

Doc 9863
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Airborne Collision Avoidance System (ACAS) Manual

Approved by the Secretary General
and published under his authority

Second Edition — 2012

International Civil Aviation Organization

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AMENDMENTS

Amendments are announced in the supplements to the *Catalogue of ICAO Publications*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

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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 Recommendation 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 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:

The Secretary General
International Civil Aviation Organization
999 University Street
Montréal, Quebec
Canada H3C 5H7



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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
ARA	Aircraft resolution advisory
ASCI	American standard code for information interchange
ASP	Aeronautical Surveillance Panel
ASR	Airborne surveillance radar
ATC	Air traffic control
ATCRBS	Air traffic control radar beacon system
CA	Capability
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 system
EICAS	Engine indication and crew alerting system
EMI	Electromagnetic interference
ERP	Effective radiated power
FAA	Federal Aviation Administration
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	The speed equal to 1 nautical mile 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
s	Seconds
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
Sense	The direction of an RA, i.e. either up or down

Sense reversal	A change in the sense of an RA. <i>Note.— In some encounters, it is necessary to reverse sense of the original RA to avoid a collision.</i>
Squitters	Unsolicited transmissions generated by Mode S transponders
SSR	Secondary surveillance radar
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
Target	A Mode S or Mode A/C-equipped aircraft which is being tracked by an ACAS equipped aircraft
TAS	Traffic advisory system
TAS	True airspeed
TAU	Time to go to closest point of approach or estimated time to collision
TAWS	Terrain avoidance warning system
TCAS	Traffic alert and collision avoidance system
TFC	Traffic
Threat	An intruder that has satisfied the threat detection criteria and requires an RA
TMA	Traffic management area
TO	Technical order
Tol	Transponder of interest
TRP	Total radiated power
TSO	Technical standard order
UAV	Unmanned aerial vehicles. (This includes ROAs.)
UF	Mode S uplink format
VFR	Visual flight rules
VSI	Vertical speed indicator
VSL	Vertical speed limit
VTT	Vertical threshold test
Whisper-Shout (W-S)	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 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 (ANSPs);
- 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 (UAVs) 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 (ATC) 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.

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.

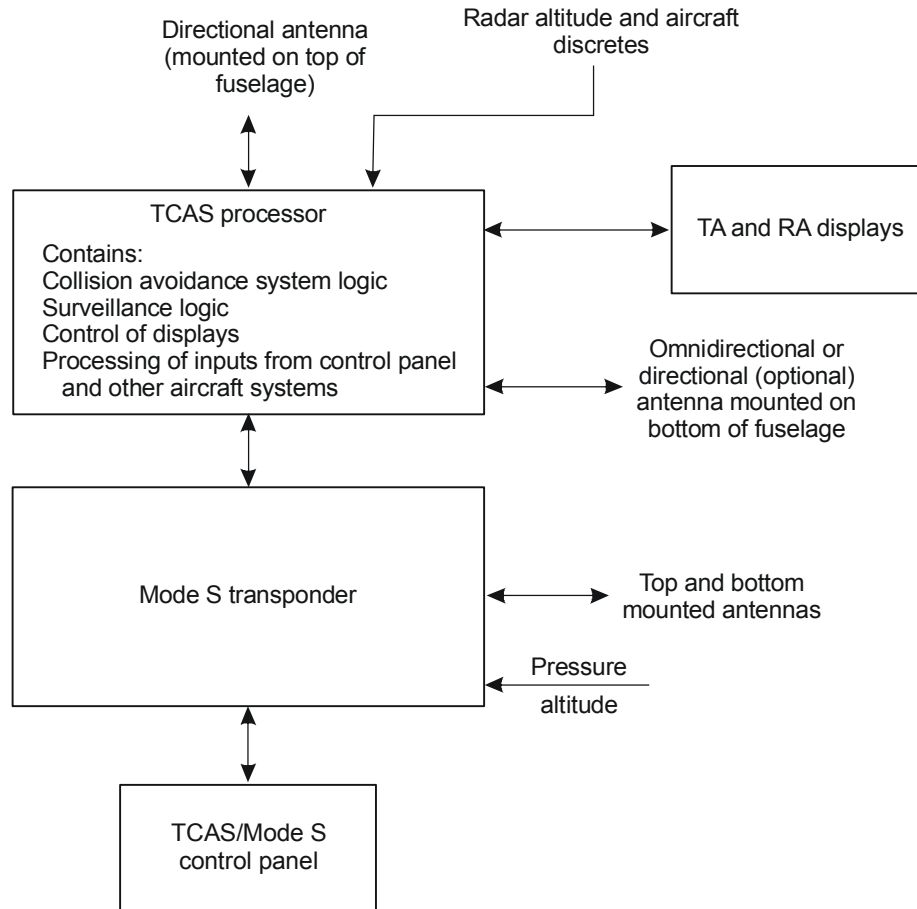


Figure 1-1. ACAS Components

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 secondary surveillance radar (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 7.6 m/s (1 500 ft/min) (depending on performance characteristics of the aircraft) in the last 300 m (1 000 ft) before levelling 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 services 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 1000 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 (FAA), United States, 2001.
- Advisory Circular (AC) 20-131A, *Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders*, FAA, United States, 1993.
- Annex 6 to the Convention on International Civil Aviation — *Operation of Aircraft*, Part I — *International Commercial Air Transport — Aeroplanes*, 2010, and Part II — *International General Aviation — Aeroplanes*, 2008, ICAO.
- Annex 10 to the Convention on International Civil Aviation — *Aeronautical Telecommunications*, Volume IV — *Surveillance and Collision Avoidance Systems*, 2007, ICAO.
- Annex 11 to the Convention on International Civil Aviation — *Air Traffic Services*, 2001, ICAO.
- *Minimum Operational Performance Standards for Secondary Surveillance Radar Mode S Transponders*, ED-73E, EUROCAE, May 2011.
- *Introduction to TCAS II Version 7*, FAA, United States, October 2000.
- *Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment*, DO-181E, RTCA, Incorporated, March 2011.
- *Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II)*, DO-185B, RTCA, Inc., July 2009.
- *Procedures for Air Navigation Services — Air Traffic Management*, (Doc 4444), 2007, ICAO.
- *Procedures for Air Navigation Services — Aircraft Operations*, Volume I — *Flight Procedures*, (Doc 8168), 2006, ICAO.
- *Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II) Hybrid Surveillance*, DO-300, RTCA, Inc., July 2009.

2.4 ACAS MANUFACTURERS

2.4.1 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 98052-5317, USA; and
- c) Rockwell Collins Inc., 400 Collins Road, NE, Cedar Rapids, IA 52402, USA.

2.4.2 The ACAS II equipment produced by these manufacturers are also known as TCAS II equipment because they are built according to the *Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS) Hybrid Surveillance*, published by RTCA, Inc. (see section 2.3). The collision avoidance logic described in these MOPS is an example of the reference logic given in some sections of this manual. Likewise, TCAS II equipment is mentioned as the reference equipment.

2.4.3 Three successive versions of TCAS II were developed and are liable to co-exist in some airspaces:

- a) version 6.04a;
- b) version 7.0, which corresponds to the MOPS published by RTCA as DO-185A;
- c) version 7.1, which corresponds to the MOPS published by RTCA as DO-185B, also published by EUROCAE as ED-143.

In parts of this manual where TCAS is mentioned either directly or through the terms of reference logic/equipment, the concerned versions will be noted when a section does not apply to all versions.

Chapter 3

FUNCTIONS AND CAPABILITIES

3.1 GENERAL

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

Note 1.— 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.

Note 2.— Consistency with non-SI units is examined in this manual, whereas the values in SI units are associated with them. The required accuracy for unit conversion may differ from other ICAO documents for technical calculations used to evaluate ACAS performance.

3.2 ADVISORIES PROVIDED

3.2.1 Traffic advisories (TAs)

TAs alert the flight crew to potential 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 (RAs)

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 s before the closest point of approach (CPA) of the aircraft. The ACAS equipment may generate a TA up to 20 s in advance of an RA. Warning times depend on sensitivity levels (SLs) 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 (SLC) 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”.

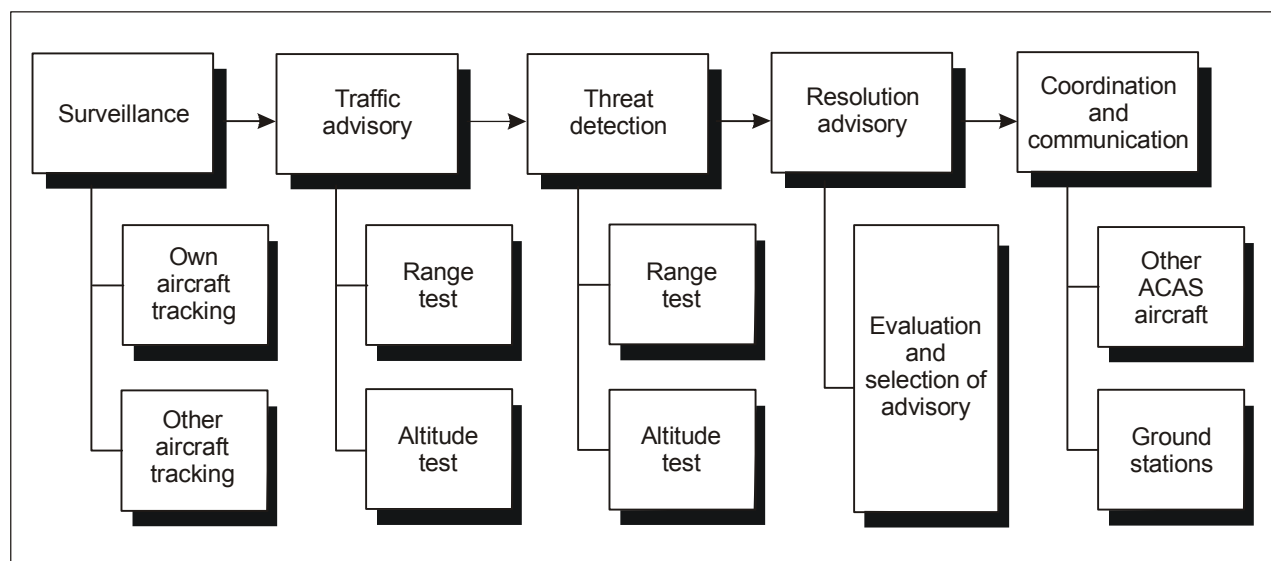


Figure 3-1. Illustration of ACAS functions

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 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 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/ km ²	aircraft/ NM ²		
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 s 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-s 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 18.5 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/km² (0.06 aircraft/NM²), 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/km², 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/km² (0.3 aircraft/NM²) 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/km², i.e. 0.06 aircraft/NM²) 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/km², i.e. 0.30 aircraft/NM²) 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 (IL) 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 IL 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 s 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 IL 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 $+54 \pm 2$ 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 22.2 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 257 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/km² (0.3 aircraft/NM²) 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 3-2). 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.

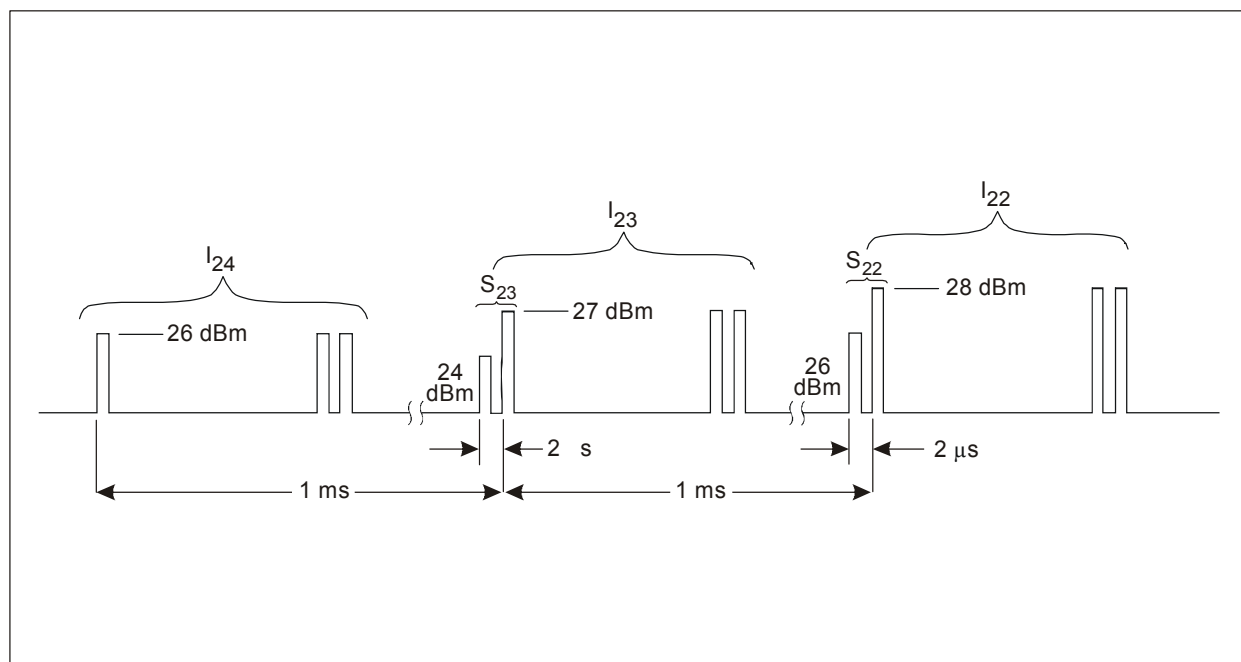


Figure 3-2. Example of timing for lowest power steps in omnidirectional whisper-shout sequence for top antenna

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 617 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 ± 61 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 ± 61 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 15.2 m (50 ft) and retained computational accuracy of at least 1.83 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:

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

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

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:

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

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:

232 m (760 ft) if coasted last interval	+	if track is not established: 0 if track is established: 610 m (2 000 ft), if 0.00 NM $\leq$ r < 315 m (0.17 NM) 305 m (1 000 ft), if 315 m (0.17 NM) $\leq$ r < 611 m (0.33 NM) 183 m (600 ft), if 611 m (0.33 NM) $\leq$ r < 1 852 m (1.00 NM) 73.2 m (240 ft), if 1 852 m (1.00 NM) $\leq$ r < 2 778 m (1.50 NM) 0 ft, if 2 778 m (1.50 NM) $\leq$ r
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- f) if the track is above 3 048 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 30.5 m (100 ft) divided by 16. The altitude prediction is rounded to the nearest 30.5 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 ± 61 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 pair wise to determine whether 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 152 m (500 ft);
- b) the range rates differ by at most 4.58 m/s (8.9 kt); and
- c) either:
 - 1) the altitudes differ by at most 30.5 m (100 ft); or
 - 2) the altitude rates differ by at most 3.0 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 61 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 20.6 m/s (40 kt), where the calculated image range rate is either (for the single-reflection case):

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

or (for the double-reflection case):

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

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 s). 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 s. 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 or 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 3 048 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 3 048 m (10 000 ft) relative altitude boundary, the altitude of targets that are beyond 3 048 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 3 048 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 s 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 5 s for use in IL. 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 152 m (500 ft) of each other and within 3 048 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-s surveillance update interval, an estimated time to collision (TAU) for the target is calculated as follows:

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

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 -3.09 m/s (-6 kt) or positive (either a slow convergence or the aircraft are diverging), the $\dot{r}$ value used to calculate TAU is -3.09 m/s (-6 kt). An SMOD value of 5.6 km ensures that ACAS will always use the nominal 1-s 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 s is interrogated at the nominal rate of once every second. A target with a TAU value greater than 60 s is interrogated at a rate of once every 5 s if the altitude of the target and own aircraft are both less than 5 486 m (18 000 ft) and at a rate of at least once every 5 s if the altitude of the target or own aircraft is greater than 5 486 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-s surveillance update intervals following receipt of the last valid reply to a tracking interrogation if the target is interrogated once every 5 s. 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-s surveillance update intervals following receipt of the last reply to a tracking interrogation whose rate is once every 5 s 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 4 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 IL 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 km² (0.3 aircraft per NM²) 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 ERP 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 3-3a defines a whisper-shout sequence that is matched to the requirements for high-density Mode A/C surveillance, and Figure 3-3b 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 3-3a 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 3-3b is reduced in power to limit interference, each interrogation and its related minimum triggering level (of the TCAS receiver) (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 3-2 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 3-3a and Figure 3-3b 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 ERP for the interrogation. All power levels are to be within ± 2 dB of nominal. The tolerance of the step increments is to be $\pm 1/2$ 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.

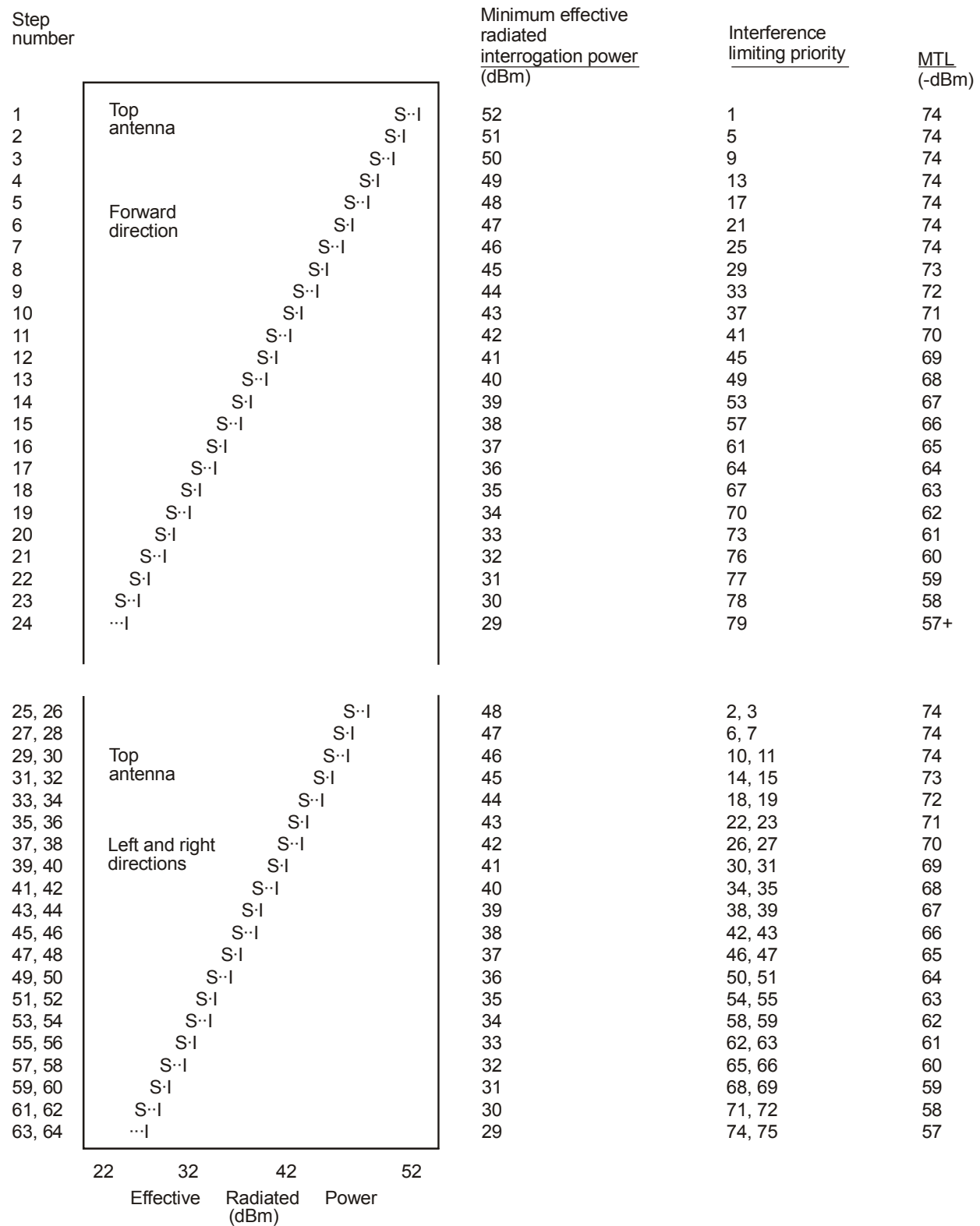
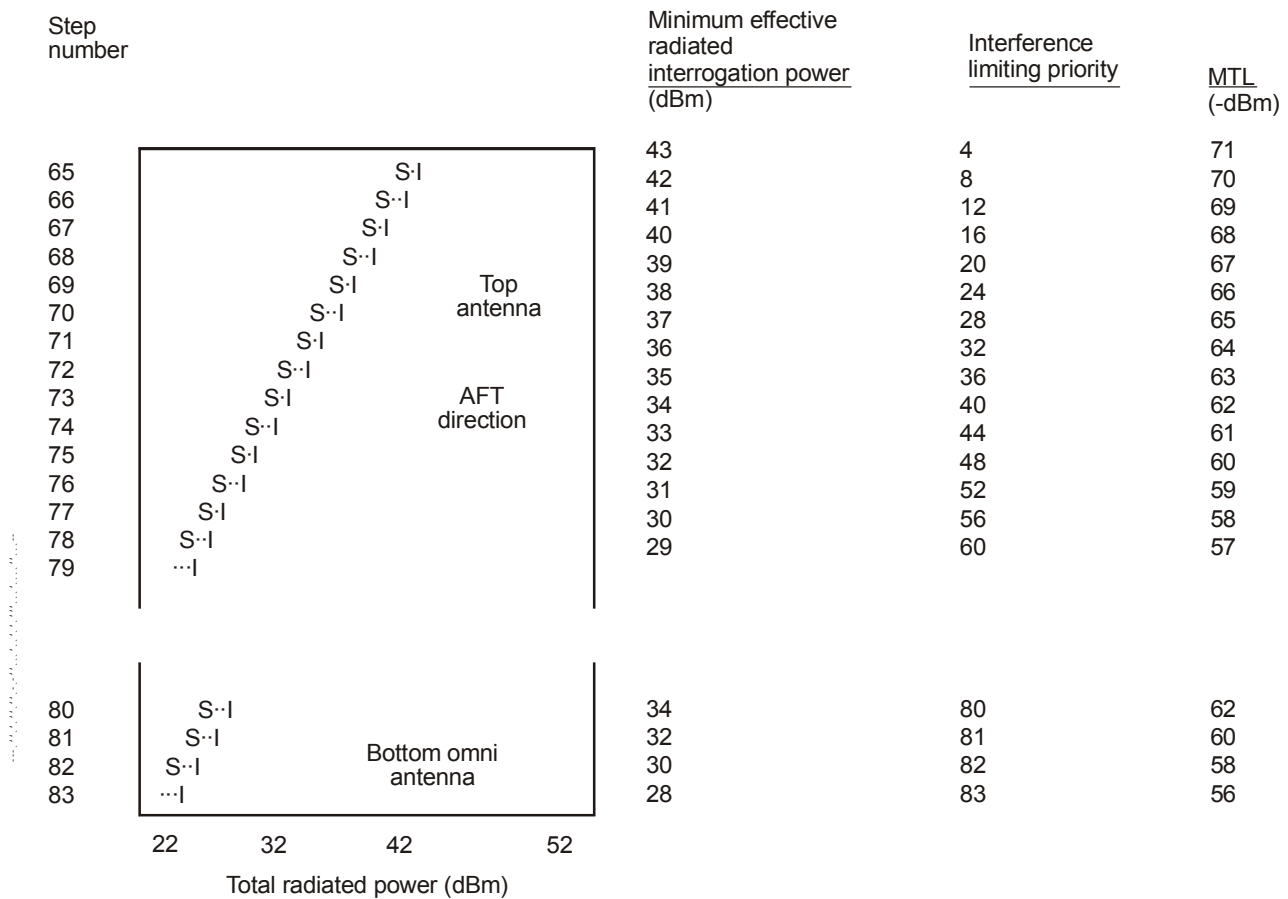


Figure 3-3a. Example of high-density whisper-shout sequence



Notes:

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

“S” indicates ERP of 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 3-3a. Example of high-density whisper-shout sequence (cont.)

Step number		Minimum effective radiated interrogation power (dBm)	Interference limiting priority	MTL (-dBm)
1	Top antenna Forward direction	S.....	Note: Each 1 dB reduction in the sequence follows the priority for the forward beam in Figure 3-3a.	74
2		S.....		74
3		S.....		72
4		S.....		68
5		S.....		64
6				60
7, 8	Top antenna Left & Right direction	S.....	Note: Each 1 dB reduction in the sequence follows the priority for the forward beam in Figure 3-3a.	74
9, 10		S.....		74
11, 12		S.....		72
13, 14		S.....		68
15, 16				64
				60
17	Top antenna Rear direction	S.....	Note: Each 1 dB reduction in the sequence follows the priority for the rear beam in Figure 3-3a.	71
18		S.....		67
19		S.....		63
20				59
16		S..	Note: Each 1 dB reduction in the sequence follows the priority for the bottom beam in Figure 3-3a.	62
17		S..		60
18		S..		58
19		..		56
		22 32 42 52		
		Min effective radiated power (dBm)		

Notes:

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

"S" indicates ERP of 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 3-3b. Example of low-density whisper-shout sequence

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 IL. 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 1 524 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 (IL)

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 5 486 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 5 486 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.

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

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

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

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; this shall include all Mode S interrogations used by the ACAS function, including those in addition to the UF = 0 and UF = 16 interrogations, except as provided in 4.3.2.2.2.1 of Annex 10, Volume IV.

Note.— UF = 19 interrogations are included in it as specified in 3.1.2.8.9.4 of Annex 10, Volume IV.

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

α = 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 $\text{Log}_{10} [n_a/n_b] / \text{Log}_{10} 25$, 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 11.1 km

(6 NM) and 5.6 km (3 NM), respectively, of own ACAS (based on ACAS surveillance). ACAS aircraft operating on the ground or 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 values of α , α^1 and α^2 are further constrained to a minimum of 0.5 and a maximum of 1.0.

In addition:

IF $[(n_b \leq 1) \text{ OR } (n_b \leq 4 \text{ AND } n_c \leq 2 \text{ AND } n_a > 25)]$ THEN $\alpha_i = 1.0$,

IF $[(n_c > 2) \text{ AND } (n_b > 2n_c) \text{ AND } (n_a < 40)]$ THEN $\alpha_i = 0.5$;

$p(i)$ = 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 ($\alpha = 1$) to uniform-in-range ($\alpha = 0.5$), 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 IL 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 IL 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 IL

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 km² (0.1 aircraft per NM²) 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 11.1 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 11.1 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 11.1 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 (30 NM) 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 ($n_b \leq 4$, $n_c \leq 2$, $n_a > 25$), 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 (ILPs)

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 α_2 according to the following expression:

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

In addition:

IF $[(n_b \leq 1) \text{ OR } (n_b \leq 4 \text{ AND } n_c \leq 2 \text{ AND } n_a > 25)]$ THEN $\alpha_1 = 1.0$;

IF $[(n_c > 2) \text{ AND } (n_b > 2n_c) \text{ AND } (n_a < 40)]$ 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 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 5 486 m (18 000 ft), both the Mode S and Mode