcome the effects of Mode A/C FRUIT. Mode S error correction permits successful reception of a Mode S reply in the presence of one overlapping Mode A/C reply.

3.9.4.2 Error correction decoding is to be used for the following replies: DF = 11 all-call replies, DF = 0 short air-air surveillance replies, and DF = 16 long air-air surveillance replies (both acquisition and non-acquisition). If DF = 17 is processed, error correction decoding is also used.

3.9.4.3 If two or more acquisition replies requiring error correction are received within the Mode S range acquisition window, it may be impractical to apply error correction to more than the first received reply. Acquisition replies other than the first do not need to be corrected when this occurs.

3.9.5 Receiver side-lobe suppression

ACAS equipment that interrogates directionally may use receiver side-lobe suppression techniques to eliminate replies (FRUIT) generated by nearby aircraft that are outside the interrogated sector. This reduces the number of replies processed during the surveillance update period.

3.9.6 Dual minimum triggering levels

If the MTL of the receiver used by ACAS is lowered to obtain longer range operation with extended squitter, provision must be made to label squitter receptions that were received at the MTL that would have been used by an unmodified ACAS receiver. Squitter receptions that are received at the conventional MTL or higher are fed to the ACAS surveillance function. Squitter receptions that are received below the conventional MTL are not used for ACAS surveillance but are routed directly to the extended squitter application. This filtering by MTL is necessary to prevent ACAS from attempting to interrogate aircraft that are beyond the range of its active surveillance capability. This would increase the ACAS interrogation rate without providing any improved surveillance performance. Use of the conventional MTL for the ACAS surveillance function preserves the current operation of ACAS surveillance when operating with a receiver with an improved MTL.

3.10 COLLISION AVOIDANCE ALGORITHMS

Note.— The guidance material on the collision avoidance logic of ACAS II is organized in two sections. This section addresses the Standards in the ACAS SARPs and elaborates on important concepts using the design features of a specific implementation of the ACAS logic as examples. Section 3.15 provides further details on the algorithms and parameters used by this particular ACAS implementation. As a consequence of this arrangement, paragraphs in this section often refer to paragraphs in the next one.

3.10.1 General

3.10.1.1 The ACAS algorithms operate in a cycle repeated nominally once per second. At the beginning of the cycle, surveillance reports are used to update the tracks of all intruders and to initiate new tracks as required. Each intruder is then represented by a current estimate of its range, range rate, altitude, altitude rate, and perhaps, its bearing. Own aircraft altitude and altitude rate estimates are also updated.

3.10.1.2 After the tracks have been updated, the threat detection algorithms are used to determine which intruders are potential collision threats. Two threat levels are defined: potential threat and threat. Potential threats warrant TAs while threats warrant RAs.

3.10.1.3 The resolution algorithms generate an RA intended to achieve a specified vertical miss distance from all threats identified by the threat-detection algorithms. Coordination with each equipped threat occurs as part of the process of selecting the RA. Pairwise coordination with each equipped threat is necessary to establish which aircraft is to pass above the other and thus guarantee avoidance manoeuvres that are compatible.

3.10.2 Threat detection

3.10.2.1 Collision threat detection is based on simultaneous proximity in range and altitude. ACAS uses range rate and altitude rate data to extrapolate the positions of the intruder and own aircraft. If the sequence of range measurements indicates that a collision could occur within a short time interval (e.g. 25 seconds) and the altitude separation is expected to be “small” at the projected time of collision, the intruder is declared a threat. Alternatively, the threat declaration may be based on current range and altitude separations that are “small”. The algorithm parameters which establish how far into the future positions are extrapolated, and which establish thresholds for determining when separations are “small”, are selected in accordance with the sensitivity level at which the threat detection algorithms are operating.

3.10.2.2 Each sensitivity level defines a specific set of values for the detection parameters used by the algorithms. These include threshold values for the predicted time to closest point of approach (CPA), and the minimum slant range at which the range test is passed. The threshold for vertical separation is a function of altitude, but not of sensitivity level.

3.10.2.3 The values used for threat detection parameters cannot be optimum for all situations because ACAS is handicapped by its lack of knowledge of intruder intent. The result is that a balance has to be struck between the need to give adequate warning of an impending collision and the possible generation of unnecessary alerts. The latter may result from encounters that are resolved at the last moment by intruder manoeuvres, and, even for simple linear flight, are an inevitable consequence of basing collision detection logic for a three-dimensional world on measurements in only two dimensions (range and altitude). Bearing plays no part in this process.

3.10.3 Alerting volume

3.10.3.1 The range test (using range data only) and the altitude test (using altitude and range data) define an alerting volume. An intruder becomes a threat when it satisfies both the range test and the altitude test.

3.10.3.2 *Alerting volume terms' description*

3.10.3.2.1 *Collision plane.* The plane containing the range vector and the instantaneous relative velocity vector originating at the intruder.

3.10.3.2.2 *Critical cross-sectional area.* A part of the plane of closest approach. Specifically, an intruder following a linear trajectory in an encounter where own aircraft also follows a linear trajectory causes an RA if and only if its intersection with the plane of closest approach lies within the critical cross-sectional area.

3.10.3.2.3 *Instantaneous relative velocity(s).* The modulus of the current value of relative velocity.

3.10.3.2.4 *Linear miss distance (m_a).* The minimum value that range will take on the assumption that both the intruder and own aircraft proceed from their current positions with unaccelerated motions.

3.10.3.2.5 *Linear time to CPA (t_a).* The time it would take to reach CPA if both the intruder and own aircraft proceed from their current positions with unaccelerated motions.

3.10.3.2.6 Given that the only information available to ACAS to make range predictions are range and range rate estimates, both the linear miss distance and the linear time to CPA are unobservable quantities.

3.10.3.2.7 The unobservable quantities, linear miss distance and linear time to CPA, are related to the observable quantities range r and range rate $\dot{r}$ by the following equality:

$$t_a = \frac{\left(r^2 - m_a^2\right)}{\left(-r\dot{r}\right)}$$

3.10.3.2.8 *Major axis.* In the context of the alerting volume, the line through the ACAS II aircraft which is parallel to the instantaneous relative velocity vector.

3.10.3.2.9 *Range convergence.* The aircraft is deemed to be converging in range if the range rate is less than or equal to zero.

3.10.4 Range test

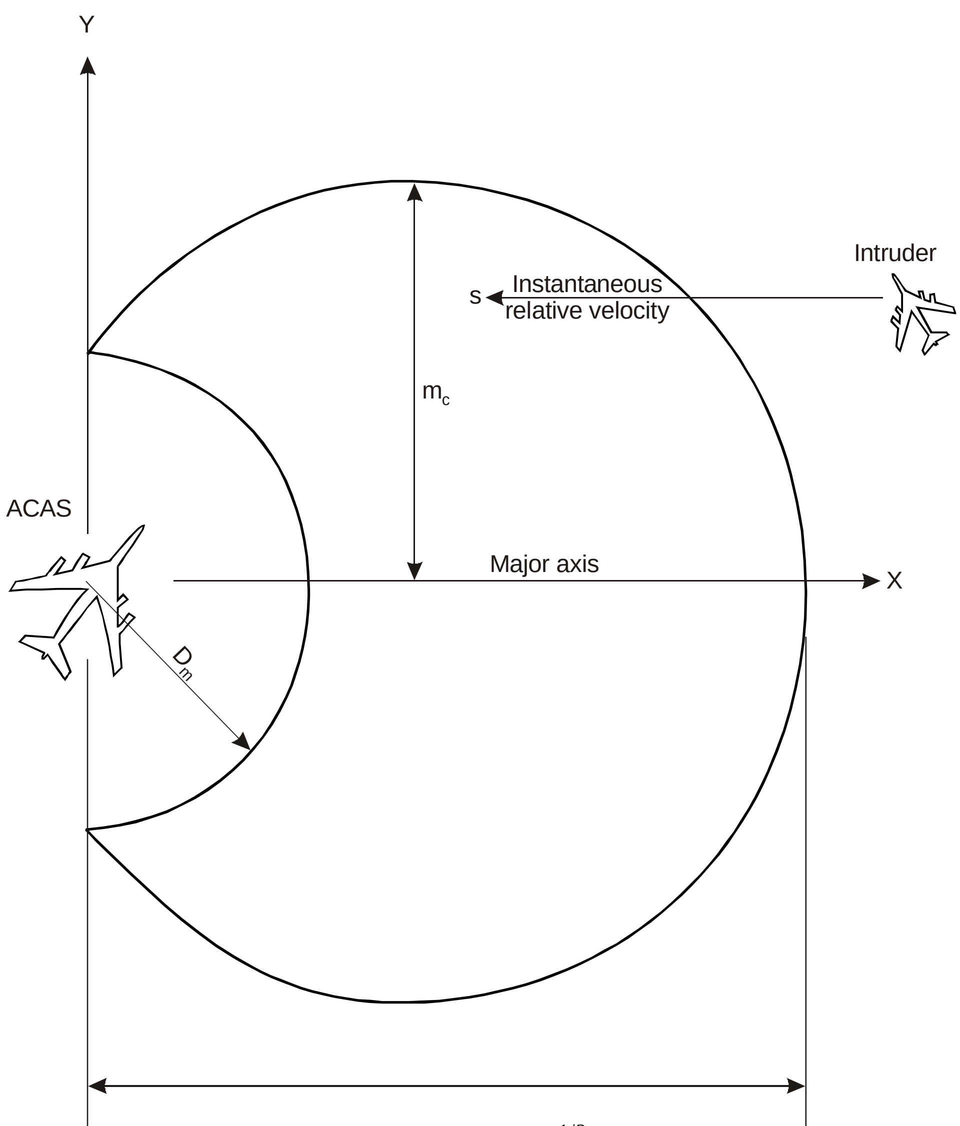
3.10.4.1 The alerting volume resulting from the range test used in the ACAS implementation described in Section 3.15 can be defined in terms of the maximum dimensions of a realizable implementation of the test which is illustrated by Figure 3-5. This shows a section through the alerting volume generated by a range test in the plane containing both aircraft and the instantaneous relative velocity vector. The alerting volume is that which would be produced by rotating the solid curve about the x axis. Note that the length of the major axis is a function of the relative speed, s. For the realizable range test, the radius of the maximum cross section through the alerting volume in a plane normal to the instantaneous relative velocity vector is m_c. This represents the maximum miss distance for which an alert can be generated if the relative velocity at the time of entry to the alerting volume is maintained to CPA. The length of the major axis is the principal feature determining warning time while m_c controls the projected miss distance, which is likely to generate an alert. Ideally, the warning time would be T seconds and m_c would be such that only intruders projected to have miss distances less than D_m (the radius of the small semi-circle in Figure 3-5) would qualify for an alert. The significance of D_m, when specified as in the ACAS implementation described in Section 3.15, is that, to a good approximation, it represents the lateral displacement experienced by an aircraft over the time T when turning with a constant acceleration of $g/3$ (bank angle = 18°). Thus an encounter with a projected miss distance of D_m when the time to CPA is T can result in a collision if either aircraft is manoeuvring with an acceleration of $g/3$. In the absence of adequate bearing rate or range acceleration data, ACAS cannot achieve the ideal. Figure 3-6 shows the maximum value for m_c (i.e. $\hat{m}_c$ as a function of relative speed and sensitivity level). When the relative speed is very low, as can occur in a tail-chase, the alerting volume produced by the range test becomes a sphere of radius D_m centred on the ACAS aircraft.

3.10.4.2 Essentially, the range test gives a positive result if, when approximately T seconds remain before CPA, the relative velocity vector can be projected to pass through a circle of radius m_c centred on the ACAS aircraft and placed in the plane normal to the relative velocity vector. Since the value of m_c is very large compared to the value for adequate vertical separation, the use of the range test alone would generate a large number of unnecessary alerts. It is therefore necessary to trim the alerting volume to more modest proportions using altitude data. Inevitably, this reduces the immunity to manoeuvres in the vertical plane.

3.10.4.3 The constraints on the range test are designed to give a nominal warning time of T seconds allowing for a manoeuvre producing a displacement of D_m normal to the relative velocity vector. It may be demonstrated that, for an encounter having a reasonably large relative velocity, the relative acceleration produced by a turning aircraft is nearly normal to the relative velocity vector. For low relative speed there can be a substantial component of acceleration in the direction of a relative velocity. Erosion of the warning time due to this component happens to be compensated by having a minimum length for the major axis of the alerting volume that is greater than sT.

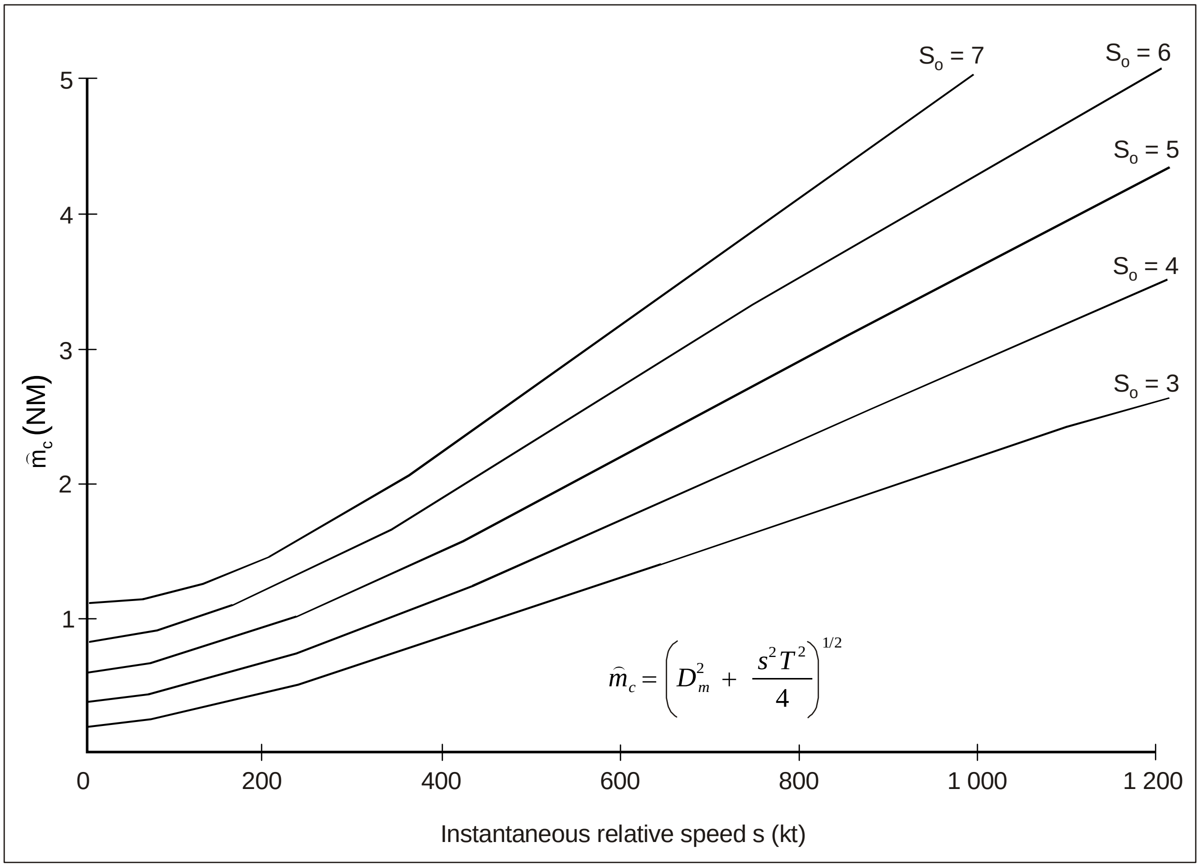
3.10.5 Altitude test

3.10.5.1 The objective of the altitude test is to filter out intruders that give a positive result for the range test but are nevertheless adequately separated in the vertical dimension. The altitude test is used to reduce alert rate in the knowledge that the standard vertical separation distances for aircraft are normally much less than the standard horizontal separation distances. An inevitable result is that the acceleration protection, nominally provided by the range test in all planes, is largely restricted to the horizontal plane. Also, even in the absence of relative acceleration, the altitude test can delay warnings if the vertical miss distance is predicted to be sufficiently large. A view in elevation of the relative motion of two aircraft is shown



$$\frac{sT}{2} + \left(D_m^2 + \frac{s^2T^2}{4}\right)^{1/2}$$

Figure 3-5. Section through alerting volume in the instantaneous collision plane



$$\hat{m}_c = \left(D_m^2 + \frac{s^2 T^2}{4} \right)^{1/2}$$

Figure 3-6. Critical miss distance

in Figure 3-7. AOB represents a plane normal to the relative velocity vector and containing the ACAS aircraft. The intruder may be horizontally displaced from the ACAS so it is not necessarily in the plane of the diagram. The essential feature of the altitude test is that it aims to give a positive result if the projected vertical miss distance is less than Z_m. In the ACAS implementation described in Section 3.15, Z_m varies with altitude in steps from 180 m (600 ft) to 240 m (800 ft).

3.10.5.2 Since the main interest is in intruders with projected miss distances less than D_m, an ideal altitude test (in combination with an ideal range test) would give a positive result if, inter alia, the relative velocity vector were projected to pass through the critical area shown by the solid outline in Figure 3-7. In practice, the altitude test and the range test tend to be satisfied if the vector passes through the larger area defined by the broken outline. Those intruders passing through the shaded areas are likely to give rise to unnecessary alerts.

3.10.5.3 The range test determines the predicted time of collision. However, an additional feature of the altitude test of the ACAS implementation described in Section 3.15 attempts to guard against the eventuality that one of the aircraft levels off above or below the other, thus avoiding a close encounter. Two types of encounter are recognized: the first in which the current altitude separation is less than Z_t (see 3.15.10.2); and a second, in which the current altitude separation is greater than Z_t and the aircraft are converging in altitude. For the first type, the altitude test requires only that the critical area is projected to be penetrated. For the second, an additional condition is that the time to reach co-altitude be less than or equal to a time threshold that is sometimes less than *T*, the nominal warning time. The effect is that warning time is controlled by the range test for intruders that are projected to cross in altitude before CPA while later warnings are given for altitude crossings beyond CPA.

3.10.6 Established threats

3.10.6.1 An established threat is an intruder that has been declared a threat and still merits a resolution advisory.

3.10.6.2 The need to give a positive result for both the range test and the altitude test on the same cycle of operation before declaring an intruder to be a threat (3.10.2.1) applies only for new threats. Subsequently, only the range test is applied and a positive result has the effect of maintaining threat status. The reason for omitting the altitude test is that a rapid pilot response, or the fact that the intruder initially only just satisfied the altitude criteria, may result in cancellation of threat status before reaching CPA.

3.10.7 Alert rate

The principal variables controlling alert rate are relative velocity, miss distance and the ambient aircraft density. The principal parameters affecting alert rate are *T*, D_m and Z_m. Alert rates can be calculated for constant velocity random traffic but the influences of see-and-avoid and ATC make such calculations for real traffic very difficult. Figure 3-6 gives some guidance on some features of an encounter that might give rise to an alert although it gives no assistance concerning the result of the altitude test. For example, it can be seen that, for sensitivity level 5 (altitudes between FL 50 and FL 100) there can be no alert if the horizontal separation is greater than 5.5 km (3 NM) and the relative speed is less than about 440 m/s (850 kt).

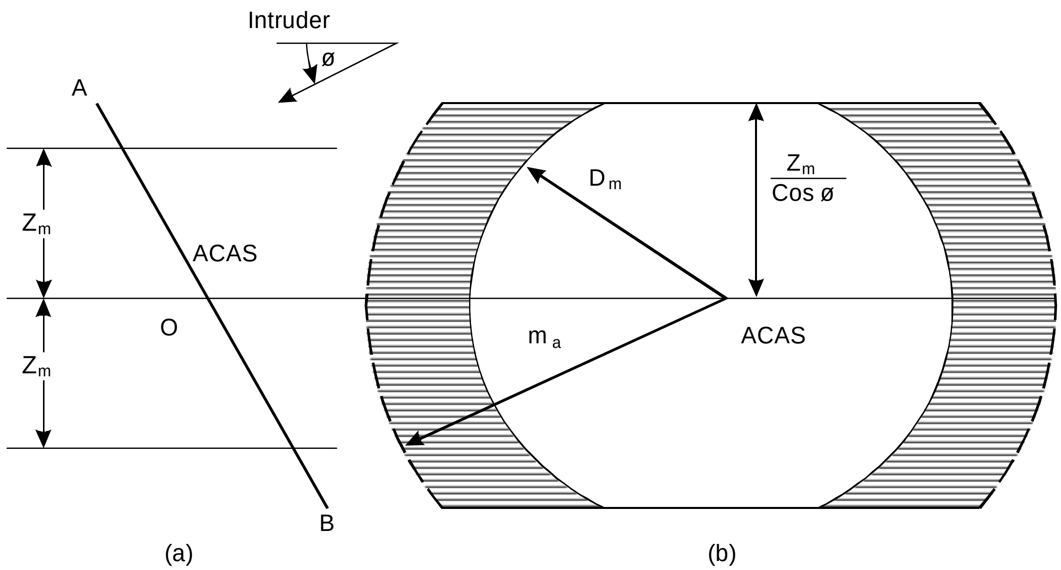


Figure 3-7. Critical area for ideal altitude test

3.10.8 Threat resolution

3.10.8.1 *Coordination.* If the threat aircraft is equipped with ACAS II or ACAS III, own ACAS is required to coordinate with the threat aircraft's ACAS via the Mode S data link to ensure that compatible RAs are selected. The nature of the advisory selected can also be influenced by the fact that the threat is ACAS-equipped.

3.10.8.2 *Classification of resolution advisories*

3.10.8.2.1 ACAS II escape manoeuvres are confined to the vertical plane and can be characterized by a sense (up or down) and a strength. The objective of an RA with an upward sense is to ensure that own aircraft will safely pass above the threat. The objective of an RA with a downward sense is to ensure that own aircraft will safely pass below the threat. Examples of RA strengths with the upward sense are "limit vertical speed" (to a specified target descent speed), "do not descend", or "climb". Examples of equivalent RA strengths with the downward sense are "limit vertical speed" (to a specified target climb speed), "do not climb", or "descend". RAs are of two types: "positive", meaning a requirement to climb or descend at a particular rate; and "vertical speed limit", meaning that a prescribed range of vertical speed must be avoided. Any advisory will also be "corrective" or "preventive". A corrective advisory requires a change in own aircraft's current vertical rate whereas a preventive advisory does not. Thus, for example, a positive RA to climb when the aircraft is already climbing at over 1 500 fpm would be preventive, rather than corrective, and would be announced "maintain vertical speed" rather than "climb". Similarly, an RA to limit vertical speed can be corrective when it requires a reduction in the pre-existing vertical rate.

Note. — In a particular implementation, a flag called the "preventive/corrective" flag indicates whether or not an RA is displayed with a green arc to provide a target vertical velocity. In early ACAS prototypes, corrective RAs were displayed using such a green arc, while preventive RAs were not. However, it was decided that certain preventive RAs, including "maintain vertical speed", should be displayed with a green arc. The ACAS logic passes a flag to the display to indicate whether a green arc is required; unfortunately, this flag has become known as the "preventive/corrective" flag even though it does not indicate whether the RA is preventive or corrective.

3.10.8.2.2 It is expected that the RA generated be consistent with flight path limitations in some regimes of flight, due to flight envelope restrictions and aircraft configurations that reduce climb capability. It is expected that the aircraft's manoeuvre limitation indications available to ACAS offer a conservative assessment of the actual aircraft performance capabilities. This is particularly true of climb inhibit. In the rare and urgent case of a high-altitude downward sense RA being reversed to a climb, it is expected that, very often, the aircraft performance capabilities needed to comply with the RA be available despite the climb inhibit. When such capabilities are not available, it is expected that the pilot will always be able to comply with the reversal at least partially by promptly levelling-off. In determining the altitude-dependent thresholds set in the ACAS logic (by pin settings specific to each aircraft type) above which climb RAs will not be issued, a flight crew is permitted to take an aircraft to the point of stall warning while responding to an RA.

3.10.8.3 *Target vertical miss distance*

3.10.8.3.1 To be certain of avoiding a collision, ACAS must provide a vertical miss distance at CPA that is commensurate with aircraft dimensions and worst-case orientation of the aircraft. Since only measured altitude data are available, due allowance must be made for altimetry errors in both aircraft. Furthermore, the avoiding action must be commenced before CPA, so it is possible that this action will be based on predicted vertical miss distance at CPA, which introduces a further source of error. These factors lead to a requirement that the RA provided to the pilot be such that the desired vertical miss distance at CPA can be achieved in the time available. This target vertical miss distance, A_l, must vary as a function of altitude because altimetry errors increase with altitude. In the ACAS implementation described in Section 3.15, A_l varies from 90 m (300 ft) to 210 m (700 ft).

3.10.8.3.2 The time to CPA cannot be estimated accurately because the miss distance is not known, the threat could manoeuvre and the range observations are imperfect. However, limits that have been found useful and acceptable are the times to CPA assuming the miss distance to take the largest value of concern (D_m) and the value zero, and that all other sources of error have been neglected. This interval is critical for encounters in which the range rate takes on very small values. By maintaining the altitude separation over the entire interval, the selection of the RA is made immune to potentially large errors in estimating the time of minimum range. Such errors can result from small absolute errors in estimating range rate. For preventive RAs, the assumption of an immediate change of rate to the limit recommended by the RA will cause the calculation to deliver a bound (upper for downward RAs, lower for upward RAs) on the altitude of own aircraft at CPA.

3.10.8.4 *Minimum disruption*

3.10.8.4.1 In principle, larger target vertical miss distances could be achieved by more vigorous escape manoeuvres, but constraints are passenger comfort, aircraft capability and deviation from ATC clearance. The ACAS parameters described in Section 3.15 below are based on an anticipation that the typical altitude rate needed to avoid a collision is 1 500 ft/min.

3.10.8.4.2 The initial choice of the sense and strength of the RA is intended, subject to the exceptions described below, to require the smallest possible change in the vertical trajectory of the ACAS aircraft, and the advisory is expected to be appropriately weakened, if possible, at later stages of the encounter, and removed altogether when the desired separation has been achieved at CPA. A prime consideration is the minimization of any departure from an ATC clearance.

3.10.8.5 *Pilot response*

The efficacy of ACAS is critically dependent on pilot response. Therefore, it is necessary for any ACAS design to make certain assumptions concerning the response of the pilot. The ACAS implementation described in Section 3.15 uses a response delay of 5 seconds for a new advisory and a vertical acceleration of $g/4$ to establish the escape velocity. The response time reduces to 2.5 seconds for subsequent advisory changes. ACAS may not provide adequate vertical separation if the pilot response delay exceeds the expected pilot response delay assumed by the design.

3.10.8.6 *Intruders in level flight*

3.10.8.6.1 Intruders that are flying level at the time of the alert and continue thereafter in level flight present few problems for ACAS (provided own pilot follows the displayed RA). If own aircraft is also in level flight the altitude prediction problem does not exist. All the ACAS aircraft has to do is to move in the direction that increases the projected vertical miss distance to the target value. Possible obstacles to this simple logic are that the ACAS aircraft may be unable to climb or may be too close to the ground to descend safely.

3.10.8.6.2 The manoeuvre limitation problems largely disappear when the ACAS aircraft is in climb or descent since the required vertical miss distance can then often be obtained simply by leveling-off, and the prediction problem is likely to be a minor one if ACAS is fed with high resolution data for own altitude.

3.10.8.7 *Intruders in climb/descent*

Intruders in climb or descent present more difficulty. It can be difficult to determine their altitude rates accurately, and it is always difficult to detect a vertical acceleration promptly. There is also evidence that a climbing or descending threat that is projected to pass close to own aircraft is more likely to level-off, thus avoiding the close encounter, than to maintain its observed altitude rate. Therefore the selection of RAs by ACAS should be biased by an expectation that threats might level-off, e.g. in response to ATC. A low confidence in the threat's tracked altitude rate may cause RA generation to be delayed pending a better estimate of this rate.

3.10.8.8 *Altitude crossing RAs*

3.10.8.8.1 Intruders that are projected to cross the altitude of an ACAS aircraft make the design of a totally effective ACAS extremely difficult because such intruders might or might not level-off. ACAS will sometimes generate altitude crossing RAs in such encounters. Some of these altitude crossing RAs have been found counter-intuitive by pilots. Indeed, such RAs require the pilot to initially manoeuvre toward the intruder. Nevertheless, encounters for which altitude crossing RAs are clearly appropriate have been observed, and it is not possible to avoid them entirely. The frequency of altitude crossing RAs is likely to depend on the management and behaviour of aircraft. It is known that aircraft climbing and descending at high rates more frequently give rise to RAs, including crossing RAs, than other aircraft. The potential effect of approaching a cleared flight level at high speed and then levelling-off in close horizontal and vertical proximity to another aircraft is described below. Measures to mitigate these effects are described in 3.10.8.9.

3.10.8.8.2 For the scenario illustrated in Figure 3-8, suppose that the alert occurs while the intruder is climbing towards the level ACAS aircraft. Given that the climb continues, the best escape strategy would be for own aircraft to descend towards the threat, in so doing crossing through the threat's altitude. A climb away could possibly provide enough vertical clearance but, for the same escape velocity, a descent will give greater clearance. If own aircraft does descend it can be seen that a hazardous situation arises if the threat levels off at the cardinal flight level below own aircraft. Such manoeuvres are commonplace in some controlled airspaces, since controllers use them to cross aircraft safely with the required altitude separation in situations where the horizontal separation is small. An ACAS design based on the choice of sense likely to give the greatest altitude separation could induce a close encounter where one would not otherwise occur. An ACAS design must include provisions to make it as immune as possible to such an eventuality.

3.10.8.9 *Provisions for avoiding induced close encounters.* In the absence of any knowledge concerning the intent of the threat, it appears reasonable to assume that the threat will continue with its current altitude rate but choose the RA in an attempt to mitigate the effect of a likely threat manoeuvre. Other features must provide for the contingency that a subsequent threat manoeuvre is detected. For example, the implementation described in Section 3.15 uses the logic described below.

3.10.8.9.1 *Biasing the choice of sense.* If a positive non-altitude crossing advisory is predicted to give at least the target vertical miss distance (A_l), then preference is given to that sense. There is evidence that, in some circumstances, altitude crossing RAs are more disruptive than non-altitude crossing RAs.

3.10.8.9.2 *Increased rate resolution advisory.* The non-crossing sense chosen as described in 3.10.8.9.1 results in own aircraft moving away from the threat, but the encounter may still not be resolved if the threat increases its altitude rate. In such a case the pilot of the ACAS aircraft can be invited to increase own altitude rate in an attempt to outrun the threat.

3.10.8.9.3 *Altitude separation test.* Sense choice biasing will not always result in an RA to move away from the threat, and the altitude separation test is provided further to decrease the chance of an induced close encounter due to a threat leveling off or reducing its altitude rate following a crossing RA. The test involves delaying the issue of the RA until the intent of the threat can be deduced with greater confidence. It is therefore not without risk of causing ACAS to be unable to resolve the encounter. The ACAS implementation described in Section 3.15 balances these conflicting risks with the logic described below.

3.10.8.9.3.1 For a scenario of the type shown in Figure 3-8, which illustrates a threat with a significant altitude rate, the alert, without this delay, would be given when the aircraft were still well separated in altitude. For example, when the warning time is 25 seconds and the altitude rate is 900 m/min (3 000 ft/min), the initial separation is 380 m (1 250 ft). If the situation is such that an altitude crossing RA would be required, i.e. biased sense choice is ineffective, ACAS delays the issue of an advisory until the difference in altitudes falls below a threshold (A_c) that is smaller than the standard IFR separation. If the threat actually levels off at any altitude before crossing that threshold, as is most likely, the alert state will either be cancelled (for level-offs outside Z_m), or a non-altitude crossing advisory will be generated. Otherwise, apart from the possibility that the threat has just overshot its cleared altitude, there is every indication that it is carrying on to, or through, own aircraft's level and the altitude crossing advisory can be issued with more confidence. If the situation is such that a non-altitude crossing advisory would be required, a reduced time threshold (T_v) is used for the altitude test. This vertical threshold test (VTT) is designed to hold off the RA just long enough so that a level-off manoeuvre initiated by the intruder might be detected.

3.10.8.9.3.2 The altitude separation test was intended principally to alleviate problems experienced in an IFR traffic-only environment. It may appear to be desirable to select the value for A_c such that altitude overshoots or even non-IFR separations are covered. However, the risk of ACAS to be unable to resolve the encounters is to be taken into careful consideration.

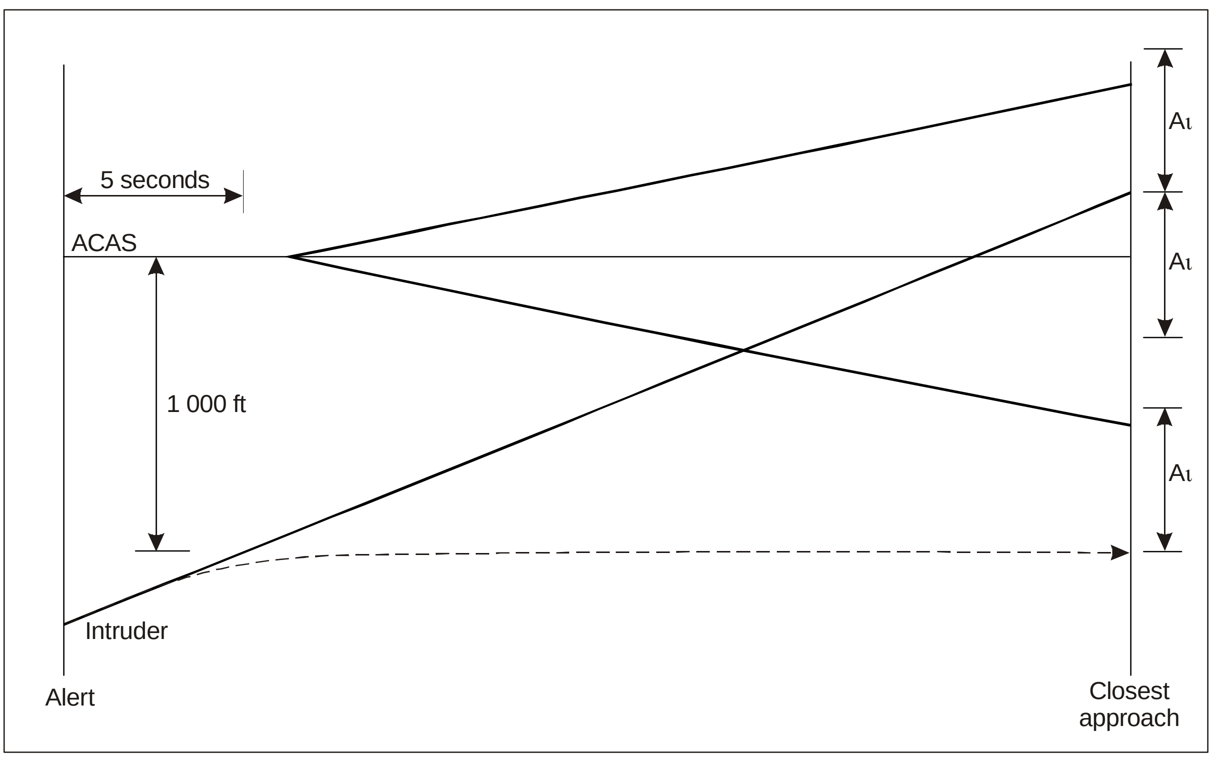


Figure 3-8. Induced close encounter

3.10.8.9.3.3 The second component of the test takes advantage of the cooperation between two equipped aircraft to further reduce the frequency of crossing RAs. An ACAS in level flight delays the choice of an RA until it has received a resolution message from the equipped intruder. The ACAS in the latter is likely to choose a reduction in its own altitude rate, and the coordination process would then result in the level aircraft choosing the non-crossing RA. In practice the delay in starting to resolve the encounter will be small, but the risk of failure to resolve is less sensitive to delay because both aircraft are taking avoiding action. The delay is limited to 3.0 s, which is normally sufficient for the threat to have initiated coordination.

3.10.8.9.4 *Sense reversal.* In spite of the precautions taken to avoid induced close encounters described above, there are still situations that are not covered. For example, in airspace containing VFR traffic, threat leveling-off can occur with a nominal separation of 150 m (500 ft). The altitude separation test would be less effective in such circumstances. When ACAS determines that a threat manoeuvre has defeated its initial choice of RA, the advisory sense can be reversed. The requirement to achieve the target vertical miss distance may be relaxed when this course of action is taken.

3.10.8.10 *Other causes of induced close encounters*

3.10.8.10.1 *Altimetry errors.* The target vertical miss distance (A_I) must include an allowance for altimetry error that is sufficient to give a high probability of not causing an ACAS-equipped aircraft to provoke a close encounter where none really existed. For gross altimetry errors, however, there remains a low probability that a close encounter will be induced when the original separation is adequate. Similarly, there is a low probability that ACAS will be unable to resolve a close encounter due to altimetry error.

3.10.8.10.2 *Mode C errors*

3.10.8.10.2.1 Errors in encoding the threat's altitude to provide Mode C data can, when sufficiently large, induce close encounters in much the same way as gross altimetry error. The incidence of such encounters will be very low in airspaces where ATC takes steps to advise the pilot that an aircraft's reported altitude is incorrect.

3.10.8.10.2.2 A more severe form of Mode C error occurs when the error is confined to the C bits. These are unchecked by ATC, which is normally content to find that an aircraft is within the specified tolerance value of its reported altitude. A stuck or missing C bit can produce an error of only 30 m (100 ft). However, such a fault can have a more serious effect on the intruder's altitude rate as perceived by ACAS and in this way can cause an induced close encounter or result in failure to resolve a close encounter.

3.10.8.10.2.3 *Contrary pilot response.* Manoeuvres opposite to the sense of an RA may result in a reduction in vertical separation with the threat aircraft and therefore must be avoided. This is particularly true in the case of an ACAS-ACAS coordinated encounter.

3.10.8.10.2.4 *Logic induced collisions.* There is a small residual of encounter geometries that the logic cannot handle satisfactorily even when the pilots respond correctly and there is no altimetry error. There is some risk of induced collision in these cases.

3.10.8.11 *Multi-aircraft and domino effect encounters*

3.10.8.11.1 ACAS takes account of the possibility of three or more aircraft being in close proximity and it is required to produce an overall RA. In such circumstances it cannot always be expected that the ACAS aircraft will achieve an altitude separation of A_I with respect to all threats.

3.10.8.11.2 Simulations based on recorded ground-based radar surveillance data and experience with ACAS have indicated that multi-aircraft conflicts are rare. There are rare instances of a “domino” effect whereby the ACAS aircraft’s manoeuvre to avoid a threat brings it into an encounter with a third aircraft, which is equipped and so on. Such an event might be expected to take place in a holding pattern, but the available evidence confirms that this is rare.

3.10.9 Vertical rate estimation

3.10.9.1 ACAS must be capable of tracking altitude information quantized in either 25 or 100 ft increments to produce estimates of aircraft vertical rates. The tracker for 100 ft data must avoid overestimating vertical rate when a jump in reported altitude occurs because an aircraft with a small vertical rate moves from one quantized altitude level to another. But response limitation cannot be achieved by merely increasing tracker smoothing, since the tracker would then be slow to respond to actual rate changes. For altitude reports quantized to 100 ft, the altitude tracker (in Section 3.15) uses special track update procedures that suppress the response to an isolated altitude transition (altitude report that differs from the preceding altitude report) without sacrificing response to acceleration. The tracker also includes several features that contribute to reliability.

3.10.9.2 Some key features of the 100 ft vertical tracking algorithm are as follows:

a) Before any altitude report is accepted for use by the update routines, tests are made to determine if the report appears reasonable (see 3.15.2.3.6), given the sequence of reports previously received. If the report appears unreasonable, it is discarded, although it may subsequently be used in checking the credibility of later reports;

b) The algorithm recursively averages the time between altitude transitions rather than altitude reports;

c) The tracker strictly limits the response to isolated altitude transitions (i.e. transitions that are not part of any trend in altitude). An isolated altitude transition results in initialization of the rate estimate to a specified modest rate in the direction of the transition. The rate estimate will be decayed toward zero on each successive scan without a transition;

d) When a transition is observed that is consistent in direction with the preceding transition, a trend is declared. The altitude rate is initialized to a value consistent with the time between the two transitions;

e) Rate oscillations due to quantization effects are suppressed when a trend or level track has been declared. During a trend period, altitude reports that indicate no altitude transition are tested to determine if the lack of a transition is consistent with the previously estimated rate. If not consistent, the rate is reset to a lower value. If consistent, the rate remains unchanged;

f) When a trend has been declared and a transition is observed, then a test is made to see if the transition is consistent in both direction and timing with the previously estimated rate. If not consistent, the rate is reset. If consistent, the rate is updated by smoothing. The transition may be due to jitter and in reality the trend may be continuing;

g) During each scan the tracker provides a track confidence index that indicates the degree of confidence that can be placed in the altitude rate estimate. “High” confidence is declared when recent altitude reports are consistent with both altitude and altitude rate estimates of the tracker. “Low” confidence is declared when altitude reports are not consistent, implying a possible vertical acceleration or when altitude reports are missing for two or more successive cycles. “Low” confidence might justify a delay in the generation of an RA; and

h) The tracker provides upper and lower bounds within which the true altitude rate is expected to lie. The altitude rate bounds are used to determine if RA generation is to be delayed and in assessing the need for a sense reversal when the altitude rate confidence is “low”.

3.10.10 Air-air coordination

3.10.10.1 *Coordination interrogations.* When ACAS declares a similarly equipped intruder to be a threat, interrogations are transmitted to the latter for RA coordination via the Mode S data link. These interrogations, which coordinate the sense of the RAs in the two aircraft, are made once per processing cycle as long as the intruder remains a threat. They are repeated, up to a maximum number of attempts, until the Mode S transponder on the other aircraft acknowledges receipt by transmitting a coordination reply.

3.10.10.2 *Resolution Advisory Complements.* RAC is a general term that is used to mean a vertical RAC (VRC) or a horizontal RAC (HRC), as appropriate. Specifically, the information provided in the Mode S interrogation is the VRC for ACAS II and the VRC or HRC for ACAS III.

3.10.10.3 *Coordination sequence*. The sequence of coordination messages and associated processing is illustrated in Figure 3-9. Failure to complete the coordination may result in the choice by the threat of an incompatible RA sense.

3.10.10.4 *Coordination protocol*

3.10.10.4.1 After declaring an equipped intruder to be a threat, ACAS first checks to see if it has received a resolution message from that threat. If not, ACAS selects an RA based on the geometry of the encounter. In either case, ACAS begins to transmit vertical sense information to the threat once per cycle in the form of an RAC in a resolution message. The RAC is “don’t pass above” when ACAS has elected to pass above the threat and “don’t pass below” when ACAS has elected to pass below the threat.

3.10.10.4.2 When an ACAS-equipped threat aircraft detects own aircraft as a threat, the threat aircraft goes through a comparable process. If for any reason the two aircraft select the same (incompatible) separation sense, the aircraft with the higher 24-bit aircraft address reverses its sense. This could happen if the two aircraft detect each other as threats nearly simultaneously or if there were a temporary link failure preventing successful communication. The effect in the cockpit of the aircraft with the higher 24-bit aircraft address is that the initial RA is announced and as soon as the RA complement of the other aircraft is taken into account, typically one second later, then a reversed sense RA will be issued. In practice, such occurrences are very rare.

3.10.10.5 *Coordination data protection*

ACAS stores the current RA and the active RAC(s) received from other ACAS-equipped aircraft that perceive own aircraft to be a threat. In order to ensure that the stored information is not modified in response to one or more ACAS while it is being used for RA selection by own ACAS, the data must be protected so that it is available to, or capable of being modified in response to, only one ACAS at a time. For example, this may be accomplished by entering the coordination lock state whenever the data store is accessed by own ACAS or offered new data from a threat ACAS. If a resolution message is received while the coordination lock state is active, the data is held until the current coordination lock state is ended. The potential for simultaneous data access by different processes within ACAS exists because incoming threat resolution messages are received asynchronously to the ACAS processing, effectively interrupting this processing.

3.10.11 Ground communication

3.10.11.1 *Report of ACAS resolution advisories to the ground.* Whenever an RA exists, ACAS indicates to the aircraft's Mode S transponder that it has an RA report available for a Mode S ground station. This causes the transponder to set a flag indicating that a message is waiting to be transmitted to the ground. Upon receipt of this flag, a Mode S sensor may request transmission of the RA report. When this request is received, own Mode S transponder provides the message in a Comm-B reply format.

3.10.11.2 *RA broadcast.* In addition, ACAS generates broadcasts at 8-second intervals while an RA is indicated to the pilot. The broadcast reports the last values taken by the parameters of the RA during the previous 8-second period even if the advisory has been terminated. This allows ACAS RA activity to be monitored in areas where Mode S ground station surveillance coverage does not exist by using special RA broadcast signal receivers on the ground. RA broadcasts are normally destined for ground equipment but are defined as uplink transmissions.

3.10.11.3 *Ground station control of threat detection parameters.* Threat detection parameters can be controlled by one or more Mode S ground stations by transmitting interrogations containing sensitivity level control (SLC) command messages addressed to the ACAS aircraft. Upon receipt of an SLC command message from a given Mode S ground station, ACAS stores the SLC command value indexed by ground station number. ACAS uses the lowest of the values received if more than one ground station has sent such a message. ACAS times out each site's SLC command separately and cancels it if it is not refreshed by another message from that site within 4 minutes. ACAS can also immediately cancel an SLC command from a ground station if a specified cancellation code is received from that station. SLC commands cannot be used within linked Comm-A interrogations.

Note.— There are no internationally agreed operational procedures for use of this capability and it is not used in practice.

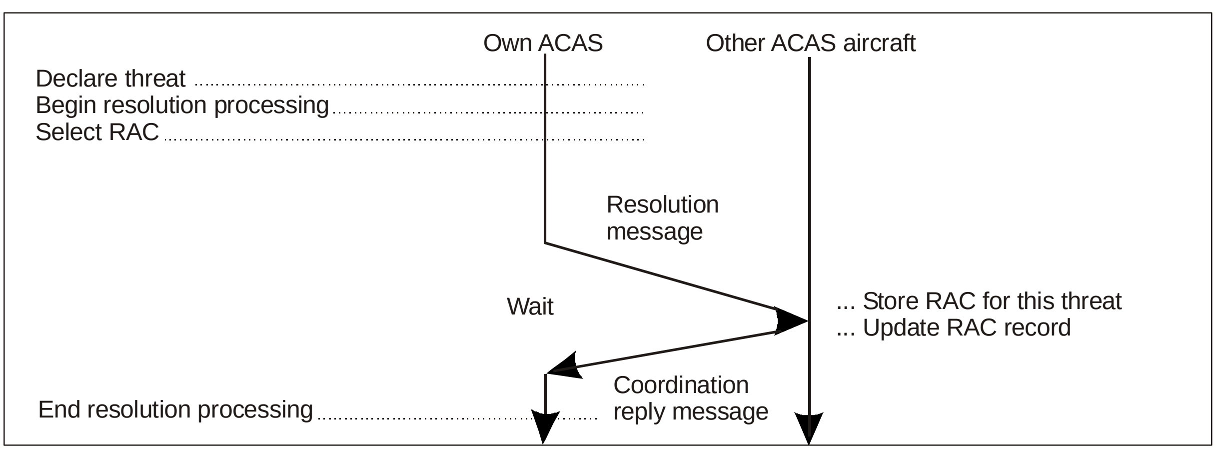


Figure 3-9. Coordination sequence

3.10.12 Sensitivity level control

Control of the ACAS threat detection parameters can be effected by means of SLC commands provided as follows:

a) as an internally generated value based on altitude band;

b) from a Mode S ground station (see 3.5.11.2); and

c) from a pilot-operated switch.

The sensitivity level used by ACAS is set by the smallest non-zero SLC command provided by these three sources. When a Mode S ground station or the pilot has no particular interest in the sensitivity level setting, the value zero is delivered to ACAS from that source and it is not considered in the selection process. The sensitivity level will normally be set by the internally generated value based on altitude band. Hysteresis is used around the altitude thresholds to prevent fluctuations in the SLC command value when the ACAS aircraft remains in the region of an altitude threshold.

3.11 COMPATIBILITY WITH ON-BOARD MODE S TRANSPONDERS

3.11.1 Compatible operation of ACAS and the Mode S transponder is achieved by coordinating their activities via the avionics suppression bus. The Mode S transponder is suppressed during and shortly after an ACAS transmission. Typical suppression periods are: a) 70 microseconds from the top antenna and b) 90 microseconds from the bottom antenna. These suppression periods prevent multipath caused by the ACAS interrogation from eliciting an SSR reply from the Mode S transponder.

3.11.2 Unwanted power restriction on a Mode S transponder associated with ACAS is more stringent than in Annex 10, Volume IV, Chapter 3 to ensure that the Mode S transponder does not prevent ACAS from meeting its requirements. Assuming a transponder undesired radiation power level of –70 dBm (Annex 10, Volume IV, Chapter 4) and a transponder to ACAS antenna isolation of –20 dB, the resultant interference level at the ACAS RF port will then be below –90 dBm.

3.11.3 An additional compatibility requirement is to keep the leakage power of the ACAS transmitter at a low level (see 3.7).

3.12 INDICATIONS TO THE FLIGHT CREW

3.12.1 Displays

3.12.1.1 ACAS implementations will typically display resolution advisory information on one or two displays. The TA display presents the crew with a plan view of nearby traffic. The RA display presents the crew with manoeuvres to be executed or avoided in the vertical plane. The TA display and the RA display may utilize separate indicators or instruments to convey information to the pilot, or the two functions may be combined on a single display. The displayed RA information can either be integrated with existing displays available on the flight deck or presented on a dedicated display.

3.12.1.2 *Traffic advisories*

3.12.1.2.1 The TA display presents the flight crew with a plan view of nearby traffic. The information thus conveyed is intended to assist the flight crew in sighting nearby traffic. Simulation has demonstrated that tabular alphanumeric displays of traffic are difficult for the flight crew to read and assimilate, and the use of this type of display as the primary means of displaying traffic information is not recommended. The TA display provides the capability to display the following information for intruders:

a) position (range and bearing);

b) altitude (relative or absolute); and

c) altitude rate indication for an altitude reporting intruder (climbing or descending).

3.12.1.2.2 The TA display may use shapes and colours to indicate the threat level of each displayed intruder (i.e. RAs and TAs) and proximate traffic. The essential differences between the tests for TA generation and the tests for threat detection are the uses of larger values for warning time.

3.12.1.2.3 Continuous display of proximate traffic is not a requirement for ACAS. However, pilots need guidance concerning proximate traffic as well as potential threats to ensure that they identify the correct aircraft as the potential threat. The word “display” is not intended to imply that a visual display is the only acceptable means of indicating the position of intruders.

3.12.1.2.4 Ideally, an RA would always be preceded by a TA, but this is not always possible; e.g. the RA criteria might be already satisfied when a track is first established, or a sudden and sharp manoeuvre by the intruder could cause the TA lead time to be less than a cycle.

3.12.1.3 *Resolution advisories*

The RA display presents the flight crew with an indication of vertical speed to be attained or avoided. The RA display may be incorporated into the instantaneous vertical speed indicator (IVSI) or into the primary flight display (PFD). The RA display may provide a means to differentiate between preventive and corrective RAs.

3.12.2 Aural and voice alerts

Aural alerts are used to alert the flight crew that a TA or RA has been issued. When the vocabulary used to announce RAs is selected, care must be taken to select phrases that minimize the probability of a misunderstood command. An aural annunciation is also provided to the flight crew to indicate that the ACAS aircraft is clear of conflict with all threatening aircraft.

3.13 CREW CONTROL FUNCTIONS

As a minimum, it is expected that a means be provided manually through flight crew action for either selecting an “AUTOMATIC” mode in which sensitivity levels are based on other inputs, selecting a mode in which only TAs are able to be issued, or selecting specific sensitivity levels including at least sensitivity level 1. When sensitivity level 1 is selected, the ACAS equipment is essentially in a “stand-by” condition. The term STAND-BY may be used to designate this selection. The current ACAS sensitivity level may be different from that selected by the flight crew. Provisions are to be made for indicating to the flight crew when ACAS is in STAND-BY or when only TAs will be issued. The control for ACAS may be integrated with the controls for the Mode S transponder, or the two systems may have separate controls. If the ACAS and Mode S controls are integrated, a means must be provided to allow the flight crew to select a transponder-only mode of operation.

3.14 BUILT-IN TEST EQUIPMENT

ACAS equipment is expected to include an automatic performance monitoring function for determining on a continuing basis the technical status of all critical ACAS functions without interfering with or otherwise interrupting the normal operation of the equipment. Provisions are to be made for indicating to the flight crew the existence of abnormal conditions as determined by this monitoring function.

3.15 TYPICAL ALGORITHMS AND PARAMETERS FOR THREAT DETECTION AND GENERATION OF ADVISORIES

Note 1.— The characteristics given below describe a reference design for the ACAS II collision avoidance logic. This description, however, does not preclude the use of alternative designs of equal or better performance.

Note 2.— Lower case mathematical symbols are used to represent variables throughout this chapter. Upper case symbols are used for parameters. The dot notation used for some parameters does not indicate that they are derived quantities but rather that they have the dimensions suggested by the notation, e.g. distance/time for a speed parameter.

3.15.1 Range tracking

Range, range rate, and range acceleration $(r, \dot{r}, \ddot{r})$ are estimated by means of an adaptive α-ß-γ tracker using for its coefficients α, ß and γ values that are decreasing with each successive range measurement until they reach their minimum values equal to 0.40, 0.10 and 0.01, respectively. The range acceleration estimate is used to estimate the expected miss distance in range at CPA, *m*, using the following formula:

$$m^2 = r^2 - \frac{r^2}{1 + r\ddot{r} / \dot{r}^2}$$

This estimate is not calculated when further calculations indicate that it may not be reliable either because of the magnitude of the estimation errors or because of a possible manoeuvre by one of the aircraft in the horizontal plane. The latter calculations rely on the age of the track, the observed accuracy of the successive range predictions, the observed consistency of the range acceleration estimates, the observed consistency of a second range track based on a linearized trajectory agreeing with the previously estimated miss distance, and the observed consistency of a rough bearing track.

3.15.2 Altitude tracking

3.15.2.1 *Sources of altitude data.* Intruder aircraft's altitude is obtained from intruder Mode C or Mode S reports. Own aircraft's altitude is obtained from the source that provides the basis for own Mode C or Mode S reports and is used at the finest quantization available.

3.15.2.1.1 *Altitude report credibility.* Before any altitude report is accepted, a test is made to determine whether the report is credible. A credibility window is calculated on the basis of the previous estimated altitude and altitude rate. The altitude report is discarded and the altitude track updated as though the report was missing (3.15.2.3.7) if the report is outside the credibility window.

3.15.2.2 *Own altitude rate.* Own ACAS aircraft's altitude rate is obtained from a source having errors that are as small as possible and in any event no greater than those of the rate output of the tracker described in 3.15.2.3.6.

3.15.2.3 *Intruder altitude tracking*

3.15.2.3.1 *Altitude tracking terms' description*

3.15.2.3.1.1 *Established rate track.* An altitude track for which the pattern of the last few altitude reports received from the intruder allows the inference that that intruder is climbing or descending with a constant, non-zero altitude rate.

3.15.2.3.1.2 *Level track.* An altitude track for which the pattern of the last few altitude reports received from the intruder allows the inference that that intruder is level.

3.15.2.3.1.3 *New track.* An altitude track newly initialized.

3.15.2.3.1.4 *Oscillating track.* An altitude track for which the pattern of the last few altitude reports received from the intruder oscillates between two or more values in a way that allows the inference that that intruder is level.

3.15.2.3.1.5 *Transition.* An altitude report for a track that is different from the last credible altitude report for that track.

3.15.2.3.1.6 *Trend.* A trend exists for the altitude rate if the two most recent altitude level transitions were in the same direction.

3.15.2.3.1.7 *Unconfirmed rate track.* An altitude track for which the pattern of the last few altitude reports received from the intruder does not allow the track to be classified in any other way.

3.15.2.3.1.8 On any cycle of tracking, each track is attributed one and only one track classification.

3.15.2.3.1.9 Any track classification is maintained until conditions for another track classification are satisfied.

3.15.2.3.2 The ACAS II tracks the altitudes of intruders. Tracking is based on automatic pressure altitude reports from their transponders, using altitude reports quantized as received. For every intruder on every cycle the tracker provides altitude and altitude rate estimates.

Note.— The function that associates Mode C altitude data with tracks is specified in Annex 10, Volume IV, Chapter 4. The altitude tracker specified below assumes that this function has been performed prior to application of the tracker.

3.15.2.3.2.1 The reference altitude tracking design assumes that, for each track, altitude reports are received at the nominal rate of one altitude report per second. However, it allows for missing reports, in other words, cases in which no altitude report has been received for a given track prior to a tracking cycle.

3.15.2.3.2.2 Intruder altitude tracks of one of two types are created and maintained. So-called 100-ft tracks are obtained when altitude reports are supplied in units of 100 ft. Such tracks are updated by a dedicated tracker referred to as the 100-ft altitude tracker. So-called 25-ft tracks are obtained when altitude reports are supplied in units of 25 ft. Such tracks are updated by a dedicated tracker referred to as the 25-ft altitude tracker.

3.15.2.3.2.3 Special logic automatically switches intruder altitude tracks between the 100-ft altitude tracker and the 25-ft altitude tracker following a confirmed change in the units in which altitude reports are supplied. Such a change is considered confirmed when three successive valid altitude reports expressed in the same units have been received.

3.15.2.3.2.4 When an altitude reporting unit change has been observed but not yet been confirmed, the existing track is coasted and the altitude report is temporarily stored. Once the unit change is confirmed, the track is re-initialized using the last altitude rate estimate computed before the change as well as all temporarily stored altitude reports.

3.15.2.3.2.5 The 25-ft tracker is an adaptive alpha-beta tracker. It is briefly described in 3.15.2.3.5.

3.15.2.3.2.6 The design of the 100-ft altitude tracker is motivated by the need for a stable altitude rate estimate when the true altitude rate of the intruder is less than 100 ft/s, in other words, less than one quantization interval per tracking cycle. This tracker estimates the altitude rate indirectly by estimating the time taken to cross one quantization level. Further details on this design are provided in 3.15.2.3.6.

3.15.2.3.3 *Altitude rate confidence.* For every intruder on every cycle, the tracker provides an indication of either “high” or “low” confidence in the altitude rate estimate (3.15.2.3.6.10 and 3.15.2.3.6.11).

3.15.2.3.4 *Altitude rate reasonableness.* The tracker provides a “best estimate” altitude rate and upper and lower bounds for this altitude rate consistent with the received sequence of reports.

3.15.2.3.5 *25 ft quantization reports*

3.15.2.3.5.1 For altitude reports quantized to 25-ft increments, an adaptive α-ß tracker is used. This tracker is adaptive in the sense that it selects among three sets of α and ß values depending on the magnitude of the prediction error, i.e. the difference between the predicted altitude and the reported altitude, as well as on the magnitude of the rate estimate. These α and ß values are:

a) α = 0.4 and ß = 0.100 when the current altitude rate estimate is less than 7.0 ft/s; otherwise;

b) α = 0.5 and ß = 0.167 when the prediction error is less than 22.5 ft; or

c) α = 0.6 and ß = 0.257, when neither c) nor b) is selected.

3.15.2.3.5.2 The tracker maintains two distinctive sets of altitude and altitude rate estimates. The first one is derived directly from the standard α-ß smoothing equations. This set is purely internal to the tracker. The second set contains the estimates passed to the collision avoidance logic. It differs from the first set as follows. The altitude estimate passed to the logic is constrained to be within one half quantization interval of the reported altitude (±12.5 ft). The altitude rate estimate passed to the logic is set equal to zero when the internal estimate decreases below 2.5 ft/s in absolute value and is kept equal to zero until the internal estimate increases beyond 5.0 ft/s in absolute value.

3.15.2.3.5.3 The tracker uses only two of the previously defined track classifications: level track and established rate track (3.15.2.3.1). It declares a track to be a level track when at least seven tracking cycles have elapsed since the last altitude transition (3.15.2.3.1). The internal rate estimate is then reset to zero. It declares the track to be an established rate track when, following two sufficiently closely spaced altitude transitions, the internal rate estimate (and thus also the rate estimate passed to the logic) increases beyond 5.0 ft/s.

3.15.2.3.5.4 Confidence in the estimates is declared "high" when the track has existed for at least four tracking cycles and the prediction error has been no greater than 22.5 ft on at least two successive tracking cycles. It is set to "low" when the prediction error is larger than 22.5 ft. It is also set to "low" when altitude reports have been missing on two successive cycles.

3.15.2.3.6 *100 ft quantization reports.* For altitude reports quantized to 100-ft increments, the performance of the altitude tracker is, in all respects, equal to or better than that of a reference tracker setting the altitude rate estimate to have an appropriate sign and the magnitude as described in this paragraph.

3.15.2.3.6.1 *Tracker variables*. The reference tracker uses the following variables:

$\dot{z}$ altitude rate estimate, m/s (ft/s);

$\dot{Z}_{gu}$ see 3.15.2.3.6.5.1;

Δz altitude difference between the current report and the most recent credible report;

T_n 1 s;

Q 30.5 m (100 ft);

t_r time since the most recent credible report, *s*;

t_p time between the two most recent altitude level transitions or, for multiple transitions within one cycle, the average time between these transitions, *s*;

t_b estimated level occupancy time after the most recent transition, *s*;

t_{bm} calculated lower bound on level occupancy time, *s*;

ß computed smoothing coefficient for t_b;

$ß_l$ limit for ß based on t_b;

b_t number of altitude levels crossed between the two most recent altitude level transitions;

$b_{\dot{z}}$ number of altitude levels crossed at the most recent rate;

ε smoothed error estimate of t_b, *s*;

d_t sign of the most recent altitude transition (= +1 for an increase in altitude; = –1 for a decrease); and

x^* value of any variable *x* before being updated following an altitude level transition.

3.15.2.3.6.2 *Report credibility.* The altitude report is regarded as being credible if either of the following conditions is satisfied:

a) $\Delta z = 0$

b) $\left|\Delta z - \dot{z}t_r\right| - Qt_r / T_n - \dot{Z}_{gu}t_r \leq 0$

3.15.2.3.6.3 *Track classification scheme*

3.15.2.3.6.3.1 *Established rate track.* An altitude track is classified as established rate if two or more successive transitions are observed in the same direction and the time interval between the two transitions is sufficiently short that the track classification would not be changed to level track during that interval (see the definition of level track), or if an observed transition is opposite in direction to an existing trend and the time since the previous transition is "unexpectedly small" (3.15.2.3.6.9.1).

3.15.2.3.6.3.2 *Level track.* An altitude track is classified as level if reports are received at the same level for longer than T_1 after the time at which the next transition was expected, if one was expected, or for more than T_2 whether or not a transition was expected (3.15.2.3.6.3.6).

3.15.2.3.6.3.3 *New track.* An altitude track is classified as new during the period between the time of the first altitude report and the first transition or until T_2 has elapsed (3.15.2.3.6.3.6).

3.15.2.3.6.3.4 *Oscillating track.* An altitude track is classified as oscillating if a transition occurs in the opposite direction to that of the immediately preceding transition, only one level has been crossed, the time interval between the two transitions is sufficiently short that the track classification would not be changed to level track during that interval (see the definition of level track) and, if the track was classified as established rate, the time since that transition is not "unexpectedly small" (3.15.2.3.6.9.1).

3.15.2.3.6.3.5 *Unconfirmed rate track.* An altitude track is classified as unconfirmed rate if a transition occurs for a new or for a level track or if a transition in the opposite direction to the previous transition occurs and more than one level has been crossed for an established, oscillating or unconfirmed rate track.

3.15.2.3.6.3.6 The following values are used:

$T_1 = 4.0$ s

$T_2 = 20$ s

3.15.2.3.6.3.7 If a track is already classified as unconfirmed rate and a transition occurs in the opposite direction to the previous one and more than one level has been crossed, the altitude rate is determined as if the track had just become classified as unconfirmed rate (3.15.2.3.6.5).

3.15.2.3.6.3.8 The tracks are classified (3.15.2.3.6.3), and the transitions between track's classifications are shown in Figure 3-10. Tracks are classified in order to determine how new measurements should be used to update the altitude rate estimate.

3.15.2.3.6.4 The magnitude of the rate is set to zero if the track is new, level or oscillating.

3.15.2.3.6.4.1 The quantities ε and $b_{\dot{z}}$ are set to zero and t_b to 100 s.

3.15.2.3.6.4.2 When a track is classified as level, all earlier transitions and any current trend are disregarded.

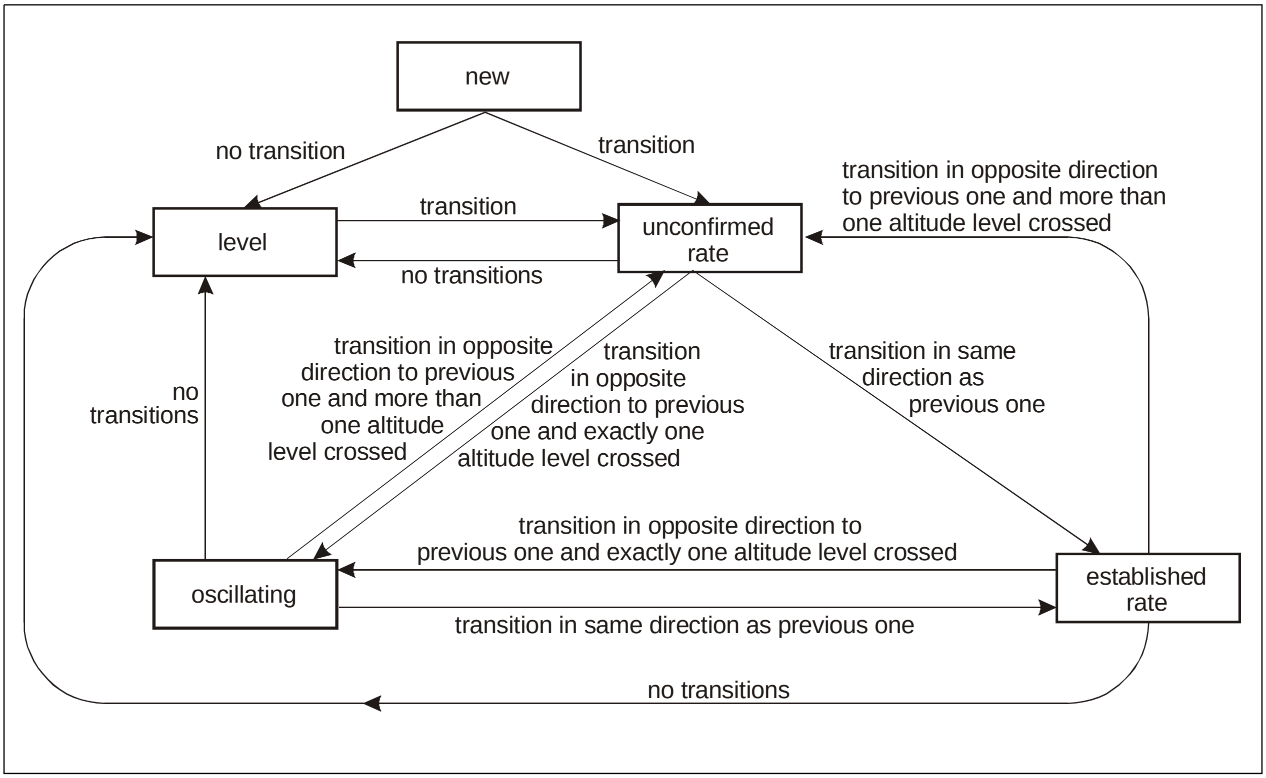


Figure 3-10. Track classification transitions

3.15.2.3.6.5 The magnitude of the rate is set to $\dot{Z}_{gu}$ when a track first becomes unconfirmed rate and then decayed each cycle from the value determined the previous cycle until another transition is observed.

3.15.2.3.6.5.1 The value of $\dot{Z}_{gu}$ is 2.4 m/s (480 ft/min) and the decay constant is 0.9.

3.15.2.3.6.5.2 The quantities ε and $b_{\dot{z}}$ are set to zero and t_b to $Q/|\dot{z}|$.

3.15.2.3.6.6 For established rate tracks the magnitude of the rate is set to the quantization interval divided by the estimated level occupancy time. The level occupancy time is estimated on receipt of transitions in the direction of the trend and held constant until the next transition either occurs or becomes overdue (3.15.2.3.6.8).

3.15.2.3.6.7 When a track is first established, the quantities ε, $b_{\dot{z}}$ and t_b are set as follows:

$$\varepsilon = 0,\ b_{\dot{z}} = 1,\ t_b = \text{maximum}\ (t_p,\ 1.4\ \text{s})$$

3.15.2.3.6.7.1 Unless the transition is early or late (3.15.2.3.6.7.2), the quantities ε, $b_{\dot{z}}$, and t_b are calculated by recursive averaging following the third and subsequent transitions as follows:

$\varepsilon' = 0.8\varepsilon^* + (t_p - t_b^*)$

$\beta_t = \frac{(t_b^* - T_n)^2}{[(t_b^*)^2 + 64T_n^2]}$ and

$b_{\dot{z}} = b_{\dot{z}}^* + b_t$ and

$\beta =$ maximum $(\frac{b_t}{b_{\dot{z}}}, \beta_1)$ and

$\varepsilon = \varepsilon'$

for $|\varepsilon'| \leq 1.35$ (or 2.85 if the most recent transition was observed following one or more missing reports);

$b_{\dot{z}}$ = 3 and

ß = 0.5 and

ε = 0.3 ε' otherwise;

and in both cases: $t_b = t_b^* + \text{ß}(t_p - t_b^*)$.

3.15.2.3.6.7.2 Early or late transitions

If $|t_p - t_b^*| > 1.5$ s (or 3.0 s if the most recent transition was observed following one or more missing reports) or b_t lies outside the range $(t_r/t_b^* + 1.1) \geq b_t \geq (t_r/t_b^* - 1.1)$, then the quantities ε, $b_{\dot{z}}$ and t_b are set as follows:

$b_{\dot{z}}$ = 1
ε = 0
t_{bm} = minimum $((0.7t_p + 0.3t_b^*), 1.4$ s)
t_b = maximum (t_p, t_{bm}).

The rate is calculated as: $\dot{z} = d_tQ/t_b$.

3.15.2.3.6.8 *Overdue transition.* The magnitude of the rate is decayed on each cycle from the value obtained on the previous cycle if reports are received at the same level for at least T_3 after the time of the next expected transition (or T_4 if the most recent transition was observed following one or more missing reports). The value of t_b is not changed in these circumstances.

3.15.2.3.6.8.1 The following values are used:

$T_3 = 1.5$ s

$T_4 = 3.0$ s

The following formula for rate decay is used:

$\dot{z} = d_tQ/[t_b + (0.3t_b + 0.5T_n)\,(0.7 + (t_l - t_b)/T_n)^2]$

where t_l = time since the most recent transition, s.

3.15.2.3.6.8.2 The quantity $b_{\dot{z}}$ is set to maximum $(2, b_{\dot{z}}^{*} - 1)$.

3.15.2.3.6.9 *Transitions due to jitter.* The magnitude of the rate is set to the value obtained on the previous cycle if a transition is observed opposite in direction to that of the trend, the immediately preceding transition followed the trend, only one level has been crossed, and the time since the immediately preceding transition is "unexpectedly small". Such a transition is subsequently treated as missing except for the requirements of 3.15.2.3.4 and 3.15.2.3.6.11 e).

3.15.2.3.6.9.1 The time since the immediately preceding transition is declared "unexpectedly small" when $t_p \leq 0.24\, t_b^*$.

3.15.2.3.6.9.2 The quantities ε, $b_{\dot{z}}$, and t_b are not changed.

3.15.2.3.6.10 *Track high confidence declaration.* "High" confidence in the tracked rate is declared when the current altitude report is credible and one or more of the following conditions are met:

a) a new track has been observed for longer than T_5 (3.15.2.3.6.10.1) without an altitude transition;

b) an unconfirmed rate track has been observed for longer than T_6 (3.15.2.3.6.10.1) without an altitude transition;

c) a track is classified as level;

d) a track is first classified as established rate;

e) for an established rate track when a transition has occurred the ratio of the observed transition time to the expected transition time (before being updated) falls between $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ (3.15.2.3.6.10.1); or the absolute value of the difference between these times is less than T_8; or the time between the most recently observed and the previous transition is longer than T_8 (3.15.2.3.6.9.1);

f) for an established rate track when a transition has occurred, the previous report was missing, $|t_p - t_b^*| \geq T_7$, $t_p/t_b^* \geq 1$ and $-t_p - T_9 \leq (t_b - t_p)\, b_t \leq T_9$;

g) a track is classified as oscillating; or

h) confidence was previously set to "high" upon processing of the last credible altitude report and conditions a) to e) of 3.15.2.3.6.11 for "low" confidence declaration are not satisfied.

3.15.2.3.6.10.1 The following values are used:

T_5 = 9 s

T_6 = 9 s

T_7 = 1.1 s

T_8 = 8.5 s

T_9 = 1.25 s

$\boldsymbol{R}_1 = 2/3$

$\boldsymbol{R}_2 = 3/2$

3.15.2.3.6.11 *Track low confidence declaration.* “Low” confidence in the tracked rate is declared when one or more of the following conditions is satisfied:

a) for a new track until condition a) in 3.15.2.3.6.10 is satisfied; or

b) for an unconfirmed rate track until condition b) in 3.15.2.3.6.10 is satisfied; or

c) when an observed transition time for an established rate track does not satisfy condition e) or condition f) in 3.15.2.3.6.10; or

d) when an expected transition is more than T_{10} (3.15.2.3.6.11.1) late; or

e) for an established rate track when the condition in 3.15.2.3.6.9 is satisfied; or

f) confidence was previously “low” and the conditions for “high” confidence declaration are not satisfied (3.15.2.3.6.10).

3.15.2.3.6.11.1 The value T_{10} = 0.25 s is used.

3.15.2.3.7 *Missing altitude reports*. When altitude reports are missing:

a) the previous value of the altitude rate estimate is maintained; and

b) confidence in the tracked rate is declared “low” when altitude reports are missing for two or more successive cycles.

3.15.3 TA generation

3.15.3.1 A TA is generated for an intruder reporting Mode C altitude when the application of both a range test (3.15.5) and an altitude test (3.15.6) gives a positive result for each in the same cycle of operation.

3.15.3.2 A TA is generated for an intruder equipped with a non-altitude-reporting transponder when the result of applying a range test (3.15.5) is positive.

3.15.4 TA warning time

3.15.4.1 For intruders reporting altitude, the range test for TAs gives a nominal warning time as follows:

S	*2*	*3*	*4*	*5*	*6*	7
TA warning time	*T*+10	*T*+10	*T*+10	*T*+15	*T*+15	*T*+13

where *S* = sensitivity level.

3.15.4.2 The values for *T* for sensitivity levels 3 to 7 are those given in 3.15.9.3.1. The value for *T* for sensitivity level 2 is 10 s.

3.15.5 TA range test

The range test for TAs has the same form as that used for threat detection (3.15.9). The values used for D_m for sensitivity levels 3 to 7 are those given in 3.15.9.1.1 incremented by $g(T_w - T)^2/6$ where T_w is the desired TA warning time. The base value for D_m for sensitivity level 2 is 0.19 km (0.10 NM).

3.15.6 TA altitude test

The altitude test gives a positive result if one of the following sets of conditions is satisfied:

a) current altitude separation is "small"; or

b) the aircraft are converging in altitude and the time to co-altitude is "small".

These terms and conditions are defined in 3.15.10.1, 3.15.10.2, 3.15.10.3 and 3.15.10.5. The time threshold for time to co-altitude is the TA warning time (3.15.4) and the values used for Z_t are as follows:

z_0 FL	below 420	above 420
Z_t m	260	370
(Z_t ft	850	1 200)

3.15.7 *RA generation*

3.15.7.1 *Intruder characteristics.* The characteristics of an intruder that are used to define a threat are:

a) tracked altitude: z_i

b) tracked rate of change of altitude: $\dot{z}_i$

c) tracked slant range: r

d) tracked rate of change of slant range: $\dot{r}$

e) sensitivity level of intruder's ACAS: S_i

For an intruder not equipped with ACAS II or ACAS III, S_i is set to 1.

3.15.7.2 *Own aircraft characteristics.* The following characteristics of own aircraft are used in threat definition:

a) altitude: z_0

b) rate of change of altitude: $\dot{z}_0$

c) sensitivity level of own ACAS (Annex 10, Volume IV, Chapter 4, 4.3.4.3): S_0.

3.15.7.3 *Altitude-band SLC command.* The reference logic selects the SLC command-based altitude band as indicated in Table 3-2.

Table 3-2. Altitude-band SLC command

Nominal altitude band	*SLC command code*	*Altitude threshold at which sensitivity level value changes*	*Hysteresis values*
0 to 1 000 ft AGL	2	1 000 ft AGL	±100 ft
1 000 ft to 2 350 ft AGL	3	2 350 ft AGL	±200 ft
2 350 ft AGL to FL 50	4	FL 50	±500 ft
FL 50 to FL 100	5	FL 100	±500 ft
FL 100 to FL 200	6	FL 200	±500 ft
above FL 200	7		

3.15.8 *Criteria for threat declaration.* An intruder becomes a threat if and only if both the following apply on the same cycle:

a) the range test gives a positive result; and

b) the altitude test gives a positive result.

Note.— RAs are not generated in Sensitivity Level 2.

3.15.8.1 *Established threat.* The threat status of an established threat is maintained on successive cycles if, as a minimum, the range test gives a positive result.

3.15.9 Range test

3.15.9.1 *Range convergence.* Aircraft are considered converging in range if the estimated range rate is less than $\dot{R}_t$. In this case the range rate estimate used in the range test is the minimum of the estimated range rate and – $\dot{R}_t$.

3.15.9.1.1 The value 3 m/s (6 kt) is used for $\dot{R}_t$.

3.15.9.2 *Range divergence.* Aircraft that are not considered converging in range are considered diverging in range. Range divergence is considered “slow” if the product of the estimated range multiplied by the estimated range rate is less than $\dot{P}_m$.

3.15.9.2.1 The following values are used for $\dot{P}_m$:

S	*3*	*4 to 6*	*7*
$\dot{P}_m$ km^2/s	0.0069	0.0096	0.0137
($\dot{P}_m$ NM^2/s	0.0020	0.0028	0.0040)

3.15.9.3 *Range test criteria.* The range test gives a positive result when one of the following conditions is satisfied:

a) both:

1) the aircraft are converging in range; and

2) the following inequality is satisfied:

$$(r - D_m^2 / r) / |\dot{r}'| < T$$

where $\dot{r}'$ = minimum $(\dot{r}, -\dot{R}_t)$; *or*

b) the aircraft are diverging in range but the range is less than D_m and the range divergence is "slow"; or

c) either a miss distance estimate could not be calculated on the current cycle or the calculated miss distance is less than H_m;

and for all other conditions the result of the range test is negative.

Note.— The formula in item a) 2) provides a practical test for the following condition: the range and range rate estimates indicate that the encounter could be such that the linear miss distance is less than or equal to D_m and the linear time to CPA is less than T.

3.15.9.3.1 The values of the parameters T, D_m and H_m are as follows:

S	*3*	*4*	*5*	*6*	*7*
T_s	15	20	25	30	35
D_m (km)	0.37	0.65	1	1.5	2.0
(D_m (NM)	0.2	0.35	0.55	0.8	1.1)
H_m (m)	382	648	1 019	1 483	2 083
(H_m (ft)	1 251	2 126	3 342	4 861	6 683)

3.15.10 Altitude test

3.15.10.1 *Altitude test terms' description*

3.15.10.1.1 Altitude divergence rate $(\dot{a})$. The rate of change of a.

3.15.10.1.2 Current altitude separation (*a*). The modulus of the current tracked altitude separation between own aircraft and the intruder.

3.15.10.1.3 Times to CPA (τ_u, τ_m). The estimated time which will be taken to reach minimum range. τ_u is the maximum value (assuming rectilinear relative motion and zero miss distance) and τ_m is the minimum value (assuming rectilinear relative motion and the maximum miss distance of interest, D_m).

3.15.10.1.4 Time to co-altitude (τ_v). The estimated time which will be taken to reach co-altitude.

3.15.10.1.5 Vertical miss distance (v_m). An estimated lower bound for the projected altitude separation at the estimated time at CPA.

3.15.10.2 *Current altitude separation.* Current altitude separation is declared “small” if $a < Z_t$ where Z_t is set equal to Z_m (3.15.10.4.2) in the reference logic.

3.15.10.3 *Altitude convergence*

3.15.10.3.1 $\dot{a}$ is calculated as follows:

$$\dot{a} = \dot{z}_o - \dot{z}_i \text{ for } z_o - z_i \geq 0$$

$$\dot{a} = \dot{z}_i - \dot{z}_o \text{ for } z_o - z_i \leq 0$$

3.15.10.3.2 The aircraft are declared converging in altitude if $\dot{a} < -\dot{Z}_c$.

3.15.10.3.3 The value of $\dot{Z}_c$ is positive and not greater than 0.3 m/s (60 ft/min).

3.15.10.4 *Vertical miss distance*

3.15.10.4.1 When the aircraft are converging in range ($\dot{r} \leq 0$), time to CPA and vertical miss distance are calculated as follows:

$$\dot{r}' = \text{minimum } (\dot{r}, -\dot{R}_t)$$

$$\tau_u = \text{ minimum } (|r/\dot{r}'|, T)$$

$$\tau_m = |(r - D_m^2/r)/\dot{r}'| \text{ for } r \geq D_m$$

$$= 0 \text{ for } r < D_m$$

$$v_{m1} = (z_o - z_i) + (\dot{z}_o - \dot{z}_i)\tau_u$$

$$v_{m2} = (z_o - z_i) + (\dot{z}_o - \dot{z}_i)\tau_m$$

$$v_m = 0 \text{ for } v_{m1}v_{m2} \leq 0 \text{, otherwise}$$

$$v_m = \text{ minimum } (v_{m1}, v_{m2}) \text{ for } v_{m1} > 0$$
$$= \text{ maximum } (v_{m1}, v_{m2}) \text{ for } v_{m1} < 0$$

3.15.10.4.2 Vertical miss distance is declared “small” if $|v_m| < Z_m$. The maximum values for Z_m are given by:

z_o *FL*	*below 200*	*200 to 420*	*above 420*
Z_m (m)	183	213	244
(Z_m (ft)	600	700	800)

3.15.10.5 Time to co-altitude

3.15.10.5.1 The time to co-altitude for $\dot{a}$ less than $-\dot{Z}_c$ is calculated as follows:

$$\tau_v = -a / \dot{a}$$

Note.— τ_v is not used if the aircraft are not converging in altitude and range.

3.15.10.5.2 τ_v is declared "small" if $\tau_v < T_v$ for encounters in which the magnitude of own aircraft's vertical rate is not more than 600 ft/min or own aircraft's vertical rate has the same sign as but smaller magnitude than that of the intruder. For all other encounters τ_v is declared "small" if $\tau_v < T$. The values of the parameters T_v are as follows:

S	*3*	*4*	*5*	*6*	*7*
T_v s	15	18	20	22	25

3.15.10.6 *Altitude test criteria*. The altitude test of the reference logic gives a positive result when any of the three following conditions is satisfied:

a) the aircraft are converging in range, the current altitude separation is "small" and the vertical miss distance is "small";

b) the aircraft are converging in range and altitude, the time to co-altitude is "small" and either the vertical miss distance is "small", or co-altitude is predicted to occur before CPA ($\tau_v < \tau_u$); or

c) the aircraft are diverging in range and the current altitude separation is "small";

and for all other conditions the results of the altitude test are negative.

3.15.11 RA types are defined in Annex 10, Volume IV, Chapter 4.

3.15.12 Delay in RA generation

An RA will be generated for all threats except in the circumstances described here or for coordination purposes.

3.15.12.1 The reference logic does not generate a new RA or modify an existing RA for a new threat when any of the following conditions are satisfied:

a) the altitude separation test (3.15.12.2) gives a negative result;

b) confidence in the tracked altitude rate of the intruder is "low" and no resolution manoeuvre would provide a predicted separation of at least A_t (3.15.12.3), whether the threat had an altitude rate equal to the upper altitude rate bound, to the lower altitude rate bound, or to any altitude rate between these bounds (3.15.2.3.4); or

c) there is "low" confidence in the threat's tracked altitude rate, the current altitude separation is greater than 46 m (150 ft), and the RA that would be selected against the threat when considered separately from other possible threats, would be altitude crossing.

3.15.12.2 *Altitude separation test*

3.15.12.2.1 The altitude rate of own aircraft is declared “small” if $|\dot{z}_o| \leq \dot{Z}_l$.

3.15.12.2.2 The value 3.0 m/s (600 ft/min) is used for $\dot{Z}_l$.

3.15.12.2.3 The delay in threat declaration is declared “acceptable” if it is less than 3.0 s.

3.15.12.2.4 The maximum altitude separation threshold, A_c, is given a value of 260 m (850 ft), when the vertical rates of own aircraft and of the threat are in the opposite directions and neither of them is “small”, and a value of 183 m (600 ft) otherwise.

3.15.12.2.5 Altitude separation is declared “minimum” if it is equal to 100 ft.

3.15.12.2.6 An encounter is declared “slow closing” if the range rate is greater than D_m/T.

3.15.12.2.7 *Test conditions*. The altitude separation test gives a negative result if the threat is a new threat and the RA that would be selected against the new threat when considered separately from other possible simultaneous threats would be either:

a) altitude crossing and either:

1) the current altitude separation exceeds A_c; or

2) the threat is equipped, a valid RAC has not been received from it, the altitude rate of own aircraft is “small”, the altitude rate of the threat is not “small”, and the delay in issuing an RA or modifying the existing RA is “acceptable”;

b) unable to generate at least “minimum” separation over the critical interval if the encounter is not “slow closing”; or

c) unable to generate at least “minimum” separation at CPA (τ_u) if the encounter is “slow closing” and either range is less than D_m or time to a range of D_m, τ_m, is less than 5 s.

Otherwise, the result of the altitude separation test is positive.

3.15.12.3 The following values are used for A_t:

z_o	A_t m	(A_t ft)
less than FL 100	61	(200)
FL 100 to FL 200	73	(240)
FL 201 to FL 420	122	(400)
greater than FL 420	146	(480)

Hysteresis of ±500 ft is applied to the boundaries between adjacent altitude layers.

3.15.12.4 When the own aircraft is level and the situation is such that non-altitude crossing advisory would be required, a reduced time threshold (T_v) is used for the altitude test. This vertical threshold test (VTT) is designed to hold off the RA just long enough so that a level-off manoeuvre initiated by the intruder might be detected.

Note.— The VTT is implemented to delay the issuance of an RA to a level ACAS-equipped aircraft when an intruder is climbing or descending to level at an adjacent altitude.

3.15.13 *Altitude separation goal.* The initial strength of the RA is selected to meet the goal of an altitude separation of at least A_l at CPA except in the circumstances described in 3.15.13.2.

3.15.13.1 The following values are used for the parameter A_l:

z_o	A_t m	(A_t ft)
less than FL 50	91	(300)
FL 50 to FL 100	107	(350)
FL 101 to FL 200	122	(400)
FL 201 to FL 420	183	(600)
greater than FL 420	213	(700)

3.15.13.1.1 Hystersis of ±500 ft is applied to the boundaries between adjacent altitude layers.

3.15.13.2 *Inadequate vertical separation*. If the restrictions on RAs (Annex 10, Volume IV, Chapter 4) preclude the generation of an RA predicted to provide an altitude separation at CPA of at least A_l, the RA is that predicted to provide the largest altitude separation at CPA consistent with the other provisions in this chapter.

3.15.13.3 *Critical interval*. Predictions for CPA are for the period of time during which a collision could occur.

3.15.13.3.1 The critical interval is that time between $\tau_{m\ell}$ and $\tau_{\mu R}$ where:

$$\dot{r}' = \text{minimum } (\dot{r}, -\dot{R}_t)$$

$$\tau_{u\ell} = \text{ minimum } (\tau^*_{u\ell}, |r/\dot{r}'|, T_e)$$

$$\tau_{m\ell} = \text{ minimum } (\tau^*_{m\ell}, |(r - D^2_m/r)/\dot{r}'|) \text{ for } r \geq D_m$$

$$\tau_{m\ell} = 0 \text{ for } r < D_m$$

where $\tau^*_{m\ell}$ and $\tau^*_{u\ell}$ are both equal to T_e for a threat that has newly passed the range test (3.15.9) and are the values of $\tau_{m\ell}$ and $\tau_{u\ell}$, respectively, on the previous cycle otherwise.

3.15.13.3.1.1 The following parameter values are used:

S	*3*	*4*	*5*	*6*	*7*
T_e, s	25	30	30	35	40

3.15.13.4 *The threat trajectory.* The RA is designed to provide altitude separations sufficient to avoid collisions with threats that:

a) continue with their current altitude rates; or

b) are climbing or descending when they first become threats and reduce their altitude rates or manoeuvre to level flight.

3.15.13.4.1 Predicted altitude separation is based on the assumption that the threat will maintain its current altitude rate except as described in 3.15.14.4 for ACAS-equipped threats.

3.15.13.5 *Own aircraft trajectory.* Predicted altitude separation at CPA is based on the following assumptions concerning the response of the ACAS II aircraft to the RA:

a) for preventive RAs, the altitude rate of own aircraft will remain within the limits specified by the RA; and

b) for corrective RAs, the trajectory of own aircraft will consist of unaccelerated flight at the current rate for $T_p + T_s$, followed by a constant acceleration $(\ddot{Z}_g)$ in the vertical plane to achieve the selected altitude rate ($\dot{Z}_g$) and thereafter unaccelerated motion at this rate.

Note.— The predicted time to CPA might be so short that the selected altitude rate, $\dot{Z}_g$, cannot be achieved.

3.15.13.5.1 The parameter T_p, which represents pilot reaction time, takes the value 5 s for the initial RA strength or 2.5 s for any subsequent RA strength.

3.15.13.5.2 The value of the parameter T_s is chosen so that it models the system delay from receipt of the relevant SSR reply to the presentation of the RA to the pilot (Annex 10, Volume IV, Chapter 4).

3.15.13.5.3 The parameter $(\ddot{Z}_g)$ takes the value 0.35g for a reversed sense RA or an increased rate RA or 0.25g otherwise.

3.15.13.5.4 If the selected altitude rate, $\dot{Z}_g$, exceeds the performance capabilities of the aircraft, a value suitable for the aircraft is substituted.

3.15.14 Restrictions on RAs

3.15.14.1 *Range of available RA strengths.* The reference logic has a capability to provide the vertical RA strength options of Table 3-3 in resolving encounters.

3.15.14.1.1 *Increased rate RAs.* The reference logic does not consider the increase climb and increase descend strength when selecting the initial strength of the RA. These RA strengths are only used when the predicted separation for the existing RA is inadequate and reversing the sense of the RA is not an acceptable option. These RA strengths are intended to convey an increased sense of urgency to the pilot. They correspond to increases in the selected altitude rate $\dot{Z}_g$ beyond > $\dot{Z}_{clm}$ or $\dot{Z}_{des}$, as appropriate.

3.15.14.1.1.1 Increases in the selected altitude rate to 13 m/s (2 500 ft/min) are generated when all the following conditions are satisfied:

a) a positive RA with the same sense is currently displayed and has been displayed for more than one cycle; and either:

1) if the threat is equipped or the current RA is not altitude crossing, confidence in the threat’s tracked altitude rate is “high” (3.15.2.3.6.10), and the current RA strength is predicted to provide an altitude separation at CPA of less than 61 m (200 ft); or

Table 3-3. RA strength options

Constraint	*Type*	$\dot{Z}_g$
Upward sense RA		
Increased climb	Positive	$> \dot{Z}_{clm}$
Climb	Positive	$\dot{Z}_{clm}$
Do not descend	VSL	0
Do not descend faster than 2.5 m/s	VSL	-2.5 m/s (-500 ft/min)
Do not descend faster than 5.1 m/s	VSL	-5.1 m/s (-1 000 ft/min)
Do not descend faster than 10 m/s	VSL	-10 m/s (-2 000 ft/min)
Downward sense RA		
Increased descend	Positive	$< \dot{Z}_{des}$
Descend	Positive	$\dot{Z}_{des}$
Do not climb	VSL	0
Do not climb faster than 2.5 m/s	VSL	+2.5 m/s (+500 ft/min)
Do not climb faster than 5.1 m/s	VSL	+5.1 m/s (+1 000 ft/min)
Do not climb faster than 10 m/s	VSL	+10 m/s (+2 000 ft/min)

2) the threat is not equipped and the current RA is altitude crossing, and 10 s or less remain until CPA and the threat's altitude at CPA is currently predicted to be less than 61 m (200 ft) above or below the current altitude of own aircraft in the case of a descend or a climb RA, respectively;

b) the time remaining to CPA is less than T_{ir} and greater than 4 s;

c) own aircraft is either descending and above 1 450 ft AGL or climbing and above 1 650 ft AGL, and increase climb RAs are not inhibited by aircraft performance limits, and

d) either τ_u (3.15.10.4.1) is not increasing or, if it is, the range to the threat is less than 3.2 km (1.7 NM).

The following values are used for T_{ir}.

S	*3*	*4*	*5*	*6*	*7*
T_{ir}, *s*	13	18	20	24	26

Note 1.— Condition 2) of a) above allows the use of an increased rate RA against a leveling-off, unequipped threat in an altitude-crossing encounter which does not qualify for a sense reversal (3.15.14.3.1). This situation can arise because the threat is leveling off with a low deceleration such that its predicted altitude at the point of CPA follows the ACAS II aircraft's current altitude on each succeeding cycle. An increased rate RA could generate additional altitude separation.

Note 2.— Condition c) prevents undesirable interactions between the collision avoidance logic and the ground proximity warning system (GPWS).

3.15.14.1.2 The default values for $\dot{Z}_{clm}$ and $\dot{Z}_{des}$ are 7.6 m/s (1 500 ft/min) and –7.6 m/s (–1 500 ft/min), respectively. If 7.6 m/s (1 500 ft/min) exceeds the aircraft's climb capability, a suitable value may be substituted to enable the generation of climb RAs. If the actual rate of climb or descent exceeds the default rate, the actual rate is substituted, if it is less than a maximum rate of 4 400 ft/min; otherwise the maximum rate of 4 400 ft/min is used.

Note.— Climbs may be inhibited in response to discrete indications, e.g. that the aircraft is at its ceiling. However, it is possible that certain aircraft will have such limited climb capability that RAs to climb at 7.6 m/s (1 500 ft/min) have to be permanently inhibited to comply with Annex 10, Volume IV, Chapter 4.

3.15.14.1.3 *RA retention.* Subject to the requirement that a descend RA is neither generated nor maintained below a specified altitude (Annex 10, Volume IV, Chapter 4), the RA is not modified if any of the following apply:

a) the range test has given a negative result but the intruder remains a threat; or

b) less than 2.5 s remain until CPA; or

c) the intruder is diverging in range but the RA has not yet been cancelled.

3.15.14.1.4 *Weakening RAs.* Subject to the requirement that a descend RA is not generated at low altitude, an RA is not weakened if any of the following conditions apply:

a) it is positive and current altitude separation is less than A_l; or

b) it (any strength) has been displayed for less than 10 s or, for a reversed sense RA, 5 s; or

c) there is “low” confidence in the threat's tracked altitude rate; or

d) the RA is a vertical speed limit RA.

Furthermore, positive RAs are not weakened beyond an RA strength allowing a return to level flight (“do not climb” for a downward RA; “do not descend” for an upward RA).

Note.— This limitation on weakening RAs does not apply to the declaration of an aircraft to not be a threat.

3.15.14.2 *Initial bias against altitude crossing*. A newly generated RA is non-crossing provided:

a) a non-crossing RA is predicted to provide an altitude separation of at least A_l at CPA; and

b) responding to a non-crossing RA with a standard response is predicted to preserve at least “minimum” vertical separation throughout the entire time interval until CPA.

3.15.14.3 *Sense reversal for an established threat*. Sense reversals are generated when the following conditions apply:

a) the threat is not equipped or the threat is equipped, has a higher aircraft address, and at least 9 s have elapsed since it became a threat and own ACAS has not previously reversed its RA; and

b) more than 4 s remain before CPA; and

c) the value of τ_μ was not already rising by the time the range to the threat was 3.2 km (1.7 NM); and

d) either:

1) i) the current RA is altitude crossing; and

ii) current altitude separation is at least 61 m (200 ft), or 30 m (100 ft) if more than 10 s remain before CPA; and

iii) either

— at the time the RA was generated the threat was predicted to cross the initial altitude of own aircraft, but currently the threat's altitude at CPA is predicted to be above or below the current altitude of own aircraft in the case of a climb or descend RA, respectively; or

— at the time the RA was generated the threat was not predicted to cross the initial altitude of own aircraft, but current estimates of the separations predicted to be achievable for climb and descend RAs at CPA show that greater separation will be obtained for a reversed sense RA; and

iv) by the time of reaching CPA, own aircraft will, with reversed sense, be able to exceed the maximum bound on the threat's altitude at CPA (projected using the maximum altitude rate bound (3.15.2.3.4)); or

2) i) the current RA is not altitude crossing; and

ii) at least one of the following:

— the threat has crossed own aircraft's altitude by at least 30 m (100 ft) in the direction of the RA sense; or

— the threat is not equipped and own aircraft has not yet crossed the altitude of the threat, but its vertical rate is opposite to the RA and an immediate manoeuvre to comply with the RA would not prevent an altitude crossing before CPA; or

— the threat is not equipped and current separation does not exceed A_c (3.15.12.2.4), the vertical rates of own aircraft and the threat exceed 1 000 ft/min in the same direction, the RA has been positive for at least 9 s, confidence in the tracked rate of the threat is high, and either an altitude crossing is predicted to occur before CPA or vertical separation at CPA is predicted to be less than 30 m (100 ft).

Note.— The sense of an RA for an established threat cannot be reversed except for coordination purposes or because the predicted separation at CPA for the existing sense is inadequate.

3.15.14.3.1 Climb RAs occurring as a result of reversals of downward-sense RAs are issued regardless of manoeuvre limitation indications.

3.15.14.4 *Strength selection for non-crossing RAs against ACAS-equipped threats.* In a conflict with an ACAS-equipped threat, in which the reference logic would normally generate a non-crossing climb or descend RA that is opposite in direction to own aircraft's existing vertical rate, an RA to limit the vertical rate to 0 ft/min will be generated instead, if the following conditions are met:

a) own aircraft and the threat are converging vertically;

b) own aircraft's vertical rate exceeds $\dot{Z}_{lo}$;

c) the threat aircraft's vertical rate is less than $\dot{Z}_{lo}$; and

d) the vertical separation that would be achieved at CPA if both aircraft were to level off exceeds $\dot{Z}_{losep}$.

3.15.14.4.1 The vertical speed limit 0 ft/min RA generated in accordance with 3.15.14.4 is retained if neither aircraft accelerates vertically toward the other with a change in rate in excess of $\dot{Z}_{l}$. Otherwise, the reference logic will immediately generate a climb or descend RA as appropriate for the RA sense.

3.15.14.4.2 The value 6 m/s (1 000 ft/min) is used for $\dot{Z}_{lo}$. The value 244 m (800 ft) is used for $\dot{Z}_{losep}$.

3.16 ACAS II USE OF HYBRID SURVEILLANCE TECHNIQUES

3.16.1 Hybrid surveillance is the technique used by ACAS to take advantage of passive position information available via extended squitter to reduce the number of active interrogations required. ACAS validates the position provided by extended squitter through direct active range measurement; extended squitter data that fails this test is not used. Initial validation is performed at track initiation. Revalidation is performed once per 10 seconds if the intruder becomes a near threat in altitude or range. Finally, regular once-per-second active surveillance is performed on intruders that become a near threat in both altitude and range. In this manner, passive surveillance (once validated) can be used for non-threatening intruders thus lowering the ACAS interrogation rate. Active surveillance is used whenever an intruder becomes a near threat. A block diagram of the hybrid surveillance algorithm is presented in Figure 3-11.

3.16.2 The reported altitude in the extended squitter position report is loaded within the Mode S transponder from the same source used to provide the altitude reported in the reply to an ACAS addressed interrogation. The altitude reported in an extended squitter position report may therefore be used to update the altitude of a track undergoing active surveillance, in the event that the transponder fails to reply to active interrogations.

3.16.3 Initial validation

3.16.3.1 A passive track is initiated by the receipt of an extended squitter with a 24-bit address that is not in the track file nor is associated with a track undergoing active surveillance. This latter case can occur if the short squitter established an active track before an extended squitter containing position reports is received.

3.16.3.2 ACAS will utilize an extended squitter for track acquisition in the same way that it utilizes a short squitter for track acquisition. After receiving the required number of squitters (as specified in Annex 10, Volume IV, Chapter 3), either extended or short, at the ACAS MTL, an attempt is made at active surveillance for a prescribed number of times. A successful reply will lead to track acquisition. An unsuccessful attempt will lead to discarding acquisition for this aircraft address, since the ADS data could not be validated. Continued receipt of extended or short squitters will lead to a subsequent acquisition attempt.

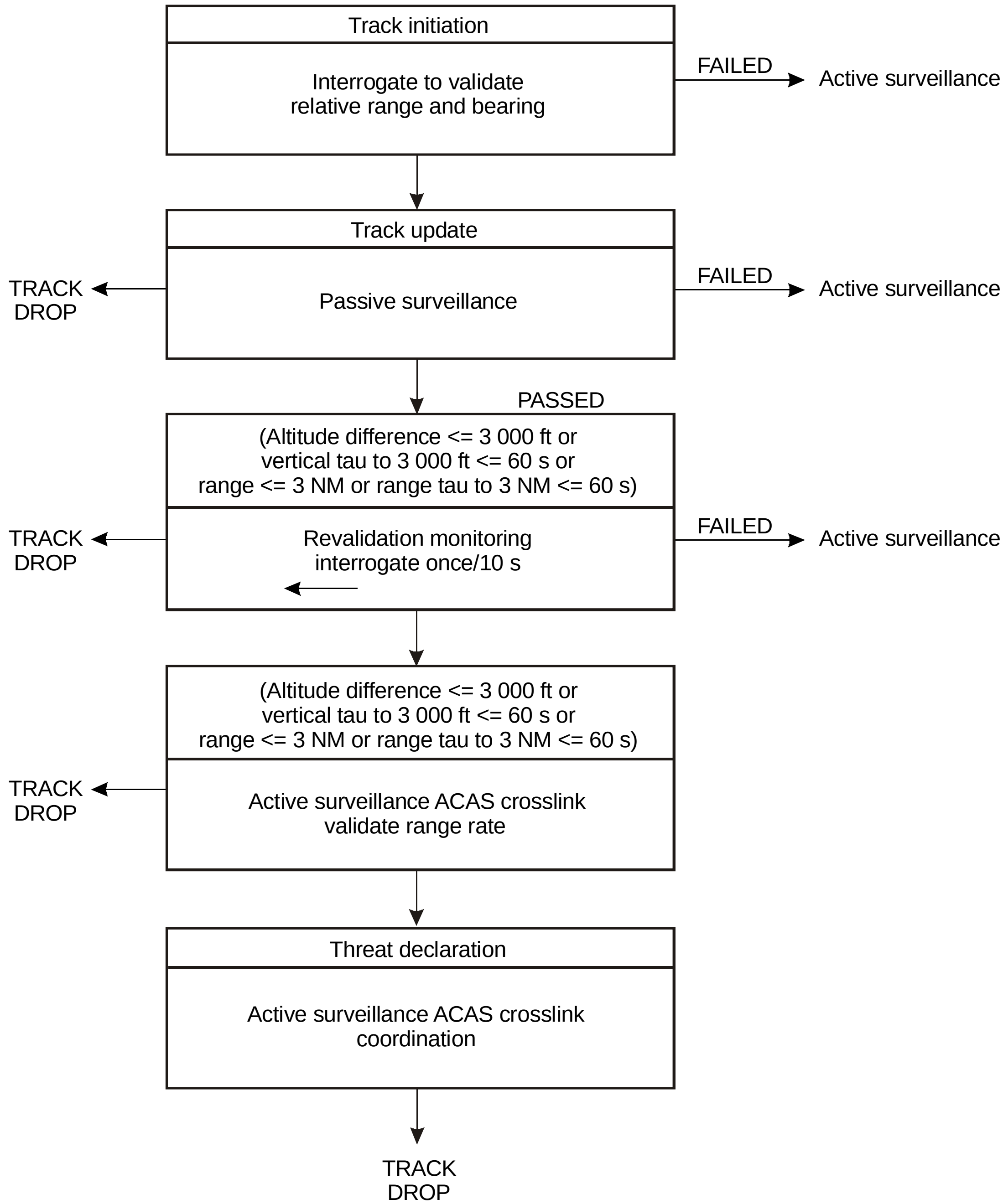


Figure 3-11. ACAS hybrid surveillance algorithm

3.16.3.3 In the case of an aircraft providing extended squitter information, a successful acquisition reply will provide the opportunity to validate the information. But in either case (short or long squitter), the same criteria for track acquisition is followed, in terms of the number of correlating squitters that are required and the number of interrogation attempts that are made.

3.16.3.4 Initial ADS information validation is performed at passive track initiation to determine if the track can be maintained on passive data. An active surveillance measurement is made using a short addressed interrogation, which may carry an ACAS cross-link command to provide the contents of register 05[HEX] (extended squitter airborne position) in the reply.

Note.— Active surveillance interrogations should include the ACAS cross-link command if the transponder is cross-link capable.

3.16.3.5 The reply to this interrogation also provides the aircraft speed capability and the reported barometric altitude in addition to the ADS-B airborne position report. The relative range and bearing computed from own aircraft and intruder reported positions is compared to the active range and bearing measurements, and the altitude provided in the position report is compared to the altitude obtained from the active interrogation. If the reported information does not agree with the range, bearing or altitude obtained via the active interrogation within limits recommended in Annex 10, Volume IV, Chapter 4, the track is declared to be an active track and future extended squitters from this aircraft are ignored by ACAS.

3.16.4 Revalidation and monitoring

If the following condition is met for an aircraft with a relative altitude ≤10 000 ft:

(Intruder altitude difference ≤ 3 000 ft OR vertical *TAU* to 3 000 ft ≤60 seconds) OR

(Range difference ≤3 NM OR range *TAU* to 3 NM ≤60 seconds)

an active interrogation is made every 10 seconds to continuously revalidate and monitor the position reports. Any detected difference will result in the aircraft being declared an active track.

3.16.5 Active surveillance

If the following condition is met for an aircraft with a relative altitude ≤10 000 ft:

(Intruder altitude difference ≤3 000 ft OR vertical *TAU* to 3 000 ft ≤60 seconds) AND

(Range difference ≤3 NM OR range *TAU* to 3 NM ≤60 seconds)

the aircraft is declared an active track and is updated on active range measurements once per second.

3.16.6 Threat evaluation declaration

If the intruder aircraft is declared to be a threat or potential threat, active range measurement continues.

3.17 PERFORMANCE OF THE COLLISION AVOIDANCE LOGIC

3.17.1 Purpose of the performance requirements

3.17.1.1 The ACAS collision avoidance logic is the part of ACAS that receives information relating to identified intruders (i.e. any aircraft for which ACAS has established a track) and generates collision avoidance advisories on the basis of that information. In any ACAS equipment it is likely to take the form of software residing in a microprocessor, and this software will implement a collection of mathematical algorithms. These algorithms might vary from one ACAS to another, and the purpose of the performance requirements for the collision avoidance logic is to ensure that the performance of the mathematical algorithms is acceptable.

3.17.1.2 The development of the collision avoidance algorithms and their implementation as software are thought of as separate processes and these standards relate to the algorithms, even though, in practice, the software used to demonstrate that the algorithms are satisfactory might be closely related to that installed with ACAS. The performance requirements for the collision avoidance logic are not intended to guarantee that the collision avoidance software is satisfactory as software, though they are an essential ingredient of such a guarantee. Satisfactory performance of the software is to be achieved by using sound software engineering practices to ensure that the algorithms are implemented reliably.

3.17.1.3 The inter-operability of the collision avoidance logics in any two equipments is achieved by ensuring that their RAs are consistent and that either RA alone is sufficient for the purpose of the system as a whole. Consistency is ensured by the requirements relating to coordination (Annex 10, Volume IV, Chapter 4). That either RA is sufficient is guaranteed by the collision avoidance logic performance requirements and, in particular, the requirement of satisfactory performance when the other aircraft is ACAS-equipped but does not cooperate.

3.17.1.4 The performance requirements are intended to provide a global guarantee that the ACAS logic in question has an overall performance that is comparable with or superior to that of other ACAS logics. They do not describe the performance of the logic in any particular airspace. For many purposes, the best method of determining or studying the performance of an ACAS logic in a particular airspace is by means of simulations based on ATC ground radar data. This possibility is discussed further in 3.17.4.4.

3.17.2 Conditions under which the requirements apply

3.17.2.1 The conditions given in Annex 10, Volume IV, Chapter 4 are specified in order to define the subsequent requirements, but satisfactory performance is required in all normal operating conditions. This is to be demonstrated by varying the conditions in which the performance measures are calculated in a way that reflects the normal variations that might be expected and ensuring that the calculated performance measures are robust, i.e. that they do not degrade sharply as the conditions assumed deteriorate.

3.17.2.2 *Surveillance errors*

3.17.2.2.1 Surveillance errors can take a number of forms:

a) a track is not formed for the intruder;

b) a track is formed late;

c) a track is dropped prematurely;

d) a track is formed but reports are not available each cycle; and

e) the reports, e.g. of range, will be subject to measurement errors.

3.17.2.2.2 While any assessment of the effectiveness of ACAS as a whole must take failure to form tracks, item a), into account, there is no need to prove that the logic is effective when it has no data.

3.17.2.2.3 Late track formation, item b), could delay the generation of RAs (perhaps because the various trackers in the logic have not converged, and the RA is delayed by low confidence) or result in an inappropriate initial RA (perhaps because the output of the trackers is used before it has converged). Best practice would be to determine the frequency of late track formation for the actual surveillance system to be used with the logic being tested.

3.17.2.2.4 Once a track is formed, missing reports can degrade the accuracy of the track or cause low confidence in the track, both of which could delay the initial RA, result in an inappropriate RA or delay changes in an RA after it has been generated. Best practice would be to determine the frequency of missing reports for the actual surveillance system to be used with the logic being tested. The probability that a report is missing on any given cycle will be a function of the range of the intruder, altitude and whether or not a report was missing on the previous cycle.

3.17.2.2.5 Actual bearing measurement errors are highly dependent on the airframe and the siting of the ACAS antenna and other antennas and obstacles fitted to the same airframe. The bearing measurements are characteristically so poor that early ACAS designs made no use of them in the collision avoidance logic. A later design, which includes a filter that inhibits RAs when the sequence of range measurements indicates a significant horizontal miss distance, used the bearing and bearing rate measurements to verify that neither aircraft is accelerating; the filter is disabled if the bearing measurements are not consistent with the diagnosed miss distance. The conditions specified in Annex 10, Volume IV, Chapter 4 are intended to cover this sort of feature in the logic.

3.17.2.2.6 ACAS installations are not required to provide bearing measurements of sufficient accuracy to provide the primary basis of a miss distance filter or any other aspect of the collision avoidance logic.

3.17.2.2.7 Range and bearing measurements are also used to determine the relative position of the intruder for use in the traffic display. The requirements for this use are much less stringent than those of the collision avoidance logic, and the models specified in Annex 10, Volume IV, Chapter 4 have no bearing on this use.

3.17.2.3 *Altitude quantization*

3.17.2.3.1 The intruder’s altitude could be available as either Mode C or Mode S reports and is thus expressed in 100 ft or 25 ft quanta. Annex 10, Volume IV, Chapter 4 specifies that 100 ft quanta be assumed for the purposes of confirming that the performance requirements are met. The performance of the collision avoidance logic is expected to be improved when the intruder’s altitude is available as 25 ft quanta, and it is desirable to confirm that this is the case.

3.17.2.3.2 In most cases, the altitude of own aircraft will be available to ACAS as a measurement prior to the formation of a Mode C or Mode S report with a resolution of 1 ft, and Annex 10, Volume IV, Chapter 4 specifies that this is assumed. For installations where it is not possible to provide the original altitude measurement to ACAS, the collision avoidance logic will have to use the Mode C or Mode S reports made by own aircraft. These reports will have a resolution of 25 or 100 ft. This is expected to degrade the performance of the logic but Annex 10, Volume IV, Chapter 4 requires that the logic be designed so that this degradation is acceptable. The logic is not expected to meet the performance requirement when altitude reports (as opposed to measurements) are used for own aircraft. The test is whether the resulting measures are judged acceptable given that they result from an installation where it has been necessary to compromise performance by using input that does not match the normal standards and whether they indicate that the logic is unduly sensitive to quantization of the altitude data for own aircraft.

3.17.2.4 *Standard altimetry error model*

3.17.2.4.1 The standard altimetry error model is needed for the calculation of the effect of ACAS on the risk of collision (3.17.3.2). Although it is based on the observed performance of operational altimeters, there is no intention that the model be used as a reference recording that performance. Still less is there an implied requirement for altimeters to match the performance described in the model whether or not they are used in conjunction with ACAS. The model is standardized solely for the purpose of defining the conditions under which the requirements relating to the performance of the collision avoidance logic apply.

3.17.2.4.2 The model describes the distribution that is to be assumed for the errors in altimeter measurements. It excludes the effect of the quantization that is needed to create Mode C or Mode S altitude reports. Nevertheless, the calculation of the effect of ACAS on the risk of collision must take full account of this quantization, and this is to be achieved by quantizing the simulated altitude measurements and thus forming simulated reports that are provided to the simulated ACAS logic.

3.17.2.4.3 The simulations of the effect of ACAS will include precise knowledge of the aircrafts' measured altitudes. Their actual altitudes are not known either to ATC or to the aircraft; they are the sum of the simulated measurement and the random altimeter error. In every encounter where the horizontal miss distance is very small, there is some risk of collision and it equals the probability that the difference in the actual altitudes of the two aircraft is small enough for them to collide. Thus the calculation of the effect of ACAS on the risk of collision (3.17.3.2) involves forming the statistical distribution of the error in the measured difference in the altitudes of the two aircraft, the convolution of two statistical distributions, one for each aircraft.

3.17.2.4.4 For the standard altimetry error model specified in Annex 10, Volume IV, Chapter 4, the probability that the actual vertical separation *d* is less than a threshold value *h* (which is taken to be 100 ft in 3.17.3.2) is as follows:

3.17.2.4.5

for $\lambda_1 = \lambda_2$ and $a \geq h$

$$Prob(|d| \leq h) =$$

$$\frac{1}{4\lambda}\exp\left(\frac{-(a+h)}{\lambda}\right)\left[\exp\left(\frac{2h}{\lambda}\right)(2\lambda+a-h)(2\lambda+a+h)\right]$$

for $\lambda_1 = \lambda_2$ and $a \ \geq h$

$$Prob(|d| \leq h) =$$

$$\frac{1}{4\lambda}\exp\left(\frac{-(a+h)}{\lambda}\right)\left[\exp\left(\frac{2a}{\lambda}\right)(2\lambda-a+h)+(2\lambda+a+h)\right]$$

for $\lambda_1 \neq \lambda_2$ and $a \geq h$

$$Prob(|d| \leq h) =$$

$$\frac{\lambda_1^2\exp\left(\frac{-a}{\lambda_1}\right)\sinh\left(\frac{h}{\lambda_1}\right)-\lambda_2^2\exp\left(\frac{-a}{\lambda_2}\right)\sinh\left(\frac{h}{\lambda_2}\right)}{\lambda_1^2-\lambda_2^2}$$

and for $\lambda_1 \neq \lambda_2$ and $a < h$

$$Prob(|d| \le h) =$$

$$\frac{\lambda_1^2\left[1-\exp\left(\frac{-h}{\lambda_1}\right)\cosh\left(\frac{a}{\lambda_1}\right)\right]-\lambda_2^2\left[1-\exp\left(\frac{-h}{\lambda_2}\right)\cosh\left(\frac{a}{\lambda_2}\right)\right]}{\lambda_1^2-\lambda_2^2}$$

where λ_1 and λ_2 are the values of λ for the two aircraft, and a is the apparent vertical separation.

3.17.2.5 *Standard pilot model*

3.17.2.5.1 The standard pilot model represents a reasonable expectation of pilots' normal reaction to RAs. However, it does not capture the full range of potential responses, for example, slow responses that undermine collision avoidance and excessively violent reactions that cause large deviations from clearance. For some responses, for example, failure to respond or a decision to move to the next flight level in response to a climb RA, it is not appropriate to examine the performance of the logic, but the following modifications to the standard model will provide an indication whether the logic is unduly dependent on an accurate pilot response.

3.17.2.5.2 In the context of Annex 10, Volume IV, Chapter 4, the reduction in the risk of collision, a suggested deficient pilot response is:

a) the pilot responds slowly, *viz.* in 8.5 s to an initial RA and in 5 s to a changed RA;

b) the pilot responds with an acceleration of 0.11 g; and

c) the pilot achieves an inadequate rate, *viz.* 500 ft/min.

3.17.2.5.3 In the context of Annex 10, Volume IV, Chapter 4, the effect of ACAS on air traffic management (ATM), a suggested excessive response is:

a) the pilot responds quickly, *viz.* in 4.7 s to an initial RA and in 1 s to a changed RA;

b) the pilot responds with an acceleration of 0.26 g;

c) the pilot achieves an excessive rate, *viz.* 3 700 ft/min; and

d) the pilot fails to respond to weakening RAs.

3.17.2.5.4 The logic is not expected to meet the performance requirements when the pilot responds as described above, but calculation of the performance measures using these non-standard pilot responses will provide some insight into the sensitivity of the logic to the accuracy of the pilot's response. The test is whether the changes in the measures are judged acceptable given that they result from an inaccurate response and whether they indicate that the logic is unduly sensitive to the response assumed from the pilot.

3.17.2.6 *Standard encounter model*

3.17.2.6.1 Effectively, there are two encounter models, one for use in risk ratio calculations (where the horizontal miss distance is small) and the other for use when assessing the compatibility of the logic design with air traffic management (ATM) (where the horizontal miss distance can be comparable with the air traffic control (ATC) horizontal separation minimum). This overcomes what would otherwise be an unacceptable simplification: both models treat the horizontal and vertical characteristics of the encounters independently.

3.17.2.6.2 The standard model is the result of an analysis of a large amount of ground radar data collected in two States. This means that one can expect the performance measures calculated using this standard model to be related to operational reality even though that is not the purpose of the calculations. The data analysed revealed very considerable variation in the airspace characteristics expressed in the encounter model depending on the location of the radar providing the data. The characteristics of the data from the two States were radically different. This implies that a standard encounter model cannot provide predictions of performance that will be valid for any specific location. However, given that a standard model is essential to the definition of standard performance, the model as standardized is considered sufficiently complex and representative.

3.17.2.6.3 To determine the parameters of the standard encounter model, for example the relative weights of the encounter classes, encounters were reconstructed from ground radar data. This required a reinterpretation of aspects of the encounters, examples of which are given below.

3.17.2.6.3.1 The definition of "Altitude layer" given for the standard encounter model is simple because it is made solely for the purpose of standardizing the collision avoidance logic. When, in the real encounters observed in the ground radar data, ground level did not correspond to a pressure altitude of 0 ft, it was necessary to distinguish between height above the ground and pressure altitude with respect to mean sea level (MSL). The method used to determine the altitude layer appropriate for an encounter observed in real radar data was to place it in Layer 1 if it occurred less than 2 300 ft above ground level (AGL) and to use the pressure altitude with respect to MSL otherwise. At locations of high altitude, one or more layers were sometimes missing.

3.17.2.6.3.2 The vertical rates of an aircraft at the beginning and the end of an encounter, $\dot{z}_1$ and $\dot{z}_2$, are, in the standard encounter model, values at precise times, *viz.* $tca - 35$ s and $tca + 5$ s. When processing the data for real encounters observed in the ground radar data, the values used for $\dot{z}_1$ and $\dot{z}_2$ were the average vertical rates over the first 10 s, i.e. [$tca - 40$ s, $tca - 30$ s], and the last 10 s, i.e. [tca, $tca + 10$ s], of the encounter.

3.17.2.6.3.3 In a similar vein, in the real encounters *tca* was the actual time at CPA, and *hmd* was the actual horizontal separation at CPA. The vertical miss distance, *vmd*, was either the vertical separation at CPA, for encounters in which $hmd \geq 500$ ft, or it was the minimum vertical separation during the period of time in which the horizontal separation of the two aircraft was less than 500 ft.

3.17.2.6.3.4 Some aspects of the standard encounter model, e.g. the magnitude of speed changes during an encounter, could not be determined from examination of the ground radar data (because of the nature of the data) and had to be specified using a general understanding of aircraft dynamics.

3.17.2.6.3.5 To put the lack of precise correspondence between the model encounters and those observed in radar data into context, it is necessary to bear in mind that the purpose of the standard encounter model is to provide a basis for standardizing the performance of the collision avoidance logic. Whilst, naturally, every realistic effort was made to ensure that the model is as faithful as possible to operational reality, precise fidelity is not required and will not have been achieved. This is not a reason for using an alternative model; the only model that is valid for assessing the performance of the collision avoidance logic against the requirements stated here is the model specified here for that purpose.

3.17.2.6.4 Any construction of the standard encounter model that can be proved equivalent to that specified in Annex 10, Volume IV, Chapter 4 is acceptable. Two examples of such equivalent alternatives are given below.

3.17.2.6.4.1 Annex 10, Volume IV, Chapter 4 specifies that the performance measures be calculated by creating sets of encounters defined by broad characteristics (specifically: the ordering of the aircraft addresses; the altitude layer; the encounter class; and the approximate value for the vertical miss distance) and combining the results from these sets by using the weights specified in the Annex. This will involve as many simulations of relatively rare types of encounters, e.g. crossing encounters, as of the more common types of encounters, e.g. non-crossing encounters. This approach ensures that the full range of possibilities within each set is properly investigated. However, the same end can be achieved by creating a number of encounters for each set that is proportional to the specified weight and combining all the encounters into one much larger pool. The only caveat on this alternative approach is that the total number of encounters must be large enough to ensure that the results from the smallest set, considered in isolation, are statistically reliable.

3.17.2.6.4.2 The statistical distributions for each of the vertical rates have been specified by requiring that first an interval be selected within which the final value is to lie, and then the final value be selected using a distribution that is uniform within the interval. This is merely a device adopted for the sake of clear presentation of the tables in Annex 10, Volume IV, Chapter 4. It would be equivalent to select the value directly using a statistical distribution that is linear within each of the intervals and for which the cumulative probability increases across each interval by an amount equal to the specified probability for that interval.

3.17.2.6.4.3 The encounters in the standard encounter model are constructed from a notional CPA outwards. The time at this notional CPA is fixed and written "*tca*" in Annex 10, Volume IV, Chapter 4. In the vertical plane, the vertical rates 35 s before *tca* and 5 s after *tca* are selected and joined by a period of acceleration if necessary, and then the altitudes in the trajectory are fixed by requiring that the vertical separation at *tca* equals the selected value for "*vmd*". In the horizontal plane, selected values for "*hmd*", the approach angle, and the aircraft speeds define the relative trajectories of the two aircraft at the time *tca*. The aircraft turns and speed changes are then imposed by modifying the trajectories before and after *tca*. At the conclusion of this process, the time at CPA only approximates *tca*.

3.17.2.7 *ACAS equipage of the intruder*

3.17.2.7.1 The standards specify three sets of conditions concerning the equipage of the intruder and the way the intruder aircraft is to be assumed to behave:

a) the other aircraft involved in each encounter is not equipped; or

b) the other aircraft is ACAS-equipped but follows a trajectory identical to that in the unequipped encounter; or

c) the other aircraft is equipped with an ACAS having a collision avoidance logic identical to that of own ACAS.

3.17.2.7.2 The first circumstance a) ensures that the logic performs satisfactorily in encounters with an unequipped intruder. The other two circumstances both test the collision avoidance logic when the other aircraft is equipped but do so from different perspectives. Circumstance b) ensures that the logic performs satisfactorily under the constraints of the coordination process, while circumstance c) ensures that the benefits to be expected when both aircraft are equipped are realized.

3.17.2.7.3 The conditions applying in circumstance b) are intended to allow own ACAS to select its initial RA but to then apply the most pessimistic reasonable assumptions about the effect of the need for coordination on the performance of the own ACAS logic. When own aircraft has the lower aircraft address, the conditions of the test imply that the sense of the RA cannot be reversed. Furthermore, the intruder does not generate an RA and an RAC until the own ACAS RA is announced because an early design included an initial coordination delay (the purpose of which was to allow the coordination to be completed and avoid the pilot seeing rapid changes in the RA); the intention of the requirement is to ensure that performance is satisfactory in spite of the deleterious effects of any such delay.

3.17.2.7.4 Circumstance c) requires that the behaviour of the two aircraft be fully cooperative, but the fact that both ACAS are using the subject logic ensures that the performance measure relates to the subject logic and that the subject logic is effective.

3.17.2.7.5 As discussed above, the performance specifications are intended to ensure satisfactory operation of the logic and not the system as a whole. To the extent that they are capable of wider interpretation in terms of the benefits of the system as a whole in an operational environment, circumstance c) might be thought to provide the more credible performance measure for ACAS-ACAS encounters. The specified performance of the logic in circumstance b) is worse than that where the intruder is not equipped, because circumstance b) invokes only the constraints imposed by coordination. However, the fact that the cooperation of an intruder cannot be guaranteed and that some pilots will fail to respond to RAs on occasion means that all three measures have operational relevance.

3.17.3 Reduction in the risk of collision

3.17.3.1 *Status of the logic risk ratio*

3.17.3.1.1 The risk ratio calculated for the purposes of Annex 10, Volume IV, Chapter 4 is a measure of the performance of the logic and not the ACAS as a whole. For example, ACAS can prevent a collision by prompting the pilot to carry out a successful visual search for the intruder and it can fail because a track is not established or the pilot ignores the RA; these are aspects of the total system that are not reflected in the calculations required for Annex 10, Volume IV, Chapter 4.

3.17.3.1.2 When considering the relevance of the “logic risk ratio” figures calculated for Annex 10, Volume IV, Chapter 4 to operations or policy decisions, it might be helpful to regard them as solely the reliability that can be attached to RAs. They express the effect that following an RA will have on the immediate risk of collision when, at the time it is issued, the pilot has no information other than the RA on which to base a decision whether to follow the RA or ignore it. As a rough guide, the collision risk created by ACAS arises from following the RA so the logic risk ratio overstates this “induced risk ratio”; on the other hand, it also overstates the capability of ACAS to prevent collisions because of the many other failure modes in the total system.

3.17.3.1.3 The figures calculated for the purposes of Annex 10, Volume IV, Chapter 4 are unsuitable as guidance concerning the effect of ACAS on the overall risk of collision in an airspace or faced by an aircraft operator.

3.17.3.2 *Calculation of the logic risk ratio*

3.17.3.2.1 The risk ratio R can be written:

$$R = \frac{\sum \textit{probability of a collision with ACAS}}{\sum \textit{probability of a collision without ACAS}}$$

where the summation is over all encounters, or, more practically, all encounters that contribute to the total risk of collision with or without ACAS. The need for the characteristics and statistics of the encounters to be representative of operational realities is standardized in Annex 10, Volume IV, Chapter 4.

3.17.3.2.2 The estimated risk of collision depends on the interpretation of the word "collision". While this problem is largely avoided by expressing the requirement in terms of the ratio between the risks of collision with and without ACAS, it is important that realistic allowance be made for the size of the largest aircraft. It would be reasonable to treat a vertical separation of less than 100 ft between the centre points of the two aircraft as if it were small enough to allow a collision. It would not be advisable to use significantly larger miss distances as approximations to collisions because it has been found that the calculated risk ratio is sensitive to the definition of "collision" even though it is a ratio.

3.17.3.2.3 If the approximation is made that a collision occurs when

$$|d| < 100 \text{ ft, where } d \text{ is the actual vertical separation}$$

then:

$$R = \frac{\sum prob(|d| < 100 \text{ ft with ACAS})}{\sum prob(|d| < 100 \text{ ft without ACAS})}$$

where now the summation is over all encounters with zero or extremely small horizontal miss distances.

3.17.3.2.4 Now introduce e, the altimeter error and a, the apparent vertical separation and note that:

$$a = d + e$$

a is conceptually the altitude separation as measured by altimeters. It should not be necessary to consider quantization errors because the modeled altimeter readings can be known with arbitrary precision in the computer simulations. They are quantized before they are provided to ACAS as modeled Mode C reports, which ACAS tracks. This is why the standard Annex 10, Volume IV, Chapter 4 excludes quantization effects.

3.17.3.2.5 Define a_{with} to be the apparent vertical separation with ACAS and $a_{without}$ to be the apparent vertical separation without ACAS. Then

$|d| < 100$ ft with ACAS

if and only if $|a_{with} - e| < 100 \ ft$

i.e. $a_{with} - 100 \ ft < e < a_{with} + 100 \ ft$

and similarly

$|d| < 100$ ft without ACAS

if and only if $a_{without} - 100 \text{ ft} < e < a_{without} + 100 \ ft$

3.17.3.2.6 Risk ratio is thus given by:

$$R = \frac{\sum prob(a_{with} - 100 \ ft < e < a_{with} + 100 \ ft)}{\sum prob(a_{without} - 100 \ ft < e < a_{without} + 100 \ ft)}$$

In order to use this formula to calculate risk ratio, the values of a_{with} and $a_{without}$ must be determined for a collection of encounters that is fully representative of all the potential actual encounters in which there is both a risk of collision without ACAS and a risk that ACAS will induce a collision. When these values of hypothetically measured altitude separation are known, knowledge of the errors in altitude measurement completes the calculation.

3.17.3.3 *Induced and unresolved risk*

3.17.3.3.1 It is not sufficient to demonstrate that ACAS will prevent collisions that might occur in its absence. The risk that ACAS logic could cause collisions in otherwise safe circumstances must be fully considered, not least because in managed airspace the number of encounters potentially facing an induced risk greatly exceeds the number of near collisions.

3.17.3.3.2 The upper limit on the logic risk ratio standardized at Annex 10, Volume IV, Chapter 4 effectively places an approximate upper limit on the ACAS-induced risk of collision. Although some other failures could cause ACAS to induce a collision, e.g. pilots manoeuvring on a TA or an RA directing the aircraft into the trajectory of an unseen third party, the induced risk is largely attributable to following RAs. In operational conditions, failure to raise or follow an RA will reduce the risk of an induced collision (even though it increases the absolute risk).

3.17.3.3.3 The requirement is that the logic is designed to reduce the risk of collision, and no distinction is drawn between risk induced by the logic and risk that it is unable to resolve. It is possible to draw such a distinction and even to subdivide the risk into that due to altimeter error and that due to inappropriate operation of the logic, but it is considered that this exercise has little value for the design of the logic.

3.17.3.4 *Use of ground radar data to calculate risk ratio*

It is possible to use encounters observed in ground radar data as the basis of the safety calculations described in 3.17.3.2. However, it is difficult to interpret the results because the calculation concerns extremely rare events and, even when many months of data are used, trajectories have to be modified to insert a risk of collision that was absent in the actual encounters. It is more practicable to use the radar data to inform the choice of the weights to be ascribed to the various encounter classes in the encounter model and thus produce a version of the idealized encounter model that is more representative of the airspace in question than the standard model presented here.

3.17.4 Compatibility with ATM

3.17.4.1 *Nuisance alert rate*

3.17.4.1.1 ACAS is required to diagnose a risk of imminent collision on the basis of incomplete information. Furthermore, this information has to be independent of that providing the primary basis for aircraft separation. It follows that there will be alerts in encounters where, from an operational perspective, there would seem to be no risk of collision. Annex 10, Volume IV, Chapter 4 requires that these nuisance alerts be as infrequent as possible.

3.17.4.1.2 The specification of a nuisance RA given in Annex 10, Volume IV, Chapter 4 is made with the view that an RA is a nuisance if normal standard separation is not clearly lost. Additionally, it is intended that the horizontal separation threshold is sufficiently stringent to require the use of a horizontal miss distance filter. The horizontal separation threshold has been set at 40 per cent of normal separation, and the vertical separation threshold has been set at a figure based on an ATC tolerance of deviations of 200 ft from altitude clearance.

3.17.4.2 *Compatible sense selection*

The requirement in Annex 10, Volume IV, Chapter 4 is not intended to constrain the manner in which dangerous encounters are resolved, but rather is based on an appreciation that the majority of RAs are likely to be generated in encounters where there is no danger of collision. It places a statistical limit on the frequency with which ACAS disrupts ATC or the normal operation of the aircraft by inverting the vertical separation of two aircraft.

3.17.4.3 *Deviations caused by ACAS*

The restrictions on the deviations that may be caused by following RAs (as per Annex 10, Volume IV, Chapter 4) limit the disruption to normal aircraft operation as well as to ATC. While deviations from altitude clearances are the most obviously disruptive to ATC, other deviations, such as that caused by an RA to climb when the aircraft is descending, could be viewed equally seriously by ATC.

3.17.4.4 *Use of ground radar data or the standard encounter model*

3.17.4.4.1 Conformity with the requirement for compatibility with ATM can be tested most convincingly using simulations based on reconstructions of actual operational encounters occurring within the coverage of ATC ground radars, provided that only a small proportion of the aircraft thus observed are equipped with ACAS. However, the results of such simulations based on actual data will reflect the particular properties of the airspace (or airspaces) in which the data were collected as much as those of the collision avoidance logic used. Thus, there are considerable practical difficulties in using real encounter data to validate collision avoidance logic, and the provisions of Annex 10, Volume IV, Chapter 4 assume the use of artificial encounters based on the standard encounter model specified in the Annex.

3.17.4.4.2 The use of the standard encounter model to obtain performance measures describing the operation of the collision avoidance logic will provide only indirect evidence concerning its operation in any particular airspace. Authorities that have access to ground radar data and wish to understand the interaction of ACAS with local ATC practices are advised to use simulations based on their ground radar data rather than the standard encounter model. In doing so, they need to note that the results can be subverted if the aircraft observed are already equipped with ACAS. They will also need to collect sufficient data to ensure that the simulated RAs derived from the data are statistically representative; for example, data collected over 100 days in one State contained very few examples of some types of RAs.

3.17.5 Relative value of conflicting objectives

The design of the collision avoidance logic for ACAS must strike an operationally acceptable balance between the reduction in the risk of collision and the disruption caused by ACAS alerts. The requirements relating to the risk of collision and the disruption to ATC are minimum standards that are known to be achievable. Other designs are only acceptable when it can be demonstrated that the risk of collision and the disruption to ATC have both been minimized as much as practicable in the context of a need to minimize the other.

3.18 INDICATIONS TO THE FLIGHT CREW

Note.— This section describes the requirements for traffic displays and resolution advisory displays that are used by certification authorities responsible for approving ACAS installations.

3.18.1 Displays

3.18.1.1 *Traffic Displays*

3.18.1.1.1 The traffic display provides the following functions:

a) aid in the visual acquisition of traffic;

b) identify intruder threat levels;

c) enhance situational awareness; and

d) instil confidence in ACAS.

3.18.1.1.2 The traffic display contains a symbol representing the location of own aircraft. The colour of the symbol is either white or cyan and different than that used to display proximate or other traffic (see 3.18.1.1.4).

Note.— *Cyan is the preferred colour of the own aircraft symbol*.

3.18.1.1.3 One or more range rings are placed at specified radii from the own aircraft symbol. The inner range ring is restricted to not being solid and is comprised of only discrete markings at each of the twelve clock positions, except in the EXPANDED mode of the navigation display or on the weather radar when both weather and ACAS information are being displayed. The markings are the same colour as the own aircraft symbol and of a size and shape that does not clutter the display. If ACAS information is shown on a shared display (see 3.18.1.1.20) that does not provide range rings (or markings), range rings are automatically provided when the ACAS information is selected.

3.18.1.1.4 Threat symbology:

a) The symbol for an RA is a red filled square;

b) The symbol for a TA is an amber or yellow filled circle;

c) The symbol for Proximate Traffic is a white or cyan filled diamond. The colour of the Proximate Traffic symbol is different than that used for the own aircraft symbol (see 3.18.1.1.2) to ensure the symbol is readable; and

Note 1.— Proximate Traffic is traffic that is within 6 NM and 1 200 ft.

Note 2. — White is the preferred colour for this symbol.

d) The symbol for Other Traffic is a diamond of the same colour as the diamond for Proximate Traffic, but outline only.

3.18.1.1.5 RA or TA traffic that is beyond the selected display range of the traffic display is indicated by placing one half the appropriate symbol at the edge of the display area at the measured bearing of the traffic. Data tags and appropriate vertical trend arrows remain fixed in the position relative to the traffic symbol defined in 3.18.1.1.6 and in 3.18.1.1.7, even if a portion of the information is masked by the edge of the active display area.

3.18.1.1.5.1 On shared displays, the off-scale symbology described in 3.18.1.1.5 is typically used unless the symbology is inconsistent with that used for other functions of the shared display. In these cases, a message of “TRAFFIC OFF-SCALE”, “OFFSCALE”, or “OFF-SCALE” is used. These messages are written in the colours specified in 3.18.1.1.4, which correspond to the traffic's threat level.

3.18.1.1.6 A data tag is used to indicate the relative altitude, if available, of the intruder aircraft and consists of two digits indicating the altitude difference in hundreds of feet. For an intruder above own aircraft, the tag is placed above the traffic symbol and preceded by a “+” sign; for one below own aircraft, the tag is placed below the traffic symbol and preceded by a “−” sign.

Note.— The “+” or “−” character is usually emphasized by using a slightly larger character set than that used for the digits.

3.18.1.1.6.1 The tag for co-altitude traffic is displayed as the digits “00”. The “00” characters are placed above the symbol if the intruder aircraft closed from above; below the symbol if the intruder aircraft closed from below. If no trend information is available, the co-altitude “00” symbol is placed below the traffic symbol.

3.18.1.1.6.2 The colour of the data tag is the same as the symbol.

3.18.1.1.6.3 The display is required to be capable of displaying relative altitudes of up to a maximum of ± 9 900 ft.

3.18.1.1.6.4 As an option, the data tag may indicate the intruder's reported altitude instead of the relative altitude between the two aircraft. If this option is implemented, a switch is provided to permit a pilot to select this type of altitude data tag. If the actual altitude is shown on a continuous basis after selection by the flight crew, it must be corrected for the local barometric pressure. If the actual altitude is not corrected for the local barometric pressure, the display of this type of data tag is limited to a maximum of 30 seconds if own aircraft is below 18 000 ft (FL180) before it automatically reverts back to the display of relative altitude. When the display of the actual altitude is selected, it must be clearly shown on the traffic display.

3.18.1.1.6.5 If implemented, the actual altitude is displayed as a three-digit number representing hundreds of feet, MSL. For example, 007 represents 700 ft MSL and 250 represents 25 000 ft MSL (FL 250). Actual altitude tags are positioned above or below the traffic symbol in a manner consistent with the relative altitude data tags. As with the display of relative altitude, the display must be capable of displaying tracked traffic up to a maximum of ± 9 900 ft of own aircraft.

3.18.1.1.7 A vertical arrow is placed to the immediate right of the traffic symbol if the vertical speed of the intruder (as determined by the ACAS tracker) is equal to or greater than 500 fpm, with the arrow pointing up for climbing traffic and down for descending traffic. The colour of the arrow shall be the same as the traffic symbol.

3.18.1.1.8 Neither a data tag nor a trend arrow is associated with the traffic symbol for an intruder that is not reporting altitude. The colours described in 3.18.1.1.4 for various threat levels are used for the display of non-altitude reporting intruders.

3.18.1.1.8.1 Advisories issued against an intruder for which bearing information is not available (No-Bearing advisories) are presented for traffic generating either a TA or an RA. The No-Bearing advisory is displayed on the traffic display. The advisory is provided via an alpha-numeric string, which presents the information in the following order: threat level: (TA or RA); range in NM; relative altitude (hundreds of feet); and the intruder vertical speed arrow. For example, “TA 5.2 −06↑” represents an intruder causing a TA at 5.2 NM with a relative altitude of −600 ft, and climbing. The alpha-numerics are written in the colours corresponding to the level of the threat, i.e. red for an RA and amber or yellow for a TA. The No-Bearing advisory may also be written using slashes to separate the different information fields and using “nm” after the range, e.g. “TA/5.2 nm/−06↑”.

3.18.1.1.8.1.1 The altitude data in a No-Bearing advisory is consistent with the selected altitude mode, i.e. relative altitude or actual altitude.

3.18.1.1.8.1.2 When a No-Bearing TA is issued against an intruder that is not reporting altitude, the altitude field of the message and the intruder vertical trend arrow are dropped. For example, a TA issued against a non-altitude reporting intruder at a range of two NM is shown as “TA 2.0”.

3.18.1.1.8.1.3 The capability to display at least two No-Bearing advisories simultaneously is required of the traffic display.

3.18.1.1.8.1.4 The recommended location of the No-Bearing advisories is dependent on the implementation of the traffic display.

3.18.1.1.8.1.5 If an intruder for which bearing information is available is displayed in the same area as the No-Bearing advisory, the intruder with the higher priority, as defined by the collision avoidance system (CAS) logic, remains readable.

3.18.1.1.9 Whenever an RA or a TA is displayed, all intruders causing an RA or TA and all Proximate Traffic within the selected display range, subject to any limitations to the maximum number of intruders that can be shown on the display, are displayed. It is recommended that other traffic within the selected display range also be displayed whenever an RA or TA is displayed to maximize the probability of the pilot visually acquiring the intruder causing the RA or TA.

3.18.1.1.10 The traffic display has the capability to display a minimum of eight intruder aircraft. All intruders being tracked by ACAS are ranked by the CAS logic, and the intruder information is sent to the display in a prioritized order. The display displays the intruders in the order received from CAS to ensure the intruders most relevant to collision avoidance are displayed. The number of intruders to be displayed is fixed.

3.18.1.1.11 The normal altitude band for the display of traffic having an established surveillance track is ± 2 700 ft from own aircraft. If an intruder causing a TA or RA is outside this altitude band, it is displayed with the appropriate relative or reported altitude displayed. Proximate and Other traffic outside the normal altitude band may also be displayed while a TA or RA is displayed.

3.18.1.1.11.1 In some installations, an optional, pilot-selectable mode is provided to permit the expansion of the normal altitude band. If this option is implemented, two additional modes, Above and Below, are provided. In the Above mode, tracked traffic is displayed if it is within the altitude band from 2 700 ft below own aircraft up to a maximum that does not exceed 9 900 ft above own aircraft. In the Below mode, tracked traffic is displayed if it is within the altitude band from 2 700 ft above own aircraft down to a maximum that does not exceed 9 900 ft below own aircraft. The upper and lower bounds of the Above and Below mode are fixed.

3.18.1.1.11.2 As a further option, some displays provide a pilot-selectable mode that permits the simultaneous selection of the Above and Below mode.

3.18.1.1.12 The selected modes of ACAS operation are shown on the traffic display. The ACAS operating mode may be manually selected by the pilot using the ACAS Control Panel or automatically by the CAS logic. In addition, the selected display range must be shown on the traffic display.

3.18.1.1.13 With the exception of the red traffic symbology described in 3.18.1.1.4 and 3.18.1.1.8.1, no RA information is displayed on the traffic display.

Note — This requirement does not apply to the TA/RA/VSI or to displays in which the TA and RA information are shown in separate sections of a display.

3.18.1.1.14 Whenever status and failure annunciations are written in text on the traffic display, the annunciations must be consistent with any existing annunciations shown on the display and must have a single meaning for all available display modes.

3.18.1.1.15 *Traffic displays with a fixed range*

Fixed range displays typically provide a display area that is between five and seven NM to the front and at least 2.5 NM to the rear of the own aircraft symbol. A two mile range ring is provided.

3.18.1.1.16 *Traffic displays with variable range*

3.18.1.1.16.1 A variable range display must provide a display range whose full scale display range is approximately 5 NM to the front and at least 2.5 NM to the rear. Other display ranges can be provided.

3.18.1.1.16.2 A range selector is provided to allow the flight crew to select the different full range scales.

3.18.1.1.16.3 A range reference (ring or markings) must be provided at either two or three NM for scales of 12 NM or less. For display ranges greater than 12 NM, at least one range reference is provided. If the variable range display is also a shared display that already provides range rings (or markings), the range references discussed in this subparagraph are not required.

3.18.1.1.17 *Part time (pop-up) displays*

3.18.1.1.17.1 A part-time display either activates (pops-up) the appropriate traffic symbology or displays the written text “TRAFFIC”, “TFC”, or “TCAS” whenever a TA or an RA occurs. The words “TRAFFIC”, “TFC”, or “TCAS” are written in amber or yellow for a TA and in red for an RA. If ACAS is issuing both a TA and an RA simultaneously, the words are written in red.

3.18.1.1.17.1.1 Provisions are provided which can be used by the pilot to select a display Mode capable of displaying the traffic symbology in implementations using the words “TRAFFIC”, “TFC”, or “TCAS”.

3.18.1.1.17.2 Once activated, the display remains active until the TA or RA is completed unless the selected display mode is changed by the pilot.

3.18.1.1.17.3 Display implementations that provide the pilot with the capability to manually switch between a part-time and a full-time display of traffic, provide a switch to make this selection, and the position of this switch must be readily discernible by inspection.

3.18.1.1.18 *Full-time displays*

A full-time display may be a dedicated display or a shared display. A full-time display may be either a fixed range display or a variable range display.

3.18.1.1.19 *Dedicated displays*

A dedicated display is a display or a display mode in which the only information shown on the display or on a designated section of the display is ACAS traffic information. A dedicated display may be either a part-time display or a full-time display.

3.18.1.1.20 *Shared displays*

3.18.1.1.20.1 A shared display is a display or a display mode in which ACAS information is shown simultaneously with other information. It is possible for a display to provide multiple display modes, some of which have the characteristics of a dedicated display and others that have the characteristics of a shared display.

3.18.1.1.20.2 Examples of shared displays include ACAS traffic information being shown on weather radar displays, navigation displays, electronic horizontal situation indicators, TA/RA/IVSIs, and EICAS/SYSTEMS displays.

3.18.1.1.21 *Display orientation*

3.18.1.1.21.1 The display of traffic may be referenced to the aircraft heading, aircraft track or magnetic/true north. On a display that provides the pilot with the capability to select various display orientations, the selected display mode must be shown on the display.

3.18.1.1.21.2 *North-up mode*

3.18.1.1.21.2.1 If traffic information is referenced to true or magnetic north (North-up mode), it can be implemented on either a part-time or full-time basis. If traffic information is displayed in this mode, the display must be a variable range display.

3.18.1.1.21.2.2 The range of the ACAS display is consistent with the navigation information. If the North-up provides range markings for the navigation information, dedicated range rings or arcs for the traffic information are not required.

3.18.1.1.21.2.3 An own aircraft symbol must be displayed when the North-up mode is selected. The own aircraft symbol is directional in shape and shown with the front of the symbol oriented in the direction of own aircraft's heading. If an own aircraft symbol is not depicted in a North-up mode, e.g. a way-point provided by a navigation system is centred on the display, traffic information cannot be displayed.

3.18.1.1.21.2.4 The traffic is displayed referenced to the front of the own aircraft symbol.

3.18.1.1.21.2.5 When a TA or RA is issued while a display is in a North-up mode, the written messages defined in 3.18.1.1.17.1 will be displayed.

3.18.1.1.21.2.6 Provisions are provided so that a pilot can switch from a North-up mode to a mode showing traffic in a heading up orientation with a single action when a TA or RA is issued.

3.18.1.2 *RA Displays*

3.18.1.2.1 The RA display provides guidance on the vertical speed or pitch angle to be flown, and the range of vertical speeds or pitch angles to be avoided, to attain or maintain the desired vertical miss distance from an aircraft causing an RA.

3.18.1.2.2 Various implementations of the RA display have been approved for use, and each implementation has unique characteristics.

3.18.1..3 *RA/VSI (Round dial VSI)*

3.18.1.2.3.1 This implementation indicates the vertical speeds to be flown and avoided using a series of red, green and black arcs displayed around the periphery of the vertical speed indicator (VSI).

Note.— The term "black arcs" refers to the area of the VSI scale, usually the background of the scale that is not illuminated by the lighted red and green arcs.

3.18.1.2.3.2 The scale of the VSI used to display RA information must have sufficient range to display the required red and green arcs for all RAs that can be generated by the collision avoidance logic. This requires a range of ± 6 000 fpm.

Note.— If the VSI does not have a range of 6 000 fpm, a means must be provided to display all corrective and preventive RAs, as well as own aircraft's actual vertical speed.

3.18.1.2.3.3 The red arcs on the RA/VSI indicate the vertical speed range that must be avoided to maintain or attain the ACAS-desired vertical miss distance from one or more intruders. The length of the red arc is adjusted as appropriate when the RA is strengthened or weakened by the CAS logic.

3.18.1.2.3.4 A green "fly-to" arc is used to provide a target vertical speed whenever a change in the existing vertical speed is desired or when an existing vertical speed (not less than 1 500 fpm) must be maintained. The nominal size of the green arc is approximately that defined by the distance between the 1 500 and 2 000 fpm marks on the VSI scale. The size of the green arc remains constant no matter where the arc is placed on the display, with the exception of the multi-aircraft encounter described in 3.18.1.2.3.8.

3.18.1.2.3.5 The green arc is either wider than the red arc or offset from the red arc to assist in visually differentiating between the red and green arcs.

3.18.1.2.3.6 The green arc remains displayed for the entire duration of the RA. Its position moves to the appropriate position when an RA is strengthened or weakened by the CAS logic.

3.18.1.2.3.7 The portions of the VSI scale not covered by either a red or green arc remain black.

3.18.1.2.3.8 For the special situation where a multi-aircraft encounter results in an RA where neither a climb nor descent is permitted, a green arc is displayed from approximately –250 fpm to +250 fpm. The remainder of the VSI scale is then illuminated with red arcs.

3.18.1.2.3.9 Inertial quickening of the vertical speed function is typically provided on these types of displays.

3.18.1.2.4 *RA/VSI (Integrated Tape VSI on a Primary Flight Display [PFD])*

3.18.1.2.4.1 This implementation indicates the vertical speeds to be flown and avoided using a series of red, green and black zones displayed within the vertical speed tape portion of the PFD.

Note.— The term "black zones" refers to the area of the VSI scale, usually the background of the scale, that is not covered by either a red or green zone.

3.18.1.2.4.2 The red zone on the RA/VSI indicates the vertical speed range that must be avoided to maintain or attain the ACAS-desired vertical miss distance from one or more intruders. The length (height) of the red zone is adjusted as appropriate when the RA is strengthened or weakened by the CAS logic.

3.18.1.2.4.3 A green “fly-to” zone is used to provide a target vertical speed whenever a change in the existing vertical speed is desired and when an existing vertical speed (not less than 1 500 fpm) must be maintained. The nominal size of the green zone is approximately that defined by the distance between the 1 500 and 2 000 fpm marks on the VSI scale. The size of the green zone remains constant no matter where the zone is placed on the display, with the exception of the multi-aircraft encounter described in 3.18.1.2.4.7.

3.18.1.2.4.4 The green zone is wider than the red zone to assist in visually differentiating between the red and green zone.

3.18.1.2.4.5 The position of the green zone moves to the appropriate position when an RA is strengthened or weakened by the CAS logic.

3.18.1.2.4.6 The portions of the VSI scale not covered by either a red or green zone remain black.

3.18.1.2.4.7 For the special situation where a multi-aircraft encounter results in an RA where neither a climb nor descent is permitted, a green zone is displayed from approximately –250 fpm to +250 fpm. The remainder of the VSI scale is then illuminated with red zones.

3.18.1.2.4.8 Inertial quickening of the vertical speed function is typically provided on these types of displays.

3.18.1.2.4.9 The scale of the VSI tape must have sufficient range to display the required red and green zones for all RAs that can be generated by the collision avoidance logic. This requires a range of ±6 000 fpm.

Note.— If the vertical speed tape does not have a range of ±6 000 fpm, a means must be provided to display all corrective and preventive RAs, as well as the own aircraft’s actual vertical speed.

3.18.1.2.5 *Pitch cues on the PFD*

3.18.1.2.5.1 This implementation indicates the pitch angles to be flown and/or avoided while responding to an RA.

3.18.1.2.5.2 A red trapezoid, or another similar geometric shape, overlaying the other information on the PFD indicates the range of pitch angles that must be avoided to maintain or attain the ACAS-desired vertical miss distance from one or more intruders. When the trapezoid is displayed, the other information shown on the PFD must remain readily discernible and readable.

3.18.1.2.5.3 The trapezoid begins at the bottom of the PFD and extends upward to the desired pitch angle for up-sense RAs; for down-sense RAs, the trapezoid begins at the top of the PFD and extends downwards to the desired pitch angle. The closed end of the trapezoid corresponds to the pitch angle that will provide the vertical speed desired by the ACAS RA.

3.18.1.2.5.4 The red trapezoid remains displayed for the entire duration of the RA. It moves as appropriate when an RA is strengthened or weakened by the CAS logic.

3.18.1.2.5.5 The use of a green “fly-to” target at the closed end of the trapezoid is permitted to provide a target pitch angle whenever a change in the existing vertical speed is desired. However, no manufacturer has implemented this permitted feature.

3.18.1.2.5.6 When an RA is displayed, a written annunciation of “TCAS”, “TFC”, or “TRAFFIC”, written in red, must be displayed in the primary field of view of each pilot. The exact implementation of the annunciation is left to the discretion of the manufacturer, but the annunciation must be compatible with the implementation of other mode annunciations.

3.18.1.2.5.7 For the special situation where a multi-aircraft encounter results in an RA where neither a climb nor descent is permitted, two red trapezoids are simultaneously displayed. One begins at the top of the PFD and extends downward to the pitch angle that will result in level flight, while the other begins at the bottom of the PFD and extends upward to the pitch angle that will result in level flight. Sufficient room is left between the two trapezoids to permit the own aircraft reference on the PFD to fit between the two trapezoids.

3.18.1.2.6 *Heads-up display (HUD)*

3.18.1.2.6.1 This implementation indicates the vertical flight path to be flown and avoided using a unique display symbology on the HUD.

3.18.1.2.6.2 A trapezoid overlaying the other information on the HUD indicates the flight path that must be flown to maintain or attain the ACAS-desired vertical miss distance from one or more intruders.

3.18.1.2.6.3 The trapezoid begins at the bottom of the display and extends upward to the desired flight path angle for up-sense RAs; for down-sense RAs, the trapezoid begins at the top of the display and extends downward to the desired flight path angle. The closed end of the trapezoid corresponds to the flight path that will provide the vertical speed desired by ACAS.

3.18.1.2.6.4 The trapezoid remains displayed for the entire duration of the RA. It moves as appropriate when an RA is strengthened or weakened by the CAS logic.

3.18.1.2.6.5 When an RA is displayed, the HUD displays a written annunciation of “TCAS” or “TRAFFIC”. The exact implementation of the annunciation is compatible with the implementation of other mode annunciations on the HUD.

3.18.1.2.6.6 A flight path target is provided whenever a change in the existing vertical speed is desired. A box consisting of lines twice the width of the lines comprising the trapezoid is displayed at the top (up-sense RA) or bottom (down-sense RA) of the trapezoid for all RAs except initial preventive RAs. The flight path target remains displayed for the entire duration of the RA. It moves to the appropriate position when an RA is strengthened or weakened by the CAS logic.

3.18.1.2.6.7 For the special situation where a multi-aircraft encounter results in an RA where neither a climb nor a descent is permitted, two trapezoids are simultaneously displayed. One begins at the top of the display and extends downward to the flight path angle that will result in level flight, while the other begins at the bottom of the display and extends upward to the flight path angle that will result in level flight. Sufficient room is left between the two trapezoids to display the flight path target box and the own aircraft reference symbol.

3.18.1.2.6.8 When an RA is displayed, some displays will automatically be decluttered by removing certain data and symbols. Items such as ground speed, mach, wind speed and direction, digital heading, digital selected course, and digital selected heading may be removed if this does not interfere with the pilot's ability to comply with the RA or operate the aircraft in compliance with the appropriate regulations and requirements. The navigation data, as well as the guidance cue, remain displayed at all times.

3.18.1.2.6.9 RA guidance is available in all display modes.

3.18.2 Aural annunciations

3.18.2.1 ACAS aural alerts are presented by voice announcements only.

3.18.2.2 An aural annunciation is generated when the first RA of an encounter is displayed and each time a subsequent change in the advisory is displayed (strengthened or weakened). An aural annunciation is also provided to indicate that the ACAS aircraft is clear of conflict with all threatening aircraft.

3.18.2.3 The aural annunciations used are shown in Table 3-4. An annunciation can be interrupted before it is completed if the CAS logic determines that a higher priority aural annunciation should be announced. The prioritization of the aural annunciations is defined in RTCA DO-185A.

3.18.2.4 The annunciations for an RA reversal and for an increase rate RA indicate the previously annunciated RA has reversed or been increased in strength, respectively. These aural annunciations are spoken with a sense of urgency.

3.18.2.5 Aural annunciations are automatically inhibited by annunciations issued by reactive and predictive wind shear systems, and ground proximity warning systems/terrain avoidance warning systems (GPWS/TAWS), which have a higher priority, and below an altitude determined by the CAS logic.

3.18.2.6 When a higher priority warning system (wind shear or GPWS) has an active warning, ACAS is automatically placed into the “TA Only” mode of operation.

Table 3-4. ACAS Aural Annunciations

RA	*Aural Annunciation*	*Visual Alert*
Corrective Climb	Climb, Climb	CLIMB
Corrective Descend	Descend, Descend	DESCEND
Altitude Crossing Climb	Climb, Crossing Climb Climb, Crossing Climb	CROSSING CLIMB
Altitude Crossing Descend	Descend, Crossing Descend Descend Crossing Descend	CROSSING DESCEND
Corrective Reduce Climb	Adjust Vertical Speed, Adjust	ADJUST V/S
Corrective Reduce Descent	Adjust Vertical Speed, Adjust	ADJUST V/S
Reversal to a Climb	Climb, Climb NOW Climb, Climb NOW	CLIMB NOW
Reversal to a Descend	Descend, Descend NOW Descend, Descend NOW	DESCEND NOW
Increase Climb	Increase Climb Increase Climb	INCREASE CLIMB
Increase Descent	Increase Descent Increase Descent	INCREASE DESCENT
Initial Preventive RA	Monitor Vertical Speed	MONITOR V/S
Non altitude crossing maintain rate RA	Maintain Vertical Speed, Maintain	MAINTAIN V/S
Altitude crossing, maintain rate RA	Maintain Vertical Speed, Crossing Maintain	MAINTAIN V/S CROSSING
Weakening of corrective RA	Adjust Vertical Speed, Adjust	ADJUST V/S
Clear of Conflict	Clear of Conflict	CLEAR OF CONFLICT

3.18.2.7 When a TA is initially issued, the aural annunciation “TRAFFIC-TRAFFIC” is spoken once. No aural annunciation is issued when an RA against an intruder reverts to a TA at the end of an encounter.

3.18.2.8 The “TRAFFIC-TRAFFIC” annunciation will be pre-empted by any annunciation associated with an RA.

3.18.3 Visual Alerts

3.18.3.1 A red visual alert is required in the primary field of view for each pilot. The red arcs on an RA/VSI display will fulfil this requirement. Likewise, conspicuous illumination of the red zones on the vertical speed tape, appropriate pitch guidance, or a suitable written message (termed a Visual Alert) on a PFD will fulfil this requirement.

3.18.3.2 If a written message is shown on the PFD, it is required to flash or otherwise be highlighted in accordance with industry alerting standards. If a written message is shown on the PFD, it will be one of the messages shown in Table 3-4.

3.18.3.3 The written message “CLEAR OF CONFLICT” is prohibited from being in red, amber or yellow.

3.19 CONTROLS

3.19.1 Means are provided to select the following modes of operation:

a) operation of Mode S transponder only. The selection of this mode places ACAS into Standby, i.e. it is not transmitting interrogations;

b) operation of the Mode S transponder and ACAS in the TA/RA mode;

c) operation of the Mode S transponder and ACAS in the TA Only mode; and

d) ACAS Self Test.

3.19.2 The controls for the Mode S transponder and ACAS are typically located on a single control panel.

3.19.3 The traffic display controls depend on the type of display used and the features available on the display. The following types of controls are used as appropriate:

a) *Altitude Range Selector.* If the traffic display provides an option for displaying proximate and other traffic with relative altitudes between ± 2 700 ft and a maximum of ± 9 900 ft (see 3.18.1.1.11.1), a switch is provided to permit a pilot to control the vertical range of the display. The control panel markings for this selector use the annotations of Above, Normal and Below, or a suitable abbreviation of these words. When the Above or Below mode is selected, it is shown on the traffic display;

b) *Range Selector.* On variable range displays (see 3.18.1.1.16), a switch is provided to permit the desired display range to be selected;

c) *Actual Altitude.* If the traffic display provides an option for displaying the actual altitude of an intruder (see 3.18.1.1.6.4), a switch is provided to change between the display of relative and actual altitude in the intruder's altitude data block;

d) *Traffic Override.* On shared displays (see 3.18.1.1.20), a switch is provided to override the traffic display and the traffic that has popped-up and is no longer required for visual acquisition, e.g. return an EICAS/SYSTEMS display to its normal function; and

e) *Display Mode Selector.* On displays that provide both a full-time and a part-time display mode, a means is provided to permit a pilot to select the desired display mode.

3.20 STATUS AND FAILURE ANNUNCIATIONS

3.20.1 Visual annunciations are provided to indicate the normal operating and the failure modes of ACAS. The colour of the annunciations conforms to industry alerting standards for information (level 0) or advisory (level 1) annunciation, as appropriate. The colour of the level 1 annunciation is amber or yellow.

3.20.2 The ACAS Traffic Display is capable of annunciating the following ACAS operating modes and failure conditions:

a) ACAS in Standby or turned off (Level 0 annunciation);

b) ACAS operating in the TA Only mode (Level 0 annunciation);

c) ACAS has failed (Level 1 annunciation);

d) The Traffic Display is unable to display traffic (Level 1 annunciation); and

e) A pilot-initiated Self Test is in progress (Level 0 annunciation).

3.20.3 The RA display provides the capability to annunciate the following ACAS operating modes and failure conditions:

a) ACAS in Standby or turned off (Level 0 annunciation);

b) ACAS operating in the TA Only mode (Level 0 annunciation);

c) the RA display has failed (Level 1 annunciation);

d) ACAS has failed (Level 1 annunciation); and

e) a pilot-initiated Self Test is in progress. (Level 0 annunciation).

3.21 ACAS LIMITATIONS

3.21.1 ACAS performance and effectiveness is limited by several system, operational and/or performance limitations. These limitations are as follows.

3.21.1.1 ACAS will not detect non-transponder equipped aircraft, or aircraft with an inoperative transponder.

3.21.1.2 ACAS will not issue RAs for traffic without an altitude reporting transponder.

3.21.1.3 ACAS will not issue advisories against aircraft having vertical rates in excess of 10 000 fpm. In addition, the design implementation may result in some short-term errors in the tracked vertical speed of an intruder during periods of high vertical acceleration by the intruder.

3.21.1.4 ACAS will not display a maintain rate RA that calls for a vertical rate greater than 4 400 fpm. This restriction arises because the VSI will not have sufficient room to display the green “fly-to” arc.

3.21.1.5 ACAS will automatically fail if the input from the aircraft’s barometric altimeter, radio altimeter or transponder is lost. If the transponder’s altitude reporting feature is disabled, ACAS will not be able to receive own aircraft’s barometric altitude and thus will automatically fail. Some installations also require a valid input from the aircraft’s inertial reference system or aircraft heading and reference system to be operational.

3.21.1.6 Certain RAs are inhibited at altitudes based on inputs from the radio altimeter. All thresholds shown below have hysteresis of ±100 ft. These inhibits are as follows:

3.21.1.6.1 All RAs are inhibited below 1 000 ft above ground level (AGL).

3.21.1.6.2 Increase Descent RAs are inhibited below 1 450 ft AGL.

3.21.1.6.3 Descend RAs are inhibited below 1 100 ft AGL.

3.21.1.6.4 Climb and Increase Climb RAs can be inhibited above predetermined altitudes or in certain aircraft configurations. These inhibits are set via programme pins during installation. ACAS includes provisions for these inhibits to be set in real time via inputs from a flight management system, but this feature is implemented on only a limited number of aircraft.

3.21.1.7 Aural annunciations are inhibited below 500 ft AGL.

3.21.1.8 Because of the interference limiting algorithms (see 3.7.3), ACAS may not display all proximate transponder-equipped aircraft in areas of high-density traffic.

3.21.1.9 The bearing displayed by ACAS is not sufficiently accurate to support the initiation of horizontal manoeuvres based solely on the traffic display. As a result, horizontal manoeuvres based solely on information displayed on the traffic display are prohibited.

3.21.1.10 Ground Proximity Warning System (GPWS) and terrain avoidance warning system (TAWS) warnings and wind shear warnings take precedence over ACAS advisories. When either a GPWS/TAWS or wind shear warning is active, ACAS aural annunciations will be inhibited and ACAS will automatically be placed in the TA Only mode.

3.22 ADDITIONAL FUNCTIONALITY

3.22.1 ACAS has the capability to communicate with the ground-based air traffic control system via Mode S when the necessary complementary features have been installed. ACAS can provide the ground system with the RAs that are displayed to the pilot. These RAs may be displayed to the air traffic controller if the technical and operational requirements defined by the user have been fulfilled. Evaluations in several States have resulted in decisions not to display RA information to the air traffic controller. Nevertheless, other States and organizations are currently investigating new approaches to the display of RA information to controllers.

3.22.2 Airborne ACAS equipment can receive sensitivity level commands from ground-based Mode S sensors. This provides the ability to uplink commands that could place ACAS in the TA Only mode or reduce the alarm thresholds in specific geographic areas.

Note.— Operational procedures must be developed and coordinated prior to transmitting sensitivity level commands from the ground. To date, this capability has not been implemented or evaluated in any State. There is strong opposition to the implementation of this functionality from at least one user group.

Chapter 4

RELATIONSHIP BETWEEN ACAS PERFORMANCE, SAFETY AND AIRSPACE CONFIGURATION

4.1 ASSUMPTIONS REGARDING AIRSPACE CONFIGURATION AND OPERATION INCLUDED IN ACAS

4.1.1 Tracking thresholds

4.1.1.1 Although ACAS can track aircraft with vertical rates in excess of 10 000 fpm, RAs are not generated against such aircraft. This is because it is difficult to predict the vertical rates with sufficient accuracy to suggest appropriate RAs. The aircraft involved are implicitly considered to be military and far more able to manoeuvre vertically than own aircraft.

4.1.1.2 Vertical accelerations that exceed ±1.25 g will cause severe errors in ACAS tracking. These manoeuvres give altitude replies that are so different from the projected level that they are considered as erroneous and ACAS continues its current altitude projections. Vertical accelerations in aircraft operating within civil airspace should be kept below ±1.25 g.

4.1.2 Horizontal distance thresholds for RAs

4.1.2.1 Although ACAS advisories are primarily based on estimated time to collision, they also can be triggered when proximity becomes too small. This may interfere with some operational procedures — for example with closely spaced parallel runways. The table below shows the threshold horizontal spacing (expressed as Distance MODification (DMOD)) at different altitudes.

Above altitude (ft)	DMOD (NM)
20 000 MSL	1.1
10 000 MSL	0.8
5 000 MSL	0.55
2 350 AGL	0.35
1 000 AGL	0.2

4.1.2.2 ACAS is designed to minimize the unnecessary alert rate when the standard vertical separation is 1 000 ft[1] below FL 420. When a smaller separation standard is used, unnecessary RAs may occur; for example, when providing 500 ft separation against VFR traffic or allowing visual clearances through the level of other traffic.

4.1.3 Timing thresholds for RAs

4.1.3.1 The surveillance range of ACAS has been designed to ensure that sufficient warning time can be provided for collision avoidance even in environments with heavy electromagnetic activity. This assumes that each aircraft does not have an excessive True Air Speed (TAS). Below FL 100 ACAS warning times will only be guaranteed when both aircraft have TAS less than 250 kts. Similarly, ACAS is not designed to provide adequate warning time for supersonic aircraft.

4.1.3.2 ACAS generates RAs when aircraft are converging and the time to potential collision is short. The warning time varies between 15 and 35 seconds depending on the geometry and altitude of the encounter. Many nuisance RAs are generated when aircraft approach within 1 000 ft of their cleared level with high vertical rates (in excess of 1 500 fpm). The problem is worse where descending and climbing aircraft level off in the same horizontal vicinity and within 1 000 ft vertically of each other. Whenever possible, airspace design should separate the areas where climbing and descending traffic level off. Certification authorities and aircraft operators should consider the acceptability of autopilot manoeuvres that allow high vertical rates just before level off. To avoid these unnecessary ACAS RAs, operational procedures should be published by States which recommend that pilots reduce the rate of climb/descent to a value between 500 and 1 500 ft/min within the last 1 000 ft before reaching the assigned level (flight level or altitude) provided that this does not increase the flight crew's work due to the need for manual leveling off. Such limitations do not apply when ATC issues a specific rate in the climb/descent clearance or instruction in order to establish or maintain separation.

4.1.4 Pilot response

4.1.4.1 Pilots are expected to comply with RAs promptly and accurately.

4.1.4.2 ACAS anticipates the following response from pilots to RAs:

a) the pilot will respond within 5 seconds to the first RA;

b) the vertical acceleration will be 0.25 g until the required vertical rate is achieved;

c) for subsequent RAs the pilot will respond within 2.5 seconds and with 0.25 g except for RA reversals and increase rate RAs; and

d) for RA reversals and increase rate RAs, the pilot will respond with 0.35 g.

4.1.4.3 Proper pilot response to RAs is expected in all airspace and in all phases of flight. The design, certification and operational approvals of ACAS have taken into account the potential for an RA to be issued at the maximum operating altitude, including certified ceiling, service ceiling and at low altitudes.

4.1.4.3.1 ACAS is one of several alerting systems that can be activated at low altitude. These systems include corrective and predictive wind shear systems and terrain avoidance warning systems

1. Note that TCAS II V6.04a assumes that the separation will be at least 2 000 ft between FL 290 and FL 410.

(TAWS). The certification of ACAS recognizes that both wind shear and TAWS alerts have a higher priority than ACAS RAs. To prevent situations from occurring where there are conflicting advisories being issued simultaneously, aircraft installations require that the ACAS processor be provided with information from wind shear and TAWS that indicates when an advisory is issued by these systems. When such an indication is received, ACAS will be automatically placed into the TA-Only mode. ACAS will remain in TA-Only for 10 seconds after the wind shear or TAWS alert is removed.

4.1.4.3.2 Climb and Increase Climb RAs will be inhibited above certain altitudes and in some landing configurations if adequate performance does not exist to comply with these types of RAs. The decision regarding whether an aircraft type will have such inhibits set is made during the certification of ACAS on each aircraft type. The certification tests are conducted for RAs issued during take-off, approach, go-around, and en route. For the en route evaluations, the initial speed is set to long range cruise at a weight, altitude, and temperature condition that provides a 0.3 g margin to buffet onset. A Climb RA is issued followed by a five second delay and then a 0.25 g acceleration to obtain a 1 500 fpm rate of climb. This rate of climb is maintained for 25 seconds. If the minimum speed at the end of the 25 seconds is at least $1.2V_s$ (V_s is stalling speed or minimum steady flight speed) or if there has been no buffet, then a climb inhibit is not permitted for the aircraft. In practice, only a limited number of climb and increase climb inhibits have been permitted for the en route cases, and all of these have been for turbo-prop aircraft. Regulatory authorities expect Climb and Increase Climb RAs to be followed even if the response takes the aircraft above the maximum altitude or aircraft ceiling for a short period of time.

4.1.4.4 A response in the opposite sense to the RA may result in collision and should be avoided in all circumstances.

4.1.5 Transponder and aircraft installation issues

4.1.5.1 ACAS will only generate RAs against intruder aircraft that provide altitude reporting via their Mode C or Mode S transponder.

4.1.5.2 ACAS relies upon the correct operation of Mode S and Mode C transponders. Some specific issues to be considered are:

a) the signal must not be blocked by electro-magnetic interference. Particular care must be taken to ensure that the 1 030/1 090 MHz RF load is not excessive;

b) the transponder should be free of faults. These may include reporting incorrect Mode S addresses, reporting wheels on ground when airborne, providing excessive interrogations or replies or providing incorrect altitude reports. Regular testing and monitoring of Mode S and Mode C transponders is therefore required;

c) supersonic aircraft can generate unreliable altitude reports during their transonic phase. These false reports can generate false RAs. The transonic phase of supersonic aircraft should therefore be kept horizontally separated from other aircraft whenever possible, and with greatly increased vertical separation when this is not possible; and

d) whenever ACAS receives a transponder reply, it assumes that this is from a real aircraft. Some cases of false RAs have been caused by transponder testing on the ground that simulated in-flight altitudes. Adequate shielding or very high simulated altitudes (>FL700) must be used to avoid such problems during Mode S or Mode C transponder tests.

4.2 INDEPENDENCE OF ACAS THRESHOLDS FROM ATC SEPARATION STANDARDS

ACAS thresholds are independent from ATC separation standards because ACAS does not strive to ensure separation, which is ATC's role, but tries to avoid collision as a last resort. Further details on this topic are contained in Section 6.2.4.

4.3 EFFECTS OF CLOSELY-SPACED AIRCRAFT ON ACAS PERFORMANCE

4.3.1 A high density of aircraft can be found in a number of circumstances. For example, clusters of transponder-equipped helicopters or gliders, clusters of ACAS-equipped aircraft, and near terminal areas around major airports. They can adversely affect ACAS performance in the following two ways.

4.3.2 A high density of ACAS-equipped aircraft can reduce the surveillance range of ACAS units down to a minimum of approximately 4.5 NM. Every ACAS unit monitors the number of other ACAS units within detection range. This information is used to limit its own interrogation rate and power, as necessary, in order to ensure that no transponder is suppressed by ACAS activity for more than 2 per cent of the time and to ensure that ACAS does not contribute to an unacceptably high FRUIT rate which would degrade ground SSR surveillance performance.

4.3.3 A high density of Mode A/C transponders can lead to garbling, FRUIT, and loss of correlated replies. The ACAS tracker performance can be degraded, possibly forming tracks with replies from two different aircraft or losing tracks momentarily. This would of course entail a reduction of the ability of the CAS logic to trigger effective collision avoidance advisories. This surveillance problem arises even with a small number of aircraft when they are in very close proximity (VFR conditions) which is the case with glider operations.

4.4 AIRSPACE DESIGN CONSIDERATIONS

4.4.1 Reduced Vertical Separation Minimum (RVSM)

4.4.1.1 RVSM implements 1 000 ft vertical separation for aircraft between FL 290 and FL 410. At these altitudes, TCAS II Version 6.04A has a vertical threshold of 1 200 ft to trigger a TA, while TCAS II Version 7 has a threshold of 700 ft. The effect of this is that Version 6.04A-equipped aircraft will receive between 30 and 50 times the number of TAs received by a Version 7-equipped aircraft.

4.4.1.2 Furthermore, TCAS II Version 7 generates only half the number of RAs compared with TCAS II Version 6.04A, and this helps to offset the increase in the number of RAs when vertical separation is reduced from 2 000 ft to 1 000 ft. For these reasons, it is recommended that:

a) TCAS II aircraft operating in RVSM airspace use TCAS II Version 7 or later;

Note.— Some States require TCAS II Version 7 or later to be installed on any TCAS-equipped aircraft operating in RVSM airspace.

b) aircraft report altitude in 25-ft increments;

c) aircrews and aircraft operating in RVSM airspace meet all appropriate certification and operational requirements; and

d) controllers be trained in ACAS operation in RVSM airspace.

4.4.2 Separation of controlled and uncontrolled airspace

When controlled and uncontrolled airspace is vertically separated by less than 1 000 ft, there is a risk of RAs being generated between ACAS-equipped aircraft operating at or near the floor of the controlled airspace if altitude reporting aircraft are operating at or near the ceiling of the uncontrolled airspace. Whenever feasible, controlled and uncontrolled airspace should be vertically separated by at least 1 000 ft.

4.4.3 Reducing the number of unnecessary RAs caused by high vertical rates prior to level-off manoeuvres

In some airspace, a majority of RAs are unnecessary RAs generated when a climbing or descending aircraft levels off at an adjacent altitude to another aircraft, i.e. with 1 000 ft of vertical separation. Research has shown that many of these RAs can be eliminated by airspace design that:

a) separates airways by 2 000 ft in geographic areas where aircraft will be leveling off in close horizontal proximity to other traffic; or

b) relocates the horizontal position where aircraft are leveling off to ensure adequate horizontal separation exists between aircraft.

Chapter 5

OPERATIONAL USE AND PILOT TRAINING GUIDELINES

5.1 GENERAL

For the system to achieve its designed safety benefits, flight crews must operate the system and respond to ACAS alerts in a manner compatible with the system design. Many ACAS alerts will involve more than one ACAS-equipped aircraft. In these coordinated encounters, it is essential that each flight crew respond in a predictable manner. The issues discussed in this section form the basis for the Pilot Training Guidelines that follow in the Section 5.3. The guidelines define the knowledge of the system and its operation that should be included in pilot training programmes and include information on system performance, proper use of ACAS controls, and proper responses to ACAS alerts. The guidelines require both academic training and manoeuvre training conducted in either aircraft simulators or other computer-based trainers. Flight crews must be tested to ensure they are wholly familiar with ACAS procedures, capabilities and limitations and are able to respond correctly to ACAS indications. Moreover, regularly scheduled recurrent training sessions shall include ACAS training. The remainder of the chapter includes findings from a review of existing pilot training programmes, examples of ACAS events in which an improper response to an RA resulted in a decrease in separation with the intruder aircraft, and a description of the procedure for reporting ACAS events to air traffic control units.

5.2 ACAS OPERATIONAL USE

5.2.1 ACAS indications are intended to assist pilots in the avoidance of potential collisions and the active search for, and visual acquisition of, conflicting traffic. For ACAS to work as designed, immediate and correct crew response to ACAS advisories is essential. Delayed flight crew response to an RA or reluctance to manoeuvre the aircraft in response to an RA for whatever reason can significantly decrease or negate the protection afforded by ACAS. Therefore, there should be a clear understanding among the flight crew of their respective responsibilities when an ACAS advisory occurs. Flight crews are expected to respond to ACAS indications in accordance with the following guidelines.

5.2.1.1 Respond to TAs by attempting to establish visual contact with the intruder aircraft and other aircraft that may be in the vicinity. Coordinate to the degree possible with other crew members to assist in searching for traffic. Do not deviate from an assigned clearance based only on TA information. For any traffic that is acquired visually, continue to maintain safe separation in accordance with current regulations and good operating practices. Pilots should not make horizontal manoeuvres based solely on information shown on the traffic display. Slight adjustments in vertical speed while climbing or descending, or slight adjustments in airspeed while still complying with the ATC clearance are acceptable.

5.2.1.2 When an RA occurs, the PF (Pilot Flying) should respond immediately by looking at the RA displays and manoeuvring as indicated, unless doing so would jeopardize the safe operation of the flight. *The pilot's instinctive reaction should always be to respond to RAs in the direction and to the degree displayed, without delay.*

5.2.1.3 If a decision is made not to respond to an RA, the flight crew negates the safety benefits provided by its own ACAS. A decision to not respond also decreases the safety benefits to all other aircraft involved in the encounter.

5.2.1.4 Manoeuvres, or lack of manoeuvres, that result in a vertical speed opposite to the sense of the RA could result in a collision with the threat aircraft.

5.2.1.5 The threat may also be equipped with ACAS, and it may manoeuvre in an unexpected direction while responding to a complementary RA that has been coordinated with own aircraft's ACAS.

5.2.1.6 Traffic acquired visually may not be the traffic causing the RA, or it may not be the only aircraft to which ACAS is responding.

5.2.1.7 Visual perception of the encounter may be misleading. It is difficult to visually determine the vertical displacement of other aircraft especially when ground reference information is unreliable or at cruise altitudes where the earth's horizon is obscured.

5.2.1.8 Respond to RAs by disconnecting the autopilot and by using prompt, smooth control inputs; manoeuvre in the direction and with the vertical rate ACAS requires. To achieve the required vertical rate (normally 1 500 ft per minute) on aircraft where the RA is displayed on a vertical speed indicator (VSI), it is recommended that the aircraft's pitch be changed using the guidelines shown in the table below. Referring to the VSI or vertical speed tape, make any further pitch adjustments necessary to place the vertical speed in the green area.

SPEED	PITCH ADJUSTMENT
.80 MACH	2 degrees
250 KIAS below 10 000 ft	4 degrees
APPROACH below 200 KIAS	5 to 7 degrees

5.2.1.8.1 On aircraft with pitch guidance for ACAS RA displays, follow the RA pitch command for initial, increase and weakening RAs.

5.2.1.9 For ACAS to provide safe vertical separation, the PF is expected to initiate the appropriate RA manoeuvre within 5 seconds of when the RA is first displayed. Deviations from assigned altitude, when responding to an RA, typically will be no more than 300 to 500 ft. RA manoeuvres should use vertical speeds within the green areas, or the indicated pitch angle, and avoid red areas on vertical speed indicators or tapes, or outlined pitch avoidance areas.

5.2.1.10 The PNF (Pilot Not Flying) should provide updates on the traffic location and monitor the response to the RA. Proper crew resource management should be applied.

5.2.1.11 Respond immediately to any "increase" or "reversal" RA. Initiation of the increase or reversal RA manoeuvre is expected within 2-1/2 seconds after issuance of the advisory. Again, fly to the green area or indicated pitch angle and avoid red areas or outlined pitch avoidance areas.

5.2.1.12 If an RA is weakened, such as a "climb" RA weakened to a "do not descend" RA, respond to the weakening RA by adjusting the aircraft's vertical speed or pitch angle as required by the RA display.

Pilots are reminded that prompt and correct reaction to the weakened RA will minimize altitude deviations and disruptions to ATC. This will also reduce the possibility of additional RAs against the intruder or other traffic.

5.2.1.13 Excessive responses to RAs are disruptive to ATC and may result in additional RAs.

5.2.1.14 If an RA manoeuvre is inconsistent with the current ATC clearance, pilots shall follow the RA.

5.2.1.14.1 ATC may have older altitude data than ACAS and does not know when ACAS issues RAs, unless notified by the pilot. It is possible for ATC to unknowingly issue instructions that are contrary to the ACAS RA indications. When one aircraft manoeuvres opposite the vertical direction indicated by ACAS and the other aircraft manoeuvres as indicated by ACAS, a collision may occur. Do not manoeuvre contrary to the RA based solely upon ATC instructions.

5.2.1.14.2 ATC may not be providing separation service to the aircraft causing the RA or the intruder may not be known to ATC, e.g. military operations in some States.

5.2.1.15 If an RA requires manoeuvring contrary to “right-of-way” rules, “cloud clearance” rules for visual flight rules (VFR), instrument flight rules (IFR), or other such criteria, pilots are expected to follow the RAs to resolve the immediate traffic conflict. Deviations from rules or clearances should be kept to the minimum necessary to satisfy an RA, but the RA must be satisfied.

5.2.1.16 If an RA response requires deviation from an ATC clearance, expeditiously comply with the current ATC clearance when the traffic conflict is resolved or the ACAS “clear of conflict” message is heard.

5.2.1.17 If an RA requires a deviation from an assigned altitude, communicate with ATC immediately after responding to the RA. The phraseology for communicating with the controller is specified in *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444).

5.2.1.18 When the RA is cleared, the flight crew should: 1) immediately return to their previously assigned clearance and advise ATC of that manoeuvre; or 2) comply with any amended clearance issued.

5.2.1.19 Stall warning, wind shear and Ground Proximity Warning System (GPWS) alerts take precedence over ACAS RAs. Pilots shall respond to these alerts instead of RAs.

5.2.1.20 Pilots should use ACAS traffic information displays to assist in establishing visual contact with other aircraft. Certain Electronic Flight Information System (EFIS) ACAS installations operating in conjunction with “track up” mode may require the pilot to make allowances for the difference between the aircraft heading and track when visually searching for nearby aircraft.

5.2.1.21 Pilots are expected to operate ACAS while in flight in all airspace.

5.2.1.22 When feasible, flight crews should use the same altitude data source that is being used by the PF to provide altitude information to ACAS and the ATC transponders. Using a common altitude source precludes unnecessary RAs due to differences between altitude data sources.

5.2.2 ACAS does not alter or diminish the pilot’s basic authority and responsibility to ensure safe flight. Since ACAS does not track aircraft that are not transponder-equipped or aircraft with a transponder failure, ACAS alone does not ensure safe separation in every case. It is particularly important that pilots maintain situational awareness and continue to use good operating practices and judgment when following ACAS RAs. Maintain frequent outside visual scan, “see-and-avoid” vigilance, and continue to communicate as needed and as appropriate with ATC.

5.2.3 The following ACAS good operating practices have been identified during the use of ACAS throughout the world.

5.2.3.1 To preclude unnecessary transponder interrogations and possible interference with ground radar surveillance systems, ACAS should not be activated (TA-only or TA/RA mode) until taking the active runway for departure and should be deactivated immediately after clearing the runway after landing. To facilitate surveillance of surface movements, it is necessary to select a mode in which the Mode S transponder can nevertheless squitter and respond to discrete interrogations while taxiing to and from the gate. Operators must ensure that procedures exist for pilots and crews to be able to select the operating mode where ACAS is disabled, but the Mode S transponder remains active.

5.2.3.2 During flight, ACAS traffic displays should be used to assist in visual acquisition. Displays that have a range selection capability should be used in an appropriate range setting for the phase of flight. For example, use minimum range settings in the terminal area and longer ranges for climb/descent and cruise, as appropriate.

5.2.3.3 The normal operating mode of ACAS is TA/RA. It may be appropriate to operate ACAS in the TA-only mode only in conditions where States have approved specific procedures permitting aircraft to operate in close proximity or in the event of particular in-flight failures or performance limiting conditions as specified by the Aeroplane Flight Manual or operator. It should be noted that operating in TA-only mode eliminates the major safety benefit of ACAS.

5.2.3.3.1 Operating in TA/RA mode and then not following an RA is potentially dangerous. If an aircraft does not intend to respond to an RA and operates in the TA-only mode, other ACAS-equipped aircraft operating in TA/RA mode will have maximum flexibility in issuing RAs to resolve encounters.

5.2.3.4 When safe, practical, and in accordance with an operator's approved operating procedures, pilots should limit vertical speeds to 1 500 fpm or less (depending on performance characteristics of the aircraft) when within 1 000 ft of assigned altitudes. This procedure will reduce the frequency of unnecessary RAs and be in conformity with the ICAO guidance contained in PANS-OPS.

5.2.3.4.1 Some States have taken actions to require vertical speed reductions when approaching an assigned altitude. These requirements, defined in the State's AIPs, were implemented as a means for reducing the probability of unnecessary RAs when an aircraft is climbing or descending to level at an adjacent altitude to another aircraft.

5.3 PILOT TRAINING

5.3.1 During the implementation of ACAS and the operational evaluations conducted by States, several operational issues were identified that were attributed to deficiencies in pilot training programmes. To address these deficiencies, a set of performance-based training objectives for ACAS II pilot training was developed. The training objectives cover five areas: theory of operation; pre-flight operations; general in-flight operations; response to TAs; and response to RAs. The training objectives are further divided into the areas of: ACAS academic training; ACAS manoeuvre training; ACAS initial evaluation; and ACAS recurrent qualification.

5.3.2 Under each of these four areas, the training material has been divided into those items that are considered essential training items and those that are considered desirable. Those items that are deemed to be essential are a requirement for each ACAS operator. In each area, a list of objectives and acceptable performance criteria is defined.

5.3.3 In developing this material, no attempt was made to define how the training programme should be implemented. Instead, objectives were established that define the knowledge a pilot operating ACAS is expected to possess and the performance expected from a pilot who has completed ACAS training. Therefore, all pilots who operate ACAS equipment are required to receive the ACAS training described below.

5.3.4 ACAS academic training

5.3.4.1 This training is typically conducted in a classroom environment. The knowledge demonstrations specified in this section may be met by successfully completing written tests or providing correct responses to non-real-time computer-based training (CBT) questions.

5.3.4.2 *Essential items*

5.3.4.2.1 Theory of operation. The pilot must demonstrate an understanding of ACAS operation and the criteria used for issuing TAs and RAs. This training should address the following topics:

a) System operation

Objective: Demonstrate knowledge of how ACAS functions.

Criteria: The pilot must demonstrate an understanding of the following functions:

1) Surveillance:

i) ACAS interrogates other transponder-equipped aircraft within a nominal range of 14 NM; and

ii) ACAS surveillance range will be reduced in geographic areas with a large number of ground interrogators and/or ACAS II-equipped aircraft. A minimum surveillance range of 4.5 NM is guaranteed for ACAS aircraft that are airborne.

Note.— If the operator's ACAS implementation provides for the use of the Mode S extended squitter, the normal surveillance range may be increased beyond the nominal 14 NM. However, this information is not used for collision avoidance purposes.

2) Collision avoidance:

i) TAs can be issued against any transponder-equipped aircraft even if the aircraft does not have altitude-reporting capability;

ii) RAs can be issued only in the vertical plane and only against aircraft that are reporting altitude;

iii) RAs issued against an ACAS-equipped intruder are coordinated to ensure complementary RAs are issued; and

iv) Failure to respond to an RA deprives own aircraft of the collision protection provided by its ACAS. Additionally, in ACAS-ACAS encounters, it also restricts the choices available to the other aircraft's ACAS and thus renders the other aircraft's ACAS less effective than were own aircraft not ACAS-equipped.

b) Advisory thresholds

Objective: Demonstrate knowledge of the criteria for issuing TAs and RAs.

Criteria: The pilot must be able to demonstrate an understanding of the methodology used by ACAS to issue TAs and RAs and the general criteria for the issuance of these advisories to include:

1) ACAS advisories are typically based on time to closest point of approach (CPA). The time must be short and vertical separation must be small, or projected to be small, before an advisory can be issued. The separation standards provided by air traffic services are different from those against which ACAS issues alerts;

2) in encounters with a slow closure rate, ACAS advisories will be issued based on distance;

3) thresholds for issuing a TA or RA vary with altitude. The thresholds are larger at higher altitudes;

4) TAs generally occur 8 to 15 seconds prior to an RA;

5) RAs occur from 15 to 35 seconds before the projected CPA; and

6) RAs are chosen to provide the desired vertical miss distance at CPA. As a result, RAs can instruct a climb or descent through the intruder aircraft's altitude.

c) ACAS limitations

Objective: To verify the pilot is aware of the limitations of ACAS.

Criteria: The pilot must demonstrate a knowledge and understanding of the ACAS limitations including:

1) ACAS will neither track nor display non-transponder-equipped aircraft, nor aircraft with an inoperable transponder;

2) ACAS will automatically fail if the input from the aircraft's barometric altimeter, radio altimeter or transponder is lost;

Note.— In some installations, the loss of information from other on-board systems such as an inertial reference system (IRS) or attitude heading reference system (AHRS) may result in an ACAS failure. Individual operators should ensure their pilots are aware of what types of aircraft system failures will result in an ACAS failure.

3) some aircraft within 380 ft AGL (nominal value) will not be displayed. If ACAS is able to determine that an aircraft below this altitude is airborne, it will display it;

4) ACAS may not display all proximate, transponder-equipped aircraft in areas of high-density traffic;

5) because of design limitations, the bearing displayed by ACAS is not sufficiently accurate to support the initiation of horizontal manoeuvres based solely on the traffic display;

6) because of design limitations, ACAS will neither display nor give alerts against intruders with a vertical speed in excess of 10 000 ft/min. In addition, the design implementation may result in some short-term errors in the tracked vertical speed of an intruder during periods of high vertical acceleration by the intruder; and

7) stall warnings, GPWS/TAWS warnings, and wind shear warnings take precedence over ACAS advisories. When either a GPWS/TAWS or wind shear warning is active, ACAS aural annunciations will be inhibited, and ACAS will automatically switch to the TA-only mode of operation. ACAS will remain in TA-only mode for 10 seconds after the GPWS/TAWS or wind shear warning is removed.

d) ACAS inhibits

Objective: To verify the pilot is aware of the conditions under which certain functions of ACAS are inhibited.

Criteria: The pilot must demonstrate a knowledge and understanding of the various ACAS inhibits including:

1) increase descent RAs are inhibited below 1 450 (±100) ft AGL;

2) descend RAs are inhibited below 1 100 (±100) ft AGL;

3) all RAs are inhibited below 1 000 (±100) ft;

4) all ACAS aural annunciations are inhibited below 500 (±100) ft AGL. This includes the aural annunciation for TAs; and

5) altitude and configuration under which climb and increase climb RAs are inhibited. ACAS can still issue climb and increase climb RAs when operating at the aircraft's maximum altitude or certified ceiling. Responses to climb RAs while operating at the maximum altitude or certified ceiling are expected to be complied with in the normal manner.

Note— In some aircraft types, climb or increase climb RAs are never inhibited.

5.3.4.2.2 Operating procedures. The pilot must demonstrate the knowledge required to operate ACAS and interpret the information presented by ACAS. This training should address the following topics:

a) Use of controls

Objective: To verify the pilot can properly operate all ACAS and display controls.

Criteria: Demonstrate the proper use of controls including:

1) aircraft configuration required to initiate a Self Test;

2) steps required to initiate a Self Test;

3) recognizing when the Self Test was successful and when it was unsuccessful. When the Self Test is unsuccessful, recognizing the reason for the failure, and, if possible, correcting the problem;

4) recommended usage of traffic display range selection. Low ranges are used in the terminal area, and the higher display ranges are used in the en route environment and in the transition between the terminal and en route environment;

5) if available, recommended usage of the Above/Below mode selector. Above mode should be used during climb and Below mode should be used during descent;

6) recognition that the configuration of the traffic display, i.e. range and Above/Below selection, does not affect the ACAS surveillance volume;

7) selection of lower ranges on the traffic display to increase display resolution when an advisory is issued;

8) if available, proper selection of the display of absolute or relative altitude and the limitations of using the absolute display option if a barometric correction is not provided to ACAS;

9) proper configuration to display the appropriate ACAS information without eliminating the display of other needed information; and

10) selection of various ACAS and transponder operating modes.

Note. — The wide variety of display implementations makes it difficult to establish more definitive criteria. When the training programme is developed, these general criteria should be expanded to cover specific details for an operator's specific display implementation.

b) display interpretation

Objective: To verify a pilot understands the meaning of all information that can be displayed by ACAS.

Criteria: The pilot must demonstrate the ability to properly interpret information displayed by ACAS including:

1) other traffic, i.e. traffic within the selected display range that is not proximate traffic;

2) proximate traffic, i.e. traffic that is within 6 NM and ± 1 200 ft;

3) non-altitude reporting traffic;

4) no bearing TAs and RAs;

5) off-scale TAs and RAs. The selected range should be changed to ensure that all available information on the intruder is displayed;

6) traffic advisories. The minimum available display range that allows the traffic to be displayed should be selected to provide the maximum display resolution;

7) resolution advisories (traffic display). The minimum available display range of the traffic display that allows the traffic to be displayed should be selected to provide the maximum display resolution;

8) resolution advisories (RA display). Pilots should demonstrate knowledge of the meaning of the red and green areas or the meaning of pitch or flight path angle cues displayed on the RA display. For displays using red and green areas, demonstrate knowledge of when the green areas will and will not be displayed. Pilots should also demonstrate an understanding of the RA display limitations, i.e. if a vertical speed tape is used and the range of the tape is less than 2 500 ft/min, how an Increase Rate RA and a Maintain Rate RA will be displayed;

9) if appropriate, awareness that navigation displays oriented “Track-Up” may require a pilot to make a mental adjustment for drift angle when assessing the bearing of proximate traffic;

Note.— The wide variety of display implementations will require the tailoring of some criteria. When the training programme is developed, these criteria should be expanded to cover details for an operator's specific display implementation.

c) Use of the TA-only mode

Objective: To verify that a pilot understands the appropriate times to select the TA-only mode of operation and the limitations associated with using this mode.

Criteria: The pilot must demonstrate the following:

1) knowledge of the operator's guidance for the use of TA-only;

2) reasons for using this mode and situations in which its use may be desirable. These include operating in known close proximity to other aircraft such as when visual approaches are being used to closely spaced parallel runways or taking-off towards aircraft operating in a VFR corridor. If TA-only is not selected when an airport is conducting simultaneous operations from parallel runways separated by less than 1 200 ft, and to some intersecting runways, RAs can be expected. If an RA is received in these situations, the pilot should follow the RA; and

3) the TA aural annunciation is inhibited below 500 ft (±100 ft) AGL. As a result, TAs issued below 500 ft AGL may not be noticed unless the TA display is included in the routine instrument scan;

d) Crew coordination

Objective: To verify pilots adequately brief other crew members on how ACAS advisories will be handled.

Criteria: Pilots must demonstrate during their preflight briefing the procedures that will be used in responding to TAs and RAs including:

1) division of duties between pilot flying and pilot not flying, including a clear definition of who will fly the aircraft during a response to an RA;

2) expected call-outs;

3) conditions under which an RA may not be followed and who will make this decision; and

4) communications with ATC.

Note 1.— Different operators have different procedures for conducting pre-flight briefings and for responding to ACAS advisories. These factors should be taken into consideration when implementing the training programme.

Note 2.— The operator must specify the conditions under which an RA need not be followed, reflecting advice published by States' Civil Aviation Authorities. This should not be an item left to the discretion of a crew.

Note 3.— This portion of the training may be combined with other training such as crew resource management (CRM).

e) Reporting requirements

Objective: To verify the pilot is aware of the requirements for reporting RAs to the controller and other authorities.

Criteria: The pilot must demonstrate the following:

1) the use of the phraseology contained in the PANS-ATM, Doc 4444; and

2) where information can be obtained regarding the need for making written reports when an RA is issued. Various States have different reporting requirements, and the material available to the pilot should be tailored to the operator's operating environment.

5.3.4.3 *Non-essential items*

a) Advisory thresholds

Objective: Demonstrate knowledge of the criteria for issuing TAs and RAs.

Criteria: The pilot needs to have an understanding of the methodology used by ACAS to issue TAs and RAs and the general criteria for the issuance of these advisories to include:

1) the TA altitude threshold being 850 ft below FL 420 and 1 200 ft above FL 420;

2) when the vertical miss distance is projected to be less than the ACAS target, an RA requiring a change to the existing vertical speed will be issued. The ACAS-desired separation varies from 300 ft at low altitude to a maximum of 700 ft above FL 300;

3) when the vertical miss distance is projected to be just outside the ACAS goal, an RA which does not require a change to the existing vertical speed will be issued. This separation varies from 600 to 800 ft; and

4) RA fixed range thresholds varying between 0.2 at low altitude and 1.1 NM at high altitude. These fixed range thresholds are used to issue RAs in encounters with slow closure rates.

5.3.5 ACAS manoeuvre training

5.3.5.1 Training pilots to properly respond to ACAS displayed information, TAs and RAs is most effective when accomplished in a flight simulator equipped with an ACAS display and controls similar in appearance and operation to those in the aircraft. If a simulator is utilized, CRM aspects of responding to TAs and RAs should be practised during this training.

5.3.5.2 Alternatively, the required manoeuvre can be carried out by means of an interactive CBT with an ACAS display and controls similar in appearance and operation to those in the aircraft. This interactive CBT should depict scenarios in which real-time responses must be made. The pilot should be informed whether or not the responses made were correct. If the response was incorrect or inappropriate, the CBT should show what the correct response should be.

5.3.5.3 The scenarios included in the manoeuvre training should include: initial RAs that require a change in vertical speed; initial RAs not requiring a change in vertical speed; maintain rate RAs; altitude crossing RAs; increase rate RAs; RA reversals; weakening RAs; RAs issued while the aircraft is at a maximum altitude, and multi-aircraft encounters. The scenarios should also include demonstrations of the consequences of not responding to RAs, slow or late responses, and manoeuvring opposite to the direction called for by the displayed RA as follows:

a) TA responses

Objective: To verify the pilot properly interprets and responds to TAs.

Criteria: The pilot must demonstrate:

1) proper division of responsibilities between the pilot flying and pilot not flying. Pilot flying should continue to fly the airplane and be prepared to respond to any RA that might follow. Pilot not flying should provide updates on the traffic location shown on the ACAS traffic display and use this information to help visually acquire the intruder;

2) proper interpretation of the displayed information. Both pilots confirm that the aircraft they have visually acquired is that which has caused the TA to be issued. Use should be made of all information shown on the display, note being taken of the bearing and range of the intruder (amber circle), whether it is above or below (data tag), and its vertical speed direction (trend arrow);

3) other available information is used to assist in visual acquisition. This includes ATC “party-line” information, traffic flow in use, etc.;

4) unnecessary requests for traffic information are not made following TAs;

5) because of the limitations described in 5.3.4.2.1.c).5), that no manoeuvres are made based solely on the information shown on the ACAS display; and

6) when visual acquisition is attained, right-of-way rules are used to maintain or attain safe separation. No unnecessary manoeuvres are initiated. The limitations of making manoeuvres based solely on visual acquisition are understood.

b) RA responses

Objective: To verify the pilot properly interprets and responds to RAs.

Criteria: The pilot must demonstrate:

1) proper division of responsibilities between the pilot flying and pilot not flying. Pilot flying should respond to the RA with positive control inputs, when required, while the pilot not flying is providing updates on the traffic location, checking the traffic display and monitoring the response to the RA. Proper CRM should be used. If the operator's procedures require the pilot-in-command to fly all RAs, transfer of aircraft control should be demonstrated;

2) proper interpretation of the displayed information. The pilot recognizes the intruder causing the RA (red square on the traffic display) and responds appropriately;

3) for RAs requiring a change in vertical speed, initiation of a response in the proper direction is made within 5 seconds of the RA being displayed. The change in vertical speed is accomplished with an acceleration of approximately 1/4 g to obtain the required vertical rate. ATC is notified of the RA response without delay after initiating the manoeuvre using the standard phraseology;

Note 1.— PANS-OPS states that in the event of an RA, pilots shall respond immediately and manoeuvre as indicated, unless doing so would jeopardize the safety of the aeroplane. Neither crossing RAs, which cause the flight crew to direct the aircraft towards the altitude of the other aircraft, nor RAs that are contrary to ATC instructions should be considered to jeopardize the safety of the aircraft; both are routine.

Note 2.— Timely notification to ATC that an RA is in progress is essential to ensure that the controller is aware of the RA and will not issue conflicting clearances or instructions. The pilot's initial responsibility after receiving an RA is to modify the aircraft's vertical speed to comply with the RA. Once the required vertical speed is established, the next responsibility is to advise ATC of the RA.

4) recognition of and the proper response to modifications to the initially displayed RA:

i) for Increase Rate RAs, the vertical speed is increased within 2-1/2 seconds of the RA being displayed. The change in vertical speed is accomplished with an acceleration of approximately 1/3 g;

ii) for RA reversals, the manoeuvre is initiated within 2-1/2 seconds of the RA being displayed. The change in vertical speed is accomplished with an acceleration of approximately 1/3 g;

iii) for RA weakenings, the vertical speed is modified to initiate a return towards level flight within 2-1/2 seconds of the RA being displayed. The change in vertical speed is accomplished with an acceleration of approximately 1/4 g; and

iv) for RAs that strengthen, the manoeuvre to comply with the revised RA is initiated within 2-1/2 seconds of the RA being displayed. The change in vertical speed is accomplished with an acceleration of approximately 1/4 g;

5) recognition of altitude crossing encounters and the proper response to these RAs;

6) for RAs that do not require a change in vertical speed, the vertical speed needle or pitch angle remains outside the red area on the RA display;

7) for Maintain Rate RAs, the vertical speed is not reduced. Pilots should recognize that a Maintain Rate RA may result in crossing through the intruder's altitude;

8) that if a justified decision is made to not follow an RA, the resulting vertical rate is not in a direction opposite to the sense of the displayed RA;

9) that the deviation from the current clearance is minimized by leveling the aircraft when the RA weakens, and when “Clear of Conflict” is annunciated, executing a prompt return to the current clearance; and notifying ATC using the standard phraseology as soon as permitted by flight crew workload after resuming the current clearance;

10) that when possible, an ATC clearance is complied with while responding to an RA. For example, if the aircraft can level at the assigned altitude while responding to a Reduce Climb or Reduce Descent RA, it should be done;

11) that when simultaneous, conflicting instructions to manoeuvre are received from ATC and an RA, the RA is followed and ATC is notified using the standard phraseology as soon as permitted by flight crew workload;

12) awareness that ACAS is designed to cope with several simultaneous threats, and that ACAS can optimize separation from two aircraft by climbing or descending towards one of them. For example, ACAS only considers intruders that it considers to be a threat when selecting an RA. As such, it is possible for ACAS to issue an RA against one intruder, which results in a manoeuvre towards another intruder that is not classified as a threat. If the second intruder becomes a threat, the RA will be modified to provide separation from that intruder;

13) the consequences of not responding to an RA and manoeuvring in the direction opposite to the RA; and

14) a prompt response is made when a Climb RA is issued while the aircraft is at the maximum altitude.

5.3.6 ACAS initial evaluation

5.3.6.1 The pilot’s understanding of the academic training items shall be assessed by means of a written test or interactive CBT that records correct and incorrect responses to questions.

5.3.6.2 The pilot’s understanding of the manoeuvre training items shall be assessed in a flight simulator equipped with an ACAS display and controls similar in appearance and operation to those in the aircraft the pilot will fly, and the results assessed by a qualified instructor, inspector or check airman. The range of scenarios shall include:

a) initial RAs requiring a change in vertical speed (Climb and Descend RAs);

b) initial RAs that require a reduction in vertical speed (negative RAs with the Adjust Vertical Speed, Adjust aural);

c) initial RAs that do not require a change in vertical speed;

d) maintain rate RAs;

e) altitude crossing RAs;

f) increase rate RAs;

g) RA reversals;

h) weakening RAs;

i) RAs issued while the aircraft is at the maximum altitude; and

j) multi-aircraft encounters.

The scenarios should also include demonstrations of the consequences of not responding to RAs, slow or late responses, and manoeuvring opposite to the direction called for by the displayed RA. All pilots should fly at least one RA scenario during each simulator training session. Captains should fly all scenarios once every three years.

5.3.6.2.1 Operators should ensure that their instructors can select all the required RA scenarios on their simulators at any time during a simulator session.

5.3.6.3 If an operator does not have access to an ACAS-equipped simulator, the initial ACAS evaluation shall be conducted by means of an interactive CBT with an ACAS display and controls similar in appearance and operation to those in the aircraft the pilot will fly. This interactive CBT shall depict scenarios in which real-time responses must be made and a record made of whether or not each response was correct. The CBT shall include all types of RAs. Pilots should complete all scenarios once every two years if CBT is used.

5.3.7 ACAS recurrent training

5.3.7.1 ACAS recurrent training ensures that pilots maintain the appropriate ACAS knowledge and skills. ACAS recurrent training should be integrated into and/or conducted in conjunction with other established recurrent training programmes. An essential item of recurrent training is the discussion of any significant issues and operational concerns that have been identified by the operator.

5.3.7.2 ACAS monitoring programmes periodically publish findings from their analyses of ACAS events. The results of these analyses typically discuss technical and operational issues related to the use and operation of ACAS. Recurrent training programmes should address the results of monitoring programmes in both the academic and simulator portions of recurrent training visits.

5.3.7.3 Recurrent training shall include both academic and manoeuvre training and address any significant issues identified by line operating experience, system changes, procedural changes, or unique characteristics such as the introduction of new aircraft/display systems or operations in airspace where high numbers of TAs and RAs have been reported.

5.4 FINDINGS FROM REVIEWS OF EXISTING TRAINING PROGRAMMES

5.4.1 A review of existing training programmes has been conducted in one State. This review encompassed major air carriers, regional air carriers, and business and corporate operators. The purpose of these reviews was to assess operators' compliance with published training guidelines.

5.4.2 The reviews consisted of reviewing an operator's manuals and training guidelines, and wherever possible, witnessing the academic and manoeuvre training.

5.4.3 The review indicated that various techniques are in use to train pilots in the use of ACAS. These techniques range from the use of academic training and a videotape to performing all ACAS-related training during the simulator portion of training.

5.4.4 These reviews have noted that some of the information contained in the operator and airframe manufacturer documentation regarding ACAS is incorrect and out of date. In some cases, the documentation referred to ACAS capabilities and limitations that were only applicable to the earliest versions of TCAS. The reviews of the simulator training indicated that a majority of the simulators did not provide the instructor with a means of training pilots on various types of RAs.

5.5 EXAMPLES OF PROBLEM ENCOUNTERS

5.5.1 Introduction

It is essential that pilots understand the potential risks of an improper response to a displayed RA. Improper pilot response to ACAS TAs and RAs may result in a reduction in vertical miss distance between the ACAS and intruder aircraft. ACAS monitoring programmes in various parts of the world have identified encounter situations with inappropriate pilot responses and these are discussed in the following sections.

5.5.2 Encounter Type 1 — RA in opposite direction to ATC instruction

5.5.2.1 *Example: ATR and Boeing 737*

5.5.2.1.1 An ATR72 was on a heading of 185º and a B737 was on a heading of 345º. Both aircraft were ACAS-equipped and level at their assigned altitude of 7 000 ft. A third aircraft, an SW3, was eastbound and level at 5 000 ft. The geometry of this encounter is shown in Figure 5-1. The controller working these aircraft was occupied with the resolution of another conflict and did not take any action with these three aircraft until the ATR72 and B737 were approximately 5 NM apart. When the controller recognized the conflict between the ATR72 and B737, the B737 was instructed to descend and maintain 6 000 ft.

5.5.2.1.2 A few seconds after the controller instructed the B737 to descend, both aircraft received RAs. The ATR72 received a Descend RA and the B737 received a Climb RA.

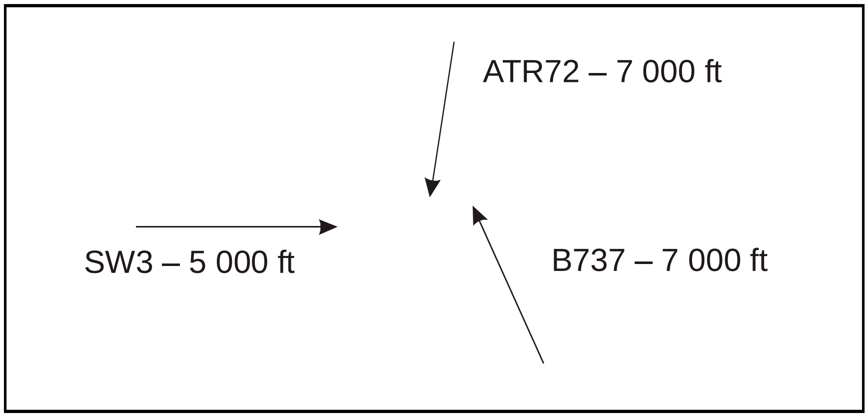


Figure 5-1. Example 1 horizontal encounter geometry

5.5.2.1.3 The ATR72 pilot initiated a descent and immediately informed the controller, using the standard ICAO phraseology, that a Descend RA had been received and was being followed. Just after receiving this notification, the controller repeated the instruction for the B737 to descend to 6 000 ft.

5.5.2.1.4 The B737 pilot did not follow the ACAS climb RA and continued to comply with the controller's instruction to descend. This manoeuvre opposite to the displayed Climb RA resulted in the ATR's ACAS issuing an Increase Descent RA. This Increase Descent RA was followed by the ATR pilot, which resulted in the ATR deviating much more than initially required by ACAS. This large vertical deviation by the ATR resulted in a secondary conflict between the ATR and the SW3.

5.5.2.1.5 The B737 pilot's response in the opposite direction to the ACAS coordinated RA resulted in the B737 and ATR being co-altitude with less than 1 NM of horizontal separation. If the B737 pilot had correctly followed the displayed Climb RA, the vertical separation between the ATR and the B737 would have been 600 ft when the two aircraft crossed horizontally. In addition, there would not have been a secondary ACAS encounter between the ATR and the SW3.

5.5.3 Encounter Type 2 — Pilot manoeuvres in opposite direction to the displayed RA

5.5.3.1 The ACAS aircraft was southbound and climbing and the intruder was also southbound and level at 17 600 ft. The initial climb rate of the ACAS aircraft was approximately 2 100 fpm, and the ACAS aircraft continued to climb with some reduction in vertical speed during the event. The VFR intruder remained level at 17 600 ft throughout the event.

5.5.3.2 When the ACAS aircraft and the intruder were approximately 3 NM apart, a TA was issued. At this time, the ACAS aircraft was climbing through 15 900 ft and the VFR intruder was level at 17 600 ft, and the ACAS aircraft was overtaking the intruder at approximately 250 kts.

5.5.3.3 When the aircraft were approximately 2.2 NM apart, ACAS issued a corrective, Do Not Climb > 2 000 FPM RA. The vertical speed of the TCAS aircraft was not reduced, and the initial RA was strengthened to Do Not Climb > 1 000 FPM. This would have occurred as the TCAS aircraft climbed through 16 500 ft and with a horizontal separation of approximately 1.9 NM. Four seconds later, the RA was further strengthened to Do Not Climb > 500 FPM. At this time, the TCAS aircraft was climbing through 16 700 ft at 3 000 fpm. One second later, the displayed RA was further strengthened to a Descend RA. One final strengthening of the RA occurred, and an Increase Descent RA was issued as the TCAS aircraft climbed through 17 500 ft.

5.5.3.4 Separation at the closest point of approach (CPA) was approximately 0.50 NM horizontally and co-altitude. If the ACAS aircraft had followed the initial RAs as expected by ACAS, the vertical separation in this encounter would have been approximately 600 ft.

5.5.4 Encounter Type 3 — Manoeuvring based on visual acquisition

5.5.4.1 A B747 and a DC10 were flying on converging tracks and both were mistakenly cleared to FL 370. When the controller detected the mistake, he attempted to reclear the DC10 to FL 350. In attempting to resolve this conflict, the controller used an incorrect callsign/flight number for the DC10.

5.5.4.2 The B747 pilot wrongly took the clearance meant for the DC10 and initiated a descent. At the same time, the B747 ACAS issued a Climb RA. However, the B747 pilot decided to not follow the RA because the B747 had visually acquired the DC10 and the descent was continued.

5.5.4.3 The DC10 pilot, who also had the B747 in sight, received a Descend RA that was followed. At the last moment, the DC10 pilot arrested the descent upon perceiving that the B747 was at the same altitude and also descending. Also at the last moment, the B747 pilot performed a sudden and violent escape manoeuvre that injured a number of passengers and flight attendants.

5.5.4.4 Because of the inappropriate manoeuvre based on visual acquisition, the B747 passed 10 metres below the DC10 with no lateral separation.

5.5.5 Encounter Type 4 — High vertical rate/level off encounter

5.5.5.1 Aircraft 1 was eastbound and level at FL 290 and Aircraft 2 was westbound and climbing. The initial climb rate of Aircraft 2 was approximately 2 000 fpm.

5.5.5.2 When the aircraft were approximately 10 NM apart, both aircraft received a TA. At this time, Aircraft 1 was level at FL 290 and Aircraft 2 was climbing through FL 274. At this point the two aircraft were closing at approximately 910 kts, and Aircraft 2 was climbing at a rate of approximately 2 400 fpm.

5.5.5.3 When the aircraft were approximately nine miles apart, ACAS issued coordinated, corrective RAs to both aircraft. Aircraft 1 received a Climb RA and Aircraft 2 received a Do Not Climb > 500 FPM RA. At this time, Aircraft 1 was still level at FL 290. When the initial RAs were issued, Aircraft 2 was climbing through FL 276 and its vertical speed was approximately 3 200 fpm.

5.5.5.4 The pilot of Aircraft 2 began reducing the vertical speed in response to the displayed RA, and within 11 seconds, the vertical speed for Aircraft 2 was less than +300 fpm. Aircraft 2 reached its maximum altitude of FL 279 and began descending as the initial RA weakened. At this point, the response of Aircraft 2 and the initiation of a climb by Aircraft 1 provided sufficient separation that the RAs weakened. Following the display of this RA, Aircraft 2 continued a reduction in vertical speed and began to descend at approximately 1 300 fpm.

5.5.5.5 Just after the Aircraft 2 RA weakened, the Climb RA for Aircraft 1 also weakened. When this weakening RA was issued, Aircraft 1 had deviated less than 100 ft from its ATC-assigned altitude.

5.5.5.6 In response to the weakened RAs, Aircraft 2 arrested its descent at FL 276 and slowly climbed back to level at FL 280. At this time, Aircraft 1 was climbing at approximately 2 700 fpm and approaching FL 293. Aircraft 1 continued to climb at rates approaching 4 000 fpm until a reduction in vertical speed was noted while climbing through FL 298.

5.5.5.7 Aircraft 1 did not comply with any of the weakened RAs and continued to climb until the event was over and “Clear of Conflict” was annunciated.

5.5.5.8 The RAs and associated altitude displacements and disruptions to the controller’s workload were a direct result of Aircraft 2 maintaining a high vertical speed while approaching its assigned altitude. It is recommended that pilots “Descend or climb at an optimum rate consistent with the operating characteristics of the aircraft to 1 000 ft above or below the assigned altitude, and then attempt to descend or climb at a rate of between 500 and 1 500 fpm until the assigned altitude is reached”.

5.5.5.9 Had this been followed, no RAs would have been issued in this encounter and thus there would have been no clearance deviations.

5.5.6 High vertical rate with altitude bust

5.5.6.1 After take-off, a TCAS-equipped A320 was climbing to FL 110 on the SID. Its rate of climb was 4 300 fpm. A Gulfstream IV on a standard approach procedure was descending to FL 120 at 3 200 fpm. Both trajectories are converging so that the aircraft will pass 0.8 NM apart and just at the moment where they will reach their respective cleared flight level.

5.5.6.2 The simultaneous horizontal and vertical convergence, combined with the high vertical rates, caused TCAS to trigger an RA, even though the standard ATC separation was being correctly applied. The A320 received an “Adjust Vertical Speed” RA when passing through FL 097, i.e. 1 300 ft below the cleared flight level, and while climbing at 4 300 fpm. This RA required a reduction in the rate of climb to a value less than 2 000 fpm. The A320 reduced the climb rate in accordance with the RA and leveled off at FL 110 as cleared by the controller.

5.5.6.3 In this event, both aircraft successfully leveled off and, subsequently, this RA was considered as operationally unnecessary. However, the RA reinforced the controller’s clearance and had only one of the aircraft failed to level-off, then there would have been 20 seconds or less until the aircraft were at the same altitude. TCAS II effectively provided a last-resort protection against an altitude level bust.

5.5.6.4 Pilots should follow RAs even if the intruder aircraft seems to be stabilizing at a proximate altitude. Situations like this can happen very quickly and there is not the time to think about all the options. Following the RA is the best way to reduce the risk of collision.

5.5.6.5 Also, it should be noted that although these events are comparatively rare, in most cases ACAS changes their outcome from being high-risk level busts or controller errors into relatively safe situations that look like nuisance level-off manoeuvres.

5.5.7 Horizontal manoeuvre made using the traffic display

5.5.7.1 Aircraft 1 and Aircraft 2 were both level at FL 290 under radar vectoring for separation. The estimated horizontal distance at the crossing was 12 NM. However, Aircraft 1’s pilot saw Aircraft 2 on his TCAS display. He thought that Aircraft 2 was “coming right at him”. He decided to turn even though he did not have any ACAS advisory nor visual contact. Because of the turn, the horizontal distance was quickly reduced to 2 NM.

5.5.7.2 This event suggests that the TCAS display was used inappropriately. TCAS bearing information is only accurate enough to help identify intruder aircraft, but not good enough to suggest horizontal manoeuvres. Furthermore, relative displays of this type are easy to misinterpret — as this example has shown.

5.5.7.3 Even if the pilot had received a TA he should not have manoeuvred. The TA is only advice to get ready for a possible RA — not a suggestion to perform an evasive manoeuvre. Such manoeuvres can be a considerable nuisance to ATC because the aircraft appears to be behaving unpredictably.

5.5.7.4 Aeroplane Flight Manual supplements prohibit pilots from manoeuvring on TAs and from performing horizontal manœuvres using the TCAS traffic display.

5.5.8 Misinterpreting "Adjust Vertical Speed Adjust" RAs

5.5.8.1 Monitoring has shown that pilots can misinterpret negative RAs with the aural annunciation "Adjust Vertical Speed Adjust" and thus significantly increase the risk of collision.

5.5.8.2 Typically the aircraft is leveling off 1 000 ft from the level of another aircraft, and the pilot has visual contact with the intruder. The aural "Adjust Vertical Speed Adjust" always requires a reduced vertical speed (slower climb or descend). If the aural is repeated, it requires an even smaller vertical rate.

5.5.8.3 Unfortunately the RA can be misinterpreted in at least two ways:

a) when only using visual contact with the intruder aircraft, the relative pitch of each aircraft can cause the pilot to think that the correct manoeuvre to avoid collision is in the opposite sense to that required by ACAS; and

b) the aural "Adjust Vertical Speed Adjust" may be repeated, indicating that a further reduction in vertical rate is required, but the pilot thinks that it is a request to maintain the vertical rate of the first RA.

5.5.8.4 Correct procedure avoids these misinterpretations: pilots should look at the RA display after each aural annunciation. This clarifies the action that the pilot needs to take. It is therefore recommended that all pilots receive simulator training for Adjust Vertical Speed Adjust RAs.

5.5.8.5 *Example encounter*

5.5.8.5.1 Aircraft 1, heading 120, is climbing to level off at FL 270. Aircraft 2, heading 350, is level at FL 280. Aircraft 1 receives a TA and at about the same time Aircraft 2 receives a climb RA, which is vigourously followed. Ten seconds later Aircraft 2's climb RA changes to Adjust Vertical Speed Adjust, requiring the pilot not to descend — but allowing a level-off manoeuvre. The pilot continues the climb — increasing the vertical rate (rather than reducing it as required by Adjust Vertical Speed Adjust).

5.5.8.5.2 Ultimately Aircraft 2 climbs over 1 000 ft and has an RA against a third aircraft which both aircraft follow correctly, and the encounter is resolved without further incident.

5.5.8.5.3 Although this can be considered as the result of overreaction to an initial RA, the increase in vertical speed just after the receipt of the "adjust vertical speed adjust" RA suggests that the pilot adjusted the vertical speed in a way that was not advised by TCAS.

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Chapter 6

CONTROLLER TRAINING GUIDELINES

6.1 OBJECTIVE

Based on the experience gained with ACAS operations, it is strongly recommended that air traffic controllers be provided with formal training programmes. The objective of these training programmes is to enable air traffic controllers to better manage advisories by:

a) understanding how ACAS works;

b) anticipating ACAS behaviour in their ATM environment;

c) understanding the responsibilities of pilots and air traffic controllers during an ACAS event; and

d) evaluating the effectiveness and necessity of ACAS events.

6.2 ACAS TRAINING PROGRAMMES

6.2.1 ACAS training should be included in all phases of air traffic controller training, starting as a part of the initial training for student air traffic controllers and ending in specific safety briefings after major incidents. Continuous training should be provided either by using regular ATC simulator runs or with special computer-based training tools like RITA (Replay Interface for TCAS Alerts), a dynamic graphical tool showing TCAS events from both the pilots' and controllers' perspectives.

6.2.2 The initial ACAS training should include the following theoretical material:

a) History — a chronological overview of ACAS development;

b) Definitions — ICAO and RTCA definitions (or differences) for ACAS and TCAS;

c) System overview and functionality — structure, functionality capabilities, limitations and the sequence of an ACAS event;

d) ACAS mandates — summary of the international and national equipage requirements;

e) ACAS operational procedures and provisions — for pilots and controllers, including the material contained in PANS-OPS, PANS-ATM and other national requirements;

f) ACAS behaviour in the operational ATM environment — technical and operational experience and problem areas; and

g) Developments — future aspects, outlook.

6.2.3 This theoretical training material may be useful for events such as ACAS information meetings, special briefing sessions or combined controller/pilot experience discussion groups at the local ATC facility.

6.2.4 Following the theoretical instruction, initial practical exercises should be conducted (e.g. ATC simulator runs or replays of specific ACAS events). The benefit of performing specific ACAS simulator training is that controllers will not be surprised when they have a real ACAS event in their operational environment.

6.2.5 In addition to the initial training described above, ACAS events should be incorporated in the practical simulator training of controllers. The choice of events should be designed to show controllers the different types of ACAS events and the variations in the responses of pilots. Additionally the controllers should practice the correct procedures and appropriate communication with the pilot. Once the ACAS event has finished, the controller should demonstrate the transition of the affected aircraft to the original clearance or instruction, or the integration into the new traffic scenario.

6.2.6 It is important for controllers to maintain their knowledge about ACAS. Therefore, ACAS should be integrated as a part of the safety or unusual incident content in the regular refresher or CBT-training courses for all active controllers. This will ensure that the controllers stay familiar with the ACAS procedures and regulatory requirements.

6.2.7 Whenever a major incident or safety issue occurs, air navigation service providers (ANSP) should develop a safety briefing or presentation, which includes all operational and technical aspects related to this particular event. The briefing should be held as soon as possible after the event to clarify this specific situation and should have mandatory participation.

6.2.8 Due to the incorporation of ACAS into the airspace and operational procedure development, specific ACAS training may be necessary before a new airspace design or ATC procedure can be introduced. The scope of this training will depend on the complexity and size of the planned implementation and can have a major influence on the entire development, even if there was initially no obvious connection to ACAS.

6.2.9 The ANSP is responsible for training controllers and other ATC specialists on ACAS and on expected flight crew responses to ACAS advisories. Familiarization flights for such specialists on ACAS-equipped aircraft should be made available.

6.3 RECOMMENDED CONTENT OF CONTROLLER TRAINING PROGRAMMES

6.3.1 Pilot operating procedures

6.3.1.1 Controllers should be aware of the types of information provided to the pilot by ACAS and the guidance provided to pilots during their ACAS training.

6.3.1.2 The pilot procedures for the use of ACAS are contained in *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168), Volume I, Part VIII, Chapter 3.

6.3.1.3 Every pilot operating an ACAS-equipped aircraft should have received training in the operation of ACAS, the interpretation of the ACAS-displayed information, and the proper response to TAs and RAs. Experience has shown that not all pilots will respond exactly the same, given the same ACAS encounter. As a result, controllers can expect some variation in the response of pilots, even between pilots from the same operator.

6.3.1.4 When a TA is issued, pilots are instructed to initiate a visual search for the traffic causing the TA. If the traffic is visually acquired, pilots are instructed to maintain visual separation from the traffic. The pilot training programmes also indicate that no horizontal manoeuvres are to be made based solely on information shown on the traffic display. Slight adjustments in vertical speed while climbing or descending, or slight adjustments in airspeed while still complying with the ATC clearance are acceptable.

6.3.1.5 When an RA is issued, pilots are expected to respond immediately to the RA unless doing so would jeopardize the safe operation of the flight. This means that aircraft will at times manoeuvre contrary to ATC instructions or disregard ATC instructions. The following points receive emphasis during pilot training:

a) do not manoeuvre in a direction opposite to that indicated by the RA because this may result in a collision;

b) inform the controller of the RA as soon as permitted by flight crew workload after responding to the RA. There is no requirement to make this notification prior to initiating the RA response;

c) be alert for the removal of RAs or the weakening of RAs so that deviations from a cleared altitude are minimized;

d) if possible, comply with the controller’s clearance, e.g. turn to intercept an airway or localizer, at the same time as responding to an RA; and

e) when the RA event is completed, promptly return to the previous ATC clearance or instruction or comply with a revised ATC clearance or instruction.

6.3.2 Controller responsibility during an RA

6.3.2.1 The procedures to be applied for the provision of air traffic services to aircraft equipped with ACAS shall be identical to those applicable to non-ACAS-equipped aircraft. In particular, the prevention of collisions, the establishment of appropriate separation and the information which might be provided in relation to conflicting traffic and to possible avoiding action should conform with the normal air traffic services procedures and should exclude consideration of aircraft capabilities dependent on ACAS equipment.

6.3.2.2 The controller procedures used during an RA are defined in the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444).

6.3.2.3 Controller training programmes should include the following guidance. When a pilot reports a manoeuvre induced by an ACAS RA, the controller:

a) shall acknowledge pilots’ reports of RAs using the phrase “ROGER”;

b) shall not attempt to modify the flight path of any aircraft involved in the RA;

c) shall not issue any clearance or instruction to any aircraft involved until the pilot reports returning to the terms of the assigned air traffic control clearance or instruction; and

d) should provide traffic information if deemed necessary.

6.3.2.4 Once an aircraft departs from its clearance or instruction in compliance with an RA, the controller ceases to be responsible for providing separation between that aircraft and any other aircraft affected as a direct consequence of the manoeuvre induced by the RA. The controller shall resume responsibility for providing separation for all the affected aircraft when:

a) the controller acknowledges a report from the pilot that the aircraft is resuming the assigned clearance or instruction and issues an alternative clearance or instruction, which is acknowledged by the pilot; or

b) the controller acknowledges a report from the pilot that the aircraft has resumed the assigned clearance or instruction.

6.3.2.5 Controller training should emphasize that the use of ACAS does not alter the respective responsibility of pilots and controllers.

6.3.2.6 It is technically possible to provide controllers with information about ACAS RAs as they occur. In spite of the guidance given to flight crew, controllers should not assume that the pilot is obeying the RA. Nor should controllers assume that the RA information presented to them is current and correct, because ACAS can modify, and even reverse, the RAs, and there is an unavoidable delay in conveying RA information to controllers. The magnitude of the delay is dependent on the technical implementation of the system used for downlinking RAs.

6.3.2.7 Table 6-1 outlines the interactions that should occur between pilots and controllers during an ACAS event.

6.3.3 Phraseology

6.3.3.1 To provide a concise means of communication between pilots and controllers when an RA occurs, phraseology has been developed and implemented by States and operators.

6.3.3.2 The phraseology to be used during an RA is contained in PANS-ATM, Doc 4444. When an RA requires a deviation from an ATC clearance, pilots are expected to notify the controller that an RA has occurred and then of the termination of the RA.

6.3.4 Independence of ACAS thresholds and ATC separation standards

6.3.4.1 Controller training programmes should ensure that controllers understand the relationship and differences between ACAS advisory thresholds and ATC separation standards.

6.3.4.2 ACAS thresholds are independent from ATC separation standards because ACAS does not strive to ensure separation (which is ATC’s role) but tries to avoid collision as a last resort. The main ACAS thresholds are time-based, not distance-based like most ATC separation standards. An ACAS with distance thresholds for collision avoidance purposes would be less safe in some encounter configurations. The alerting thresholds used by ACAS were developed to ensure that errors in altimetry and delays in pilot responses would not compromise the safety provided by ACAS. The following considerations elaborate on these views.

6.3.4.3 The main objective of ATC is to ensure safe separation between aircraft. In most controlled airspaces, two aircraft are considered safely separated if the vertical distance between them is greater than a vertical separation standard or if the horizontal distance between them is greater than a horizontal separation standard. Both separation standards depend mostly on the accuracy of the aircraft position

Table 6-1. Controller/pilot interaction during an ACAS event

ACAS Event Interaction	
AIRCREW	CONTROLLER
Traffic Advisory TA	
Shall not manoeuvre their aircraft in response to traffic advisories (TAs) only	Remains responsible for ATC separation
Should prepare for appropriate action if an RA occurs; but as far as practicable, pilots should not request traffic information	If requested by the aircrew, shall give traffic information
Resolution Advisory RA	
Shall respond immediately and manoeuvre as indicated, unless doing so would jeopardize the safety of the aeroplane	Shall not attempt to modify the flight path of an aircraft responding to an RA
Shall follow the RA even if there is a conflict between the RA and an Air Traffic Control (ATC) instruction to manoeuvre	Shall not issue any clearance or instruction to the aircraft involved until the pilot reports returning to the terms of the assigned ATC clearance or instruction
Shall never manoeuvre in the opposite sense to an RA, nor maintain a vertical rate in the opposite sense to an RA	Shall acknowledge the report by using the phrase ROGER
When deviating from an air traffic control instruction or clearance in response to any RA, shall: — as soon as permitted by flight crew workload, notify the appropriate ATC unit of the deviation; — immediately inform ATC when they are unable to comply with a clearance or instruction that conflicts with an RA	If requested by the aircrew, shall give traffic information Ceases to be responsible for providing separation between that aircraft and any other aircraft affected as a direct consequence of the manoeuvre induced by the RA
Shall promptly comply with any subsequent RAs issued by ACAS	
Shall limit the alterations of the flight path to the minimum extent necessary to comply with the resolution advisories	
Clear of Conflict	
Shall promptly return to the terms of the ATC instruction or clearance when the conflict is resolved Shall notify ATC after initiating a return to or resuming the current clearance	Shall resume responsibility for providing separation for all the affected aircraft when he acknowledges: — a report from the pilot that the aircraft is resuming the assigned ATC clearance or instruction and issues an alternative clearance or instruction which is acknowledged by the pilot — a report from the pilot that the aircraft has resumed the assigned ATC clearance or instruction

provided to the controller. In practice, the vertical separation standard varies from 1 000 ft to 2 000 ft, and the horizontal separation varies from 3 NM (in Traffic Management Areas [TMAs]) to 80 NM (oceanic tracks). Once the distance between two aircraft falls below one of the standards, the controller no longer has a safety margin, and the controller's certainty of the aircraft relative positions decreases rapidly.

6.3.4.4 ACAS collision avoidance is based on the time before a possible collision between the ACAS-equipped aircraft and the altitude-reporting intruder. Depending on the configuration of the encounter and the speed of both aircraft, the ACAS time threshold corresponds to different distances. For example, consider two aircraft leveled at FL 180 with a speed of 330 kt. In a head-on encounter, the distance at which an RA could occur would be 5.5 NM, while in a 90-degree crossing, it would be only 3.9 NM. Depending on circumstances, an RA can be triggered well within the ATC separation standards or can be triggered well beyond the ATC separation standards.

6.3.4.5 In operation, the geometry that most frequently highlights the independence of ACAS thresholds from ATC separation standards is the 1 000 ft level-off geometry. In this configuration, one aircraft manoeuvres in the vertical plane with the intent of leveling-off on a FL 1 000 ft apart from a level aircraft. When both aircraft are also in close horizontal proximity, and since the CAS logic does not know any pilot's intent, the vertical speed of the first aircraft can be sufficient to trigger a resolution advisory. In cases of altitude busts, this improves a hazardous situation. However, frequently both aircraft are (and should remain) separated in the view of ATC, and this behaviour causes many RAs where there is no loss of separation. The number of such unnecessary RAs for 1 000 ft level-offs can be reduced by separating vertical convergence from horizontal convergence through airspace changes or by slowing the vertical rates of leveling-off aircraft either through procedural changes or through FMS flight profile changes.

6.3.5 Relationship between ACAS and short-term conflict alert

6.3.5.1 ACAS and short-term conflict alert (STCA) algorithms were developed and operate independently of each other. ACAS has more frequent surveillance updates (once per second) than STCA, while STCA has more information than ACAS regarding an aircraft's intended flight path.

6.3.5.2 Operational experience has shown that there will be encounters in which the ACAS RA will be issued without an STCA alarm and that there will be encounters in which STCA alarms occur without an RA being issued. Controllers should consider ACAS and STCA as separate, independent systems.

6.3.5.3 Controller training programmes should address the interaction between ACAS and the STCA implementation at their workplace. This portion of the controller training should include replays and analyses of actual events where STCA, ACAS or both were triggered.

6.3.6 ACAS capabilities, limitations and operation

6.3.6.1 While not direct users, controllers are directly affected by the capabilities, limitations and operation of ACAS. As such, controller training programmes should ensure that controllers are aware of the following ACAS characteristics.

6.3.6.1.1 *The thresholds used by ACAS for issuing RAs*

6.3.6.1.2 ACAS has the ability to modify the initially issued RA as the encounter geometry changes. The modified RAs can call for a weakening of the initial RA to minimize clearance deviations once the ACAS-desired vertical miss distance is obtained, or there has been an increase in vertical speed or a reversal of the direction of the initial RA.

6.3.6.1.3 The initial RA will be modified if the response to the RA results in another aircraft becoming a threat.

6.3.6.1.4 In some encounter geometries, ACAS will issue an RA that requires the ACAS-equipped aircraft to cross through the intruder aircraft's altitude. This manoeuvre is selected only when the non-altitude crossing RA will not provide the desired separation.

6.3.6.1.5 ACAS will neither detect nor issue advisories against aircraft that are not equipped with an operating transponder.

6.3.6.1.6 ACAS will issue TAs against altitude reporting and non-altitude reporting intruders but will not issue RAs against non-altitude reporting intruders.

6.3.6.1.7 ACAS will track multiple aircraft and if two or more intruders meet the criteria for the issuance of an RA simultaneously, the RA issued will provide separation from all intruders.

6.3.6.1.8 In an encounter with another ACAS-equipped aircraft, the aircraft will coordinate their RAs to ensure they are complementary.

6.3.6.1.9 Current systems may display targets to the pilot at long ranges, e.g. 30-40 NM. However, reliable ACAS surveillance is only guaranteed out to 14 NM in en route airspace with low traffic density. As traffic density increases, reliable ACAS surveillance progressively diminishes to a guaranteed minimum of 4.5 NM.

6.3.6.1.10 The response to an RA can result in a loss of standard ATC separation with either the aircraft causing the RA or a third aircraft. If the third aircraft becomes a threat while the RA is still displayed, the RA will be modified to provide the ACAS-desired vertical miss distance from both aircraft. However, because of the differences in the RA thresholds and ATC separation standards, the modification to the RA is likely to occur after ATC separation is lost.

6.3.6.1.11 ACAS can detect and discard short-term, spurious errors in Mode C replies. However, no techniques exist that allow it to detect a constant bias error or offset. Thus, ACAS will accept Mode C replies that are erroneous, and it is possible to issue an RA based on these inputs. PANS-ATM contains procedures that permit a controller to request that the altitude reporting function of the transponder be disabled. To prevent RAs caused by erroneous Mode C reports, it is essential that this procedure be implemented and followed. Controller training programmes should emphasize the danger of allowing erroneous Mode C reports to continue. In view of the 150 m (500 ft) separation between VFR and IFR aircraft in some States, it is recommended that the tolerance for requesting the discontinuance of altitude reporting be reduced from 90 m (300 ft) to 60 m (200 ft).

Chapter 7

SPECIAL USES OF ACAS

Note. — New applications should not unduly affect the existing ATM environment. Therefore, thorough investigations and validation by civil aviation authorities are necessary prior to any operational use to ensure compatibility with existing services.

7.1 MILITARY USES OF ACAS IN FORMATION OPERATIONS

7.1.1 Introduction

7.1.1.1 There is a continuing interest in use of ACAS in military formation operations. Desired uses include situational awareness and collision avoidance both among formation members and against non-formation aircraft. Typical formation sizes include four to six aircraft. In extreme cases, the formation could conceivably consist of 30 or more closely spaced aircraft. Regardless of the formation size, the formation may operate in high-density civil airspace.

7.1.1.2 Use of ACAS in formation operations can severely impact both ATC by reducing the availability of transponders to ATC surveillance and ACAS collision avoidance by reducing ACAS surveillance range for high-speed encounters in airspace between 10 000 and 18 000 ft altitude.

7.1.1.3 The purpose of this section is to examine the compatibility issues between an ACAS-equipped military formation and ATC and civil ACAS requirements from a surveillance perspective, and to provide guidance on proper use of ACAS in formation operations. The recommendations and requirements in this section apply only to a military ACAS unit operating in formation mode.

7.1.1.4 This chapter discusses the impact of ACAS II on the performance of ATC and ACAS in formation aircraft, presents technical options to the ACAS II design to improve compatibility with ATC and civil ACAS, as well as operational procedures for military formations employing both ACAS II and modified ACAS II to further improve compatibility with ATC and ACAS. The chapter also presents the measured impact on ATC and ACAS surveillance by a formation composed of aircraft equipped only with ACAS conforming to the ACAS SARPs. It does not address performance associated with new forms of military ACAS.

7.1.2 Compatibility with civil ACAS and ATC

7.1.2.1 The extent to which a military formation using ACAS will impact on the surveillance performance and collision avoidance capability of a civil ACAS depends on a number of factors. These include the existing level of civil ACAS traffic, the altitude of the civil ACAS, and the location and altitude of the military formation relative to a high-density terminal area.

7.1.2.2 The altitude level of the victim ACAS is particularly significant in terms of impact. At altitude levels above 18 000 ft, the ACAS interference limiting is insensitive to the ACAS count, both within 30 NM and within 6 NM, and would therefore be unaffected by the presence of ACAS in a military formation.

7.1.2.3 Since ACAS interference limiting is not allowed to reduce transmit power by more than 10 dB, ACAS operating in a terminal area below 10 000 ft will retain sufficient surveillance range to provide timely advisories in encounters controlled by terminal airspeed restrictions. A military formation would therefore be expected to have limited additional effect on the collision avoidance capability of ACAS operating in terminal areas below 10 000 ft.

7.1.2.4 The critical altitude region with respect to the impact of a military formation on ACAS is between 10 000 and 18 000 ft. Additional interference limiting caused by closely spaced ACAS aircraft in formation can seriously impair the ability of an ACAS to provide a timely advisory in the high-speed encounters likely in this kind of airspace.

7.1.2.5 A military formation equipped with Mode S transponders can impact on ATC surveillance since it causes an increase in the number of Mode S interrogations hence affecting the availability of each transponder.

7.1.2.6 The following sections address in greater detail the significant compatibility issues associated with an ACAS-equipped military formation operating in civil ACAS and ATC airspace and suggest means for reducing the impact of the military formation to acceptable levels.

7.1.2.6.1 *Impact on civil ACAS surveillance*

7.1.2.6.1.1 A formation of military aircraft that includes operating ACAS equipment can significantly increase the amount of interference limiting of a nearby civil ACAS by contributing to the number of ACAS observed in its vicinity. This will reduce surveillance range and potentially degrade collision avoidance capability for civil ACAS operating between 10 000 and 18 000 ft altitude. The extent of the impact depends on the location of the formation relative to a terminal area and to the number and spacing of military aircraft that have operating ACAS equipment.

7.1.2.6.1.2 Another potential cause of civil ACAS interference limiting power reduction, although to a lesser extent, is the added Mode S interrogation activity due to the presence of a large number of military aircraft with operational Mode S transponders. For a civil ACAS between 10 000 and 18 000 ft altitude, and depending on existing conditions, this could also have an impact on collision avoidance.

7.1.2.6.2 *Impact on ATC transponder utilization*

7.1.2.6.2.1 The availability of an ATC transponder for ATC secondary surveillance and ACAS surveillance depends on the utilization of the transponder by both air and ground interrogators. The standards adopted for the ACAS interrogator design are intended to limit utilization of a transponder by all ACAS to a maximum of 2 per cent within a one-second period. An attempt to achieve this limit is accomplished by controlling the interrogation rate and power of each ACAS through its interrogation limiting function.

7.1.2.6.2.2 A military formation consisting of a large number of Mode S transponder-equipped aircraft and operating in a high-density ACAS environment could increase the pre-existing total ACAS Mode S interrogation rate observed by a nearby victim Mode S transponder. Although most of the additional interrogations would not be addressed to the transponder, it would still have to process each one, thus increasing unavailability. The extent to which this becomes significant depends on the Mode S-equipped aircraft density in general and on the pre-existing level of Mode S interrogations. The closer to a high-density airport a military formation operates, the more severe the impact will be since the pre-existing transponder utilization will be at or close to the acceptable limit.

7.1.2.6.3 *Impact on civil ACAS logic*

ACAS coordinates the RAs in encounters between two ACAS-equipped aircraft, and this can limit the freedom of either ACAS to select the RA that is most appropriate from its perspective and to reverse its selection of RA sense. For this reason, it is essential that military flight crews follow ACAS RAs or that ACAS on military aircraft is operated in TA-only mode.

7.1.3 Technical options to improve compatibility with civil ACAS and ATC

7.1.3.1 Based on the military/civil compatibility issues discussed in 7.1.2, the following three sub-paragraphs list various technical functions of a military formation ACAS that could potentially reduce the impact on ATC and civil ACAS to acceptable levels and enable effective collision avoidance against military formation aircraft. The three sub-paragraphs deal with military surveillance between formation aircraft, military surveillance of non-formation aircraft, and the military collision avoidance function of the formation aircraft.

7.1.3.2 *Surveillance between military formation aircraft*

The following applies to surveillance of formation members by each other for the purpose of formation station keeping.

a) Use military Mode S transponders and GNSS receivers capable of generating and transmitting an extended squitter containing GNSS-derived own aircraft state data;

b) Use hybrid surveillance techniques to reduce or eliminate active interrogations;

    1) Maximize the number of military formation aircraft operating in either full passive mode (i.e. no active ACAS interrogations) or using extended squitter position data (i.e. limited active interrogations for validation of GNSS position). A fully passive mode is preferable if use of non-validated GNSS data is acceptable;

    2) Use a special form of active surveillance for formation aircraft that matches the required receiver sensitivity and transmit power (including ACAS broadcast) to the spatial extent of the formation. This is an attractive alternative in the event that a long-term GNSS failure requires active interrogations; and

    3) Special active or passive surveillance is limited to surveillance of formation member aircraft only via use of a military Mode S address or internal identification;

c) Switch between the military formation and non-formation modes of ACAS when entering and leaving a formation configuration. In switching to formation mode, all formation aircraft would disable their normal active ACAS surveillance function, except as noted below, and revert to a passive form of surveillance. An exception would be those formation aircraft selected to retain normal active ACAS function for surveillance of non-formation aircraft. These aircraft would still perform passive surveillance of formation members. All formation aircraft, including the ones retaining an active capability, would indicate formation flight status. In exiting a formation all aircraft would switch to the normal ACAS non-formation mode;

d) Use a fallback procedure in event of an indicated GNSS failure:

1) Revert to inertial navigation system (INS) for a period consistent with INS drift characteristics or to area navigation (RNAV) capable alternatives;

2) If a GNSS failure persists beyond an acceptable INS drift period, revert to low power active surveillance using transmit power consistent with formation size;

3) Revert to normal military formation mode when GNSS recovers; and

4) Use unencrypted short squitter transmissions from formation Mode S transponders to enable collision avoidance of formation aircraft by non-formation ACAS.

7.1.3.3 *Surveillance between military formation ACAS and civil ACAS*

a) Use normal active ACAS with hybrid surveillance and ACAS broadcast for military formation aircraft selected to retain active ACAS surveillance capability against non-formation aircraft; and

b) Use non-encrypted short squitter transmissions from formation Mode S transponders to enable surveillance and collision avoidance of formation aircraft by non-formation ACAS.

7.1.3.4 *Collision avoidance capability of formation aircraft*

a) Selected formation aircraft retaining normal ACAS functions are limited to TA-only capability against non-formation aircraft and would indicate unequipped to a non-formation ACAS; and

b) A modified TA function is used in all formation aircraft to aid station keeping and collision avoidance between formation members. The new parameters of the TA function should be tailored to account for the closer aircraft separations in the formation.

7.1.4 Operational procedures for an ACAS-equipped military formation that provide compatibility with ATC and civil ACAS

7.1.4.1 Based on the military/civil compatibility issues discussed in 7.1.2, the following list presents operational procedures for a military formation ACAS that would help to reduce the impact on ATC and civil ACAS.

7.1.4.1.1 *Altitude of formation operations*

Conduct ACAS formation operations at the highest altitudes possible. Military ACAS formations operating above 25 000 ft altitude have relatively less impact on civil ACAS surveillance and transponder availability than formations operating below 20 000 ft and are able to operate with greater numbers of active ACAS and Mode S transponders.

7.1.4.1.2 *Location of formation operations relative to a terminal area*

Conduct ACAS formation operations as far from a high-density terminal area as possible. If the military formation operates at sufficient range from a terminal area, its impact on ATC and civil ACAS could be at acceptable levels regardless of its altitude. The minimum acceptable range of the formation to the terminal area is dependent on formation size, number of operating military ACAS, and the existing levels of ACAS and ATC interference, or expressed in another way, the existing ACAS and Mode S transponder density.

7.1.4.1.3 *Size of formation operations*

7.1.4.1.3.1 Limit the number of ACAS within the formation to as few as possible.

7.1.4.1.3.2 Military ACAS systems that provide further reductions in electromagnetic interference than ACAS may not be subject to the same formation size, range and altitude constraints as aircraft equipped with ACAS.

7.1.5 Measured impact of military formation ACAS and Mode S transponders on ATC and civil ACAS and guidance for use of formations

7.1.5.1 The results presented below were derived using a simulation involving different formation sizes and numbers of formation ACAS at various locations relative to the Dallas-Ft. Worth (DFW) terminal area. Based on the results of the simulation, general guidance is presented on acceptable use of formations in the vicinity of a high-density terminal area. There is no attempt to provide a single set of universal rules for formation operation since each area could be unique with respect to operational procedures and electromagnetic influences. Each State is responsible for analysing its present and future terminal airspace in order to develop formation requirements applicable to that State.

7.1.5.2 Although these results may be applicable to a number of other high-density terminal areas, particularly in the same State, it is acknowledged that ATC separation procedures, flight operations, and the electromagnetic environment worldwide can be significantly different. For this reason, it is suggested that civil aviation authorities in various States, in conjunction with interested users and equipment manufacturers, evaluate differences between their specific environment and the one used here and modify their formation operation requirement accordingly.

7.1.5.3 *Terminal area traffic and ACAS model*

7.1.5.3.1 The impact of a military formation on a civil ACAS and ATC transponder in the vicinity of the DFW terminal area was determined using a computer-based simulation programme. Both the civil ACAS and ATC transponder as well as the military formation are operating between 10 000 ft and 20 000 ft altitude and within a range of 40 NM from DFW. The programme uses DFW radar traffic data and ACAS modeling to determine ACAS interrogation rates and resultant victim transponder utilization. In addition, the simulation enables the determination of ACAS surveillance range degradation caused by the effect of nearby formation ACAS on interference limiting. The DFW traffic model contains approximately 110 aircraft within 60 NM of DFW. For this simulation, all air carrier aircraft in the traffic model were assigned active-only ACAS equipage and the remainder Mode A/C equipage. This results in approximately 48 civil ACAS II aircraft and 25 civil Mode A/C aircraft within 30 NM of DFW.

7.1.5.3.2 For each scenario in the simulation a victim civil ACAS and ATC transponder aircraft was modeled as flying at an altitude between 11 000 ft and 17 000 ft and in a straight path from 40 NM east to 40 NM west of DFW.

7.1.5.4 *Military formation model*

7.1.5.4.1 The military formation size, flight characteristics and aircraft equipage were modeled by adding additional specific aircraft to the DFW traffic database depending on the scenario requirements. The military formation characteristics are based on "U.S. Air Force 2000 C-130 Operational Procedures". The formation selected for this simulation is a VFR in-trail formation consisting of 3-aircraft cells in which followers 1 and 2 are co-altitude and spaced 2 000 ft and 4 000 ft longitudinally and ± 500 ft laterally relative to the cell leader. Cell leaders are spaced 12 000 ft longitudinally.

7.1.5.4.2 The orientation of the formation is stationary, parallel and offset 2 NM relative to the in-bound victim ACAS and transponder aircraft for each scenario. Four formation sizes of 30, 21, 12 and 6 aircraft were modeled for the evaluation. Each of the four formation sizes was simulated at 11K, 14K, 17K, 20K, 25K, 30K and 35K ft altitude and at 5, 10, 20 and 32 NM from DFW. Each formation aircraft is equipped with a Mode S transponder.

7.1.5.4.3 For 384 of the 452 scenarios performed, every third formation cell leader aircraft, beginning with the first is equipped with an ACAS to provide a 6-NM ACAS spacing. This results in 4 ACAS for the 30-aircraft formation, 3 ACAS for the 21-aircraft formation, 2 ACAS for the 12-aircraft formation, and 1 ACAS for the 6-aircraft formation. A second set of 44 scenarios examines the impact of a 6-A/C and 12-A/C all ACAS formation on a civil ACAS and transponder and a third set of 24 scenarios examines the impact on ACAS and transponder by formations containing various numbers of ACAS up to the maximum for each formation size.

7.1.5.5 *Simulation results in DFW airspace*

The following subsections summarize the measured impact on ACAS surveillance range and transponder utilization of both the existing environment and that environment with the formation added. Results of formation impact are presented separately as a function of formation size, distance from DFW, formation altitude, formation Mode S transponder equipage, and number of formation ACAS.

7.1.5.5.1 *Impact on the existing non-formation DFW airspace*

7.1.5.5.1.1 The results indicate that the surveillance range of an ACAS operating at 11 000 ft altitude and within 10 NM of DFW was degraded from 14 NM to 7 NM by the existing non-formation environment. Surveillance improves at higher ACAS altitudes and is fully recovered to 14 NM by 17 000 ft altitude or when ACAS is beyond 10 NM of DFW.

7.1.5.5.1.2 The utilization of a transponder operating at 11 000 ft altitude and within 10 NM of DFW was degraded to a peak value of 3 per cent due to the existing environment. Utilization improved to 2.7 per cent at a transponder altitude of 17 000 ft.

7.1.5.5.2 *Impact of formations, with an ACAS spacing of 6 NM within the formation, on an ACAS and transponder at 11 000 ft altitude*

The impact of a formation on ACAS surveillance and transponder utilization shows the same improvement as a function of ACAS altitude as observed for the existing environment. As a result, the effect of a formation is presented for the worst-case ACAS and transponder altitude of 11 000 ft.

7.1.5.5.2.1 *Impact as a function of formation size.* The surveillance range of an ACAS operating within 10 NM of DFW is degraded to 5 NM (70 per cent of the non-formation surveillance range) in the presence of a 30-aircraft formation also operating at 11 000 ft and located 5 NM from DFW. ACAS surveillance improves with decreasing formation size and is 6.3 NM (90 per cent of non-formation range) for a 6-aircraft formation. Transponder utilization under the same formation conditions is a maximum of 4.4 per cent for the 30-aircraft formation and improves to 3.4 per cent for the 6-aircraft formation.

7.1.5.5.2.2 *Impact as a function of formation distance from DFW.* ACAS surveillance impact by a 30-aircraft formation at 11 000 ft and 5 NM from DFW gradually improves from 5 NM (70 per cent of non-formation range) to 6.3 NM (90 per cent of non-formation range) as the formation distance increases to 32 NM. As formation size decreases to 6 aircraft, the surveillance range achieves the non-formation value of 7 NM. Under the same 30-aircraft formation conditions, transponder utilization improves from 4.4 per cent at 5 NM to 3.3 per cent at 32 NM. For a 6-aircraft formation at 32 NM, transponder utilization is no longer degraded by the formation.

7.1.5.5.2.3 *Impact as a function of formation altitude.* Both ACAS surveillance and transponder utilization are relatively insensitive to formation altitude within the region of 11 000 to 20 000 ft and within the region of 25 000 to 35 000 ft for each of the conditions of formation size and distance. A change in performance occurs in transitioning from 20 000 to 25 000 ft formation altitude when ACAS surveillance improves by about 20 per cent and transponder utilization decreases by about 10 per cent, e.g. from 3.0 per cent to 2.7 per cent.

7.1.5.5.3 *Impact of the number of formation ACAS on ACAS surveillance and transponder utilization*

7.1.5.5.3.1 Increasing the number of ACAS in a formation can degrade ACAS surveillance range significantly. The amount of degradation depends on the formation size, altitude and distance from DFW. For a formation below 23 000 ft altitude, it varies from a 50 per cent surveillance reduction for an all-ACAS 30-aircraft formation within 10 NM of DFW to no degradation for an all-ACAS 6-aircraft formation at 20 NM from DFW.

7.1.5.5.3.2 At a formation altitude above 23 000 ft, ACAS surveillance range improves by 20 per cent for all formation configurations. At these altitudes, an all-ACAS 6-aircraft formation can fly directly over DFW without impacting on ACAS surveillance.

7.1.5.5.3.3 The number of ACAS aircraft within a formation has relatively little effect on transponder utilization.

7.1.5.5.4 *Impact of Mode S transponder equipage on ACAS surveillance and transponder utilization*

7.1.5.5.4.1 The number of Mode S transponder-equipped aircraft in a formation can have a significant effect on transponder utilization. For example, the degradation on utilization varies more or less linearly from a 10 per cent increase (e.g. from 3.0 per cent to 3.3 per cent) for a 6-aircraft Mode S formation to a 50 per cent increase for a 30-aircraft Mode S formation.

7.1.5.5.4.2 The impact of Mode S-equipped formation aircraft on ACAS surveillance range is less severe. A maximum ACAS surveillance range reduction of 10 per cent occurs as a result of formations operating with 30 to 12 Mode S transponder aircraft below 23 000 ft altitude and within 10 NM of DFW. No surveillance degradation occurs as a result of a 6-aircraft Mode S formation, 30- to 12-aircraft Mode S formations operating at 20 NM or more of DFW, or due to any formation operating above 23 000 ft.

7.1.5.6 *Suggested formation size and location requirements for operation in DFW-like airspace*

7.1.5.6.1 The following guidance on military formation operation in high-density terminal airspace is based on a maximum allowed ACAS II surveillance and transponder utilization degradation by a military formation of 10 per cent and 20 per cent, respectively. Although it is understood that these values may be subject to debate, they appear reasonable and are used here to provide initial guidance for operation of formations in civil airspace.

7.1.5.6.2 Figure 7-1 illustrates the required combination of formation location and number of formation Mode S and ACAS II aircraft to maintain a maximum 10 per cent ACAS II surveillance degradation and a maximum 20 per cent transponder utilization degradation.

7.1.5.6.3 When the formation location is within 30 NM of the DFW terminal area, the greatest impact on an ACAS II and transponder occurs when the ACAS II and transponder are within 10 NM of DFW. As the formation location moves beyond 30 NM of the centre, the impact on an ACAS II and transponder within 10 NM becomes less significant as more formation ACAS II no longer contribute to the ACAS II NTA value and received formation Mode S interrogations are at lower power levels.

7.1.5.6.4 When the formation location is beyond 30 NM of DFW, the greatest impact on an ACAS II and transponder occurs when the ACAS II and transponder are located adjacent to the formation. This impact on transponder utilization is related to the number of formation Mode S transponders, and the impact on ACAS II surveillance is related to the number of formation ACAS II units. The upper limit on the number of Mode S and ACAS II aircraft in a formation in order to maintain a maximum 10 per cent ACAS II surveillance degradation and a maximum 20 per cent transponder utilization degradation, regardless of formation location, depends on the size of the formation. The limit is 21 formation ACAS for formations of up to 24 Mode S aircraft, 19 ACAS up to 27 Mode S aircraft, 18 ACAS up to 30 Mode S aircraft, and 8 ACAS for the maximum allowed 60-Mode S aircraft formation.

7.1.6 Military formation ACAS training

In addition to the ACAS training specified in Section 5.3, pilots operating ACAS systems in formations should receive training on the unique aspects of these operations.

7.1.7 Certification of formation ACAS

The recommended procedures for obtaining certification and operational approval for ACAS used in military formations are addressed in Section 11.3.

7.2 ACAS INSTALLATIONS ON ROTARY WING AIRCRAFT

7.2.1 Introduction

7.2.1.1 Helicopter operations worldwide can and have involved concentrations of helicopters flying in close proximity to each other. These include public and sporting events that require transportation of people associated with the event, local rescue operations, government security measures, and military operations. Air traffic data over a period of three years has shown that a yearly Grand Prix event in one State results in a large number of supporting helicopter flights. The data indicate that the number of helicopters within a 10 NM radius of the event and up to 1 500 ft altitude is at least 80 and could be as high as 100, which would result in a density of 0.32 Mode C aircraft/NM^2 within at least 10 NM.

Formation altitude >23K ft

Formation Mode S	Allowed number of formation ACAS aircraft as a function of number of formation Mode S aircraft														→
3 A/C	3														3
6 A/C	6														6
9 A/C	5	6	8	9											9
12 A/C	4	6	8	10	12										12
15 A/C		6	9	12	15										15
18 A/C				14	18										18
21 A/C					21										21
24 A/C					16	20	21								21
27 A/C						13	16	19							19
30 A/C						6	8	10	12	16	18				18
60 A/C								5	6	8					8

3.6% transponder utilization exceeded in this region with no formation ACAS

60 A/C values are estimates

Altitude <23K ft

Formation Mode S															→
3 A/C	2	3													3
6 A/C	2	3	4	5	6										6
9 A/C	1	2	4	5	7	8	9								9
12 A/C				5	7	8	9	10	12						12
15 A/C					6	7	8	9	10	15					15
18 A/C						7	7	8	9	13	16	18			18
21 A/C							7	7	8	11	14	18	21		21
24 A/C							5	6	6	9	12	15	18	21	21
27 A/C								4	5	7	10	12	15	19	19
30 A/C								3	4	6	8	10	12	18	18
60 A/C									1	2	2	3	4	6	8

3.6% transponder utilization exceeded in this region with no formation ACAS

60 A/C values are estimates

0 12.5 15 20 25 30 35 40 45

Formation distance from DFW (NM)

Figure 7-1. Formation size, number of ACAS and airspace restrictions to maximum 10 per cent ACAS and 20 per cent transponder

7.2.1.2 There is a desire on the part of some users to equip these helicopters with some form of surveillance to provide situational awareness. Forms of equipment considered for this purpose include ACAS I or an ACAS II without resolution advisory capability. The use of either of these in a large formation or cluster of helicopters can have a deleterious effect on nearby civil ACAS II performance as discussed in the following paragraphs. Any other forms of equipment will also require assessment.

7.2.1.3 ACAS II without resolution advisory capability are not SARPs compliant. As a first approximation, they would have the same effect on the SSR environment as correctly configured ACAS II. This adverse effect is acceptable for ACAS II because of the safety advantages provided by ACAS II RAs.

7.2.2 Impact of a cluster of Mode A/C transponder-equipped helicopters on ACAS II and ATC surveillance

7.2.2.1 A large number of closely spaced Mode A/C-equipped helicopters can cause a potentially serious Mode C synchronous garble problem for ACAS II and ACAS I aircraft flying above the cluster, for the ACAS I-equipped helicopters themselves, and for ATC surveillance. For example, assuming a uniform-in-area distribution of 100 Mode A/C-equipped helicopters at a yearly Grand Prix event in one State, an ACAS II could see in the forward beam up to 14 such helicopters within a ±1.7 NM garble range of a Mode A/C threat at 5 NM and up to 28 helicopters within ±1.7 NM of a threat at 10 NM. These values are 1.5 to 3 times the number of Mode C aircraft that ACAS II was designed to handle in a density of 0.3 Mode C aircraft/NM^2 within 5 NM of own aircraft. Analyses indicate that ACAS II should be able to degarble replies against a threat at 5 NM when the largest number of Mode C aircraft in the forward beam within ±1.7 NM of the threat is 9 aircraft. ATC secondary surveillance of these helicopters can also be impacted by synchronous garble.

7.2.2.2 In reality, Mode C synchronous garble can easily be much more severe than stated above since the distribution of helicopters may deviate from uniform-in-area to cause much higher localized densities. Simulation work done in one region, using a projected 2005 civil traffic scenario, indicates that overall Mode C surveillance can be degraded when there are 5 aircraft in the forward beam within 5.2 NM of the ACAS II aircraft.

7.2.2.3 In addition, Mode C transponder-equipped helicopters will cause ACAS II to transmit the higher whisper-shout sequence, which will advance the onset of interference limiting.

7.2.2.4 The obvious solution to this problem is the use of Mode S transponders on helicopters that may possibly be used in operations involving large numbers of other helicopters.

7.2.3 Impact of a cluster of ACAS I-equipped helicopters on ACAS II and ATC surveillance

7.2.3.1 Some helicopters have been equipped with an ACAS I and Mode C transponder to provide situational awareness or assist in see-and-avoid. In low-density airspace with a small number of helicopters operating individually, ACAS I:

a) provides Mode C surveillance without a synchronous garble problem;

b) provides an adequate range for see-and-avoid; and

c) does not impact on ACAS II surveillance.

7.2.3.2 In high-density airspace, simulations show that small clusters of ACAS I helicopters may create high interference and significant degradation of surveillance performance for ATC and other ACAS. It is recommended that States investigate the impacts of ACAS I operations in high-density airspace where and when deemed necessary.

7.2.3.3 In a large cluster of helicopters, equipage with an ACAS I and Mode C transponder will result in the synchronous garble problem for both ACAS II and ACAS I.

7.2.4 Impact of a cluster of helicopters using ACAS II surveillance techniques on the surveillance performance of other ACAS II

Some helicopter users have elected to improve the surveillance range capability of an ACAS I by either providing the ACAS I with the ACAS II interference limiting function (as allowed in one State) or by using an ACAS II without the resolution advisory capability. When such helicopters are operated in clusters or formations, the considerations described in 7.1 apply.

7.3 ACAS INSTALLATIONS ON UNMANNED AERIAL VEHICLES

7.3.1 As the use of Unmanned Aerial Vehicles (UAVs) or Remotely Operated Aircraft (ROAs) increases in civil and military operations, there is increased interest in the installation of ACAS on UAVs. UAV operators have stated that ACAS could provide collision protection for the UAV, provide situational awareness for any UAV ground pilot, and enable airspace access by meeting worldwide aircraft equipage requirements.

7.3.2 The airspace access reasoning is based on two primary factors: first, the largest UAVs meet the weight requirements of the 2005 ICAO ACAS mandate; and second, they consider acceptance of UAV operation to be more likely if the UAV can interact with the ATC system in the same way as a standard aircraft (implying that the UAV should have the same equipage as a standard aircraft).

7.3.3 There is no basis for interpreting the ICAO requirement to fit ACAS as a requirement for UAVs.

7.3.4 Further safety studies and analyses are necessary to assess the safety impact of ACAS-on-UAV operation before its operation is permitted.

7.3.5 Implementation options and corresponding issues/concerns

7.3.5.1 The various implementation options identified to provide collision avoidance protection for UAVs are:

a) ACAS II executing RAs autonomously;

b) ACAS II with a ground pilot executing RAs;

c) ACAS II operating in TA/RA mode, but prohibited from executing RAs;

d) ACAS II with procedural restrictions;

e) ACAS limited to only providing TAs:

i) ACAS II limited to operating in TA-only mode;

ii) An ACAS I system utilizing ACAS II surveillance; and

iii) ACAS I;

f) Mode S only; and

g) new ACAS system for UAVs.

The following paragraphs outline the benefits, issues, safety and acceptability associated with each implementation option.

7.3.5.1.1 *ACAS II executing RAs autonomously*

In this implementation the UAV always executes the ACAS RA with the correct timing and level of response. Issues to be addressed prior to implementation include: (1) whether the ACAS hardware and software and associated avionics can be certified to the level of criticality needed for autonomous operation; and (2) whether the reported altitude of intruders in the UAV environment is sufficiently reliable and/or accurate to allow removal of a pilot reasonableness check.

7.3.5.1.2 *ACAS II with ground pilot executing RAs*

7.3.5.1.2.1 Implementations in which a ground pilot executes RAs generate a concern similar to that of the autonomous implementation, in that the ground pilot may not have sufficient situational awareness to provide a pilot reasonableness check. The pilot situational awareness level would depend on the type of information provided to the ground pilot. For example, simply downlinking the ACAS traffic display to the ground pilot would not allow the pilot to recognize cases of incorrect altitude reporting.

7.3.5.1.2.2 A second concern is the reliability and/or potential unavailability of the air-ground-air data link. The communication protocols and the probability of successful communication need to be defined and factored into ACAS safety studies. Degradation in link performance would have to be detected and handled (e.g. reverting to TA-only operation upon detection of a link failure) appropriately.

7.3.5.1.2.3 A third concern is the pilot response delay introduced by the air-ground-air communication link. Studies have shown that delayed responses degrade ACAS performance and the safety provided by the system. Also of concern is the interaction of a delayed response with the ACAS-ACAS reversal logic. Simulations have revealed encounters in which one aircraft’s delayed response to an RA leads to a sense reversal in both aircraft, potentially causing altitude crossings at close range and decreasing separation.

7.3.5.1.2.4 Two types of communication links can be considered: line of sight and beyond line of sight. For either type, the maximum RA response time must be determined. The concern, especially with beyond line of sight communication with multiple relays, is that the RA response time assumed by ACAS may not be possible.

7.3.5.1.3 *ACAS II operating in TA/RA mode, but prohibited from responding to RAs*

In this implementation, ACAS II would be fully operational except that there would be no response to ACAS RAs. This is not acceptable because it increases the risk of collision with other ACAS-equipped aircraft. ACAS on the other aircraft would operate less effectively than it would were the UAV not equipped with ACAS.

7.3.5.1.4 *ACAS II with procedural restrictions*

This implementation considers a UAV equipped with ACAS II but operated with procedural restrictions. The restrictions might include limiting the UAV to special use airspace for the climb and/or descent phases of flight, requiring an escort aircraft in certain airspace, or requiring selection of TA-only mode in phases of flight that are deemed problematic for RA execution (e.g. when the UAV is beyond line-of-sight communication from the ground pilot, or when crossing altitude encounters are very likely to occur).

7.3.5.1.5 *TA-only operation*

7.3.5.1.5.1 Three different implementations are considered for this option: (1) ACAS II operating in TA-only mode; (2) ACAS II surveillance without RA capability; and (3) ACAS I as defined in Annex 10, Volume IV. These implementations would be used for situational awareness. The limited range capability of ACAS I will make its use less desirable than the other two options for some UAVs.

7.3.5.1.5.2 Users should be aware that the primary design objectives for ACAS were collision avoidance and minimization of interference to the SSR environment, and therefore its ability to support situational awareness is limited. There is no guarantee that it will track and display all aircraft that the pilot might consider relevant.

7.3.5.1.5.3 PANS-OPS, Volume I, Part VIII, Chapter 3 prohibits pilots from manoeuvring their aircraft in response to TAs only.

7.3.5.1.6 *Installation of a Mode S transponder on the UAV*

It would be operationally desirable to equip UAVs with 25-ft altitude reporting Mode S transponders. This allows the UAV to be better seen by both ACAS-equipped aircraft and ground controllers. ACAS aircraft can thus issue RAs against the UAV and resolve any conflicts that arise.

7.3.5.1.7 *New ACAS system for UAVs*

It is recognized that refinements to the UAV ACAS surveillance and/or CAS logic might be warranted or new modules might be needed to compensate for loss of the on-board pilot. Any such refinements would need to be carefully evaluated to ensure that the new system is effective and the performance of existing ACAS equipment is not degraded.

7.3.6 Safety analyses and related tasks

7.3.6.1 Tasks outlined in this section define actions that should be completed by a UAV operator or State regulatory authority prior to authorizing the operation of ACAS equipment on UAVs.

7.3.6.2 *Develop a "Concept of Operations"*

A Concept of Operations is necessary before any ACAS-on-UAV implementation can be analysed. The Concept of Operations may include: information on flight characteristics of the UAV; implementation option selected (e.g. ACAS II executing RAs autonomously, TA-only mode, Mode S only, etc.); communication protocols (if applicable) between ground pilot and UAV; information available to the ground pilot; identification of the airspace used for different phases of flight (e.g. restricted military airspace for take-off and landing); rate of climb/descent to/from cruise altitude; cruise altitudes; and methods for handling error conditions (e.g. air-ground-air link problems and UAV flight malfunctions).

7.3.6.3 *Define a UAV encounter model*

7.3.6.3.1 An encounter model represents the types and frequency of encounters a UAV will experience.

7.3.6.3.2 An encounter model specific to UAVs is necessary for the following reasons:

a) flight characteristics of UAVs may differ from those of manned aircraft;

b) flight profiles may differ from manned aircraft; and

c) the flight environment may differ; e.g. UAVs might take off from a remote area or a restricted airspace.

7.3.6.4 *Estimate logic risk ratio*

7.3.6.4.1 The term “logic risk ratio” limits the consideration to the effect of the CAS logic, omitting other factors, e.g. surveillance performance, that could affect the safety of the end-to-end ACAS system (see 3.17).

7.3.6.4.2 The logic risk ratio for ACAS installed on a UAV must be calculated. Although the CAS logic installed in a UAV might be identical to the CAS logic in a standard aircraft, the logic risk ratio for the UAV installation could differ due to various factors, e.g. pilot response delays, the UAV-specific encounter model, or the unique UAV flight envelope.

7.3.6.5 *Develop a UAV-specific event tree*

7.3.6.5.1 The event tree, or “fault tree,” provides both a qualitative and quantitative means to identify and analyse failure modes in the end-to-end system. It identifies all significant means by which a collision (or a near-collision) can occur, organizes them into a logical structure to study the processes leading to failure, and systematically identifies the root causes and interactions.

7.3.6.5.2 ACAS event trees typically assume that if the pilot of the ACAS aircraft visually acquires a conflicting aircraft, he/she will avoid it. For UAVs, the branch addressing the effect of pilot visual acquisition must be modified. Any resulting increase in collision risk may need to be addressed by other means.

7.3.6.6 *Assess ACAS performance in UAV-aircraft coordinated encounters*

7.3.6.6.1 Of special concern is the effect of any UAV response delay on the current ACAS-ACAS reversal logic. Simulations have shown that a late response on the part of one aircraft can lead to multiple altitude crossings at close range and result in much-reduced vertical separation.

7.3.6.6.2 In past ACAS safety studies, separate studies have focused on ACAS-ACAS coordinated encounters and characterized the performance of the ACAS-ACAS logic under stressing conditions. These studies should be tailored to the specifics of UAV operation.

7.3.6.7 *Document criticality requirements and other issues*

The situational awareness of a UAV pilot or system will differ from manned aircraft. Therefore for any failures in ACAS, different compensation mechanisms may be required, e.g. equipment redundancy or higher software certification levels.

7.3.6.8 Resolution of policy and regulatory issues in each State or region is required. Issues to be addressed include pilot/remote operator licensing, integration of UAV operations into the civilian airspace system/airspace management, legal aspects of UAV operations and security requirements.

Chapter 8

SAFETY AND ELECTROMAGNETIC ENVIRONMENTAL ASSESSMENTS

8.1 SAFETY ASSESSMENT

8.1.1 The need for safety assessments

8.1.1.1 The purpose of ACAS is to reduce the risk of mid-air collision and thus provide a safety benefit. To quantify the benefit of fitting ACAS II, safety assessment studies must be performed. These studies should consider both the effects of ACAS on the environment and of the environment on ACAS.

8.1.1.2 Safety assessments have shown that when correctly implemented, ACAS II is a valuable safety net. This has been confirmed by operational experience. However, additional safety assessments could still be required before ACAS is initially introduced into a new airspace.

8.1.1.3 Even when ACAS II is operational in an airspace, further safety assessments may still be required to quantify the impact of the introduction of changes in the ATM environment (e.g. RVSM) on the efficacy of ACAS II. Any changes in ACAS II also need to be quantified for their impact on all ATM environments.

8.1.1.4 Finally, such safety assessments can suggest improvements to operations that maximize the safety benefits brought by ACAS II.

8.1.2 Risk ratio

8.1.2.1 The safety level of an airspace is characterized by the risk of collision in this airspace. The effect of ACAS II on the risk of collision is usually expressed through a measure referred to as “risk ratio”, which expresses the risk of collision in the airspace with ACAS as a ratio to the risk of collision without ACAS.

8.1.2.2 The risk ratio is a relative measure. ACAS II does not make flight safe; it makes it safer, and the extent to which it makes it safer is expressed as a fraction of the risk of collision in the absence of ACAS. A risk ratio of 0.2, or 20 per cent, means that ACAS removes 80 per cent of the risk of collision.

8.1.2.3 A risk ratio can also be derived for aircraft rather than airspace. This compares the risk of collision for any aircraft equipped with ACAS to the risk of collision for any aircraft without ACAS.

8.1.2.4 The situation is made more complex when considering the effects of additional equipage because the presence of aircraft already equipped with ACAS will lower the risk ratio. Hence, risks may need to be compared with the existing environment, rather than a theoretical environment without ACAS.

8.1.3 Standard encounter models

8.1.3.1 Ideally, the determination of an ACAS II risk ratio requires collecting a large set of encounters, on which the risk of collision before and after the change is introduced in the airspace can be measured.

8.1.3.2 In practice, the analysis of many years of radar data is required. Therefore, it is more practical to construct this set of encounters by developing a stochastic model for collision risk encounters and then tuning the model to the characteristics of real encounters gathered from several countries.

8.1.3.3 The result of this approach is a set of tables assigning a probability to the values that some parameters describing the configuration of the encounter and the flight of the aircraft involved can take. These tables are given in the ACAS SARPs and constitute the encounter model discussed in 3.17.

8.1.3.4 While this model is fine for a general safety assessment of ACAS II, it must be noted that it represents a generalized, composite airspace. Air traffic consists of varying mixtures of aircraft types and is managed in different ways in different regions. As a consequence, ACAS II cannot be equally safe in all regions. So, in order to conduct safety assessments whose results are focused on a region, it is necessary to build a specific encounter model.

8.1.4 Calculation of risk ratio

8.1.4.1 *Unresolved and induced risk of collision*

8.1.4.1.1 When simulating the ACAS II logic on the generated encounters, two cases can occur which have an adverse contribution to the risk ratio:

a) the encounter presents a risk of collision and the ACAS II resolution fails to avoid it. This is an unresolved risk of collision; and

b) the encounter does not present a risk of collision and the ACAS II resolution creates it. This is an induced risk of collision.

8.1.4.1.2 Note that the induced risk of collision may become an important factor in the residual risk of collision. In other words, in airspaces in which ACAS has substantially reduced the overall risk of collision, when a collision does occur, it is possible that ACAS will be a causal factor in that collision.

8.1.4.2 *Logic risk ratio*

Calculations of risk ratio can be made for the collision avoidance logic considered in isolation (the “logic risk ratio”) and for the system considered as a whole including pilot response, the environment, etc. (the “full system risk ratio”). Logic risk ratio calculations typically assume that all other aspects of the system operate as intended. They are mostly used for testing potential improvements to the ACAS logic. They are also essential components in determining the full system risk ratio.

8.1.4.3 *Technical factors*. The following technical factors have been taken into account when calculating risk ratio.

8.1.4.3.1 The proportion of aircraft reporting in 25-ft increments relative to aircraft reporting in 100-ft increments has an impact on the efficacy of ACAS II. The more aircraft that report in 25-ft increments, the better ACAS II performs.

8.1.4.3.2 The known trajectories of the aircraft are based on altimeter measurements and are thus in error — they are only approximate. Altimeter errors must be included in order to recover the “true” altitudes of the two aircraft. To this end, an altimeter error model (see Section 3.17.2.4) was developed in the ACAS SARPs.

8.1.4.4 *Environmental factors*

In an encounter that presents a risk of collision, two ACAS-equipped aircraft will coordinate their resolution advisories. As a result, the proportion of aircraft not fitted with ACAS II in the considered airspace is a major factor influencing the safety benefits brought by ACAS II. The more ACAS II-equipped aircraft in the airspace, the better ACAS II performs.

8.1.4.5 *Human Factors*

8.1.4.5.1 The ACAS II logic selects resolution advisories assuming that the pilot will react in accordance with a standard response model described in the ACAS SARPs. This model assumes the pilot responds to the advisory within 5 seconds and then manoeuvres at 0.25 g to obtain the advised vertical speed.

8.1.4.5.2 Monitoring programmes have observed underreaction and overreaction to resolution advisories. Such reactions have a detrimental effect on the efficacy (underreaction) or operational acceptability (overreaction) of ACAS. Non-response to advisories has also been observed, and this has the effect of removing all safety benefits from ACAS resolution advisories.

8.1.4.5.3 Reactions contrary to the resolution advisory are occasionally observed. Such reactions are considered dangerous and some have resulted in accidents.

8.1.4.5.4 A study by a group of States examined the effects of pilot reactions to resolution advisories on the logic risk ratio of ACAS and disruptions to ATC caused by these advisories. Data were recorded from a large number of actual resolution advisories. The recorded data showed that there were generally three types of pilot response models. These were identified as:

a) a “standard pilot” who responds according to the ACAS SARPs, i.e. responds within 5 seconds and with 0.25 g to obtain 1 500 fpm;

b) a “smooth pilot” who responds within 8.5 seconds and with 0.11 g and achieves 500 fpm; and

c) a “strong pilot” who responds within 4.7 seconds and with 0.26 g and achieves 3 700 fpm.

8.1.4.5.5 Simulations with these different response models showed extreme differences in the risk ratio and very significant differences in disruptions to ATC as a result of the differences in deviation from assigned altitude. The normal risk ratio, based on the standard SARPs response model, is 9.0 per cent. For the smooth pilot it was 63.3 per cent and for the strong pilot it was 6.3 per cent. The large increase for the smooth pilot was a result of an increase in the number of near mid-air collisions (NMACs) and induced NMACs resulting from the slower and weaker response. Although the strong pilot had a slight decrease in risk ratio, the deviation from assigned altitude averaged 140 per cent higher than the standard pilot. For the standard pilot, deviation from assigned altitude in response to a resolution advisory is generally less than 600 ft with only 0.5 per cent of encounters exceeding this value. For the strong pilot, the number of deviations exceeding 600 ft was increased by 1 122 per cent. Such large altitude deviations can be disruptive to air traffic control procedures. The study shows the importance of responding to resolution advisories using the “standard response model” parameters.

8.2 ELECTROMAGNETIC ENVIRONMENT ASSESSMENT

8.2.1 The need for continual assessment of the electromagnetic environment

8.2.1.1 ACAS safety benefits have been quantified based on the distribution and density of aircraft in the national and international airspace and confirmed by operational experience. ACAS safety benefits continue to be sensitive to future changes in both the airspace characteristics used for the safety assessment as well as on the impact of future changes in the RF environment as it affects ACAS surveillance. It is therefore important for CAAs to be aware of the possible impact of these changes and be prepared to monitor and assess their impact on ATC and on the safety benefits of ACAS.

8.2.1.2 The ACAS collision avoidance and surveillance functions were designed and tested to operate effectively in airspace in which aircraft separations are characterized according to normal civil ATC separation standards. Furthermore, ACAS surveillance was designed to provide sufficient surveillance range for protection against aircraft with relative closing speeds of: a) up to 500 kt when operating in transponder-equipped aircraft densities of 0.3 aircraft per square NM and b) up to 1 200 kt in densities of 0.06 aircraft per square NM. Any decrease in aircraft separations, relaxation of speed restrictions, or increase in density can reduce the ACAS safety benefit.

8.2.1.3 Any change in airspace electromagnetic and aircraft environment from that assumed during the design of ACAS can have a serious impact on ACAS surveillance and on the validity of the ACAS threat detection parameters and therefore on the safety benefit of ACAS. Also, any environmental changes can increase ACAS utilization of transponders.

8.2.1.4 CAAs should continually monitor ACAS operational performance in airspace in which air traffic growth (for both ACAS and non-ACAS) is expected. CAAs should assess the effects of ACAS on the electromagnetic environment whenever changes in separation assurance techniques are likely to result in reduced separation standards and whenever fabrication and use of ACAS-based equipment for special civil and military operations are underway or being considered.

8.2.1.5 The knowledge gained from airspace monitoring and assessment will enable:

a) the development of operational constraints on the use of ACAS, Mode S or Mode A/C transponder aircraft operating in clusters or formations in civil airspace in order to protect the performance of ACAS and ATC;

b) optimization of civil operational procedures within current ACAS constraints; and

c) if necessary, implementation of required modifications to ACAS to prevent additional interference due to the changes in the civil air traffic structure.

8.2.1.6 Specific activities that can change the airspace environment and impact on ACAS safety and which require continual awareness and assessment on the part of civil aviation authorities are:

a) relaxation of terminal area speed restrictions;

b) allowed reduction in ATC separation of aircraft;

c) increased densities of ACAS II aircraft and aircraft using ACAS II surveillance but with TA-only capability;

d) density of TCAS I (including Traffic Advisory Systems [TAS]) aircraft in excess of 20 per cent of the ACAS II population;

e) use of Mode A/C transponders with and without TCAS I and TAS in civil and military fixed-wing aircraft and helicopters operating in large clusters;

f) use of Mode S transponders in a large cluster or formation;

g) use of ACAS II in military formations;

h) expanded and unauthorized use of operationally restricted military ACAS-based units;

i) use of ACAS II on helicopters; and

j) use of ACAS on Unmanned Aerial Vehicles.

8.2.2 Simulation results using local density and electromagnetic environment

8.2.2.1 A study was conducted in Europe to evaluate the effectiveness of ACAS interference limiting algorithms as well as the concept of Hybrid Surveillance. Several scenarios had been developed and a total of 14 simulations were performed to analyse the following aspects:

a) impact of ACAS on MSSR/Mode S surveillance performance if ACAS implements the modified interference limiting algorithm;

b) ACAS surveillance performance if ACAS implements the modified interference limiting algorithm;

c) impact of ACAS on MSSR/Mode S surveillance performance if ACAS implements Hybrid Surveillance techniques;

d) ACAS surveillance performance if ACAS implements Hybrid Surveillance techniques; and

e) clustering of ACAS-equipped aircraft on ground-based and airborne surveillance performance.

8.2.2.1.1 For validation purposes a second study with selected scenarios and simulation runs was conducted afterwards. Even with some differences in several of their absolute values, which can be related to the different characteristics and assumptions that had been used within the two simulation tools, the latter results showed the same trends as the original results.

8.2.2.2 *Impact of ACAS on MSSR/Mode S performance*

Since ACAS is using the SSR frequencies, ACAS interrogations and replies may cause additional impacts upon the SSR air traffic control system. On the downlink, replies generated in response to ACAS interrogations may interfere with replies caused by SSR interrogators. On the uplink, two interference mechanisms have to be distinguished. Firstly, a transponder on-board an ACAS-equipped aircraft is suppressed during each own ACAS interrogation. Secondly, a transponder may be taken off the air by processing interrogations originating from other ACAS aircraft. In order to limit the impact of ACAS on the SSR system, ACAS units are obliged to control their interrogation rates and transmitter power by the application of an interference limiting procedure (ILP). To explore the effects of the ACAS surveillance and interference limiting concept on MSSR/Mode S system performance under various conditions, a number of scenarios were analysed in detail as shown in Table 8-1.

Table 8-1. Simulation scenario definition

Scenario	*Percentage of*						
	MS-I	*MAC-I*	*ACAS-I*	*MS-T*	*MAC-T*	*MKXII-T*	*MKXIIMS-T*
A01	0 %	100 %	90 %	50 %	50 %	28 %	72 %
A02	24 %	76 %	90 %	50 %	50 %	28 %	72 %
A03	24 %	76 %	50 %	90 %	10 %	28 %	72 %
A04	100 %	0 %	50 %	90 %	10 %	28 %	72 %
A05	24 %	76 %	75 %	90 %	10 %	28 %	72 %
A06	24 %	76 %	75 %	100 %	0 %	0 %	100 %
A07	100 %	0 %	50 %	100 %	0 %	28 %	72 %
A08	24 %	76 %	75 %	100 %	0 %	0 %	100 %
A09	100 %	0 %	75 %	100 %	0 %	0 %	100 %

MS-I: civil ground stations equipped with a MSSR/Mode S interrogator;
MAC-I: civil ground stations equipped with a MSSR/Mode A/C interrogator;
ACAS-I: civil Mode S transponder-equipped aircraft with an ACAS interrogator;
MS-T: civil aircraft equipped with a Mode S transponder;
MAC-T: civil aircraft equipped with a Mode A/C transponder;
MKXIIMS-T: military aircraft equipped with a Mode S capable transponder;
MKXII-T: military aircraft equipped with a non-Mode S capable transponder.

From the investigations performed, the following conclusions could be drawn:

a) the ACAS interference limiting algorithm meets the 2 per cent limit in all scenarios analysed. In all scenarios analysed, Mode A/C decode efficiency is about 5 per cent below Mode S decode efficiency. Synchronous garbling is the main reason for the loss of Mode A/C replies. In all scenarios analysed, the Mode S detection is 100 per cent, an effect that can be explained by the fact that Mode S avoids synchronous garbling by means of interrogation scheduling and, furthermore, in case of failure, the re-interrogation function can be invoked. Although reply efficiency and decode efficiency show some variations for the scenarios analysed, these variations are nearly not reflected in code and Mode S detection. This can be explained by the fact that the failure of a single interrogation/reply interaction can be compensated in case of Code A/C detection by the transmission of more than required interrogations during an antenna dwell and in case of Mode S detection by the re-interrogation function;

b) the order in which the ACAS interference limiting algorithms are applied warrants further investigation as it seems this may have a significant impact on the nature of any power reductions that are applied to an ACAS unit;

c) a transition from a mixed MSSR/Mode S interrogator environment to a full Mode S interrogator environment will reduce interrogator receiver utilization by about 10 per cent relative to a mixed MSSR/Mode S interrogator environment. Mode S decode efficiency is 2-3 per cent lower in a scenario with an equally shared Mode A/C and Mode S transponder environment than in the other scenarios analysed. Therefore the implementation of a Mode S ground infrastructure, especially within a high-density terminal control area (TMA), would be beneficial. A transition from an equally shared Mode A/C and Mode S transponder environment to a predominated Mode S transponder environment will reduce interrogator receiver utilization by about 40 per cent relative to an equally shared Mode A/C and Mode S transponder environment. In a predominated Mode S transponder environment and in a full Mode S transponder environment, the ACAS contribution to the overall transponder utilization accounts for about 30-40 per cent;

d) the overall transponder utilization is increased at least by a factor of two if military interrogators are taken into account. If military interrogators are taken into consideration, interrogator receiver utilization will be more than doubled. The activity of military interrogators can reduce decode efficiency by 2-3 per cent. However, it should be noted that the Mode S re-interrogation rate is slightly increased; and

e) it should also be noted that the simulations were performed with all involved interrogators using monopulse SSR techniques; the use of sliding-window techniques would have further significant (negative) effects on the above results.

8.2.2.3 *ACAS surveillance performance*

8.2.2.3.1 Concerning ACAS surveillance performance, it is postulated that ACAS is capable of operating in most air traffic densities without any significant performance degradation. Although ACAS is able to operate up to a range of 30 NM, the required nominal surveillance range of ACAS is 14 NM. However, when operating in high density, the interference limiting function may reduce system range to approximately 5 NM, which is still adequate to provide sufficient surveillance performance in the TMA. Furthermore, it is required that a track be established with a probability of at least 90 per cent for aircraft within the surveillance range.

8.2.2.3.2 In order to explore the performance of ACAS surveillance under various conditions, the same scenarios were considered as analysed to determine MSSR/Mode S system performance. From the results achieved, the following conclusion could be drawn:

a) the current solution for ACAS implementation offers a valid compromise between Interference Limiting and System Surveillance Performance. ACAS interrogators deployed in close proximity to Frankfurt airport typically suffer more than twice the FRUIT seen by interrogators at greater distances. As such, they would typically be required to reduce Mode C power and Mode S power by 10 dB and 13 dB, respectively (the maximum allowable reductions as per 3.7.3.7.6). An increase of the number of ACAS interrogators from 50 per cent to 75 per cent in a full Mode S transponder and interrogator environment will raise the interrogator receiver utilization by not more than 10 per cent (relative to the 50 per cent ACAS deployment);

b) in an equally shared Mode A/C and Mode S transponder environment, more than half of the interrogator receiver utilization is caused by ACAS at interrogators deployed close to the airport. At greater distances, the ACAS contribution is approximately 20 per cent. The Mode C round-trip reliability can be quite low. Thereby, synchronous garbling is the driving factor. A transition from an equally shared Mode A/C and Mode S transponder environment to a predominated Mode S transponder environment will decrease the Mode C power reduction. Concurrently, the Mode S power reduction is raised. Mode A/C surveillance can significantly be improved due to the reduction of garbling. In a predominated Mode S transponder environment and in a full Mode S transponder environment, the ACAS portion of the overall interrogator receiver utilization accounts for about 20-30 per cent; and

c) a transition from autonomous-operated Mode S stations to an operation in clusters within a mixed MSSR/Mode S interrogator environment will reduce interrogator receiver utilization by about 10 per cent (relative to the autonomous scenario).

8.2.2.4 *ACAS Hybrid Surveillance*

8.2.2.4.1 Mode S transponders generate an unsolicited reply in the Mode S downlink format DF11 once per second known as "Mode S squitter". The squitter contains the unique Mode S address of the aircraft and is utilized by ACAS interrogators for the acquisition of Mode S transponders. For the future, an expansion of the squitter technique is intended by introducing so called Mode S Extended Squitters. Mode S Extended Squitters shall be used to broadcast aircraft-derived data to airborne and ground users. The introduction of Mode S Extended Squitter provides further means to reduce ACAS interrogation rates by a new ACAS surveillance technique termed ACAS Hybrid Surveillance (See Section 3.16). The purpose of ACAS Hybrid Surveillance is to incorporate passively received data transferred via Mode S Extended Squitter while at the same time maintaining the independence of ACAS as an active surveillance system. In order to explore the effects of ACAS Hybrid Surveillance on MSSR/Mode S system performance, various scenarios, as shown in Table 8-2, were analysed in detail.

8.2.2.4.2 From the results achieved the following conclusion could be drawn:

a) neither set of modeling shows any clear benefit in terms of RF impact of introducing Hybrid Surveillance and a reduction in the levels of Mode A/C FRUIT is in the near term a more important factor in improving the RF environment. In the environment simulated, ACAS Hybrid Surveillance affects the performance of ground interrogators only slightly. However, in increasing traffic densities (especially in high-density TMAs) the ground environment will benefit in the future from the lower interference levels; and

b) the application of ACAS Hybrid Surveillance will stabilize the surveillance range of ACAS-equipped aircraft making it, to some extent, independent of most aircraft densities. In particular, in the vicinity of major airports, power and surveillance range reduction will become effective later compared with normal ACAS operation.

Table 8-2. Hybrid surveillance scenarios

Scenario	*Percentage of*							
	MS-I	*MAC-I*	*ACAS-I*	*ACAS-HS*	*MS-T*	*MAC-T*	*MKXII-T*	*MKXIIMS-T*
B01	0 %	100 %	100 %	20 %	50 %	50 %	28 %	72 %
B02	24 %	76 %	100 %	20 %	50 %	50 %	28 %	72 %
B03	24 %	76 %	75 %	20 %	90 %	10 %	28 %	72 %
B04	24 %	76 %	75 %	80 %	90 %	10 %	28 %	72 %
B05	100 %	0 %	75 %	80 %	90 %	10 %	28 %	72 %

MS-I: civil ground stations equipped with a MSSR/Mode S interrogator;
MAC-I: civil ground stations equipped with a MSSR/Mode A/C interrogator;
ACAS-I: civil Mode S transponder-equipped aircraft with an ACAS interrogator;
ACAS-HS civil ACAS-equipped aircraft applying Hybrid Surveillance;
MS-T: civil aircraft equipped with a Mode S transponder;
MAC-T: civil aircraft equipped with a Mode A/C transponder;
MKXIIMS-T: military aircraft equipped with a Mode S capable transponder; and
MKXII-T: military aircraft equipped with a non-Mode S capable transponder.

8.2.2.5 *Impact of ACAS clusters on the ATM environment and performance of other ACAS*

8.2.2.5.1 To support safe air traffic operation ACAS has been standardized by ICAO. TCAS is the implementation available today. TCAS systems are divided into TCAS I, which is mainly operated by commuter aircraft, helicopters and general aviation, and TCAS II, which is operated on turbine-powered business aircraft and commercial air transport aircraft. While TCAS I supports “see and avoid” with the capability to generate TAs, TCAS II is also capable of generating RAs against potential threat aircraft. TCAS II (Version 7) is compliant with ICAO ACAS II standards. Regional and global mandates have been published to equip aircraft with ACAS II.

8.2.2.5.2 ACAS/TCAS I is not foreseen to be operated in international airspace. However, industry is advertising products and therefore some of the important aspects were investigated. The goal of the analysis was to explore effects of clustered ACAS/TCAS interrogators in the vicinity of Frankfurt airport upon the MSSR/Mode S, ACAS II and TCAS I surveillance performance. To achieve this goal, three scenarios, denoted by C01, C02 and C03, were analysed in detail. The three scenarios under examination were defined on the basis of scenario A05 described earlier. The three scenarios C01, C02 and C03 defined for the analysis differed from scenario A05 with respect to additional numbers of aircraft equipped with ACAS/TCAS interrogators and Mode S transponders. Beside the interrogators and transponders deployed in scenario A05, the three scenarios under examination included:

a) Scenario C01: 5 additional aircraft deployed in one cluster at Frankfurt/Kreuz (motorway junction), each equipped with an ACAS II interrogator and a Mode S transponder;

b) Scenario C02: 36 additional aircraft (5 at Frankfurt/Kreuz [the same as in scenario C01], 18 clustered at Frankfurt/Waldstadion [stadium], and 13 clustered at

Frankfurt/Messe [fairgrounds]), each equipped with an ACAS II interrogator and a Mode S transponder; and

c) Scenario C03: 36 clustered aircraft (the same as in scenario C02), each equipped with an TCAS I interrogator and a Mode S transponder.

8.2.2.5.2.1 It should be noted that the three scenarios considered in the study included no military interrogators. Furthermore, it should be pointed out that the 12 Mode S interrogators were supposed to be operated as autonomous Mode S sites without any clustering.

8.2.2.5.2.2 Since Frankfurt has been defined as the area of interest, the ASR sites Frankfurt/Süd and Frankfurt/Nord were chosen as Interrogators of Interest (IoI) for the analysis of MSSR/Mode S system performance. Thereby, Frankfurt/Süd, referenced in the scenario database by index 15, was modelled as a MSSR/Mode S station, while Frankfurt/Nord, index 9, was assumed to be operated as a MSSR/Mode A/C interrogator. For the ASR sites Frankfurt/Süd, all transponders within a surveillance range of 100 NM were defined as Transponders of Interest (ToIs). Concerning Frankfurt/Nord, all transponders within a coverage of 60 NM were regarded as ToIs. The selected IoIs along with their ToIs formed the sample of the SSR system, for which the performance had to be explored. It should be noted that, although the transponders within the surveillance range were considered as ToIs only, the signal load was produced by all interrogators and transponders deployed in the scenario.

8.2.2.5.2.3 To investigate the surveillance performance of ACAS II, the aircraft referenced in the scenario database by the indices 1048 and 1049 were chosen as ACAS II IoIs. Thereby, IoI 1048 represented an overflight at an altitude of 15 000 ft and at a distance of 6.3 NM from the SSR site Frankfurt/Süd. IoI 1049, at a height of 5 000 ft and a distance of 5.2 NM, was regarded as an approach for landing at Frankfurt airport.

8.2.2.5.2.4 For the analysis of TCAS I surveillance performance, the aircraft with the index 1014 was selected as IoI. IoI 1014 is one of the 5 aircraft at Frankfurt/Kreuz added to the scenario.

8.2.2.5.3 *Effects of ACAS clustering on ground performance*

8.2.2.5.3.1 Due to the equal ground environment, Mode A/C interrogation rates, Mode A/C-only rates, and the UF11 rates induced by ground interrogators are the same for all scenarios analysed. The UF4 and UF5 rates are slightly increased due to higher numbers of Mode S-equipped aircraft. The number of interrogations generated by airborne interrogators depends on the number of aircraft in the vicinity, but are raised by a factor of three to eight if aircraft in clusters are taken into account.

8.2.2.5.3.2 In all cases, the highest transponder utilization is achieved in close proximity to the airport. In “normal” scenarios, the overall transponder utilization is well below 2 per cent. For the Frankfurt simulation, a small cluster of 5 additional ACAS increases transponder utilization up to the 2 per cent limit. Further, 31 ACAS II units in 2 clusters raise the maximum transponder utilization induced by ACAS II to 7.7 per cent, contributing with more than 70 per cent to the peak overall transponder utilization. In that case, the 2 per cent criterion is not satisfied by almost all transponders within a range of 8 NM to the airport. Substituting the 36 ACAS II units by TCAS I interrogators reduces the maximum ACAS transponder utilization. However, the limits are still violated by a remarkable number of transponders within 5.5 NM to the airport suffering a utilization by ACAS of significantly more than 2 per cent.

8.2.2.5.3.3 The decrease in transponder reply efficiency seems to some extent to be proportional to the number of aircraft in a cluster (5, 13, 18), since the worst case degradation varies between 7 per cent and 16 per cent.

8.2.2.5.3.4 Although the Mode A/C interrogation rates remain the same, the Mode A/C FRUIT rates are increased with the density of aircraft. This is induced by replies of the additional transponders. The Mode A/C FRUIT rate is further increased when the additional ACAS II units are replaced by TCAS I interrogators due to a higher reply efficiency. The Mode C-only rates and the DF0 rates induced by ACAS II increase when the ACAS II density rises. A tremendous increase of the DF0 rates is predicted if three clusters with a total of 36 additional ACAS II units are taken into consideration, which reflects the significant increase of UF0 interrogation rates. If TCAS I equipage is assumed for the 36 additional aircraft, Mode C-only and UF0 FRUIT is considerably reduced, but a very huge rate of extra Mode C FRUIT is achieved. In both scenarios, the relevant amount of FRUIT (DF0 resp. Mode C) induced by the 36 additional units deployed in 3 clusters is increased by a factor of about 15.

8.2.2.5.3.5 The interrogator receiver utilization caused by ground stations, and as a consequence decode efficiency, are only slightly affected by the scenario variations analysed. The moderate increase of receiver utilization obtained is due to replies of the transponders added and slightly raises re-interrogation rates of the Mode S stations. Five additional ACAS II units clustered in close vicinity of Frankfurt airport increase the interrogator receiver utilization slightly, but 36 ACAS II units increase interrogator receiver utilization significantly. In this case, the utilization caused by ACAS II is raised by a factor of more than six. This results in a decode efficiency reduction of 3 per cent for Frankfurt/Süd and even 11 per cent for Frankfurt/Nord. The considerable reduction at the IoI Frankfurt/Nord is mainly caused by the additional aircraft which are deployed in three clusters resulting in a large number of garbling situations. As expected, the decoding of Mode S replies is less affected.

8.2.2.5.3.6 Furthermore, interrogator receiver utilization caused by airborne systems is nearly doubled if those additional 36 interrogators are fitted with TCAS I (instead of ACAS II). Despite that, the Mode A/C decode efficiency is slightly improved, while the Mode S decode efficiency is reduced to nearly the same amount.

8.2.2.5.3.7 There is only a slight impact on the success of a single interrogation/reply interaction performed by the two IoIs, if the 5 ACAS II interrogators deployed at Frankfurt/Kreuz are taken into account. Especially at IoI Frankfurt/Nord, round-trip reliability for Mode A/C interactions is reduced considerably, with the 36 additional airborne units.

8.2.2.5.3.8 In case of 36 clustered ACAS II units, Code A/C detection is significantly decreased at an MSSR sensor in particular. The mean values are reduced by 11 per cent for Mode A and by 12 per cent for Mode C. The decrease is mainly caused by the transponders deployed in the clusters causing a lot of garbled replies. Some of these transponders cannot be acquired by the MSSR sensor (Code Detection < 20 per cent). Equipping the additional aircraft with TCAS I units does not change the situation.

8.2.2.5.3.9 On the contrary, in all cases Mode S detection probability varies only slightly and achieves 100 per cent for more than 88 per cent of the ToIs. The minimum detection probability obtained among the remaining ToIs drops to 95 per cent in the worst case.

8.2.2.5.4 *Airborne clusters and ACAS II surveillance performance*

8.2.2.5.4.1 ACAS interrogators on the surface at Frankfurt airport would typically need to reduce Mode C power and Mode S power by 10 dB and 13 dB, respectively (maximum allowable reductions as per 3.7.3.7.6). If the 5 ACAS II units at Frankfurt/Kreuz are taken into consideration, power reduction is only slightly increased for other ACAS II interrogators. The Mode C power reduction is between 7-8 dB within a range of 18 NM to the SSR site Frankfurt/Süd. Mode S power has to be reduced by most of the ACAS units deployed within 13 NM of Frankfurt/Süd by more than 7 dB. Adding the set of 36 ACAS II units, the surveillance range of ACAS II interrogators within a range of 30 NM and 20 NM, respectively, is affected to the same amount.

8.2.2.5.4.2 When the ACAS II interrogators on board of those 36 aircraft are replaced by TCAS I units, the remaining ACAS II interrogators in the Frankfurt area are allowed to transmit surveillance interrogations at slightly higher power again, reaching the values mentioned above.

8.2.2.5.4.3 Although Mode A/C interrogation rates are the same in all scenarios, the Mode A/C FRUIT rates are decreased when the 36 ACAS II interrogators are taken into account. This is due to two contrary effects. On one hand, the transponders added are producing extra FRUIT. On the other hand, the reply efficiency is significantly decreased which results in a reduction of reply rates. This effect overbalances the first one.

8.2.2.5.4.4 If the clustered 36 ACAS II units are replaced by TCAS I interrogators, reply efficiency is improved inducing much higher Mode A/C FRUIT rates. The significant variation of interrogator receiver utilization for the three scenarios analysed is mainly caused by ACAS, the contribution of ground stations varies only weakly. Interrogator receiver utilization is nearly doubled if the additional 36 clustered ACAS II units are taken into account. Converting these units to TCAS I interrogators, receiver utilization at the two ACAS II IoIs analysed is further raised.

8.2.2.5.4.5 At ACAS II IoI 1048, decode efficiency for Mode C-only replies is only weakly affected by the scenario variations. But decode efficiency for Mode S replies is considerably reduced in the TCAS I scenario. This is a consequence of the huge Mode C FRUIT rates resulting in high interrogator receiver utilization. Nevertheless, this IoI is an example which shows that the altitude and range filter improve ACAS surveillance performance while passing high-density airports. However, the round-trip reliability for the ToIs under surveillance (only two) is significantly decreased by the activity by clustered aircraft, since both ToIs are suffering a quite high signal load. This considerably reduces the ability of the transponders to reply to interrogations of the ACAS II IoI 1048.

8.2.2.5.4.6 On the other hand, IoI 1049 decode efficiency is significantly decreased if clustered ACAS II interrogators are detected in the vicinity. Round-trip reliability for the three Mode A/C ToIs under surveillance in particular is considerably reduced. Replacing the 36 clustered ACAS II interrogators by TCAS I units improves decoding of Mode C replies while Mode S decoding is further reduced, as already noticed for ground-based sensors. In general, the variation of the probabilities for achieving at least one successful interrogation/reply interaction during a one-second surveillance interval reflects the variation of the round-trip reliability.

8.2.2.5.4.7 Concerning Mode S surveillance performance of the IoI 1049, round-trip reliability for Mode S transactions is reduced by the activity of the clustered ACAS II units. The mean value, calculated across the 24 ToIs, is decreased from 90 per cent to 84 per cent. Round-trip reliability is significantly further decreased when the 36 ACAS II interrogators are substituted by TCAS I units. The average across all 55 ToIs is reduced down to 61 per cent. Thereby, especially the round-trip reliability for the ToIs deployed in the clusters is significantly affected. Primarily, the reason for the reduction is the drop of decode efficiency to 79 per cent caused by the huge Mode C FRUIT produced in response to TCAS I interrogations. But the loading at the transponders under surveillance of IoI 1049 is increased above average as well and, as a consequence, reply efficiency for the interrogations of IoI 1049 is also significantly decreased to 73 per cent.

8.2.2.5.5 *TCAS I clusters and surveillance performance in high-density airspace*

8.2.2.5.5.1 All TCAS I interrogators have to reduce transmitter output power by 15 dB relative to the peak power. The power reduction of the TCAS I units results in a surveillance range of 4.7 NM in the forward sector, 3 NM in the right and left sector, and 1.9 NM in the aft sector. For Mode A/C transponders with lower sensitivity, the surveillance range is further reduced to 3.3 NM in the forward beam, 2.1 NM in the right and left beam, and 1.3 NM in the aft beam.

8.2.2.5.5.2 On average, each ToI was able to reply to 90 per cent of the interrogations of interest. However, since the majority of replies were garbled, the IoI was able to correctly decode only 4.7 per cent of the signals received.

8.2.2.5.5.3 A round-trip reliability of 50 per cent was obtained only for one ToI, located at a range of 4.3 NM. Two ToIs, very close to the IoI, achieved a round-trip reliability of about 40 per cent and the probability of successfully completing a single interrogation/reply transaction was below 20 per cent for the remaining targets.

8.2.2.5.5.4 However, the probability of correctly decoding at least one valid reply during a one-second surveillance interval is above 50 per cent for 10 per cent of ToIs. For about 31 per cent of the ToIs the probability is equal to zero, which means that these ToIs are never seen by the TCAS I interrogator. For the remaining 20 per cent or so of ToIs, the probability is somewhere between 0.2 per cent and 30 per cent. Therefore, a probability of 0.2 per cent can be interpreted such that the IoI gets an altitude information of the target only every 500 s in average. A probability of 30 per cent means an update every three seconds.

Chapter 9

ACAS PERFORMANCE MONITORING

9.1 NEED FOR ACAS MONITORING PROGRAMMES

9.1.1 Operational evaluations conducted worldwide to identify operational and technical issues have been extremely valuable in the development and updating of ACAS provisions.

9.1.2 These operational evaluations have also contributed to the improvement of ACAS II equipment. When modifications have been made to the ACAS II logic, or ACAS II has been introduced into new types of airspace, or changes have been made to airspace configuration and operation, some operational issues have been identified and resolved. Therefore, it is prudent to continue monitoring the operational performance of ACAS and to retain the expertise and tools to analyse any questionable circumstances that may be observed and, if required, to develop solutions.

9.1.3 Monitoring via controller reports is typically mandated by a State, e.g. based on an AIC. Aviation authorities may place requirements on operators for pilot-reporting of ACAS encounters. Data provision from Mode S, ACAS recordings and other means is on a voluntary basis.

9.1.4 In the longer term ACAS monitoring can become part of overall safety monitoring regulations. Harmonized procedures are developed for reporting all incident types, including ACAS. In particular, ACAS analysis should become a normal part of Airprox analysis, and statistics about ACAS during Airproxes can be fed into ACAS monitoring. Whenever a standard set of tools is available for safety monitoring, ACAS monitoring tools should be included. This approach is supported in Europe.

9.2 MONITORING PROGRAMME OBJECTIVES

The ACAS monitoring programmes of States should have the following key objectives:

a) continuing the validation of the safety benefits and operational acceptability of ACAS;

b) assessing the impact of ACAS, airspace, and ATC procedure modifications on collision avoidance system performance and the identification of any new issues;

c) ensuring sufficient surveillance performance exists for both ACAS and ATC purposes;

d) identifying pilot/controller training issues;

e) assessing the operational and technical performance of ACAS in a current and future ATM environment; and

f) maintaining an adequate level of expertise in the areas of ACAS significant event analysis and problem resolution.

9.3 DESCRIPTION OF CURRENT MONITORING PROGRAMMES DATA SOURCES

9.3.1 Many States and organizations have conducted ACAS monitoring programmes for a number of years. These existing programmes have identified multiple sources of data that can be used to effectively monitor and assess the performance of ACAS. These data sources are discussed in the following sections.

9.3.2 *Pilot and controller reports*. Whenever pilots and controllers observe an RA or a significant ACAS event, they should be able to submit an ACAS event form of the type shown in Appendices 1 and 2, respectively. Copies should be sent to a central collection and analysis centre, e.g. an ICAO-identified Regional Evaluation Centre. Optionally, these reports may also be analysed locally. The use of pilot and controller reports has been demonstrated to be an effective means of obtaining data related to the operation and performance of ACAS II.

9.3.3 *Observer reports*. The use of observer reports has also been demonstrated to be an effective means of complementing the data obtained from pilot and controller reports.

9.3.4 *ACAS surveys*. When data are required on a particular subject, a survey may be conducted. This is most valuable when standard pilot or controller reports do not capture the data or opinions. Where written ACAS surveys are utilized, their effectiveness is increased if short, pointed questions are used.

9.3.5 *Airborne recorded data*. ACAS manufacturers have provided dedicated recorders to some States for airborne use with their equipment. Among other parameters, these devices record the position of other aircraft and the status of the ACAS system during an RA or a TA. The use of data recorders has been demonstrated as an effective means of obtaining reliable, factual information that allows unbiased performance analysis of ACAS surveillance and logic. Onboard quick access flight recorders and optional ACAS internal recorders may also provide data about ACAS events. Equipment manufacturers have incorporated an internal data recording capability into their ACAS hardware.

9.3.6 *Mode S RA downlink*. Mode S ground stations can obtain RA downlink messages from aircraft. This provides objective information about the nature of the RA, ACAS equipage, and the intruder’s position or identification. These types of data can be used to identify problems with ACAS operation, to identify geographic areas where ACAS operations are impacting ATC operations, and to identify geographic areas where ATC operations and procedures adversely affect ACAS performance.

9.3.7 *RF environment recorders*. Specialized omnidirectional receivers exist that record all 1 030 MHz and 1 090 MHz signals. These can be used to detect RAs, to verify air-to-air ACAS messages, and to assess electromagnetic interference.

9.3.8 *ATC radar data*. Any of the data sources described above may show that an ACAS RA has occurred. In these cases, it is often useful to obtain ATC radar data associated with the event. This can be used to replay and simulate the event for better understanding, even in cases where the RA information was not captured via the RA downlink. ATC radar data have been shown to be important in assessing the performance of ACAS II and in assessing any impacts of an RA on ATC operations.

9.3.9 *Flight plans*. The flight plans for the aircraft involved in an RA may also help investigations, especially when used in conjunction with the radar data for a specific event.

9.3.10 *ATC/pilot voice communication tapes*. Pilot and controller voice communication tapes can provide additional information regarding the event. These data have been very important in the analyses of certain RAs.

9.4 METHODS OF DATA ANALYSIS

9.4.1 Existing monitoring programmes have developed and validated a number of effective methods for analysing the aforementioned data. The following sections outline these analysis techniques.

9.4.2 *ACAS logic-based simulations*. There are several software tools available that take radar data and allow the replay of an event. They can also simulate standard responses by pilots. For a single event this is invaluable for operational understanding and also for validation of the ACAS logic. Several simulations have been developed that allow the positions of the aircraft involved in the event to be altered slightly so that multiple variations of the same event can be analysed. By combining the results of many such events, statistics about ACAS performance and pilot responses can be obtained.

9.4.3 *Database analysis*. Data obtained from pilots, controllers, observers, recorders and other sources are often put into a database to facilitate analyses of the data. This may be supplemented by manual assessment of the issues involved with each event. These data are then used for highlighting issues of concern and completing statistical evaluation of ACAS performance.

9.4.4 *ACAS performance simulations and flight trials*. Simulation models are available for analyses of recorded data. These evaluations may discover problem areas that require further evaluation and possible flight trials.

9.4.5 *ACAS RF compliance and interference measurements*. Measurements are first made to estimate parameters in electromagnetic environment models. Further measurements are made to validate these environmental models and ensure that electromagnetic interference is suitably limited.

9.5 PRODUCTS OF MONITORING AND ANALYSES PROGRAMMES

9.5.1 The results of analyses conducted by monitoring programmes need to be shared between States, the States' regulatory authorities, and other monitoring programmes. This sharing of information is most effective when there is some consistency in the types of reports produced by the monitoring and analyses programmes. The following two types of reports are produced by numerous States' monitoring activities and have been found to be valuable.

9.5.1.1 *Statistical reports of ACAS performance*. In the past, several States have produced reports which were based on the data collected via their monitoring programmes. These reports provided key information that allowed for the identification and resolution of technical and operational problems.

9.5.1.2 *Event reports*. When pilots or controllers report an RA, further data are often collected. All data are then analysed and a report on the event is created. This gives feedback to operational staff, operators, civil aviation authorities and ATC authorities about incidents they have experienced.

9.5.2 Existing monitoring programmes have used these initial analyses to develop more detailed analyses of identified problems and issues. These analyses have resulted in the following types of reports or actions being completed. State regulatory authorities and air traffic service providers often use these reports to implement mandatory changes to procedures, regulations, and in some rare cases, to the ACAS logic:

- Procedural changes (ATC and aircraft) to alleviate difficulties with ACAS noted in operational reports.

- ACAS performance reports, noting difficulties with the logic, surveillance, displays or any other part of the ACAS system.

- Reports on the ACAS surveillance performance in the SSR environment and reports on impacts of ACAS operation on the existing SSR environment.

- Technical non-compliance reports. Sometimes analysis will detect technical faults in aircraft, e.g. faulty transponders. The reports are sent to the operator concerned and the appropriate regulatory authority.

- Training issues. The overall effectiveness of ACAS depends heavily upon pilots and controllers correctly following their procedures during an RA. As the result of analysis, particularly when procedures are not well followed, training topics for pilots and controllers are identified.

9.6 HARMONIZATION OF MONITORING DATA

9.6.1 For monitoring programmes to achieve their maximum potential for monitoring and evaluating ACAS performance, they must be harmonized to allow for the comparison of the data collected by the various States in a number of different airspaces. Past experience in monitoring the performance of ACAS II has shown that it is highly desirable for States to share the results of data collected in these programmes. It is expected that monitoring ACAS performance will result in the desire or necessity to share similar information as the use of ACAS becomes more widespread. In order to compare the results in a meaningful manner, it is recommended that States follow the standards defined in the following sections.

9.6.1.1 *Pilot Report Form*. Appendix 3 contains the recommended list of items to be included on the Pilot Report Form. This form, along with the ATC Report form, provide the basis for identifying ACAS issues, frequency of occurrences, and amplifying information relating to an ACAS event. Appendix 1 is a sample Pilot Report Form.

9.6.1.2 *ATC Report Form*. Appendix 4 contains the recommended list of items to be included in the ATC Report Form. This form, along with the Pilot Report form, provide the basis for identifying ACAS issues, frequency of occurrences, and amplifying information relating to an ACAS event. Appendix 2 is a sample ATC Report Form.

9.6.1.3 *ACAS recorders*. ACAS recorders have been valuable in the past when addressing technical issues related to ACAS performance. Appendix 5 contains the recommended minimum list of data to be provided by dedicated ACAS recorders. All known ACAS recorders support the recording of the data shown in this list.

9.6.1.4 *Definitions for ACAS monitoring programmes*. To allow a meaningful exchange of the results of monitoring programmes, it is highly desirable to use standard definitions and terms in the description of the events examined by the programmes. This recommended list is contained in Appendix 6.

9.7 RECOMMENDED ACAS PROBLEM REVIEW PROCESS

9.7.1 Step 1 — Collection of data and analysis at State level. This process has been described in the previous sections of this chapter.

9.7.2 Step 2 — Identification of significant trends and events for potential international discussion. National analyses will identify problems that may be relevant for other States, or where more information or assistance is required from other States to assess their significance. Two types of data will identify these problems:

- Statistical data will show trends of known issues.

- Individual events will identify new problems.

9.7.3 Step 3 — Exchange of data and discussion of specific problems at an international level. When issues of international importance are known, data will be exchanged internationally and the problems discussed through the appropriate ICAO fora. Individual contacts between States' experts outside of these fora will be necessary, especially when urgent action is required.

9.7.4 Step 4 — Dissemination of information about international problems to all relevant authorities. The experts from the appropriate ICAO fora will inform their States' authorities and other relevant organizations about problems found and resolutions proposed. This information will also be disseminated to all Contracting States through ICAO.

Chapter 10

ACAS-RELATED TRANSPONDER PERFORMANCE MONITORING

10.1 NEED FOR TRANSPONDER MONITORING PROGRAMMES

10.1.1 The ACAS operational evaluations described in Chapter 9 have also identified many issues related to transponder design, implementation, installation and use that have caused anomalous ACAS performance. The interaction between ACAS and transponders is critical. Therefore, any ACAS monitoring programme should include provisions for: (1) monitoring the performance of Mode S and Mode A/C transponders; and (2) ensuring that periodic testing of transponders and their installation, and appropriate calibration are conducted.

10.1.2 Improper transponder performance can significantly reduce, and in some cases totally eliminate, the safety benefits provided by ACAS.

10.1.3 Some examples for transponder malfunctions and their impact on ACAS are provided in the following sections. These sections describe transponder issues that have been detected during ACAS monitoring programmes, and where appropriate, describe the corrective actions taken to resolve the identified problems.

10.2 TRANSPONDER ISSUES AND THEIR IMPACT ON ACAS

10.2.1 Incorrect reporting of on-ground and airborne status

10.2.1.1 Some aircraft report being airborne when on the ground; other aircraft report being on the ground when airborne. The transponder receives this indication from an air/ground discrete input. Such occurrences may be constant or intermittent. An intermittent indication may occur when airborne, and a temporary power interrupt causes the transponder to recycle and come up for one second in the default on-the-ground state.

10.2.1.2 ACAS will not track aircraft that indicate they are on the ground. Thus, if an airborne aircraft is indicating that it is on the ground, it will be invisible to ACAS. An aircraft that is on the ground and indicating it is airborne will be tracked by ACAS, but may not been seen by ATC. This can result in issuance of unnecessary TAs and RAs and the inability of the flight crew or ATC to identify the aircraft causing the TA or RA.

10.2.1.3 Some examples for transponder malfunctions and their impact on ACAS are provided in the following sections.

10.2.2 Aircraft invisible to ACAS

10.2.2.1 *Terra TRT-250 Transponder*. When these Mode A/C transponders are interrogated by an ACAS Mode C-Only All-Call, which contains P1, P3 and P4 pulses, the transponder ignores the P1 and P3 combination and processes the P3 and P4 pulses as a suppression pair. This prevents the transponder from replying to the ACAS interrogations, and thus aircraft equipped with this type of transponder are invisible to ACAS and to some Mode S ground stations. An Airworthiness Directive (AD 95-01-01) was issued by the FAA, with an effective date of 6 February 1995, to require modification to the transponder to eliminate this problem. This AD required that all TRT-250 transponders be modified no later than 6 August 1995.

10.2.2.2 *Narco AT-150 Transponder*. This transponder exhibits the same characteristics as the Terra TRT-250 transponder. Improper processing of the P4 pulse results in this transponder failing to respond to Mode C interrogations from Mode S interrogators and ACAS. Narco issued a Service Bulletin to correct the problem, and the FAA issued an Airworthiness Directive (2004-08-16) to require the modification of these transponders. Modification of affected transponders was required to be completed by 1 December 2004.

10.2.3 Altitude resolution switching between 100 ft and 25 ft

Collected data have shown instances where the altitude resolution of the reported altitude has changed between 100 and 25 ft. The causes of these changes are unknown. Such changes can result in erratic tracking of altitude and altitude rates, leading to inappropriate TAs and RAs.

10.2.4 Aircraft indicating 25 ft altitude resolution while reporting with 100 ft resolution

Rockwell Collins Mode S transponders TDR-94 (Collins Part Number 622-9352-004) and TDR-94D (Collins Part Number 622-9210-004), when connected to Gillham altitude encoders, will incorrectly set the altitude resolution status to indicate 25 ft resolution. *Note: All Gillham altitude encoders provide data with 100 ft resolution*. The reported altitude is correct at all times, but ACAS is expecting inputs of 25 ft because the 25-ft resolution bit is set. This results in erratic tracking of altitude and altitude rates, leading to inappropriate TAs and RAs. The FAA issued AD 2002-06-06 with an effective date of 3 May 2002. Because this AD required modifications to be made by 3 February 2003, all affected transponders should have been repaired.

10.2.5 Incorrect Mode S addresses

10.2.5.1 Aircraft equipped with a Mode S transponder are required to have a unique address that complies with ICAO Annex 10, Volume III, Part I, Chapter 9. In some cases, aircraft have been observed with an address that includes all zeros or all ones. ACAS will not track aircraft equipped with these illegal addresses.

10.2.5.2 Cases have also been detected where the same Mode S address is seen on multiple aircraft. ACAS will not correctly track multiple aircraft with the same Mode S address that are operating in the same geographic area.

10.2.6 Incorrect downlinking of RA information

10.2.6.1 Whenever an RA is issued, ACAS sends details of the RA to the transponder. This information is updated once per second. The RA information should be maintained in the transponder for a period of 18 seconds after the RA is terminated so the information can be transmitted to the ground if requested. The following types of problems have been observed.

10.2.6.1.1 *Horizontal RAs*. RA information is buffered in ACAS prior to being sent to the transponder. Interrupt problems may cause this information to be corrupted. The corrupted information may be interpreted by the ground as horizontal RAs. These are invalid because ACAS II does not issue horizontal RAs.

10.2.6.1.2 *Failure to retain RA information*. The RA information was not retained for the required 18-second period after the clear of conflict.

10.2.6.1.3 *All zero RA reports*. The downlinked RA reports do not contain any information.

10.2.6.1.4 Failure to clear Aircraft Resolution Advisory (ARA) and Resolution Advisory Complement (RAC) fields in the downlinked RA reports.

10.2.6.1.5 *Downlink Request (DR) TCAS Information Not Indicated*. Comm-B formats DF=4, 5, 20 and 21 contain a 5-bit downlink field that indicates to a ground site that information is available for transmission to the ground. Failure to set the TCAS bit (DR=2) in a Version 7 transponder results in the ground not knowing the information is available and therefore does not request the transmission of the data to the ground.

10.2.6.1.6 *Corrupted Intruder Altitude in RA Report*. The altitude data for a Mode A/C intruder is corrupted in the RA report generated by one manufacturer's Version 7 transponder.

10.2.6.2 These incorrect RA downlink reports do not affect the operation of ACAS. However, these errors will affect the safety of any operational systems that show downlinked RAs to controllers. They are also likely to confuse ACAS monitoring programmes.

10.2.7 Mode S address change in transponder

10.2.7.1 Civil aircraft equipped with a Mode S transponder are required to have a unique, fixed address that complies with ICAO Annex 10, Volume III, Part I, Chapter 9. In some cases, an aircraft's Mode S address has been observed to change in flight. This may cause tracking problems within ACAS. Such tracking problems may result in an improper RA being issued.

10.2.7.2 One cause of this problem has been identified as a loose pin connection at the transponder. It is essential that periodic transponder inspections and maintenance requirements include provisions for checking wiring and other mechanical installation provisions for degradation.

10.2.7.3 According to current requirements, a civil transponder should read the Mode S address at power-up and then disregard any subsequent changes in the address.

10.2.7.4 Some military transponders are capable of changing Mode S address for operational purposes while in flight.

10.2.8 ACAS failure to track aircraft with Mode S transponders squittering a capability code of seven (7)

A Mode S transponder squitter contains a 3-bit capability (CA) downlink field used in DF11, the All-Call reply and acquisition squitter. An interface problem involving one manufacturer's ACAS and another's transponder, resulted in a failure of ACAS to track aircraft. The transponder was transmitting a CA=7. Squitters were being rejected by the TCAS due to the CA=7, and tracks were not established. When ground interrogators interrogated the transponder with a UF4, 5, 20 or 21, the CA code would change to another value and would be tracked. This problem has been fixed by the manufacturers.

10.2.9 Incorrect Parity/Interrogator (PI) code

10.2.9.1 A Mode S Only All Call interrogation (UF 11) transmits an Interrogation Identification (II) code that is a unique code for a given airspace. The transponder is expected to return that same code, in the form of the Parity/Interrogator (PI) code. If the transponder responds with a different code in the PI field than what was received in the II field, the reply will be treated as FRUIT by the interrogator and ignored. The failed transponder always sets the PI=0 regardless of what was received in the II field. This results in a Mode S ground sensor being unable to track these transponders.

10.2.9.2 The United Kingdom's CAA issued AD 001-01-2003 that required modification to the Honeywell MST 67A-SW2 transponder. This AD required compliance by 31 March 2003. This directive required elimination of the corrupted PI field in Mode S Format DF-11 so that the unit produces a correct response to a Mode S All Call. In addition to the CAA's AD, France issued CN 2003-036 (AB) and The Netherlands issued BLA 2002-036 shortly afterwards to address the same issue.

10.2.10 Failure to track military transponder

Above 30 800 ft, APX-64 military transponders transmit an Mode A/C reply that contains an additional pulse after the P3 pulse. As a result of this additional pulse, one manufacturer's TCAS II will not initialize track these aircraft. These transponders are known to be installed on some States' military aircraft. The U.S. Air Force published a Technical Order (TO) containing a fix for this problem and required implementation of this TO in United States aircraft. Other States were notified of this TO.

10.2.11 Failure to reply to coordination interrogations

A Rockwell Collins TDR-94D (Collins Part Number 622-9210-002) transponder sometimes does not pass received coordination messages to its TCAS. A failed condition is not indicated, and the transponder continues to respond to surveillance interrogations. This condition occurred when the TDR-94D attempted to execute a Mode S Self Test while the message processor was still processing a UF=0 interrogation. The FAA issued AD 93-04-02 with an effective date of 26 March 1993. Compliance with this AD was required by 26 September 1993. This problem could result in an unsafe RA being issued in a coordinated encounter.

10.2.12 Phantom RAs

The following activities can cause TCAS to establish tracks and issue phantom RAs:

a) transponder repair stations located near airports transmitting altitudes during transponder testing without proper shielding;

b) Air Traffic Control facilities using transponders near airports to assist radar calibration. To prevent this problem, information on the operation of position adjustable range reference orientation transponders (PARROTs) and transponder test facilities is provided in the *Manual of Secondary Surveillance Radar (SSR) Systems* (Doc 9684);

c) military aircraft, prior to takeoff, performing transponder checks;

d) military ships operating transponders when docked or underway and close to shore;

e) transponder suppression bus failure results in own aircraft establishing a track on itself; and

f) corruption of Mode C replies, e.g. aircraft operating in formations causing synchronous garble, or transponders operating out of specification pulse width.

10.3 ALTIMETRY DATA QUALITY

10.3.1 Measurement errors

10.3.1.1 The vertical spacing between two conflicting aircraft is measured as the difference between own altitude and the intruder's altitude as reported in its Mode C or Mode S reply.

10.3.1.2 Errors in altimetry can cause two types of effects: first, if the aircraft are on a near-collision course, errors could indicate safe passage, and the impending near mid-air collision might not be resolved by ACAS; second, if the aircraft are on a near-collision course, but are separated in altitude, errors could lead to an ACAS manoeuvre in the wrong direction which could induce an even closer encounter.

10.3.1.3 ACAS attempts to achieve a difference of at least 90 m (300 ft) below FL 50 (more at higher altitude) between aircraft at CPA based on reported altitude. Thus, if the combination of intruder and ACAS altimetry errors approached 90 m (300 ft), there would be a greatly increased risk of collision despite the presence of ACAS. Studies of the expected altimetry errors of both ACAS and non-ACAS aircraft at altitudes from sea level to FL 400 have concluded that the risk is essentially negligible if both aircraft are equipped with high accuracy altimetry systems that can achieve root-sum-square (RSS) errors of approximately 15 m (50 ft). It was further concluded that if an ACAS with high accuracy altimetry operates in a traffic environment consisting of typical general aviation aircraft (with RSS errors of approximately 30 m (100 ft), normally distributed), then altimetry errors will occasionally lead to inadequate ACAS RAs. However, this will not occur often enough to seriously interfere with the effectiveness of the system. Performance was considered to be inadequate if both aircraft in an encounter had a low accuracy altimetry system. This led to the requirement that ACAS possess a high accuracy system.

10.3.2 Altitude bit failure

If the Mode C or Mode S altitude reports from the intruding aircraft contain bit errors, ACAS may develop erroneous estimates of the vertical position and/or rate of the intruder. These errors can have effects similar to the effects of measurement errors.

10.3.3 Credibility of own aircraft altitude

All sources of own altitude data are required to be checked for credibility, including fine altitude data (which can come from various sources: gyro, air data computer, etc.) and radar altitude data.

10.3.4 Wrong sense advisories or incorrect intruder altitude displayed

10.3.4.1 Multiple occurrences of reported RAs considered to be in the wrong direction were based upon pilot observation and in some cases, controller verification. The RAs resulted from erroneous altitude information when Gillham code was being used for the altitude input. A stuck bit in the Gillham altitude resulted in incorrect altitudes being transmitted in response to radar and ACAS interrogations.

10.3.4.2 Transponders associated with the occurrences were manufactured by Bendix, Rockwell Collins, and Wilcox. Investigations indicated that the transponders were Mode C transponders that had a single Gillham altitude input. These investigations resulted in ADs being issued by the United Kingdom, (CAA Airworthiness Directive 001-08-99, dated 16 August 1999) the United States, (FAA Airworthiness Directive 99-23-22-R1 issued 16 December 1999), and other States. The ADs required testing at defined intervals to detect and correct any discrepancies with the Mode C transponder(s), air data computer and associated aircraft wiring connections.

10.3.5 General aviation monitoring

10.3.5.1 General aviation aircraft equipped with Mode A/C transponders were monitored for altitude reporting accuracy. Twenty-one of 548 transponders reported altitudes that deviated by more than 200 ft from the correct altitude. This reinforces the need for ongoing maintenance of transponders and monitoring of transponder performance while operating in the airspace.

10.3.5.2 One hundred and fifteen transponders did not provide an altitude response during testing. Insufficient warm-up time is considered to have been the problem with these transponders.

10.4 ACAS AND TRANSPONDER TEST EQUIPMENT

10.4.1 Transponder test equipment

10.4.1.1 In the United States, Title 14 of the Code of Federal Regulations (CFR) Part 43, Appendix F, dated 18 August 1989, provides specifications for capabilities that must be included in transponder test equipment. It is noted that this regulation has been updated since the implementation of TCAS/ACAS started in the U.S., but does not address any TCAS/ACAS interface requirements.

10.4.1.2 There are no ICAO provisions related to transponder test equipment.

10.4.2 ACAS test equipment

There are no known regulations or requirements associated with the development, production and use of ACAS test sets.

10.4.3 MODEST Mode S transponder tester

All transponders used with ACAS are expected to conform to Mode S transponder minimum operational performance standards (MOPS) (RTCA DO181 or EUROCAE ED-73). EUROCONTROL has built a Mode S Transponder Tester (MODEST) that performs the full set of MOPS tests upon a transponder. It reports which tests work correctly and gives details about any tests that fail. Mode S transponder manufacturers can verify their transponders using this facility.

Chapter 11

CERTIFICATION AND OPERATIONAL APPROVALS

11.1 BASIS FOR EXISTING EQUIPMENT AND INSTALLATION CERTIFICATION

11.1.1 Existing Equipment Approvals

11.1.1.1 ACAS equipment is currently available from several vendors. While each vendor's implementation is slightly different, they provide the same core functions, and the collision avoidance and coordination logic contained in each implementation is the same.

11.1.1.2 ACAS equipment has been certified in the United States under Technical Standard Order (TSO) C119b, *Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS II.* Equipment certified under this TSO must meet the minimum performance standards set forth in Section 2 of RTCA, Inc. (RTCA) Document No. DO-185A, *Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment,* dated 16 December 1997, with the exceptions listed in Appendix 1 of the TSO. DO-185A equipment meets the ACAS requirements contained in Annex 10, Volume IV.

11.1.1.3 The software in ACAS equipment was developed in accordance with RTCA/DO-178B, *Software Considerations in Airborne Systems and Equipment Certification,* dated 1 December 1992.

11.1.1.4 Because the CAS logic is specified in DO-185A and is required to be used by all ACAS suppliers, extensive testing of the CAS logic was performed prior to the approval of DO-185A. The development of the CAS logic was conducted in accordance with DO-178B, and a CAS logic test suite was developed and provided to the equipment suppliers to use in their development and testing. Additional documentation related to the testing conducted during the development of the CAS logic is available from the Federal Aviation Administration, William J. Hughes Technical Center, Aircraft/Avionics Branch (ACT-370), Atlantic City, NJ 08405, USA, 1 609 485-5036.

11.1.1.5 The Mode S transponder that is installed with ACAS is certified in the United States under Technical Standard Order (TSO) C112, *Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment.* Equipment certified under this TSO must meet the minimum performance standards set forth in Section 2 of RTCA Document No. RTCA/DO 181, *Minimum Operational Performance Standards For Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment,* dated March 1983, and Change 1 to RTCA/DO-181, dated 13 November 1984, and Change 2 to RTCA/DO-181, dated 17 January 1986, as amended by the TSO. RTCA has subsequently published DO-181A, DO-181B, and DO-181C. The EUROCAE equivalent document to DO181 is ED-73. The latest published version of this document is ED-73B.

11.1.1.6 The TSO approvals for the ACAS and Mode S equipment indicate that a manufacturer's equipment implementation meets the appropriate performance requirements and performs its intended function.

11.1.2 After the ACAS equipment receives TSO approval, the next step in the certification process is to obtain approvals to install the equipment in various aircraft types. Approval installations typically have been obtained through the Supplemental Type Certificate (STC) process. Aircraft manufacturers have also included ACAS installation approval as part of an aircraft's Type Certificate for in-production aircraft.

11.1.2.1 Individual States have their own process for approving the installation of ACAS equipment. The following sections describe the process used in one State for approving ACAS installations via the STC process. The use of this process requires that the equipment has already received TSO approval. The STC process is split into two phases; the initial STC and follow-on STCs.

11.1.3 *Initial STC*. Testing of the first of a manufacturer's ACAS systems for its initial approval in an aircraft is conducted to verify that the design and installation perform their intended functions under the expected operating conditions. The testing further confirms that there are no adverse interactions between ACAS and existing aircraft systems, and that any prior equipment approvals have not been compromised. Obtaining the initial STC generally requires a combination of ground tests, basic flight tests, and flight tests involving planned encounters with another ACAS-equipped aircraft. The initial STC is typically obtained using a manufacturer's non-commercial, transport category aircraft.

11.1.3.1 The initial STC ground testing includes the following elements.

11.1.3.1.1 *Bearing Accuracy Tests*. Bearing estimation accuracy of the ACAS system is demonstrated as installed in the aircraft. The bearing accuracy is typically measured using a fixed transponder location while rotating the test aircraft on a compass rose while measuring the bearing angles at 30-degree intervals. Alternately, the airplane is fixed and the transponder is moved.

11.1.3.1.2 *Sensor failures*. Simulated failures of the aircraft sensors integrated with ACAS are evaluated to determine that the resulting system failure state agrees with the predicted results.

11.1.3.1.3 *Electromagnetic Interference (EMI)*. A flight deck EMI survey is made to verify that the ACAS equipment is not a source of objectionable conducted or radiated interference to previously installed systems or equipment, and that operation of the ACAS equipment is not adversely affected by conducted or radiated interference from previously installed systems and equipment.

11.1.3.1.4 The general arrangement and operation of controls, displays, circuit breakers, annunciators and placards of the ACAS system are evaluated.

11.1.3.1.5 *Self-Test*. The TCAS self-test features and failure mode displays and annunciators are evaluated.

11.1.3.1.6 Testing is accomplished to verify that the pressure altitude source and radio altimeter are properly interfaced with the ACAS equipment.

11.1.3.1.7 Verification that the wind shear and GPWS/TAWS warnings and ACAS voice alerts are compatible is accomplished. This testing also verifies that wind shear or GPWS/TAWS warnings can be clearly understood and that ACAS is automatically switched to the TA-Only Mode when ACAS and wind shear voice or GPWS/TAWS announcements simultaneously occur.

11.1.3.1.8 The performance of the ACAS traffic display is verified by observing available traffic in the area.

11.1.3.1.9 The system installation is evaluated to ensure satisfactory identification, accessibility and visibility during both day and night conditions.

11.1.3.1.10 The proper response of the ACAS logic to configuration discretes, including inhibits of climb or increase climb RAs, and changes in logic or function with aircraft configuration, altitude or speed is verified.

11.1.3.1.11 The wiring of the correct Mode S identification code and maximum airspeed is verified.

11.1.3.1.12 If connected, the altitude alerter inputs to ACAS are verified, as is the ACAS logic's ability to correctly weaken or strengthen the displayed RA using the altitude alerter input.

11.1.3.2 Basic flight tests are conducted to verify proper operation of the ACAS equipment in flight. The basic flight tests consist of the following elements.

11.1.3.2.1 During all phases of flight, the performance of other systems is monitored to verify there is no mutual interference between ACAS and another aircraft system. All installed systems, including the weather radar, are operating during the flight test.

11.1.3.2.2 The volume and intelligibility of the ACAS aural messages during both low and high cockpit noise levels (idle descent at low speed and high power at Vmo) with headset covering outboard ear only (when appropriate) and without headsets is evaluated.

11.1.3.2.3 A demonstration is conducted to verify that traffic information remains valid and usable when the aircraft is pitched ±15 degrees and rolled approximately 30 degrees of bank during normal manoeuvres by observing area traffic in the traffic advisory display.

11.1.3.2.4 The effective surveillance range of ACAS, including target azimuth reasonableness and track stability, is assessed via the traffic display.

11.1.3.2.5 ACAS is evaluated for non-interference during coupled Autopilot and Flight Director approaches to the lowest minimums approved for the aircraft.

11.1.3.2.6 All pilot-selectable modes of the ACAS are evaluated to determine that they perform their intended function and that the operating mode is clearly and uniquely shown.

11.1.3.2.7 Any previously installed aircraft systems that have been changed as a result of the ACAS installation are re-evaluated for proper operation.

11.1.3.3 *Planned Encounter Flight Tests*. These flight tests demonstrate adequate ACAS surveillance and verify smooth, predictable ACAS performance. The following encounters between the ACAS aircraft and a dedicated intruder aircraft are flown to ensure that the ACAS aircraft system performs its intended function by generating TAs and RAs and is consistent with DO-185A. The intruder aircraft is equipped with transponders capable of Mode A, Mode C, and for those tests making it necessary, Mode S, and ACAS. The planned encounter flights cover the envelope of encounter speeds, altitudes and geometries that have in the past identified flaws in surveillance, logic and antenna mechanization that were not detected earlier by bench tests. The following encounter geometries are used in these tests:

a) intruder overtaking ACAS aircraft (from the aft quadrants); and

b) head-on:

   i) low and high closure speeds;

   ii) above climb limit, ACAS to ACAS;

iii) ACAS against Mode C with ACAS above intruder and above climb limit (intent is to force ACAS aircraft to descend);

iv) at 3 000 ft over calm water to evaluate multipath protection;

c) converging;

d) crossing (intruder above ACAS, descending or vice versa).

11.1.3.3.1 The TA-only mode is evaluated during planned encounters.

11.1.3.3.2 Encounters with a mix of intruder transponder modes (A, C and S) are conducted, but primary emphasis is placed on ACAS-to-ACAS coordination and on Mode C replies from the intruder aircraft.

11.1.3.3.3 The performance of ACAS during encounters with ACAS both above and below the intruder is evaluated.

11.1.3.3.4 The effect of electrical transients (bus transfer) during encounters is evaluated.

11.1.4 *Follow-On Approvals (STC or Amended TC)*. Testing of ACAS systems for follow-on approvals (previously approved ACAS equipment installed in a different aircraft type) is conducted to verify that the design and installation performs its intended function under the expected operating conditions, that there are no adverse interactions between the ACAS and existing aircraft systems, and that prior approvals of present aircraft equipment have not been compromised. The applicant should provide a test plan which includes adequate testing to perform the verification that the design and installation performs its intended function when installed in a different aircraft type under the expected operating conditions, that there are no adverse interactions between the ACAS and existing aircraft systems, and that prior approvals of present aircraft equipment have not been compromised. Obtaining the follow-on STC generally requires a combination of ground tests, basic flight tests, and flight tests involving planned encounters with a Mode C-equipped aircraft, or the use of a suitably located fixed transponder. The test plan should contain, as a minimum, the following elements:

11.1.4.1 *Ground Tests*. The ground tests for a follow-on approval include the following tests:

a) Evaluation of the general arrangement and operation of controls, displays, circuit breakers, annunciators and placards of the ACAS system;

b) Evaluation of the ACAS self-test features and failure mode displays and annunciators;

c) Verification that the pressure altitude source and radio altimeter are properly interfaced with the ACAS equipment;

d) Measurement of the performance of the directional antenna for 360 degrees coverage at 30-degree intervals, as specified under basic certification ground tests;

e) Evaluation of the ACAS system installation for satisfactory identification, accessibility and visibility during both day and night conditions;

f) Determination that any configuration discretes associated with the ACAS logic, including inhibits of climb RAs, operate properly;

g) Verification that the Mode S identification code and maximum airspeed are correct;

h) Verification that the wind shear and GPWS/TAWS warnings and ACAS voice alerts are compatible. Also, verification that wind shear and GPWS/TAWS warnings can be clearly understood and that ACAS is automatically switched to the TA-only mode when ACAS and wind shear or GPWS/TAWS voice announcements simultaneously occur;

i) If connected, verification that the altitude alerter is providing correct data to ACAS and that the ACAS logic correctly weakens or strengthens the displayed RA using the altitude alerter input.

11.1.4.2 *Flight tests*

Follow-on approvals (STC or Amended STC) of ACAS typically do not require additional flight testing, provided the appropriate testing is performed on the ground to verify the proper operation of ACAS, and that the flight testing required for an initial STC has been completed.

11.1.5 Flight Manual

The Flight Manual provides the appropriate system limitations and procedures and a comprehensive description of all normal modes of operation including what actions are expected by the flight crew in each case. All follow-on approvals require the preparation and approval of a Flight Manual.

11.2 OPERATIONAL APPROVALS

11.2.1 *Aircraft Operator Approvals*. Once the required aircraft and equipment certification activities described in Section 11.1 have been completed, and prior to operating the installed ACAS equipment, aircraft operators need to obtain operational approval from their regulatory authorities. Operational approval pertains to changes to training (pilot and maintenance personnel) and maintenance programmes, manuals, operational procedures, Minimum Equipment Lists (MEL) and other areas necessary for safe and effective ACAS use. It also addresses the qualification of aircrews through the approved training programmes. An airworthiness TC or STC for an ACAS system alone does not constitute operational approval for use of ACAS. The following sections briefly discuss the items that should be considered prior to granting ACAS operational approval to an operator.

11.2.1.1 *Pilot training programmes*

11.2.1.1.1 Requirements for pilot training programmes are shown in PANS-OPS. In addition to the training requirements contained in PANS-OPS, proper ACAS use should be a discussion item during all line checks and route checks.

11.2.1.1.2 Aircraft operators should document their approach to ACAS training in training manuals and other training documentation, and if required, have the updated documents approved by the appropriate regulatory authority.

11.2.1.2 *Maintenance requirements*

11.2.1.2.1 ACAS-related maintenance procedures are approved or accepted as part of an operator’s initial maintenance manual approval or as an approval to a maintenance manual revision.

11.2.1.2.2 An operator's maintenance procedures should be consistent with the ACAS equipment manufacturer's maintenance procedures.

11.2.1.2.3 An operator must provide adequate ACAS training to its maintenance personnel and any contract maintenance personnel supporting the operator. Maintenance training includes, but is not limited to, topics addressing installation, aircraft modifications, correction of reported ACAS anomalies/discrepancies, use of ACAS test equipment, test procedures, MEL and dispatch requirements, and return to service authorizations. The training procedures should also address testing installed transponders and automatic pressure altitude reporting equipment on the ground in such a way that false targets are not generated in airborne ACAS systems.

11.2.1.3 *Minimum equipment list (MEL) requirements*

11.2.1.3.1 Operators must formulate necessary ACAS-related revisions to their MEL for each particular fleet type. All MEL revisions must be consistent with the approved Master MEL (MMEL) for the specific aircraft type.

11.2.1.3.2 Currently, some regions have an ACAS MEL requirement of 10 days, taking into account the difficulty of obtaining spare parts and limited experience in isolating and correcting ACAS problems. Some regions, with mature implementations, have determined that a 3-day MEL is justified. The shorter MEL period is desirable for all regions. Some operators have voluntarily made ACAS a required dispatch item for some routes.

11.2.1.4 *Manuals and other publications*

Aeroplane flight manuals, operating manuals, checklists, maintenance manuals, general policy manuals, and other manuals, publications, and written material affected by ACAS operation must be amended to describe ACAS equipment, procedures and operational policies. Any amendments must be approved by the appropriate regulatory authority.

11.2.1.5 *Pilot operating procedures*

An operator must define how its crews will operate ACAS and respond to TAs and RAs. The topics to be addressed by these procedures include, but are not limited to, information provided by ACAS; limitations of manoeuvres based on visual acquisition of other aircraft; the proper response to RAs; the return to an ATC clearance following an RA; the interaction between ACAS and other aircraft systems; effects of improper use of ACAS; use of various operating modes (i.e. Standby, TA Only, TA/RA) while airborne and on the ground; and event reporting requirements.

11.2.2 CAA operational approvals

A CAA can issue operational clearances/approvals for the installation and operation of any specific airborne equipment in its national airspace. These clearances/approvals shall prevent a decrease of the safety performance of the ATC surveillance ground infrastructure and other ACAS systems due to the implementation of these specific airborne equipments. The clearance can be issued on a temporary or permanent basis and can limit the operation of these systems in terms of:

a) the maximum number of equipped aircraft;

b) specific types of operation;

c) restrictions in the use of airspace; or

d) operational limitations, e.g. requiring aircraft to limit their vertical speeds when approaching an ATC-assigned altitude.

11.3 CERTIFICATION AND APPROVAL OF MILITARY SYSTEMS

11.3.1 Military aircraft can be equipped with systems that have an ACAS function. The ACAS function will meet the SARPs for civil ACAS. It is expected that the ACAS function will have been certified in accordance with the appropriate TSO or an equivalent process.

11.3.2 Certification of military systems that include an ACAS function

11.3.2.1 Additional functions (e.g. to assist formation flying) can be included in military systems that have an ACAS function. This will be done in a manner that does not interfere with the safe operation of other ACAS or the ATC system. These military systems will be compatible with civil systems when operating in civil airspace.

11.3.2.2 The ACAS function may be modified to support military-specific operations as long as it continues to meet the SARPs for civil ACAS.

11.3.2.3 These systems will be certified by military authorities.

11.3.3 Coordination with local civil aviation authorities

11.3.3.1 Military systems that use elements of an ACAS function for other than approved civil-type operation (e.g. ACAS surveillance for station keeping) will be coordinated on a State-by-State basis.

11.3.3.2 Documentation related to the certification of the ACAS functions of these military systems should be available upon request to local civil aviation authorities. This documentation includes, but is not limited to, standards defining the system, test results and the basis of certification.

Appendices

Appendix 1

SAMPLE PILOT REPORT, ACAS EVENT FORM

Your participation in the reporting of ACAS events is essential to the success of ongoing evaluation of ACAS performance. Please complete and return this questionnaire as quickly as possible. The information contained herein will be used only to assess the operation of ACAS and will not be released to the public in a manner which allows the identification of you or the airline. The information WILL NOT be used to initiate or pursue enforcement action against you or the crew. Once the data are entered into the ACAS evaluation databases the questionnaire will be maintained for no longer than 60 days, at which time it will be destroyed. Please fill out the form in full and check all that apply.

Reporting Pilot: ________________ Date: _____/_____/_____ Time: __________ UTC
Origin: _________ Destination: _________ Call Sign: __________ A/C Type: _________
Registration number: __________
SSR-Code: ____________ ATC Control name: ____________
ATC Control frequency: _______________
Actual altitude: ___________ Cleared altitude: ___________
Own position: _______________________________________
(LAT/LONG or Nav Aid/Radial/Range)
Phase of flight: Departure (Take-off to 10 000 ft) Climb (10 000 ft to Cruise)
Cruise Descent (Cruise to 10 000 ft) Holding pattern Approach (Below 10 000 ft)

INTRUDER AIRCRAFT (If known)
Call Sign: _____________ A/C Type: Commercial General aviation Military Other
Make/Model: _____________ Actual altitude: ___________ Cleared altitude: ___________
Did you have the aircraft in visual contact? Yes No
If yes: Before/after TA. Before/after RA.
Was a TA issued? Yes No
Were multiple TAs issued against the same intruder? Yes No
Initial RA issued: Descend, Descend Climb, Climb Monitor Vertical Speed
Climb, Crossing Climb Descend, Crossing Descend
Maintain Vertical Speed, Maintain Maintain Vertical Speed, Crossing Maintain
. Adjust Vertical Speed, Adjust ________ ft/min
Did the initial RA change to any of the following?
Adjust Vertical Speed, Adjust Increase Climb Increase Descent Climb, Climb Now
Descend, Descend Now Descend, Descend Climb, Climb
Intruder's range at RA? __________ Intruder's bearing at RA? ___________
Intruder's relative altitude at RA: ____________ft
Estimated closest proximity: Range ____________NM Altitude ____________NM

Your response to the RA was: Climb Descend Change in vertical rate Turn
No response No response necessary
Was the event reported to ATC? Yes No
Did ATC provide a traffic information on the intruder? Before RA After RA No
Did the RA conflict with ATC instructions? Yes No

If you did not follow the RA, please explain why:

REMARKS (Please provide comments/concerns on this encounter):

Appendix 2

SAMPLE CONTROLLER REPORT, ACAS EVENT FORM

This questionnaire is designed to provide you with a vehicle for your comments on ACAS implementation and integration into the ATC system. The questionnaire also provides a means to analyse ACAS performance. The form should be filled out any time you become aware an ACAS EVENT has been reported. Once the data are entered into the database, the questionnaire will be destroyed. Please fill out the form in full and check all that apply.

DATE: _______________ TIME: ________________(UTC) ATC Unit: ______________
Sector: _________________
ATC standard separation: ____________ horizontal ___________ vertical
Position: ___________________________
(LAT/LONG or Nav Aid/Radial/Range)

AIRCRAFT #1 REPORTING ACAS EVENT

Call Sign: __________ SSR Code: _________ IFR VFR
Aircraft type: Air carrier General Aviation Military Other
Actual altitude at RA: ___________ Cleared altitude: ___________
Phase of flight (check one): Departure (Take-off to 10 000 ft) Climb (10 000 ft to cruise)
Cruise Descent (Cruise to 10 000 ft) Holding pattern Approach (Below 10 000 ft)
Was a TA reported by the crew? Yes No Was an RA reported by the crew? Yes No
Observed pilot response: Descend Climb Turn No response
Observed deviation from given ATC clearance: _________ horizontal _________ vertical
Was the aircraft in radar coverage? Yes No

Description of Event:
____
____
____
____

OTHER AIRCRAFT INVOLVED IN THE ACAS EVENT

Call Sign: __________ SSR Code: _________ IFR VFR
Aircraft type: Air carrier General Aviation Military Other
Actual altitude at RA: ___________ Cleared altitude: ___________
Phase of flight (check one): Departure (Take-off to 10 000 ft) Climb (10 000 ft to cruise)
Cruise Descent (Cruise to 10 000 ft) Holding pattern Approach (Below 10 000 ft)
Was a TA reported by the crew? Yes No Was an RA reported by the crew? Yes No
Observed pilot response: Descend Climb Turn No response
Observed deviation from given ATC clearance: _________ horizontal _________ vertical
Was the aircraft in radar ADS-B coverage? Yes No Not under Control

Did EXCESSIVE radio transmission conversation occur? Yes No
Was the event or the pilots' use of ACAS disruptive to your ATC tasks? Yes No

Remarks:

Appendix 3

RECOMMENDED LIST OF ITEMS TO BE INCLUDED ON PILOT REPORT FORM

Own Aircraft
- Reporting pilot (Name optional)
- Date
- Time (UTC)
- Origin
- Destination
- Call sign
- Registration
- Aircraft type
- SSR-code
- ATC (Name/Frequency)
- Actual altitude/FL
- Cleared altitude/FL
- Phase of flight (Departure/Climb/Cruise/Descend/Holding Pattern/Approach)
- Position (LAT/LONG or Nav Aid/Radial/Range)

Other traffic involved in the TCAS event (if known)
- Call sign
- AC Type (Air-carrier/GA/Military/Other)
- Make/Model
- Actual altitude/FL
- Cleared altitude/FL
- Visual Contact Y/N (Before/after TA/RA)

Description of the event including sequence of events
- TA issued (Yes/No)
- Multiple TAs against the same intruder (Yes/No)
- Initial RA issued (types)
- Initial RA changed to (types)
- Intruder range at RA
- Intruder bearing at RA
- Intruder relative altitude at RA
- Estimated closest proximity (horizontal/vertical)
- Pilot responses (Climb/Descend/Change in vertical rate/Turn/
  No response/No response necessary)

Question Area
- Was the event reported to ATC? (Yes/No)
- Did ATC provide traffic information on the intruder? (Before RA/After RA/No)
- Did the RA conflict with ATC instructions? (Yes/No)

If you did not follow the RA, please explain why.

Remarks

Appendix 4

RECOMMENDED LIST OF ITEMS TO BE INCLUDED ON CONTROLLER REPORT FORM

Date
Time (UTC)
ATC Unit
Sector
Appropriate ATC standard separation (horizontal nm / vertical ft)
Position (LAT/LONG or Nav Aid/Radial/Range)
Aircraft #1 reporting ACAS event
- Call sign
- SSR-code (Transponder)
- IFR/VFR
- Aircraft type (Air carrier/GA/Military/Other)
- Actual altitude/FL
- Cleared altitude/FL
- Phase of flight (Departure/Climb/Cruise/Descend/Holding Pattern/Approach)
- TA reported (Yes/No)
- RA reported (Yes/No)
- Observed pilot response (Climb/Descend/Level off/Turn/No response)
- Observed deviation from given ATC clearance (horizontal/vertical)
- Radar coverage (Yes/No)
- Description of the event

Other aircraft involved in the ACAS event
- Call sign
- SSR-code (Transponder)
- IFR/VFR
- Aircraft type (Air carrier/GA/Military/Other)
- Actual altitude/FL
- Cleared altitude/FL
- Phase of flight (Departure/Climb/Cruise/Descend/Holding Pattern/Approach)
- TA reported (Yes/No)
- RA reported (Yes/No)
- Observed pilot response (Climb/Descend/Level off/Turn/No Response)
- Observed deviation from given ATC clearance (horizontal/vertical)
- Radar coverage (Yes/No/Not under Control)

Question Area
- Did excessive radio transmission conversation occur? (Yes/No)
- Was the event or the pilot’s use of ACAS disruptive to your ATC tasks? (Yes/No)

Remarks

Appendix 5

RECOMMENDED LIST OF DATA TO BE PROVIDED BY DEDICATED ACAS RECORDERS

Identifying information
- Date
- Time
- TCAS version
- Intruder equipage

Positions at time of RA
- Time of the initial RA
- Position of the recording ACAS
  - Heading
  - Altitude
  - Altitude rate
  - Height above ground
- Position of the other aircraft
  - Bearing
  - Range
  - Range rate
  - Altitude
  - Altitude rate

Position at minimum separation
- Time of minimum separation
- Range
- Relative altitude

Description of the event
- Sequence of advisories
- RA severity
- Change of operating mode
- Multi-aircraft encounter (Flag)
- Track drop (Flag)

Appendix 6

LIST OF DEFINITIONS USED BY MONITORING PROGRAMMES

ACAS II. An ACAS which provides vertical resolution advisories (RAs) in addition to traffic advisories (TAs).

Altitude crossing RA. A resolution advisory is altitude crossing if own ACAS aircraft is currently at least 30 m (100 ft) below or above the threat aircraft for upward or downward sense advisories, respectively.

Closest point of approach (CPA). The occurrence of minimum range between own ACAS aircraft and the intruder. Range at CPA is the smallest range between the two aircraft and time at CPA is the time at which it occurs.

Corrective RA. A resolution advisory that advises the pilot to deviate from the current flight path.

Horizontal miss distance (HMD). The horizontal range between two aircraft at the closest point of approach.

Increased rate RA. A resolution advisory with a strength that recommends increasing the altitude rate to a value exceeding that recommended by a previous climb or descend RA.

Potential threat. An intruder deserving special attention either because of its close proximity to own aircraft or because successive range and altitude measurements indicate that it could be on a collision or near-collision course with own aircraft. The warning time provided against a potential threat is sufficiently small that a traffic advisory (TA) is justified, but not so small that a resolution advisory (RA) would be justified.

Preventive RA. A resolution advisory that advises the pilot to avoid certain deviations from the current flight path, but does not require any change in the current flight path.

Resolution advisory (RA). An indication given to the flight crew recommending a manoeuvre intended to provide separation from all threats; or a manoeuvre restriction intended to maintain existing separation.

Reversed sense RA. A resolution advisory that has had its sense reversed.

Sensitivity level (SL). An integer defining a set of parameters used by the traffic advisory (TA) and collision avoidance algorithms to control the warning time provided by the potential threat and threat detection logic, as well as the values of parameters relevant to the RA selection logic.

Threat. An intruder deserving special attention either because of its close proximity to own aircraft or because successive range and altitude measurements indicate that it could be on a collision or near-collision course with own aircraft. The warning time provided against a threat is sufficiently small that an RA is justified.

Traffic advisory (TA). An indication given to the flight crew that a certain intruder is a potential threat.

RA classifications

False RA. The ACAS II system generated an advisory which was based on a false track created by erroneous surveillance data or an onboard system malfunction.

Phantom RA. A form of a false RA in which the TCAS II system generated an advisory against a non-existing threat aircraft.

Unclassifiable RA. The ACAS II system generated an advisory that cannot be classified because of insufficient data.

Unnecessary RA. The ACAS II system generated an advisory in accordance with its technical specifications in a situation where there was not or would not have been a risk of collision between the aircraft.

Useful RA. The ACAS II system generated an advisory in accordance with its technical specifications in a situation where there was or would have been a risk of collision between the aircraft.

Types of data standards

These standards should be used in the description of ACAS events for the types of data that can be derived from the different sources. Any diversion from these given standards should be mentioned in the description.

RAs. Resolution advisories may be referred to by one or more of the following:

1. Climb RA
2. Descend RA
3. Crossing RA
4. Reversal RA
5. Increase RA
6. Reduce/adjust RA
7. Maintain vertical speed RA
8. Monitor vertical speed RA

RA geometry. The geometry of an RA may be referred to by one or more of the following:

1. High vertical rate
2. Vertical crossings
3. Level-level
4. Head on
5. Parallel arrival
6. Tail chase
7. Horizontal track crossings
8. Offset

Phase of flight. The phase of flight of the involved aircraft should only be described using the following six phases:

1. Departure
2. Climb
3. Cruise

4. Descend
5. Holding pattern
6. Approach

Pilot response. The response of a pilot to an RA should only be measured by the following pilot reactions:

1. Climb
2. Descend
3. Turn
4. Did not respond
5. No response necessary
6. Reduction of the vertical rate

If more detail of the pilot response is available or required, the response should be classified as:

a) Pilot responded in accordance with the RA
b) Pilot responded with a vertical rate change less than indicated by the RA
c) Pilot responded with a vertical rate change greater than indicated by the RA
d) Pilot response was a manoeuvre in an opposite sense to the RA
e) Pilot responded by switching the system to TA-only mode
f) Pilot responded by switching the system to Standby
g) Pilot responded by switching the transponder to Off
h) Pilot response was a horizontal manoeuvre.

Appendix 7

ADVICE CONCERNING THE INTERCEPTION OF CIVIL AIRCRAFT

A7.1 INTRODUCTION

A7.1.1 Airborne Collision Avoidance Systems (ACAS) are implemented worldwide and generate not only Traffic Advisory (TA) messages, but recommend evasive manoeuvres (Resolution Advisories, RAs) to avoid collision with any intruding aircraft. Due to the time-critical nature of this last-resort safety net, pilots have to follow an RA immediately.

A7.1.2 During a possible Air Policing Mission (hot intercept), civil aircraft might perform evasive manoeuvres, which could be interpreted as non-friendly action by the Interceptor Pilot and could lead to negative consequences stemming from the reaction of the Interceptor Pilot.

A7.1.3 From a military point of view there are two main scenarios to be discussed:

— a demonstrative intercept with a military escort mission; or

— a covert unexpected approach towards a selected target.

A7.1.4 Currently, there is no provision to distinguish between these two kinds of intercept. In addition, safe situation control on the ground can be improved in various regions of the world using capabilities implemented with Mode S.

A7.2 ADVICE FOR NON-MODE S-EQUIPPED FIGHTER AIRCRAFT

A7.2.1 Arrangements to be used by military fighter aircraft for covert intercepts

A7.2.1.1 When closing in on an aircraft to be intercepted, the military pilot disables Mode C. (Some military users switch the transponder off or to “Standby” resulting in no reply to any interrogation.) In this procedure, the lack of altitude information will prevent all RAs.

A7.2.1.2 At least under peace-time conditions Mode A transmissions should be enabled at all times to make the fighter aircraft visible for SSR/IFF ground radar systems (but without altitude information).

A7.2.2 Arrangements to be used by military fighter for demonstrative intercepts

A7.2.2.1 During this type of intercept, it is highly desirable to avoid RAs, even though the intercepted aircraft detects the approaching Interceptor. There is no other alternative for non-Mode S-equipped fighters than to eliminate the altitude value in Mode C messages. In this case, only the framing pulses will be transmitted. If there is no altitude value in the Mode C messages, ACAS will detect the military aircraft, but only TAs can be generated. Ground-based systems can track the fighter aircraft, but without altitude information.

A7.2.2.2 There should be an indication on the control panel or the IFF function display of the fighter aircraft when the altitude reply information is inhibited in this way.

A7.3 ADVICE FOR MODE S-EQUIPPED FIGHTER AIRCRAFT

A7.3.1 *Covert intercepts* are intended to prevent the fighter from responding to ACAS interrogations while the fighter can still respond to ATC ground-based interrogations.

A7.3.1.1 In this case, the intercepting pilot will select an Intercept Mode. Under these conditions all replies to UF0 (short air-air surveillance) and UF16 (long air-air surveillance) interrogations will be suppressed. Nevertheless the fighter’s transponder will respond to all ground-based ATC system interrogations. Therefore, the fighter remains visible to ATC.

A7.3.1.2 The fighter with activated Intercept Mode will continue to be a threat to all ACAS-equipped aircraft, if the Intercept Mode is not cancelled after the end of the mission.

A7.3.2 *Demonstrative intercepts* are intended to keep the Interceptor visible to both the intercepted aircraft and to ground surveillance.

A7.3.2.1 To avoid that an ACAS-equipped aircraft generates an RA against an approaching Mode S-equipped fighter, the height value in ACAS replies (DF 0 or 16) must be suppressed, but replies are still available for Mode S ground interrogations. If there is no altitude information in the replies to ACAS interrogations, the fighter will be recognized by ACAS, but only TAs can be generated. For ground-based Mode S interrogators there will be no difference from the normal behaviour, and the controllers have control of the whole air situation.

A7.3.2.2 A software change will be necessary to military Mode S transponders on fighter aircraft, and when the Intercept Mode is enabled there should be an indication within the pilot’s normal viewing area.

— END —