# 18

# TCAS II

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## 18.1 Introduction

The Traffic Alert and Collision Avoidance System (TCAS) provides a solution to the problem of reducing the risk of midair collisions between aircraft. TCAS is a family of airborne systems that function independently of ground-based air traffic control (ATC) to provide collision avoidance protection. The TCAS concept makes use of the radar beacon transponders carried by aircraft for ground ATC purposes and provides no protection against aircraft that do not have an operating transponder.

TCAS I provides proximity warning only, to aid the pilot in the visual acquisition of potential threat aircraft. TCAS II provides traffic advisories and resolution advisories (recommended evasive maneuvers) in a vertical direction to avoid conflicting traffic. Development of TCAS III, which was to provide traffic advisories and resolution advisories in the horizontal as well as the vertical direction, was discontinued in favor of emerging systems such as the ADS-B system discussed elsewhere in this book. This chapter will focus on TCAS II.

Based on a congressional mandate (Public Law 100-223), the Federal Aviation Administration (FAA) issued a rule effective February 9, 1989 that required the equipage of TCAS II on airline aircraft with more than 30 seats by December 30, 1991. Public Law 100-223 was later amended (Public Law 101-236) to permit the FAA to extend the deadline for TCAS II fleetwide implementation to December 30, 1993. In December of 1998 the FAA released a Technical Standard Order (TSO) that approved Change 7, resulting in the DO-185A TCAS II requirement. Change 7 incorporates software enhancements to reduce the number of false alerts. TCAS equipage on aircraft with 30 or more seats has been mandated in India, Argentina, Germany, Australia, and Hong Kong by the year 2000.

## 18.2 Components

TCAS II consists of the Mode S/TCAS Control Panel, the Mode S transponder, the TCAS computer, antennas, traffic and resolution advisory displays, and an aural annunciator. Figure 18.1 is a block diagram of TCAS II. Control information from the Mode S/TCAS Control Panel is provided to the TCAS computer via the Mode S Transponder. TCAS II uses a directional antenna, mounted on top of the aircraft. In addition to receiving range and altitude data on targets above the aircraft, this directional antenna is used to transmit interrogations at varying power levels in each of four 90° azimuth segments. An omnidirectional transmitting and receiving antenna is mounted at the bottom of the aircraft to provide

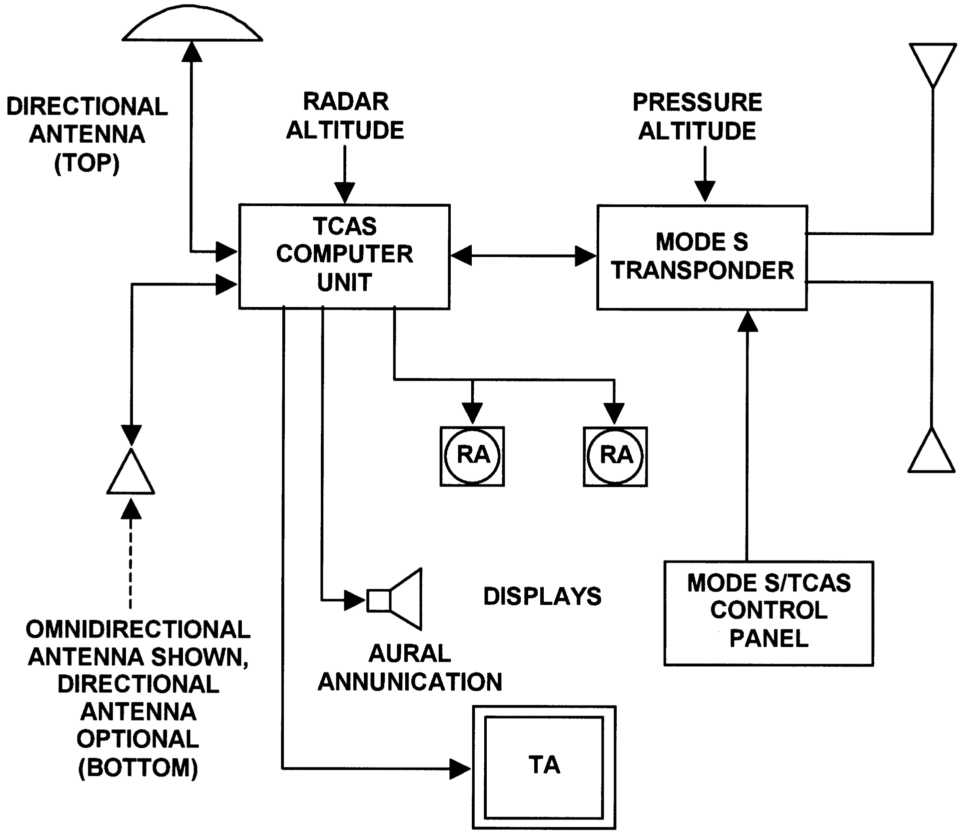


**FIGURE 18.1** TCAS II block diagram.

TCAS with range and altitude data from traffic that is below the aircraft. TCAS II transmits transponder interrogations on 1030 MHz and receives transponder replies on 1090 MHz.

The Traffic Advisory (TA) display depicts the position of the traffic relative to the TCAS aircraft to assist the pilot in visually acquiring threatening aircraft. The Resolution Advisory (RA) can be displayed on a standard Vertical Speed Indicator (VSI), modified to indicate the vertical rate that must be achieved to maintain safe separation from threatening aircraft. When an RA is generated, the TCAS II computer lights up the appropriate display segments and RA compliance is accomplished by flying to keep the VSI needle out of the red segments. On newer aircraft, the RA display function is integrated into the Primary Flight Display (PFD). Displayed traffic and resolution advisories are supplemented by synthetic voice advisories generated by the TCAS II computer.

## 18.3 Surveillance

TCAS listens for the broadcast transmission (squitters) which is generated once per second by the Mode S transponder and contains the discrete Mode S address of the sending aircraft. Upon receipt of a valid squitter message the transmitting aircraft identification is added to a list of aircraft the TCAS aircraft will interrogate. Figure 18.2 shows the interrogation/reply communications between TCAS systems. TCAS sends an interrogation to the Mode S transponder with the discrete Mode S address contained in the squitter message. From the reply, TCAS can determine the range and the altitude of the interrogated aircraft.

There is no selective addressing capability with Mode A/C transponders, so TCAS uses the Mode C only all-call message to interrogate these types of Mode A/C transponders at a nominal rate of once per

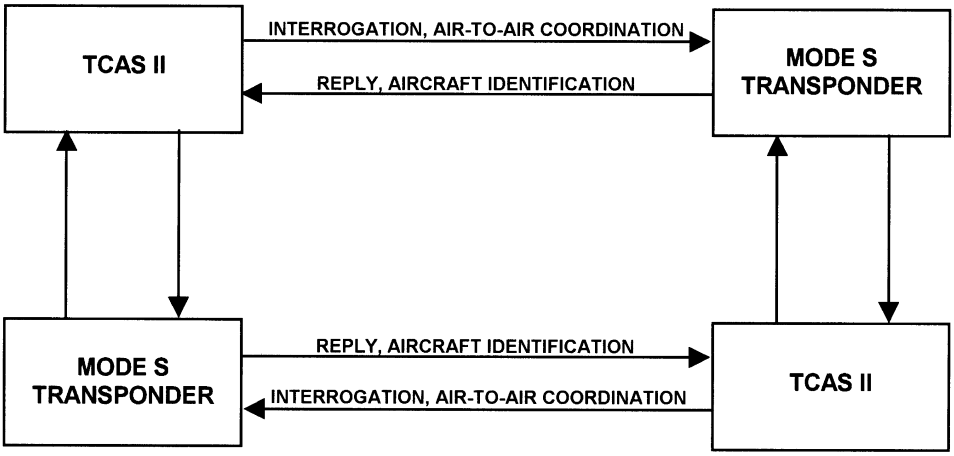


**FIGURE 18.2** Interrogation/Reply between TCAS systems.

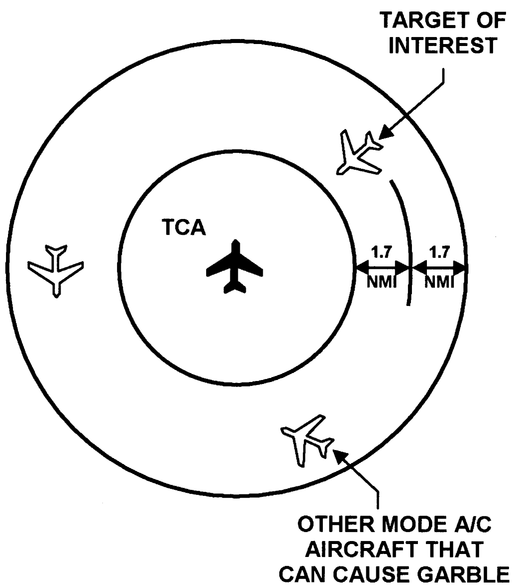


**FIGURE 18.3** Synchronous garble area.

second. Mode C transponders reply with altitude data while Mode A transponders reply with no data in the altitude field. All Mode A/C transponders that receive a Mode C all-call interrogation from TCAS will reply. Since the length of the reply is 21 μs, Mode A/C-equipped aircraft within a range difference of 1.7 nmi from the TCAS will generate replies that overlap each other, as shown in Figure 18.3. These overlapping Mode A/C replies are known as synchronous garble.

Hardware degarblers can reliably decode up to three overlapping replies. The Whisper-Shout technique and directional transmissions can be used to reduce the number of transponders that reply to a single interrogation. A low power level is used for the first interrogation step in a Whisper-Shout sequence. In the second Whisper-Shout step, a suppression pulse is first transmitted at a slightly lower level than the first interrogation, followed 2 μs later by an interrogation at a slightly higher power level than the first interrogation. The Whisper-Shout procedure shown in Figure 18.4 reduces the possibility of garble

**TABLE 18.1** Sensitivity Level Selection Based on Altitude

| Altitude (in Feet) | Sensitivity Level | Tau Values (in Seconds) TA | RA |
|---|---|---|---|
| 0–1,000 AGL | 2 | 20 | N.A. |
| 1,000–2,350 AGL | 3 | 25 | 15 |
| 2,350–5,000 MSL | 4 | 30 | 20 |
| 5,000–10,000 MSL | 5 | 40 | 25 |
| 10,000–20,000 MSL | 6 | 45 | 30 |
| 20,000–42,000 MSL | 7 | 48 | 35 |
| Greater than 42,000 MSL | 7 | 48 | 35 |

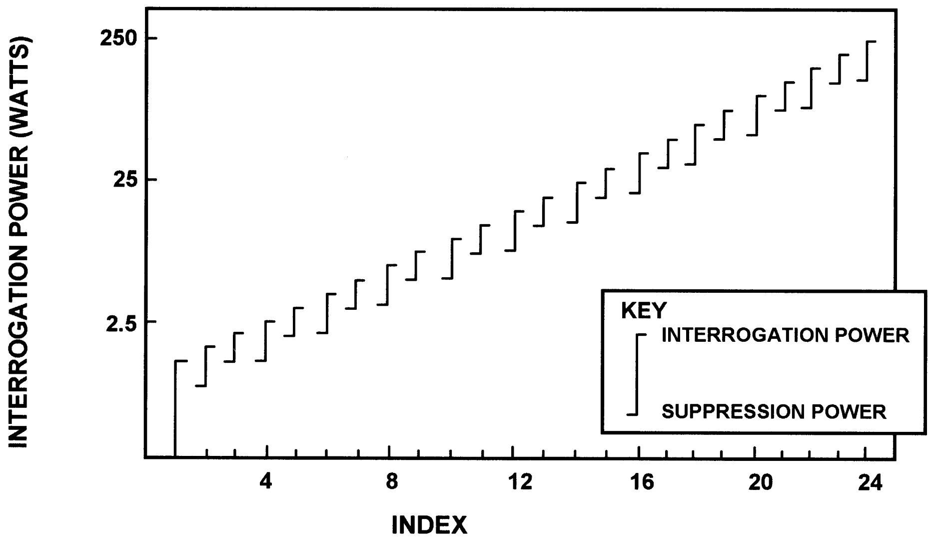


**FIGURE 18.4** Whisper-Shout interrogation.

by suppressing most of the transponders that had replied to the previous interrogation, but eliciting replies from an additional group of transponders that did not reply to the previous interrogation. Directional interrogation transmissions further reduce the number of potential overlapping replies.

## 18.4 Protected Airspace

One of the most important milestones in the quest for an effective collision avoidance system is the development of the range/range rate (tau). This concept is based on time-to-go, rather than distance-to-go, to the closest point of approach. Effective collision avoidance logic involves a trade-off between providing the necessary protection with the detection of valid threats while at the same time avoiding false alarms. This trade-off is accomplished by controlling the sensitivity level, which determines the tau, and therefore the dimensions of the protected airspace around each TCAS-equipped aircraft.

The pilot can select three modes of TCAS operation: STANDBY, TA-ONLY, and AUTOMATIC. These modes are used by the TCAS logic to determine the sensitivity level. When the STANDBY mode is selected, the TCAS equipment does not transmit interrogations. Normally, the STANDBY mode is used when the aircraft is on the ground. In TA-ONLY mode, the equipment performs all of the surveillance functions and provides TAs but not RAs. The TA-ONLY mode is used to avoid unnecessary distractions while at low altitudes and on final approach to an airport. When the pilot selects AUTOMATIC mode, the TCAS logic selects the sensitivity level based on the current altitude of the aircraft. Table 18.1 shows the altitude thresholds at which TCAS automatically changes its sensitivity level selection and the associated tau values for altitude-reporting aircraft.

The boundary lines depicted in Figure 18.5 show the combinations of range and range rate that would trigger a TA with a 40s tau and an RA with a 25s tau. These TA and RA values correspond to sensitivity level 5 from Table 18.1. As shown in Figure 18.5, the boundary lines are modified at close range to provide added protection against slow closure encounters.

## 18.5 Collision Avoidance Logic

The collision avoidance logic functions are shown in Figure 18.6. This description of the collision avoidance logic is meant to provide a general overview. There are many special conditions relating to particular geometry, thresholds, and equipment configurations that are not covered in this description. Using surveillance reports, the collision avoidance logic tracks the slant range and closing speed of each target to determine the time in seconds until the closest point of approach. If the target is equipped with an altitude-encoding transponder, collision avoidance logic can project the altitude of the target at the closest point of approach.

A range test must be met and the vertical separation at the closest point of approach must be within 850 ft for an altitude-reporting target to be declared a potential threat and a traffic advisory to be generated. The range test is based on the RA tau plus approximately 15 s. A non-altitude-reporting target is declared a potential threat if the range test alone shows that the calculated tau is within the RA tau threshold associated with the sensitivity level being used.

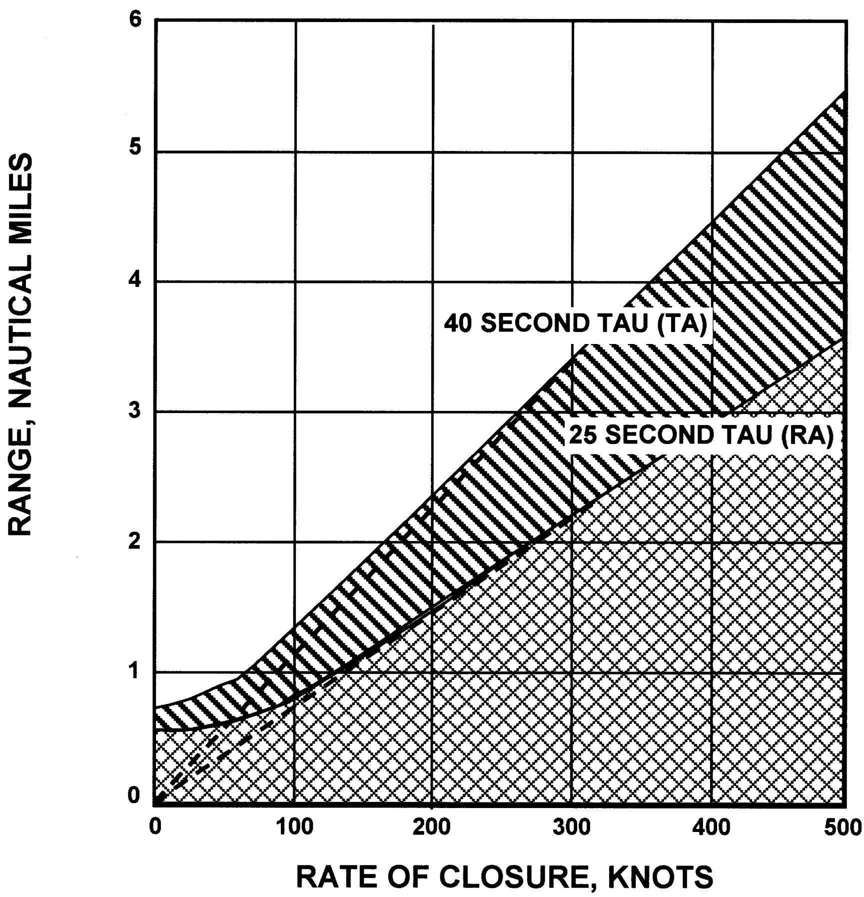


**FIGURE 18.5** TA/RA Tau values for sensitivity level 5.

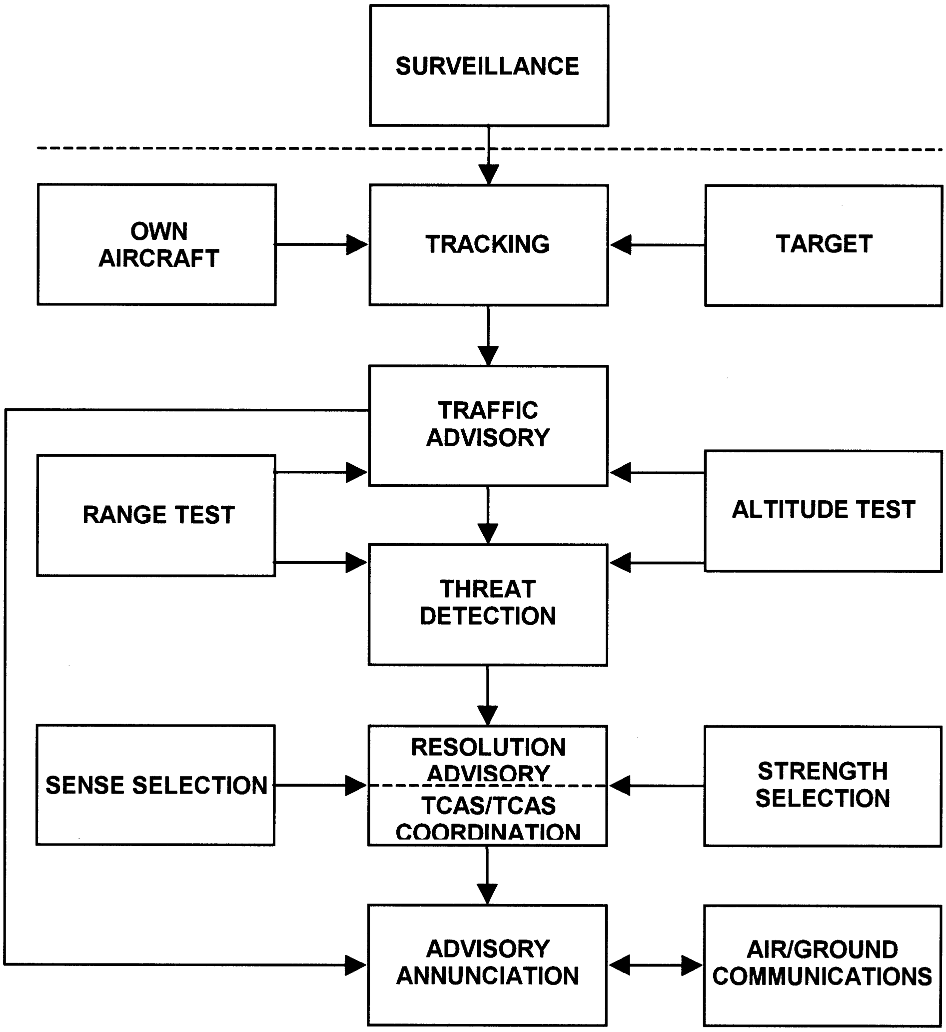


**FIGURE 18.6** CAS logic functions.

A two-step process is used to determine the type of resolution advisory to be selected when a threat is declared. The first step is to select the sense (upward or downward) of the resolution advisory. Based on the range and altitude tracks of the potential threat, the collision avoidance logic models the potential threat's path to the closest point of approach and selects the resolution advisory sense that provides the greater vertical separation. The second resolution advisory step is to select the strength of the resolution advisory. The least disruptive vertical rate maneuver that will achieve safe separation is selected. Possible resolution advisories are listed in Table 18.2.

In a TCAS/TCAS encounter, each aircraft transmits Mode S coordination interrogations to the other to ensure the selection of complementary resolution advisories. Coordination interrogations contain information about an aircraft's intended vertical maneuver.

## 18.6 Cockpit Presentation

The traffic advisory display can either be a dedicated TCAS display or a joint-use weather radar and traffic display (see Figure 18.10). In some aircraft, the traffic advisory display will be an electronic flight

**TABLE 18.2** Resolution Advisories

| Upward Sense | Type | Downward Sense |
|---|---|---|
| Increase Climb to 2500 fpm | Positive | Increase Descent to 2500 fpm |
| Reversal to Climb | Positive | Reversal to Descend |
| Maintain Climb | Positive | Maintain Descent |
| Crossover Climb | Positive | Crossover Descend |
| Climb | Positive | Descend |
| Don't Descend | Negative vsl | Don't Climb |
| Don't Descend >500 fpm | Negative vsl | Don't Climb >500 fpm |
| Don't Descend >1000 fpm | Negative vsl | Don't Climb >1000 fpm |
| Don't Descend >2000 fpm | Negative vsl | Don't Climb >2000 fpm |

*Note:* Any combination of climb and descent restrictions may be given simultaneously (normally in multi-aircraft encounters); fpm = feet per minute; vsl = vertical speed limit.


**FIGURE 18.7** Standardized symbology for TA display.

instrument system (EFIS) or flat panel display that combines traffic and resolution advisory information on the same display. Targets of interest on the traffic advisory display are depicted in various shapes and colors as shown in Figure 18.7.

The pilot uses the resolution advisory display to determine whether an adjustment in aircraft vertical rate is necessary to comply with the resolution advisory determined by TCAS. This determination is based on the position of the vertical speed indicator needle with respect to the lighted segments. If the needle is in the red segments, the pilot should change the aircraft vertical rate until the needle falls within the green "fly-to" segment. This type of indication is called a corrective resolution advisory. A preventive resolution advisory is when the needle is outside the red segments and the pilot should simply maintain the current vertical rate. The green segment is lit only for corrective resolution advisories. Resolution advisory display indications corresponding to typical encounters are shown in Figure 18.8.

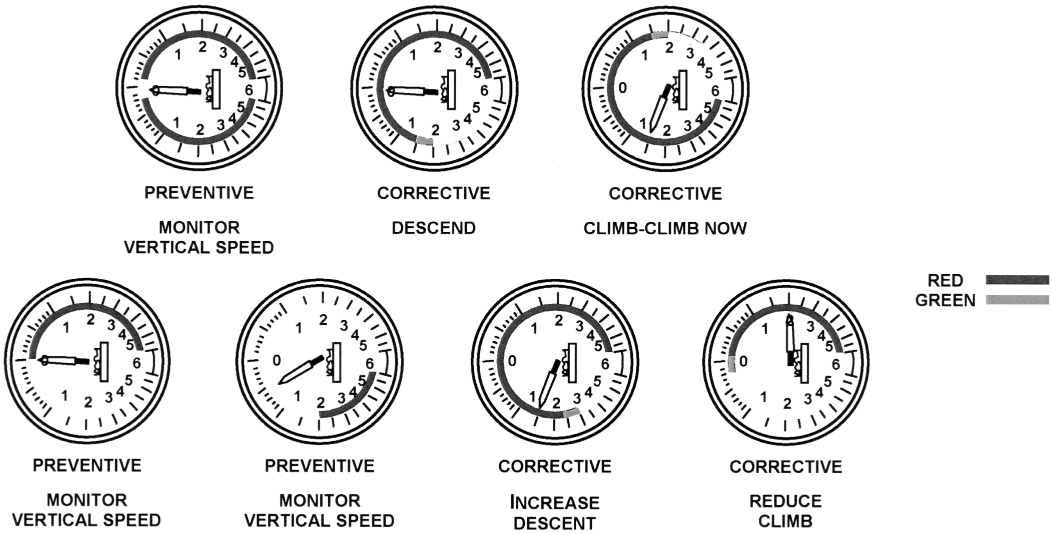


**FIGURE 18.8** Typical resolution advisory indications.


**FIGURE 18.9** Combined traffic advisory/resolution advisory display.

Figure 18.9 shows a combined traffic advisory/resolution advisory display indicating a traffic advisory (potential threat 200 ft below), resolution advisory (threat 100 ft above) and nonthreatening traffic (1200 ft above). The airplane symbol on the lower middle section of the display indicates the location of the aircraft relative to traffic. Figure 18.10 shows an example of a joint-use weather radar and traffic display.


**FIGURE 18.10** Joint use weather radar and traffic display.