U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: AIRWORTHINESS AND OPERATIONAL APPROVAL OF TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEMS (TCAS II) AND MODE S TRANSPONDERS

Date: 10/3/88 **Initiated by:** ANM-110 **AC No:** 20-131 **Change:**

1. PURPOSE. This advisory circular (AC) provides guidance material for the airworthiness and operational approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S transponders. Like all AC material, this AC is not mandatory and does not constitute a regulation. It is issued for guidance purposes and to outline a method of compliance with the rules. In lieu of following this method without deviation, the applicant may elect to follow an alternate method, provided the alternate method is also found by the Federal Aviation Administration (FAA) to be an acceptable means of complying with the requirements of the Federal Aviation Regulations (FAR). Because the method of compliance presented in this AC is not mandatory, the terms "shall" and "must" used herein apply only to an applicant who chooses to follow this particular method without deviation.

2. RELATED DOCUMENTS.

a. Related Federal Aviation Regulations. Portions of the FAR, as presently written, can be applied for the design, substantiation, certification and operational approval of TCAS II and Mode S transponders. Sections which prescribe requirements for these types of systems include:

§ 25.301 Loads.
§ 25.303 Factor of safety.
§ 25.305 Strength and deformation.
§ 25.561 Emergency Landing Conditions--General.
§ 25.603 Materials.
§ 25.609 Protection of Structure.
§ 25.629 Flutter.
§ 25.1301 Function and installation.
§ 25.1303 Flight and navigation instruments.
§ 25.1307 Miscellaneous equipment.
§ 25.1309 Equipment, systems, and installations.
§ 25.1321 Arrangement and visibility.
§ 25.1322 Warning, caution, and advisory lights.
§ 25.1331 Instruments using a power supply.
§ 25.1333 Instrument systems.
§ 25.1335 Flight director systems.
§ 25.1351 Electrical systems and equipment: General.
§ 25.1353 Electrical equipment and installations.
§ 25.1355 Distribution system.
§ 25.1357 Circuit protective devices.
§ 25.1381 Instrument lights.

§ 25.1431 Electronic equipment.
§ 25.1541 Markings and placards.
§ 25.1581 Airplane Flight Manual: General.
§ 25.1585 Operating procedures.
§ 121.401 Training program: General.
§ 121.403 Training program: Curriculum.
§ 121.407 Training program: Approval of airplane simulators and other training devices.
§ 121.415 Crewmember and dispatcher training requirements.
§ 121.418 Differences training: Crewmembers and dispatchers.
§ 121.419 Pilots and flight engineers: Initial, transition, an upgrade ground training.
§ 121.427 Recurrent training.
§ 135.21 Manual requirements.
§ 135.323 Training program: General.
§ 135.325 Training program and revision: Initial and final approval.
§ 135.327 Training program: Curriculum.
§ 135.329 Crewmember training requirements.
§ 135.335 Approval of aircraft simulators and other training devices.
§ 135.345 Pilots: Initial, transition, and upgrade ground training.
§ 135.351 Recurrent training.

b. Advisory Circulars.

AC 20-115A Radio Technical Commission for Aeronautics Document RTCA/DO-178A.

AC 25.1309-1A System Design and Analysis.

AC 25-11 Transport Category Airplane Electronic Display Systems.

AC 120-XX Procedures and Criteria for Determining the Type Rating Requirements for an Aircraft.

c. Technical Standard Orders.

TSO-C112 Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment.

TSO-C119 Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS II.

d. Industry Documents.

(1) Radio Technical Commission for Aeronautics (RTCA) document DO-160B, Environmental Conditions and Test Procedures for Airborne Equipment; RTCA document DO-178A, Software Considerations in Airborne Systems and Equipment Certifications; RTCA document DO-181, Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment; RTCA document DO-185, Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance Systems (TCAS) Airborne Equipment. These documents can be obtained from the RTCA, One McPherson Square, Suite 500, 1425 K Street Northwest, Washington, D.C. 20005.

(2) Aerospace Recommended Practice (ARP) 926A, Fault/Failure Analysis Procedure; ARP 1834, Fault/Failure Analysis Guidelines for Digital Equipment; and ARP 1068A, Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft. These documents are available from the Society of Automotive Engineers, Inc. (SAE), 400 Commonwealth Drive, Warrendale, PA 15096.

3. DEFINITIONS. The following definitions are applicable to this AC.

a. Advisory. A message given to the pilot containing information relevant to collision avoidance.

b. Air traffic control (ATC). A generic term for a joint civil/military system for controlling traffic within a specific area.

c. Air traffic control radar beacon system (ATCRBS). A secondary surveillance radar system having ground-based interrogators and airborne transponders capable of operation on Modes A and C.

d. Alert. Indicator (visual or auditory) which provides information to the flightcrew in a timely manner about a nonnormal situation.

e. Corrective resolution advisory. A resolution advisory that advises the pilot to deviate from current vertical speed, e.g., CLIMB when the aircraft is level.

f. Failure. The inability of a system, subsystem, unit, or part to perform within previously specified limits.

g. False advisory. An advisory caused by a false track or a TCAS malfunction.

h. Intruder. A target that has satisfied the TCAS II threat detection logic and thus requires a traffic advisory.

i. Mode A. Type of secondary surveillance radar (SSR) equipment which provides a selected 4096 code reply (nonaltitude) when interrogated.

j. Mode C. Type of secondary surveillance radar (SSR) equipment which provides a reply with aircraft altitude information when interrogated.

k. Mode S. Type of secondary surveillance radar (SSR) equipment which provides replies to Mode A and Mode C interrogations and discrete address interrogations from the ground or air.

l. Preventive resolution advisory. A resolution advisory that advises the pilot to avoid certain deviations from the current vertical speed because certain vertical speed restrictions exist.

m. Proximate traffic. Nearby aircraft which are neither an RA nor a TA.

n. Resolution advisory (RA). Oral and visual information provided to the flightcrew to avoid a potential collision.

o. Resolution display. A display which depicts caution or warning areas above or below the TCAS equipped aircraft.

p. Sense. A direction that a resolution advisory may take: Either UP or DOWN relative to existing flight path of own aircraft.

q. Threat. A target that has satisfied the threat detection logic and thus requires a resolution advisory.

r. Traffic. An aircraft within the surveillance range of TCAS.

s. Traffic advisory (TA). Information given to the pilot pertaining to the position of another aircraft in the immediate vicinity. The information contains no resolution information.

t. Traffic display. A display of the horizontal position of transponder equipped aircraft relative to the TCAS equipped aircraft.

4. SCOPE. The material provided in this AC addresses the design aspects, characteristics, mechanization, testing, training, and the criticality of system failure cases for TCAS II and Mode S transponders. The guidance material is directed at systems which provide traffic advisories and resolution advisories in the vertical axis only (TCAS II) and where the operational performance standards are defined in technical documents that were developed by a joint air transport industry/government group (RTCA Special Committee SC-147).

5. BACKGROUND. The airline industry has been working through the Air Transport Association since 1955 to find a workable collision avoidance system. It was not until the mid-1970s, however, that research centered upon the use of signals from ATCRBS airborne transponders as the cooperative element of a collision avoidance system. This technical approach allows a collision avoidance capability on the flightdeck which is independent of the ground system. In 1981, the FAA announced its decision to proceed with the implementation of an aircraft collision avoidance concept called the Traffic Alert and Collision Avoidance System (TCAS). The concept is based upon agency and industry development efforts in the areas of beacon-based collision avoidance systems and air-to-air discrete address communications techniques utilizing Mode S airborne transponder message formats.

A short time later, prototypes of TCAS II were installed on two Piedmont Airlines B-727 aircraft, and were flown on regularly scheduled flights. Although the displays were located outside the view of the flightcrew and were seen only by trained observers, these tests did provide valuable information on the frequency and circumstances of alerts and their potential for interaction with the ATC system. On a follow-on phase II program, a later version of TCAS II was installed on a single Piedmont Airlines B-727, and the system was certified in April 1986 and subsequently approved for operational evaluation in early 1987. Since the equipment was not developed to full standards, the system was only operated in visual meterological conditions. Although the flightcrew operated the system, the evaluation was primarily for the purpose of data collection and its correlation with flightcrew and observer observation and response.

Later versions of TCAS II manufactured by Bendix/King Air Transport Avionics Division were installed and approved on United Airlines airplanes in early 1988. Similar units manufactured by Sperry Dalmo Victor (SDV) are expected to be installed and approved on Northwest Airlines airplanes in late 1988. This Limited Installation Program will operate TCAS II units approved for operation as a full time system in both visual and instrument meteorological conditions on four different aircraft types. The operational evaluation programs are expected to continue through 1988 and to validate the operational suitability of the systems.

6. SYSTEM DESCRIPTION. The TCAS II is an airborne traffic alert and collision avoidance system that interrogates ATC transponders in nearby aircraft and uses computer processing to identify and display potential and predicted collision threats. The system is designed to protect a volume of airspace around the TCAS II equipped aircraft. The system will provide appropriate aural and visual advisories to the flightcrew to provide adequate separation when the computer analysis of the intruding aircraft transponder replies predict a penetration of the protected airspace. The system provides two types of advisories. Traffic advisories indicate the relative positions of intruding aircraft that are approximately 40 seconds from the closest point of approach and may a short time later require a resolution advisory. They also provide the flightcrew the opportunity to visually acquire the intruding aircraft. A resolution advisory will produce a threat resolution in the form of a vertical maneuver that will increase separation when the computer predicts the intruder aircraft is within approximately 25 seconds from the closest point of approach.

The system provides two types of flightdeck displays. A traffic advisory display indicates the relative position of proximate ATC transponder equipped aircraft. A resolution advisory display for each pilot indicates the appropriate vertical maneuver to avoid a threat. The TCAS II aircraft must be equipped with a Mode S ATC transponder which provides air-to-air communications for coordinating the resolution maneuvers between TCAS equipped aircraft. The Mode S transponder also provides discrete address replies to interrogations from ground stations and other TCAS II equipped aircraft as well as the capability to respond to Mode A and Mode C ATCRBS interrogations.

The TCAS II system can only generate resolution advisories for intruders equipped with operative Mode S or Mode C transponders, which provide information on the altitude of the intruder. Traffic advisories which display the relative position of the intruder can be generated for aircraft with operative Mode S, Mode C or Mode A transponders. The TCAS II equipment is viewed as a supplement to the pilot who, with the aid of the ATC system, has the primary responsibility for avoiding mid-air collisions. The TCAS II system provides no indication of traffic conflicts with aircraft without operative transponders.

7. AIRWORTHINESS CONSIDERATIONS.

a. Certification Program. This AC provides guidance for the installation of TCAS II equipment and Mode S transponders. The system displays information and provides advisories in a number of formats. The degree of system integration to perform these functions is extensive and as a result, the applicant's program must be directed toward airworthiness approval through the type certification or supplemental type certification process.

b. Certification Plan. A comprehensive certification plan should be developed by the applicant. It should include how the applicant plans to comply with the applicable certification requirements and should provide a listing of the substantiating data and necessary tests. Also, a system description and an estimated time schedule should be included. A well developed plan will be of significant value both to the applicant and the FAA.

c. Equipment Installation.

(1) Mode S Transponder. A Mode S transponder is required for TCAS II operation. It is an enhanced version of existing ATCRBS transponders that is interoperative and compatible with the current ATCRBS system. Each aircraft equipped with a Mode S transponder is assigned a discrete address code. Mode S also provides the air-to-air data link between TCAS II equipped aircraft to coordinate resolution maneuvers. This ensures that the resolution advisory displayed in one TCAS II equipped aircraft is compatible with the maneuver displayed in the other TCAS II equipped aircraft. It has the capability to provide a data link between the equipped aircraft and the ground, and performs all the functions of current Mode A and C transponders. A Mode S transponder may be installed independently or in conjunction with a TCAS II installation. The performance standard for Mode S is provided in paragraph (a)(1), Minimum Performance Standard, of Technical Standard Order (TSO)-TSO-C112. The discrete aircraft address for the Mode S transponder must be obtained from the FAA Aeronautical Center, Oklahoma City, Oklahoma, prior to installation in each U.S. registered aircraft.

(2) Pilot Control.

(i) A means to select the following modes of operation must be provided.

(A) Operation of the Mode S transponder only.

(B) Operation of the TCAS II and Mode S transponder simultaneously.

(C) Operation of the ATCRBS transponder only, if installed. It must not be possible to operate the TCAS II and ATCRBS transponder or the Mode S and ATCRBS transponder simultaneously.

(D) Operation of TCAS II in the TA only mode (sensitivity level 2).

(E) A means to select the standby mode (sensitivity level 1).

(F) A means to select the assigned ATCRBS code.

(G) A means to initiate the transponder "IDENT" function.

(H) A means to initiate the TCAS II self-test (flight deck location optional).

(I) A means to supress transponder altitude reporting.

(ii) The following optional controls may be provided.

(A) Selection of the weather radar only.

(B) Control to select the display of traffic within selected altitude bands.

(C) Selection of the weather radar and traffic display simultaneously.

(D) Selection of actual or relative altitude of traffic.

(3) Antennas. The active Mode S transponder shall have a top and bottom omni-directional antenna. The TCAS II shall have a top directional antenna and a bottom omni-directional or directional antenna.

(i) Directional antennas. For an aircraft installation, the TCAS II directional antenna should be located on the top forward fuselage as close to the centerline as possible. If more than one directional antenna is provided, locate the second antenna in a similar manner on the lower fuselage. The TCAS II antennas should be mounted on the aircraft with at least 20 db. isolation from other L-band frequency antennas. Since the antenna diameter may be large, some structural considerations may be necessary and a centerline offset resulting in an angular offset of up to 5 degrees is acceptable. The maximum height of the directional antenna is expected to be approximately 1 inch, and therefore is not considered susceptible to icing effects in the general area of the proposed installation. Otherwise, anti-icing provisions should be considered. Section 3 of Volume I of Document RTCA/DO-185 provides antenna selection and performance criteria. For rotorcraft and turboprop aircraft, the location and performance of the directional antenna must be investigated for minimum blockage and to ensure that the rotors or propellers do not interfere with system operation.

(ii) Omni-directional antennas. The TCAS II antennas should be mounted on the aircraft with at least 20 db. isolation from other L-band frequency antennas. The Mode S transponder antennas shall be mounted at locations chosen for adequate isolation and signal coverage. These antennas may be standard ATCRBS transponder antennas.

(iii) Structural analysis. A structural analysis of the antenna installations showing compliance with the applicable FAR should be submitted to the FAA. This includes the structural provisions for a beam steering unit (if installed) if it is not mounted in a standard avionics rack.

(4) The TCAS II Processor. The TCAS II processor unit computes information to identify and to display potential and predicted collision targets, and to issue resolution advisories to avoid the intruder. The TCAS II processor unit must comply with the environmental requirements and minimum performance standards specified in TSO-C119. A manufacturer of TSO equipment may obtain authorization to produce equipment which deviates from the detailed criteria of the TSO. The FAA aircraft certification office which is approving the initial installation of the TCAS II equipment must verify that the TCAS II processor design does not differ from the criteria specified in RTCA Document DO-185, Volumes I and II, Changes 1 through 5, Minimum Operational Performance

Standards for Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment and FAA Report Number DOT/FAA/FA-88/3, Required Modifications to the Traffic Alert and Collision Avoidance System (TCAS II) Minimum Operational Performance Standards (MOPS).

(5) Equipment Compatibility. An evalution should be made to show that the TCAS II system will communicate with other approved TCAS II systems made by other manufacturers. This evaluation should include a TCAS II to TCAS II coordination demonstration, or equivalent, with at least one other manufacturer's approved TCAS II system. If it can be shown for a specific design that communication link failures are no more hazardous than encountering a Mode C intruder, then these tests are not necessary. Also, after completing mature bench tests, future certification experience may show that these tests are no longer necessary.

(6) Aircraft Performance.

(i) An aircraft's climb capability when operating at or near its maximum approved operating altitude is affected by the available excess thrust and aircraft kinetic energy (ability to safely trade airspeed for climb rate). Discrete information shall be provided to TCAS II to indicate the all-engine climb limit capability of the aircraft in which TCAS II is installed. The inhibit of a climb RA should not be enabled at high altitude if the aircraft has adequate performance available. Adequate performance includes the following conditions or considerations.

(A) Critical weight and altitude combination at 1.3g to buffet onset.

(B) Long range cruise speed.

(C) Perform a 1500 feet per minute climb for 30 seconds.

(D) The minimum speed during the maneuver must be the higher of 1.2 V_S or buffet onset.

(E) The ability to accelerate and return the aircraft to the initial speed and altitude (an undershoot of approximately 200 feet is permissible).

(ii) An aircraft's low altitude climb capability during takeoff, approach or landing is significantly affected by the aircraft's configuration, initial climb speed (kinetic energy) and the initial airspeed margin from the current stall speed. A means must be provided to inhibit TCAS II "climb" and for TCAS II "increase climb" RAs whenever these TCAS II maneuvers cannot be safely accomplished. Engine-out considerations are not required.

NOTE: It is expected that certain low speed commuter transport aircraft will be required to inhibit both TCAS II "climb" and "increase climb" RAs whenever the flaps are not retracted. It is also expected that most air carrier turbojet transports will be required to inhibit the "increase climb" RA whenever the flaps are not retracted.

(A) The following conditions or considerations apply for the takeoff/initial climb analysis.

1 Maximum takeoff gross weight.

2 Maximum takeoff power.

3 Highest (largest deflection) approved takeoff flap setting.

4 Initial airspeed (at RA) 1.4 V_{S1}.

5 From the initial steady state climb, rotate the airplane at 1.25g to attain + 1500 feet per minute and hold + 1500 feet per minute for 20 seconds. Recover at 0.75g to attain -1500 feet per minute until reaching the original climb speed.

6 The minimum acceptable airspeed during the RA portion of the maneuver is 1.2 V_{S1}.

NOTE: The total duration of the RA should be 25 seconds.

(B) The following conditions or considerations apply in determining if an inhibit is required for the increased climb RA.

1 Conditions 1 through 4 apply from paragraph 7c(6)(ii)(A) above.

2 Initial steady state climb at 1.4 V_{S1}.

3 Rotate the aircraft at 1.25g to attain + 1500 feet per minute climb and hold for 10 seconds. Then rotate at 1.25g to attain + 2500 feet per minute climb and hold until the total duration of the RA (25 seconds) has elapsed. Recover at 0.75g to -1500 feet per minute descent to acquire the original climb speed.

4 The minimum acceptable airspeed during the RA portion of the maneuver is 1.2 V_{S1}.

(C) The following conditions or considerations apply for the preapproach flap configurations when operating in the terminal area. In this case, the flaps are less than normal approved approach flaps.

1 Conditions 5 and 6 of paragraph 7c(6)(ii)(A) and conditions 3 and 4 of paragraph 7c(6)(ii)(B) apply.

2 Maximum landing weight.

3 Maximum go-around power.

4 Landing gear retracted.

5 Flaps less than normal approved, approach flaps.

6 Initial airspeed 1.6 V_{S1}.

(D) The following conditions or considerations apply for the landing configuration. It may be assumed that when a climb RA occurs when the aircraft is in the landing configuration, the pilot will initiate a go-around procedure when complying with the TCAS II RA.

1 Conditions 5 and 6 of paragraph 7c(6)(ii)(A) and conditions 3 and 4 of paragraph 7c(6)(ii)(B) apply.

2 Maximum landing weight.

3 Maximum go-around power.

4 Approach flaps.

5 Landing gear retracted.

6 Initial airspeed 1.4 V_{S1}.

7 Aircraft Interfaces.

(i) Pressure altitude information. The pressure altitude data should be obtained from the most accurate source available in the aircraft and shall correspond to that being transmitted by the associated Mode S transponder. The accuracy of the altitude data shall be at least that specified in Appendix A of RTCA DO-185. It shall be shown that the resolution of the altimetry source is compatible with TCAS II. The altitude source with the finest compatible resolution should be used. The resolution should be in increments of 10 feet or less. Information should also be provided to indicate when the pressure altitude information is invalid.

(ii) Radio altitude information. Radio altitude information shall be provided to TCAS II to inhibit DESCEND resolution advisories below 700 feet AGL, INCREASE DESCEND resolution advisories below 1800 feet AGL, all resolution advisories below 500 feet AGL, and aural traffic advisories below 400 feet AGL, to allow automatic sensitivity level selection when close to the ground, and to determine that individual targets are on the ground. Information shall also be provided to indicate when the radio altitude information is invalid.

(iii) Discrete information such as flaps, slat, landing gear, etc., should be provided to ensure that the TCAS II logic can consider the aircraft performance capability described in paragraph 7c(6).

(iv) Aircraft identification. Discrete information shall be provided to the Mode S transponder for the unique aircraft Mode S identification code.

(v) Attitude. Information of pitch and roll attitude may be provided to assist with stabilization of the directional antenna function to assure surveillance and TA display data remain unaffected by aircraft normal maneuvers. If attitude information is used by TCAS II, the information shall also be provided to indicate when the attitude data are invalid.

(vi) Heading. Information of aircraft heading may be provided for use of surveillance reference and for the TA display reference presentation. Information shall also be provided to indicate when the heading data are invalid.

(vii) System failure display. A display should be provided to indicate when resolution advisories are not possible due to failure of the TCAS II equipment or any of its sensors or displays.

(8) Traffic Display.

(i) Purpose. The primary purpose of the traffic display is to aid the flightcrew in the visual acquisition of threat aircraft. This is accomplished by displaying the intruder aircraft's horizontal and vertical position relative to the TCAS II equipped aircraft. The TCAS II systems will provide traffic information on Mode A (no altitude data available), Mode C, and Mode S transponder equipped aircraft. A secondary purpose of the traffic display is to provide the flightcrew with confidence in proper system operation and to give them time to prepare to maneuver the aircraft in the event TCAS II issues a resolution advisory.

(ii) Description. The traffic display may take several forms. Traffic displays may be independent, stand-alone, integrated and time-shared with digital color radar, integrated with the flightcrew's Instantaneous Vertical Speed Indicators (IVSI), or integrated with other displays such as Electronic Horizontal Situation Indicators (EHSI), navigation, or other multi-function displays. If the traffic display uses a multi-function display that is shared with other services such as ACARS, a TA or RA condition must preempt all other shared services.

(iii) Symbology/Feature Criteria. The FAA has worked closely with industry, NASA, and pilots with TCAS experience in an effort to standardize TCAS II symbology and features. A consensus has been reached for many TCAS II symbols and they are provided in this AC. Other symbology and features may be used provided the applicant uses human factors technology to demonstrate that a clear and substantial benefit can be derived by its use. Otherwise, the traffic display must depict or provide the following symbology, features, or information:

(A) Own Aircraft Symbol. This should be an aircraft-like symbol. For fixed range displays, it should be located so as to provide a minimum of 3NM range to six o'clock position (indicating the intruder is 3NM behind the TCAS II equipped aircraft) and a minimum of 6NM range to the twelve o'clock position (indicating the intruder is 6NM in front of the TCAS II equipped aircraft). The symbol color should be white, or cyan and should be the same color as the range ring.

(B) The Threat Aircraft at the Traffic Advisory (TA) Level. This symbol should be shaped as a circle and should be solid amber in color. This symbol must be positioned to depict its relative bearing and distance to the TCAS II aircraft.

(C) The threat aircraft at the resolution advisory (RA) level. This symbol should be shaped as a square and it should be solid red in color.

(D) Proximate Aircraft. When a TA or RA is present, a symbol should be depicted for ATC transponder equipped aircraft within + 1200 feet relative altitude and 6NM (or the minimum range, whichever is less). This symbol should be shaped like a diamond and colored solid white or cyan but not the same color as own aircraft symbol. It is required to display proximate traffic only when the requirements to display a TA or an RA exist. The display of proximate traffic under these circumstances will assist the pilot in the detection of the intruder aircraft. Proximate traffic may also be displayed even when no TA or RA exists.

(E) Other Traffic. Other nonthreat traffic may be displayed. This symbol should be shaped as an open diamond and should be the same color as proximate traffic.

(F) Relative Altitude Display. Relative altitude is the difference between the intruder's altitude and the TCAS II equipped aircraft's altitude. This should be presented in a digital format rounded off to the nearest one hundred feet. This digital information should be centered on the threat aircraft symbol and positioned above or below the threat symbol when the threat aircraft is above or below the TCAS II aircraft respectively. The digital data should include a leading zero and a plus or minus sign as appropriate. For example, -05 positioned below the threat symbol would indicate the threat aircraft is 500 feet below the TCAS II aircraft. This digital data should conform to the color of the threat aircraft symbol. Coaltitude situations should be depicted as "00" (without the + or - symbol).

(G) The Range "Ring". There should be markings surrounding the own aircraft symbol at each of the twelve o'clock positions. These markings may be small dots, small lines or indices, or asterisks. A solid range ring is not recommended due to clutter. This range ring should have a radius of 2NM. The entire range ring must be depicted, and the color should be the same as own aircraft symbol.

(H) Off Scale Symbology. A symbol should depict the threat aircraft at the TA and RA levels whenever the threat aircraft exceeds the displayed range on the traffic display. This symbol shall be indicated by placing one half of the appropriate symbol, with a full data tag, at the edge of the active display area in the direction of the measured bearing of the target. Alternate symbology for displays other than compensated vertical speed indicators is an arrow located at the target bearing with the relative altitude next to the arrow.

(I) No Bearing Display. When the TCAS II system uses a bottom omni-directional antenna and the upper directional antenna loses track on the intruder aircraft, the threat aircraft can no longer be depicted on the traffic display with the correct bearing. However, the relative altitude (if available) and range should be digitally presented. This information must be colored to conform to the threat level (amber for TAs and red for RAs). In addition, a "NO BRG" message (as appropriate to the threat level) should be presented with target data such as "TA 1.2 - 06" (a target creating a TA at 1.2NM, 600 feet below and climbing) or "RA 0.6 00" (a target creating an RA at 0.6NM coaltitude) tabulated below the caption.

(J) Mode A Transponder Equipped Aircraft. A data tag shall not be associated with the symbol for targets which are not reporting altitude. Note that an RA will not be generated for targets not reporting altitude.

(K) Intruder Vertical Speed. A vertical arrow should be located immediately to the right of the relative altitude display if the vertical speed of the intruder is equal to or greater than 500 feet per minute with the arrow pointing up for climbing traffic and down for descending traffic. The color of the tag should be the same as the symbol.

(L) TA Only Mode. The ability to inhibit the RA mode of operation should be provided to prevent unwanted RAs. This feature should be pilot selectable, and suitably annunciated.

(iv) Optional Features/Symbology.

(A) Compass Heading. Aircraft heading and/or a compass rose may be included in the traffic display, and it should be colored white.

(B) Actual Intruder Altitude. A means to depict the traffic's pressure altitude or flight level may be provided. This information may replace the relative altitude information but must be appropriately labeled to preclude misinterpretation. Automatic reversion to relative altitude is required in the event of a TA or RA. The displayed intruder altitude may be compensated by use of own aircraft altimeter setting.

(C) Automatic Range Reversion. For traffic displays that incorporate a variable range feature, the means to automatically revert to a desired fixed range when a TA occurs may be provided. This feature may be required depending upon the maximum range selectable, the number of targets displayed and the flightcrew's ability to correctly view and interpret the intruder information.

(D) Maximum Number of Displayed Targets. There currently are no requirements to establish a maximum number of displayed targets when TA or RA conditions do not exist. However the pilot's ability to rapidly and correctly interpret intruder information can be reduced by unnecessary nonthreat targets. Traffic displays with less than 12 square inches should be limited to a maximum of four targets when a TA or RA is presented to ensure readability of the relative altitude tag. The logic for displaying traffic should be as follows:

1 Display all RA traffic - then

2 Display all TA traffic - then

3 Display proximate traffic in order of range from own aircraft. Only the closest proximate traffic in the aft quadrant need be considered.

NOTE: Once a target is displayed, it should not be removed until the TA or RA condition no longer exists.

(E) Traffic Display Switch. A switch may be provided which will display all traffic within the range of the display and within 2700 feet

vertically of own aircraft. This switch may be either momentary or a lock-on type of switch.

(F) Extended Altitude Surveillance Switch. A switch may be provided to select the viewing of traffic from 2700 feet below own aircraft to the upper limit of surveillance and the viewing of traffic from 2700 feet above own aircraft to the lower limit of surveillance.

(9) Resolution Display.

(i) Purpose. The purpose of the resolution display is to provide each pilot with the information to readily correct the aircraft flight path or to prevent a maneuver that could cause insufficient vertical separation.

(ii) Description. The resolution display may be integrated with the two primary IVSIs on the flightdeck. These displays depict arcs in the vertical speed scale that must be avoided in order to maintain safe vertical separation. The pilot's task is to maneuver the aircraft promptly to achieve a vertical speed just out of the illuminated arc or to maintain a vertical speed out of the illuminated arc if currently not in it.

(iii) Symbology. The resolution display must depict a red illuminated arc for corrective RAs. Corrective RAs should also depict a green "fly to" symbol; for example, when a climb RA is issued on a round dial IVSI, a red colored arc should be depicted (adjacent to the IVSI scale) from -6000 FPM to +1500 FPM and a green arc from +1500 FPM to approximately 2100 FPM. The resolution display must also depict an illuminated arc to be avoided for preventive RAs. A green "fly to" arc is not required in this case since the current aircraft vertical speed is satisfactory. The color of the preventive should be red.

(iv) Warning flags must be provided for TCAS failures (TCAS or unable to generate RAs) and the TA only mode. Electrical IVSI failures must also be indicated if the resolution display is associated with the IVSI.

(v) Resolution advisories should be inhibited below 500 feet AGL.

(10) Caution/Warning Lights.

(i) Discrete caution and/or warning lights may be installed which are separate from the traffic display. The purpose of these additional indicators is to annunciate the presence of potentially threatening intruder aircraft at times when the pilot's attention may be diverted from the primary TCAS display. Two different discrete TCAS II annunciators have been used:

(A) A discrete amber caution indicator which annunciates the presence of a TCAS II TA. Installation of this discrete caution message is optional. If installed, the caution light should be inhibited below 400 feet AGL.

(B) A discrete red warning indicator which annunciates the presence of a TCAS II RA. This red warning must be located in the pilot's primary field of view and is a required part of TCAS II. An IVSI with a lighted

red arc, or an alphanumeric message on the Electronic Attitude Direction Indicator is acceptable in lieu of discrete warning indicators.

(ii) Because of the numerous TCAS II advisories expected in service, the basic aircraft master caution and warning system should not be interfaced with these TCAS II caution/warning discretes. Overuse of the primary aircraft caution and warning system would tend to reduce its effectiveness in annunciating non-TCAS II system failures.

(iii) Discrete visual alerts should remain on until cancelled by the pilot or until the intruder is no longer considered a threat by TCAS II.

(11) Aural Alerts.

(i) Each TCAS II aural alert should be annunciated by a dedicated voice message over a cockpit speaker at a volume adequate for clear understanding at high cockpit noise levels, but not excessively loud at low noise levels. The evaluation includes the case where a flight crewmember is wearing a headset, when appropriate.

(ii) The TCAS TA should be annunciated by the voice message "TRAFFIC, TRAFFIC," stated once and then inhibited until the next TA.

(iii) The TCAS II resolution advisories should be annunciated by the following voice messages, as appropriate:

(A) "CLIMB, CLIMB, CLIMB" (Climb at the rate shown on the IVSI or other suitable indicator.)

(B) "DESCEND, DESCEND, DESCEND" (Descend at the rate shown on the IVSI or other suitable indicator.)

(C) "VERTICAL SPEED RESTRICTED, VERTICAL SPEED RESTRICTED" (Assure that vertical speed is out of the illuminated IVSI arc, or complies with another suitable indicator.)

(D) "REDUCE VERTICAL SPEED, REDUCE VERTICAL SPEED" (Reduce vertical speed to a speed out of the illuminated arc.)

(E) "MAINTAIN VERTICAL SPEED, MAINTAIN VERTICAL SPEED" (Safe separation is based upon maintaining the current vertical speed.)

(F) "CLEAR OF CONFLICT" (Range is increasing, and separation is adequate; return to assigned clearance.)

(G) "CLIMB, CROSSING CLIMB, CLIMB, CROSSING CLIMB" (Safe separation will best be achieved by climbing through the intruder's flight path.)

(H) "DESCEND, CROSSING DESCEND, DESCEND, CROSSING DESCEND" (Safe separation will best be achieved by descending through the intruder's flight path.)

(iv) The following voice messages are required to annunciate enhanced TCAS II maneuvers when the initial RA does not provide sufficient vertical separation. These messages must connote increased urgency.

(A) "INCREASE CLIMB, INCREASE CLIMB" (Received after "CLIMB" advisory, and indicates additional climb rate required to achieve safe vertical separation from a maneuvering intruder.)

(B) "INCREASE DESCENT, INCREASE DESCENT" repeated 2 times. (Received after "DESCEND" advisory, and indicates additional descent rate required to achieve safe vertical separation from a maneuvering intruder.)

(C) "CLIMB - CLIMB NOW, CLIMB - CLIMB NOW" (Received after a "DESCEND" resolution advisory and indicates a reversal in sense is required to achieve safe vertical separation from a maneuvering intruder.)

(D) "DESCEND - DESCEND NOW, DESCEND - DESCEND NOW" (Received after a "CLIMB" resolution advisory and indicates a reversal in sense is required to achieve safe vertical separation from a maneuvering intruder.)

(v) All TCAS II aural alerts must be inhibited below 400 feet AGL.

(vi) Both increases and decreases in the threat level must be aurally annunciated. However decreases in threat level need only be annunciated once, e.g., a vertical speed restriction which follows a climb RA should only be annunciated once.

(vii) In general, other messages which are clear and unambiguous will be evaluated on an individual basis. Messages which use negatives should not be used (e.g., "DON'T CLIMB").

d. Software Verification and Validation. The verification and validation of TCAS II software using the procedures outlined below are required for the first installation of a manufacturer's TCAS II equipment. These procedures shall also be applied to subsequent software changes to a manufacturer's TCAS II equipment. A manufacturer may provide a design that partitions the software which affects resolution advisories from other software (level 3) such as that necessary for the traffic display. If the partitioned software is initially approved by the FAA, verification and validation for the level 3 software may be accomplished by the TCAS II manufacturer using the minor change authority of the TSO system.

(1) The verification and validation of the TCAS II software represents a unique challenge because the collision avoidance algorithms, commonly called "CAS logic," as contained in Volume II of Document RTCA/DO-185 represents a software design specification. However, the surveillance software necessary to establish and maintain the relative tracks of nearby transponder equipped aircraft and the software necessary to provide the interface with the Mode S transponder and with other aircraft sensors and displays must be developed by the manufacturer of the TCAS II equipment. This hybrid approach to the specification of the software requirements and design does not permit the direct application of the software criteria contained in Document RTCA/DO-178A. The CAS logic has been provided by Volume II of RTCA/DO-185.

(2) If software is used for the displays of TCAS II resolution advisories or in the operation of the Mode S transponder data link, the verification and validation of this software should be done to level 2, as defined in Document RTCA/DO-178A. These procedures should also be applied where the TCAS II manufacturer develops the software requirements for the TCAS II processor associated with functions other than the CAS logic. Where the software design is specified by Volume II of Document RTCA/DO-185, the manufacturer of the TCAS II processor should conduct code walk-throughs and develop and perform module tests and module integration tests to verify that the specified software design has been implemented correctly.

(3) The functional tests required by TSO C-119 as described in Volume I of Document RTCA/DO-185, do not provide complete testing for the TCAS II processor software. The TCAS II manufacturer must develop additional functional tests which correspond to the detailed requirements which it develops for the TCAS II processor. The potential consequences of software errors on the TCAS II processor require that the manufacturer provide a structural coverage analysis to show complete test coverage of all instructions at the source code. This may be accomplished by a combination of module tests, module integration tests and functional tests.

(4) Equipment produced in accordance with a technical standard order may have obtained FAA concurrence that the software for the equipment was produced in accordance with the criteria of Document RTCA/DO-178A for a particular software level. Nevertheless, it is the responsibilty of the applicant who first installs a manufacturer's TCAS II equipment in an aircraft to demonstrate to the appropriate FAA aircraft certification office (ACO) that the system software used for the TCAS II equipment, Mode S transponder and new sensors and displays necessary to provide resolution advisories has been developed in accordance with the criteria outlined above. Data from the TSO process may be sufficient to establish that the appropriate verification and validation has been accomplished, but the ACO may require additional tests and analysis of the software for the installed TCAS II system. Subsequent installations of the same TCAS II equipment on other aircraft types do not require any additional verification if the software is not changed.

e. System Safety Analyses. A false resolution advisory has the potential of causing a mid-air collision. Failures of the TCAS II equipment and its associated sensors and displays which could provide a false resolution advisory must be improbable. This should be established using the methods described in AC 25.1309-1A, System Design and Analysis. It is expected that a failure modes and effects analysis (FMEA) and a quantitative probability analysis of the TCAS II equipment, Mode S transponder, and altitude information source will be necessary to establish that an incorrect resolution advisory is improbable. For the purposes of a numerical analysis, the probability of an incorrect resolution advisory without a TCAS II failure indication should be on the order of 1.0×10^{-5} per flight hour in the enroute environment and 1.0×10^{-4} per flight hour in the terminal area. The frequency of encounters which would produce a resolution advisory can be assumed to be once per 200 hours in the enroute enviroment and once per 10 hours in the terminal area, unless the applicant can establish different frequencies based on operational data. These analyses should be provided for the first installation of a particular model of TCAS II equipment. Subsequent installations of the same equipment in other aircraft may

make use of the same analyses with particular attention to the differences in altitude sensors.

f. Test and Evaluation (Initial Approval). Testing of the first of a manufacturer's TCAS II system for its initial approval in an aircraft should be conducted to verify that the design and installation performs its intended function under the expected operating conditions, that there are no adverse interactions between the TCAS II and existing aircraft systems, and that prior approvals of present aircraft equipment have not been compromised. The applicant should provide a test plan that includes adequate testing to perform this verification. This test plan will generally require a combination of ground tests, basic flight tests, and flight tests involving planned encounters with another TCAS II equipped aircraft. The use of other than a transport category aircraft for either the TCAS II installation or for the air-to-air cooperative flights is acceptable. The test plan should contain, as a minimum, the following elements:

(1) Ground Tests.

(i) Bearing Accuracy Tests. Bearing estimation accuracy of the TCAS II system shall be demonstrated as installed in the aircraft. The bearing accuracy may be measured using a calibrated antenna range that allows precise echo-controlled, far-field, angle-of-arrival measurements at or slightly above zero degrees elevation and over 360 degrees in azimuth. The bearing accuracy may also be measured using a fixed transponder location while rotating the test aircraft on a compass-rose while measuring the bearing angles at 30 degree intervals. Alternately, the airplane is fixed and the transponder may be rotated. Manual readout of the bearing estimate may be accomplished directly from a plan position display on the traffic advisory display. Alternatively, the bearing estimates may be automatically recorded or may be read from a special test display. A maximum error of + 15 degrees in azimuth is acceptable; however, larger errors are acceptable in the area of + 45 degrees from the tail and the area is not visible form the cockpit. In this case, aircraft structure may interfere with the signal path.

(ii) Sensor failures. Simulated failures of the aircraft sensors integrated with TCAS II should be evaluated to determine that the resulting system failure state agrees with the predicted results. These tests should be part of the ground test plan.

(iii) Elecromagnetic Interference (EMI). A flightdeck EMI survey should be made to determine that the TCAS II equipment is not a source of objectionable conducted or radiated interference to previously installed systems or equipment, and that operation of the TCAS II equipment is not adversely affected by conducted or radiated interference from previously installed systems and equipment. Attention should be given to possible interference with TCAS II equipment from weather radar, particularly if operating in the C-band.

(iv) Evaluate the general arrangement and operation of controls, displays, circuit breakers, annunciators, and placards of the TCAS system.

(v) Self Test. Evaluate the TCAS self test features and failure mode displays and annunciators.

(vi) Verify that the pressure altitude source and radio altimeter are properly interfaced with the TCAS equipment.

(vii) Prior to any cooperative flight tests at any altitude involving the TCAS II equipped aircraft and another aircraft, both aircraft should be flown in close formation to assure matched altimetry readouts. These checks should be flown at the speeds and altitudes to be used for the tests.

(viii) Verify the performance of TCAS II traffic display by observing any available area traffic.

(ix) Evaluate the TCAS II system installation for satifactory identification, accessibility, and visibility during both day and night conditions.

(x) Determine that any configuration discretes associated with the TCAS II logic operate properly. (Changes in logic or function with aircraft configuration, altitude, or speed.)

(2) Basic Flight Tests.

(i) During all phases of flight, determine if there is any mutual interference with any other aircraft system. Weather radar should be operating during the flight test.

(ii) Evaluate TCAS II aural messages for acceptable volume and intelligibility during both low and high cockpit noise levels (idle descent at low speed, and high power at V_{MO}) with and without headsets. If the TCAS II TEST is used to simulate voice announcements, insure that the audio level is not changed by use of the TEST function.

(iii) Demonstrate that traffic information remains valid and usable when the aircraft is pitched and rolled during normal maneuvers by observing area traffic in the traffic advisory display.

(iv) Evaluate the effective surveillance range of the traffic display, including target azimuth reasonableness and track stability. Use of targets of opportunity or a nontransport (low-speed) aircraft as a target for these tests is permissible.

(v) Determine that any configuration discretes associated with the TCAS II logic operate properly unless previously demonsrated during ground tests. (Changes in logic or function with aircraft configuration, altitude, or speed.)

(vi) Perform the flight tests necessary to verify that the aircraft performance considerations of paragraphs 7c(6)(i) and (ii) have been properly implemented for the aircraft/engine combination for which the approval is sought. These aircraft performance considerations address the inhibit of climb RAs at high altitude at certain aircraft conditions and the inhibit of climb and increased climb RAs at certain aircraft configurations and conditions during low altitude terminal area operation.

(vii) Evaluate TCAS for noninterference during coupled Autopilot and Flight Director approaches to the lowest minimums approved for the aircraft.

(viii) Verify the GPWS warnings and TCAS II voice alerts are compatible. Also, verify that GPWS warnings can be clearly understood when TCAS II voice announcements simultaneously occur. If TCAS II and GPWS aural warnings have been prioritized, insure that GPWS has the higher priority.

(ix) Evaluate all selectable modes of the TCAS II to determine that they perform their intended function.

(x) Reevaluate any previously installed aircraft systems that have required changes as a result of the TCAS II installation. (e.g., EFIS, FD, PFD, ND, IVSI, interface, etc.)

(3) Planned Encounter Flight Tests. The objective of these flight tests is to demonstrate adequate TCAS II surveillance and to verify smooth, predictable TCAS II performance. Having established appropriate safety rules, static system leak test (if necessitated by having opened the system), and altimeter correlation between the encounter aircraft and the TCAS aircraft, the following encounters between the TCAS II aircraft and a dedicated intruder aircraft should be flown to insure that the TCAS II aircraft system performs its intended function by generating TAs and RAs and is consistent with RTCA/DO-185. The intruder aircraft should be equipped with transponders capable of Mode A, Mode C, and for those tests making it necessary, Mode S, and TCAS II. These tests are also intended to expose the installed TCAS II system to a reasonable number of carefully controlled encounters which are likely in service. This matrix covers the envelope of encounter speeds, altitudes, and geometries which have in the past identified flaws in surveillance, logic, and antenna mechanization that were not detected earlier by bench tests.

(i) Intruder overtaking TCAS II aircraft (from the aft quadrants).

(ii) Head-on.

(A) Low and high closure speeds.

(B) Above climb limit, TCAS II to TCAS II.

(C) TCAS II against Mode C with TCAS II above intruder and above climb limit (intent is to force TCAS II aircraft to descend.)

(D) At 3000 feet over calm water to evaluate multipath protection.

(iii) Converging.

(iv) Crossing (intruder above TCAS II, descending or vice versa.)

(v) Evaluate the TA only mode during planned encounters.

(vi) A mix of intruder transponder modes (A, C, and S) should be evaluated, but primary emphasis should be on TCAS II to TCAS II coordination, and on Mode C replies from the intruder aircraft.

(vii) Evaluate a mix of encounters with TCAS II both above and below the intruder.

(viii) If a flight test is necessary to insure compatibility with other designs, verify correct air-to-air coordination between the test TCAS II and another manufacturer's previously approved equipment (see paragraph 7c(5)).

(ix) Evaluate the effect of electrical transients (bus transfer), during encounters. The TCAS II should not experience adverse effects. No false TAs or RAs should be generated as a result of electrical transients. Normal TCAS II functions and displays should be restored within approximately 3 seconds.

(4) Mode S Transponder Flight Tests. The flight tests desribed by this section may be used to obtain the certification of a stand-alone Mode S transponder installation. These tests should also be used to evaluate a Mode S transponder which is intended for use with a TCAS II installation. The purpose of these tests is to primarily verify that the installed antenna(s) are compatible with the Mode S transponder and provide an adequate response to ground radar interrogations during normal aircraft maneuvers. In addition, the flight test is a demonstration that the Mode S transponder functions properly as installed and does not interfere with other aircraft electronic equipment. The need for a detailed flight test is reduced when the Mode S Transponder and antenna installation is identical or similar to that of previously approved ATCRBS transponder installation.

(i) If the Mode S transponder uses a single antenna which is installed at or near the same location used by a previously approved ATCRBS transponder antenna, the test aircraft should be at a point 80NM or more from the nearest ATCRBS ground facility at a high enough altitude to be within line-of-sight of the ground station. The transponder code, altitude reporting and "IDENT" features of the transponder should be exercised while the aircraft is flown through a 360 degree turn in the cruise configuration. There should be no transponder dropouts, uncontrollable ringing, or other objectionable behavior observed by the ground controller.

(ii) If the Mode S transponder uses a top mounted antenna in addition to a bottom mounted antenna located at or near the same location used by a previously approved ATCRBS transponder antenna, conduct the flight test of paragraph 7f(4)(i) above and in addition, fly the aircraft to a point at least 10NM from the nearest ATCRBS ground facility at the minimum obstruction clearance altitude or 2000 feet above the ground radar antenna height, whichever is higher. The proper operation of the spatial diversity of the top mounted antenna should be demonstrated by flying a 360 degree turn with a 30 degree bank angle with the landing gear down and the flaps in the landing configuration. There should be no transponder dropouts or other objectionable behavior observed by the ground controller.

(iii) If a Mode S transponder is installed in an aircraft which does not have a previously approved ATCRBS transponder installation or which uses a bottom mounted antenna location which differs significantly from that used by a previously approved ATCRBS transponder antenna, the following flight tests should be conducted.

(A) Climb and Distance Coverage. Beginning at a distance of at least 10NM from, and an altitude of 2000 to 3000 feet above that of the radar facility and using a transponder code assigned by the ATC, fly on a heading that will pass the aircraft over the facility. At a distance of 5 to 10NM beyond the facility, fly the aircraft at its normal maximum climb attitude to within 90 percent of the maximum altitude for which the aircraft is certificated, maintaining the aircraft at a heading within 5 degrees of the track from the radar facility. After reaching the maximum altitude for which the aircraft is certificated, fly level at the maximum altitude to 160NM for turbojet and some turboprop powered airplanes (or 80NM for most other aircraft) from the nearest radar facility. Communicate with the ground radar personnel for evidence of transponder dropout. During the flight, check the "ident" mode of the ATC transponder to assure that it is performing its intended function. There should be no dropouts (no return for two or more sweeps). Uncontrollable ringing that hinders use of the ground radar is unsatisfactory.

(B) Long Range Reception. At 90 percent of maximum certificated altitude perform left and right 360 degree turns, at bank angles of 8 - 10 degrees. The aircraft should be at least 160 (or 80)NM from the nearest radar facility. During these turns, the radar displays should be monitored and there should be no signal dropouts.

(C) High Angle Reception. Perform two 360 degree turns, one to the right and one to the left, at bank angles of 8 to 10 degrees with the airplane at a distance of 50 to 70 NM from the nearest radar facility and at an altitude of at least 35,000 feet or within 90 percent of the maximum altitude for which the aircraft is certificated. There should be no dropouts. Switch the transponder to a code not selected by the ground controller. The aircraft secondary return should disappear from the scope. The controller should then change his control box to "common sense" and a single slash should appear on the scope at the aircraft's position.

(D) High Altitude Cruise. Within 90 percent of the aircraft's maximum certificated altitude or its maximum operating altitude beginning at a point 160 (or 80)NM from the nearest radar facility fly on a course which will pass over the radar facility. There should be no transponder dropout or "ring-around".

(E) Surveillance Approach. Beginning at or above 90 percent of the maximum certificated altitude of the aircraft, perform a letdown and approach to a runway of an airport served by Airport Surveillance Radar (ASR) having an ATCRBS facility. The approach should be made at the maximum normal rate of descent and normal approach and landing configuration for the aircraft and should continue down to an altitude of 200 feet or less above the ground radar antenna elevation. Not more than one dropout should occur for any 10 sweeps during final approach. Uncontrolled ringing that hinders use of the ground radar is unsatisfactory.

(F) Holding and Orbiting Patterns.

1 At an altitude of 2000 feet above the radar antenna or minimum obstruction clearance altitude (whichever is greater) with landing flaps and gear extended, fly left and right 360 degree turns approximately 10 miles from the radar facility. There should be no signal dropouts.

2 At an altitude of 2000 feet above the radar antenna or minimum obstruction clearance altitude (whichever is greater) fly 45 degree sectors of left and right 10 mile orbital patterns around a radar facility with gear and landing flaps extended. There should be no signal dropouts.

(G) Altitude Reporting. Conduct a functional test of the altitude encoder by comparison with ATC-displayed altitudes. Verify correspondence at several altitudes between ATC readings and the Captain's altimeter, when set at or corrected to 29.92 inches of mercury.

g. Follow-On Approvals (STC or Amended TC). Flight testing of TCAS II systems for follow-on approvals (previously approved TCAS II equipment installed in a different aircraft type) should be conducted to verify that the design and installation performs its intended function under the expected operating conditions, that there are no adverse interactions between the TCAS II and existing aircraft systems, and that prior approvals of present aircraft equipment have not been compromised. The applicant should provide a flight test plan that includes adequate testing to perform this verification. This test plan will generally require a combination of ground tests, basic flight tests, and flight tests involving planned encounters with a Mode C equipped aircraft, or the use of a suitably located fixed transponder. The test plan should contain, as a minimum, the following elements:

(1) Ground tests.

(i) Evaluate the general arrangement and operation of controls, displays, circuit breakers, annunciators, and placards of the TCAS II system.

(ii) Evaluate the TCAS II self test features and failure mode displays and annunciators.

(iii) Verify that the air data computer and radio altimeter are properly interfaced with the TCAS II equipment.

(iv) Evaluate the performance of the directional antenna for 360 degrees coverage at 30 degree intervals.

(v) Evaluate the TCAS II system installation for satisfactory identification, accessibility, and visibility during both day and night conditions.

(vi) Determine that any configuration discretes associated with the TCAS II logic operate properly. (Changes in logic or function with aircraft configuration, altitude, or speed.)

(2) Flight Tests.

(i) Proper operation of the traffic display should be verified by observing proximate traffic, at least one traffic advisory and at least one resolution advisory. Confirm that the appropriate aural alerts occur correctly with the traffic advisory and resolution advisory. The advisories may be generated by:

(A) Planned encounters with an intruder aircraft operating a transponder with Mode C capability.

(B) Encounters with an operating Mode C transponder installed at a fixed ground location which reports an appropriate test altitude.

(C) Encounters with aircraft targets of opportunity.

(D) The use of suitable test equipment, during ground tests.

(ii) During all phases of flight, determine if there is any mutual interference with any other aircraft system.

(iii) Evaluate TCAS II aural messages for acceptable volume and intelligibility during both low and high cockpit noise levels (idle descent at low speed, and high power at V_{MO}) with and without headsets. If the TCAS II TEST is used to simulate voice announcements, insure that the audio level is not changed by use of the TEST function.

(iv) Evaluate the effective surveillance range of the traffic display, including target azimuth reasonableness and track stability. Use of a nontransport (low-speed) Mode C equipped aircraft as a target or a fixed transponder or suitable test equipment for these tests is permissible.

(v) Evaluate the Mode S transponder air-to-ground ATCRBS function against an appropriate ground facility.

(vi) Determine that any configuration discretes associated with the TCAS II logic operate properly unless previously demonstrated during ground tests. (Changes in logic or function with aircraft configuration, altitude, or speed.)

(vii) Perform the flight tests necessary to verify that the aircraft performance considerations of paragraphs 7c(6)(i) and (ii) have been properly implemented for the aircraft/engine combination for which the approval is sought. These aircraft performance considerations address the inhibit of climb RAs at high altitude at certain aircraft conditions and the inhibit of climb and increase climb RAs at certain aircraft configurations and conditions during low altitude terminal area operation.

(viii) Evaluate TCAS II for noninterference during coupled Autopilot and Flight Director approaches to the lowest minimums approved for the aircraft.

(ix) Verify the GPWS warnings and TCAS II voice alerts are compatible. Also, verify that GPWS warnings can be clearly understood when TCAS

II voice announcements and GPWS simultaneously occur. If TCAS II and GPWS aural warnings have been prioritized, ensure that GPWS has the higher priority.

(x) Evaluate all selectable modes of the TCAS II to determine that they perform their intended function.

(xi) Reevalute any previously installed aircraft systems that have required changes as a result of the TCAS installation (e.g., EFIS, FD interface, etc.)

h. Airplane Flight Manual Supplement (AFMS). The AFMS should provide the appropriate system limitations and emergency procedures and a comprehensive description of all normal modes of operation including what actions are expected by the flightcrew in each case. Appendix 1 provides an example of the elements and extent of detail that may be shown by a typical AFMS (specific performance data and procedures may vary with system design and aircraft type).

8. OPERATIONAL APPROVAL.

a. How to Obtain Operational Approval. In order for TCAS II to be used in air carrier service (Part 121 and Part 135 operators), operational approval must be obtained from the Office of Flight Standards, Air Transportation Division. Requests for approval should be submitted to the responsible FAA Aircraft Evaluation Group (AEG) at the time TCAS II certification (TC or STC) application is made. The AEG personnel will conduct TCAS II system evaluations and submit findings to the Office of Flight Standards, Air Transportation Division, for recommended flightcrew qualification and training program approval. The AEG will also submit to the Office of Flight Standards, Air Transportation Division, for approval, TCAS II inoperative items to be included in the appropriate Master Minimum Equipment List.

b. Ground Training.

(1) A detailed description of the equipment, components, and modes of operation of TCAS II should be reviewed with the flightcrew. This discussion should specifically emphasize, but may not be necessarily limited to the following items:

(i) TCAS II control panel.

(ii) Traffic display.

(iii) Resolution display.

(iv) Warning displays.

(v) Caution displays (if installed).

(vi) Aural warning system equipment.

(2) A discussion of the FAA approved Airplane Flight Manual (AFM) TCAS II limitations including:

(i) Nontransponder-equipped aircraft.

(ii) Air traffic control interaction.

(iii) Procedures for returning to previous clearance after responding to a TCAS II advisory.

(3) An overview of the operational procedures associated with the use of TCAS II. The training program should include a detailed discussion of the normal and nonnormal procedures included in the AFM.

(i) Each feature of the TCAS II traffic display should be explained in sufficient detail to ensure that the flightcrew is aware of what actions, if any, are required.

(ii) The resolution display should be explained in sufficient detail to ensure that the flightcrew is aware of what actions, if any, are required.

(iii) The TCAS displays and the aural annunciations should be explained in sufficient detail to ensure that the flightcrew is completely aware of what actions, if any, are required.

c. Flight Training.

(1) Experience with this type of device has indicated a need to ensure the complete transfer of system knowledge from the classroom to the cockpit. Due to the uniqueness of this device and its associated functions and displays, the training program should include some type of real time interactive capability. This would allow the flightcrew to experience the dynamics of the TCAS II displays and to reinforce the classroom discussions. Technology exists for computer-based, interactive training devices. The training program should include a definitive method of ensuring that the flightcrew demonstrate a complete understanding of the potential use of TCAS II.

(2) Flightcrew training should be accomplished in a simulator or equivalent Advanced Training Device (ATD) that has been approved by the FAA. If the training program does not include a simulator or ATD, the applicant must demonstrate that equivalent training is accomplished by the use of other training aids and/or devices. All substitute training methods, which may include flight training instructors, training aids and/or devices, will be evaluated individually by the FAA and a determination made as to their acceptability.

(3) The following items are to be covered on both initial, transition and differences training and at least once annually during recurrent training/proficiency checks for both pilot in command and second in command:

(i) Controls and indicators.

(ii) System operations.

(iii) Recognition and proper reaction to significant failures of the system.

(iv) AFM limitations.

(4) If the training program does not include a simulator or ATD, an alternate training method must be developed and presented for approval to the FAA to confirm an adequate level of knowledge and understanding of TCAS II. It is highly recommended that this validation process include some type of interactive training device.

Thomas E. McSweeny

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APPENDIX 1

AIRPLANE FLIGHT MANUAL SUPPLEMENT

DESCRIPTION

The TCAS II is an on-board collision avoidance and traffic situation display system with computer processing to identify and display potential and predicted collision targets, and issue vertical resolution advisories on the pilot's and copilot's instantaneous vertical speed indicator (IVSI) to avoid conflict. From the transponder replies, TCAS II determines relative altitude, range, and bearing of any aircraft equipped with a Mode C or S transponder. From this, TCAS II will determine the threat using standardized algorithms. Threat aircraft with Mode A transponders will not provide altitude information; therefore TCAS II will not issue resolution advisories for these threats. The TCAS II will not detect aircraft without transponders.

The TCAS II has three cockpit displays: one dedicated cathode ray tube (CRT) for traffic advisories (TA) and two modified IVSIs for resolution advisories (RA). The TA is informative and indicates potential threats approximately 40 seconds prior to closest approach. The RA displays a threat resolution in the form of a vertical maneuver if the potential conflict is projected to occur within approximately 25 seconds.

The TCAS II is a single system installation consisting of one TCAS II processor, one top-mounted high resolution bearing antenna, one bottom-mounted blade antenna, one Mode S transponder with control panel, one traffic advisory display with control panel, two resolution advisory displays, caution/warning indicators, one overhead speaker for voice messages and associated wiring.

The TCAS II provides two levels of threat advisories:

> If the traffic gets within approximately 40 seconds of projected Closest Point of Approach (CPA), it is then considered an intruder, and an aural and visual traffic advisory is issued. This level calls attention to a developing collision threat using the traffic advisory display (CRT) and the voice message, "TRAFFIC TRAFFIC." It permits mental and physical preparation for a possible maneuver to follow, and assists the pilot in achieving visual acquisition of the threat aircraft.
>
> If the intruder gets within approximately 25 seconds of CPA, it is considered a threat and an aural and visual resolution advisory is issued. This level provides a recommended vertical maneuver using modified IVSIs and voice messages to provide adequate vertical separation from the threat aircraft, or prevents initiation of a maneuver that would place the TCAS II aircraft in jeopardy.

The TCAS II will resolve multiple aircraft encounters. The TCAS II is considered a back-up system to the "SEE-AND-AVOID" concept and the ATC radar environment.

The TCAS II resolution advisories should be annunciated by the following voice messages, as appropriate:

(A) "CLIMB, CLIMB, CLIMB" (Climb at the rate shown on the IVSI or other suitable indicator.)

(B) "DESCEND, DESCEND, DESCEND" (Descend at the rate shown on the IVSI or other suitable indicator.)

(C) "VERTICAL SPEED RESTRICTED, VERTICAL SPEED RESTRICTED" (Assure that vertical speed is out of the illuminated IVSI arc, or complies with another suitable indicator.)

(D) "REDUCE VERTICAL SPEED, REDUCE VERTICAL SPEED" (Reduce vertical speed to a speed out of the illuminated arc.)

(E) "MAINTAIN VERTICAL SPEED, MAINTAIN VERTICAL SPEED" (Safe separation is based upon maintaining the current vertical speed.)

(F) "CLEAR OF CONFLICT" (Range is increasing, and separation is adequate; return to assigned clearance.)

(G) "CLIMB, CROSSING CLIMB, CLIMB, CROSSING CLIMB" (Safe separation will best be achieved by climbing through the intruder's flight path.)

(H) "DESCEND, CROSSING DESCEND, DESCEND, CROSSING DESCEND" (Safe separation will best be achieved by descending through the intruder's flight path.)

The following voice messages are required to annunciate enhanced TCAS II maneuvers when the initial RA does not provide sufficient vertical separation. These messages must connote increased urgency.

(A) "INCREASE CLIMB, INCREASE CLIMB" (Received after "CLIMB" advisory, and indicates additional climb rate required to achieve safe vertical separation from a maneuvering intruder.)

(B) "INCREASE DESCENT, INCREASE DESCENT" repeated 2 times. (Received after "DESCEND" advisory, and indicates additional descent rate required to achieve safe vertical separation from a maneuvering intruder.)

(C) "CLIMB - CLIMB NOW, CLIMB - CLIMB NOW" (Received after a "DESCEND" resolution advisory and indicates a reversal in sense is required to achieve safe vertical separation from a maneuvering intruder.)

(D) "DESCEND - DESCEND NOW, DESCEND - DESCEND NOW" (Received after a "CLIMB" resolution advisory and indicates a reversal in sense is required to achieve safe vertical separation from a maneuvering intruder.)

All TCAS II aural alerts are inhibited below 400 feet AGL.

Figure 1

TCAS/TRANSPONDER CONTROL PANEL

TCAS/Transponder Function Selector
TEST - Holding the TCAS/Transponder function selector in TEST for 2 to 3 seconds will activate the system test sequence. In the TEST position, maintenance messages may be read on the display. Discretion must be used when selecting TEST in flight, since both TCAS and the Transponder will be inhibited for approximately 20 seconds. The function selector is spring loaded to STBY.

STBY - Activates TCAS and XPDR warmup cycles.

XPDR - Transponder is on. TCAS is in warmup cycle.

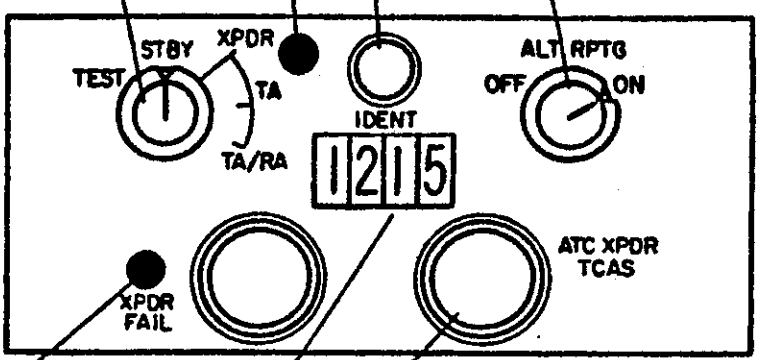
TA - Transponder is on. Only the "TRAFFIC ADVISORY", or "TA", function of TCAS is on. No "RESOLUTION ADVISORIES" will be received in this position. The written warning "TA ONLY" will appear on the display, and the yellow "RA OFF" flag will be in view on both IVSI's.

TA/RA - Transponder is on. All TCAS functions are on. No TCAS flags should be present on either IVSI.

Warning Light (Amber)
Indicates both transponders are on.

IDENT Button
Causes the word IDENT to flash in the aircraft data block on the ATC display.

ALT RPTG Selector
Provides automatic altitude reporting to ATC.



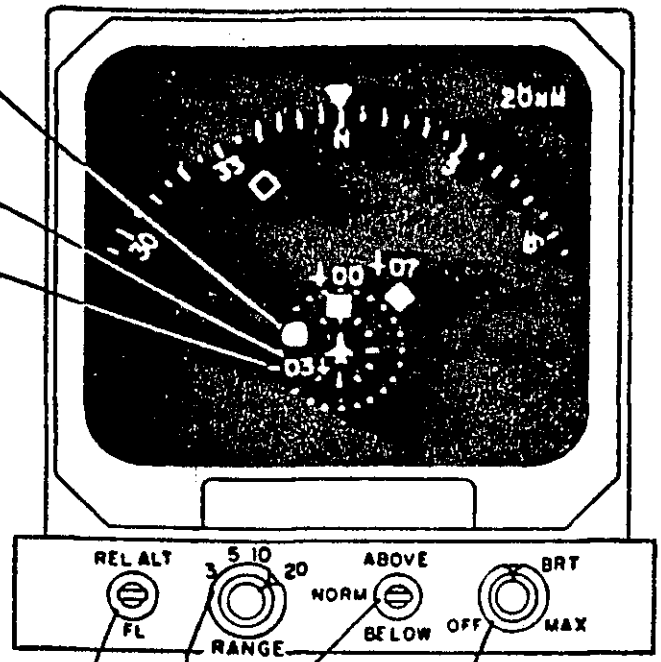
XPDR FAIL Light (Red)
Indicates a transponder system failure when the transponder is on. Comes on during *"TEST"*, but goes off after approximately 3 seconds if the transponder is OK.

Code Indicator
Indicates code selected with the code selectors.

Code Selectors
Select the transponder code. Left and right selectors consist of a large knob and a small knob. Each controls one digit of the code.

Figure 2

TCAS - TRAFFIC DISPLAY



(↑) and (↓)
Arrows indicate that the target is climbing (↑) or descending (↓) at a rate of at least 500 fpm.

Relative Altitude
In hundreds of feet.

(+) and (-)
A "+" preceding the relative altitude block indicates the target is above you, and a "-" indicates it is below.

Target Aircraft Symbols (Examples)

- Unfilled white diamond. Non-threatening traffic without altitude reporting.

+07 - Solid white diamond. Proximity traffic 700 feet above, climbing. Non-threatening, altitude reporting traffic within 1200 feet vertically and 4nm horizontally. Aircraft without altitude reporting will be assumed to be co-altitude and will be displayed as a solid diamond when within 4nm even though they may not be within 1200 feet vertically.

-03 - Solid yellow circle. "TA", 300 feet below, descending.

+00 - Solid red square. "RA", level at your altitude.

Paddle Switch REL ALT/FL Switch
REL ALT - Paddle switch is spring loaded to the center position. Display shows REL ALT in hundreds of feet above (+) or below (-) your aircraft.

FL - Momentary contact allows display of traffic flight levels, referenced to 29.92, for 15 seconds. Your FL is displayed in lower left corner. Three digits are shown, except for negative flight levels which are shown as -XX (example -03 is negative 300 feet)

TCAS RANGE
The compass arc is always set at range selected by the range knob. Ranges of 3, 5, 10 or 20 nm are selected.

BRT Knob
Controls brightness of the display.

ABOVE NORM BELOW Switch
ABOVE - Displays altitude reporting traffic from 2700 feet below to 7000 feet above.

NORM - Displays altitude reporting traffic from 2700 feet below to 2700 feet above.

BELOW - Displays altitude reporting traffic from 2700 feet above to 7000 feet below.

OWNSHIP
Airplane symbol in white just below the center of CRT.

COMPASS ARC
This arc is a repeater of the Captains compass.

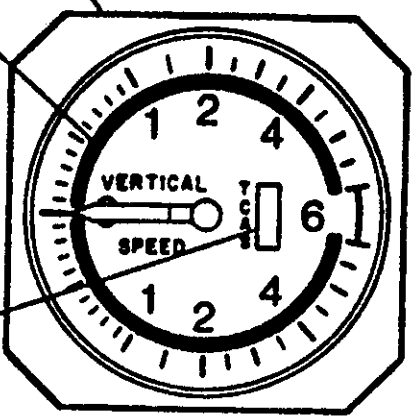
RANGE RINGS
2 nm - Small ring with ticks at clock positions. 5 NM - Large ring made of dots.

Figure 3

TCAS INSTANTANEOUS VERTICAL SPEED INDICATOR

INSTANTANEOUS VERTICAL SPEED INDICATOR
Indicates vertical speed in feet per minute.

RED/GREEN EYEBROW LIGHTS
Eyebrow lights are invisible until they come "on" as part of a TCAS "RESOLUTION ADVISORY", or system "TEST". These lights come "on" to indicate a vertical speed regime which will provide safe traffic separation.



IVSI STATUS WINDOW FLAGS

BLACK - Normal operation.

RED FLAG - Indicates unuseable TCAS information.

YELLOW "RA OFF" FLAG - Always displayed when TCAS/Transponder function selector is in STBY or TA. Will also be displayed with selector in RA/TA if "RAs" are inhibited and/or inoperative.

NOTE
The IVSI is a normal instantaneous vertical speed indicator, and the presence of the lights or the flags will not interfere with the ability of the needle to indicate vertical speeds.

Figure 4

TCAS EXAMPLES

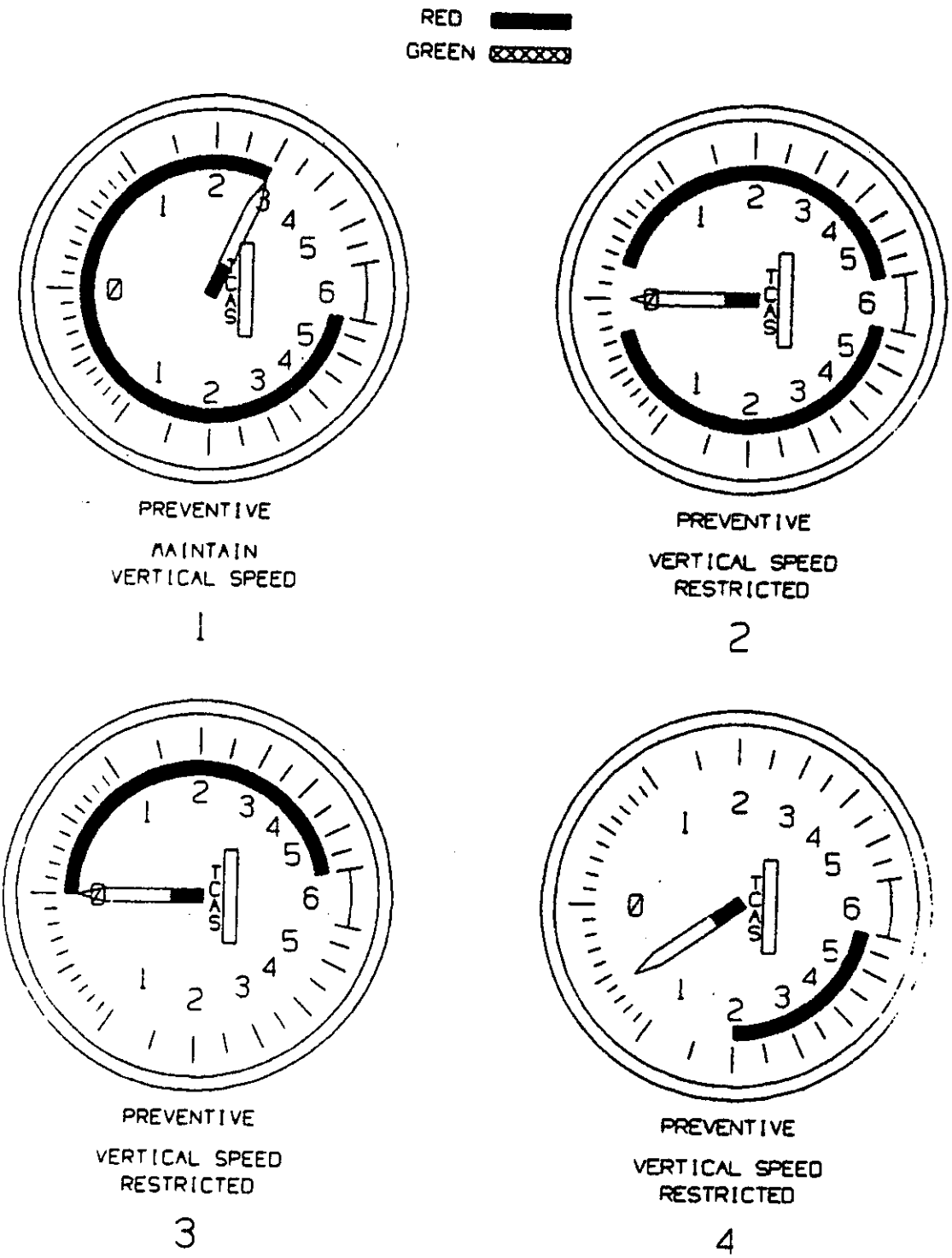
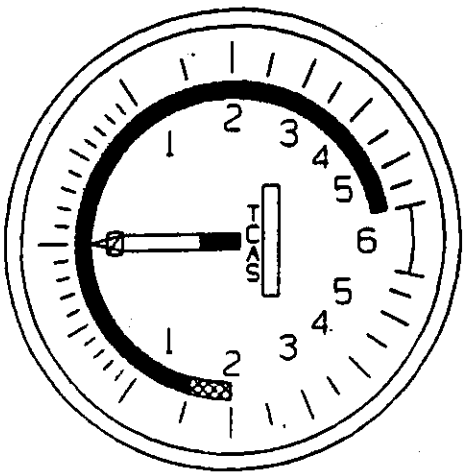


Figure 5

TCAS EXAMPLES

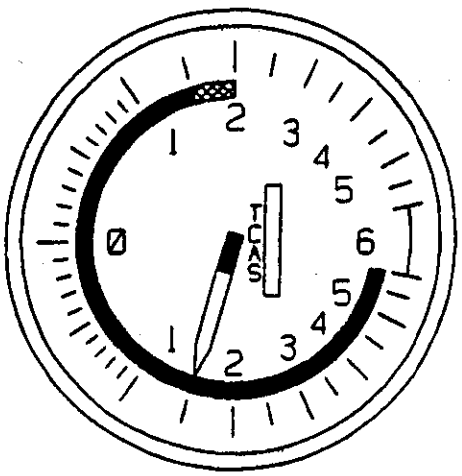
RED
GREEN



CORRECTIVE

DESCEND

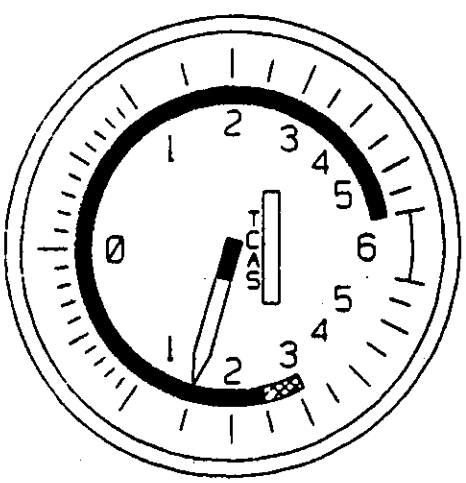
5



CORRECTIVE

CLIMB - CLIMB NOW

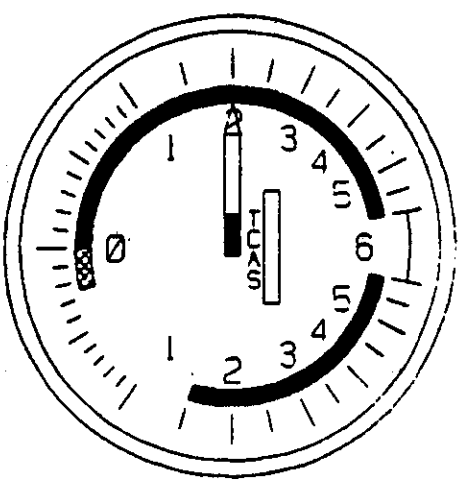
6



CORRECTIVE

INCREASE
DESCENT

7



CORRECTIVE

REDUCE
VERTICAL SPEED

8

SECTION 1 - LIMITATIONS

- TCAS II is approved for use in VMC and IMC.
- The pilot must not initiate evasive maneuvers using information from the traffic display only or on a traffic advisory only, without visually sighting the traffic. These displays and advisories are intended only for assistance in visually locating the traffic and lack the resolution necessary for use in evasive maneuvering.
- Compliance with TCAS resolution advisories is required unless the pilot has better information about the traffic, or has visually located the other aircraft, and can maintain safe separation. However, maneuvers which are in the opposite direction of the RA are extremely hazardous and are prohibited unless they are the only means to assure safe separation.
- When TCAS II voice message, "CLEAR OF CONFLICT" is announced, the pilot must promptly return to the previous ATC clearance.
- If ATC requires that transponder altitude reporting be disabled, TCAS must be turned off.

SECTION 2 - EMERGENCY PROCEDURES

- If a "CLIMB" RA occurs with an engine inoperative, it may be necessary to use go-around thrust and bleed airspeed at a modest rate (maximum 1.5 kt/sec) to achieve the RA indicated 1500 ft/min rate of climb.

SECTION 3 - NORMAL PROCEDURES

1. TCAS II Operating Characteristics:
   - "CLIMB" RAs are inhibited above FL350.
   - "DESCEND" RAs are inhibited below 700 feet AGL.
   - "INCREASE DESCEND" RAs are inhibited below 1800 feet AGL.
   - All RAs are inhibited below 500 feet AGL.
   - The TCAS surveillance may not function at distances less than 900 feet.
   - TA voice message is inhibited below 400 feet AGL.
   - There can be a case where the threat aircraft track or altitude information is lost during an RA. In this case, the RA will terminate without a "CLEAR OF CONFLICT" annunciation.
   - The TCAS RA algorithms are based on the pilot initiating the initial maneuver within approximately 5 seconds, and within approximately 2 1/2 seconds if an additional corrective RA (increase or reverse) is issued.
   - When WX-ONLY mode is selected, traffic information, traffic advisories, and resolution advisories are inhibited on the weather radar scope.

Therefore, this mode should be used only in the event TCAS interferes with weather information.

2. Pilot Initiated TCAS II Self-Test:

   - o The TCAS II should be tested using the pilot-initiated self-test feature during cockpit preparation.
   - o Use of the self-test function in flight will inhibit TCAS II operation for up to 20 seconds depending upon the number of targets being tracked.
   - o The ATC transponder will not function during some portion of the self-test sequence.

3. Ground Operation:

   - o The TCAS should not be selected ON until just prior to takeoff.
   - o The TCAS should be selected OFF immediately after clearing runway following landing.

4. TCAS II Range Selection:

   - o A 10 NM range should be selected for takeoff, low altitude climb, approach and land and below 10,000 feet.
   - o A 20 NM range should be selected for high altitude cruise.
   - o The range selected has no effect on the TCAS II logic giving TAs and RAs.

5. TA Only Selection:

   - o The TA position should only be used to preclude unnecessary RAs when operating near closely spaced parallel runways.
   - o The TA position delays TA advisories to 20 seconds of predicted closest point of conflict regardless of altitude. Therefore, this mode should not be used at high altitude.

6. The TCAS II/GPWS Conflict:

While it is extremely rare, TCAS II may, under certain conditions, issue a DESCENT advisory at the same time that a GPWS alert is issued. This event occurs when the TCAS II aircraft is descending at a high vertical rate while close to the ground and simultaneously encounters a threat aircraft that results in a descend advisory from TCAS II. For this condition to occur, the TCAS II aircraft must be descending greater than 1900 feet per minute prior to receiving the TCAS II advisory. If this condition occurs, the GPWS alert should be followed and a pull-up should be initiated immediately.

SECTION 4 - PERFORMANCE

No change.