

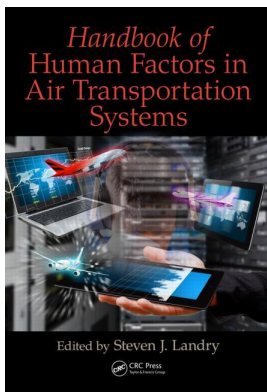
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Steven J. Landry

### **The Design of the Air Traffic Control System**

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# 3 The Design of the Air Traffic Control System

*Michael Nolan*

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## INTRODUCTION

The primary function of an air traffic control (ATC) system is to keep aircraft participating in the system separated from one another. Secondary reasons for the operation of an ATC system are to make more efficient use of airspace and to provide additional service to pilots such as traffic information, weather avoidance, and navigational assistance.

Not every aircraft may be required to participate in an ATC system, however. Each nation's regulations only obligate certain aircraft to participate in the ATC system. ATC participation in each country may range from mandatory participation of all aircraft to no-ATC services offered at all.

The level of ATC services provided is usually based on each nation's priorities, technical abilities, weather conditions, and traffic complexity. To more specifically define and describe the services that can be offered by an ATC system, the International Civil Aviation Organization (ICAO) has defined different aircraft operations and classes of airspace within which aircraft may operate. Different rules and regulations apply to each type of aircraft operation, and these rules vary depending on the type of airspace within which the flight is conducted. Although ICAO publishes very specific guidelines for the classification of airspace, it is the responsibility of each country's aviation regulatory agency to categorize its national airspace.

## AIRCRAFT OPERATIONS

*Visual meteorological conditions* (VMC) are defined as weather conditions in which pilots are able to see and avoid other aircraft. In general, pilots flying in VMC conditions comply with visual flight rules (VFR). VFR generally require that three to five miles of flight visibility be maintained at all times, that the aircraft remain clear of clouds, and that pilots have the responsibility to see and avoid other aircraft. Pilots provide their own air traffic separation. The ATC system may assist the pilots and may offer additional services, but the pilot has the ultimate responsibility to avoid other air traffic.

*Instrument meteorological conditions* (IMC) are generally defined as weather conditions in which the visibility is below that required for VMC or whenever the pilot cannot remain clear of clouds. Pilots operating in IMC must comply with instrument flight rules (IFR), which require the filing of a flight plan, and ATC normally provides air traffic separation. Pilots may operate under IFR when flying in VMC conditions. Under these circumstances, ATC will separate only those aircraft complying with IFR. VFR aircraft provide their own separation, and IFR aircraft have the responsibility to see and avoid VFR aircraft.

## AIRSPACE CLASSES

National governments define the extent to which they wish to offer ATC services to pilots. In general, ICAO recommendations suggest three general classes of airspace within which different services are provided to VFR and IFR pilots. These three general classes are uncontrolled, controlled, and positive controlled airspace.

Uncontrolled airspace is that within which absolutely no aircraft separation is provided by ATC, regardless of weather conditions. Uncontrolled airspace is normally that airspace with little commercial aviation activity.

Controlled airspace is that within which ATC separation services may be provided to certain select categories of aircraft (usually those complying with IFR). In controlled airspace, pilots flying VFR must remain in VMC and are not normally provided ATC separation and therefore must see and avoid all other aircraft. Aircraft who wish to utilize ATC services in controlled airspace must file a flight plan and comply with IFR. IFR aircraft are permitted to operate in VMC and IMC. When operating within controlled airspace, IFR aircraft are separated by ATC from other aircraft operating under IFR. When operating in VMC in controlled airspace, IFR pilots must see and avoid aircraft operating under VFR.

**TABLE 3.1**  
**Requirements for Operation and ATC Services Provided to Flight Operations**  
**within General Airspace Categories**

	<b>Uncontrolled Airspace (Class G Airspace)</b>	<b>Controlled Airspace (Class C, D and E Airspace)</b>	<b>Positive Controlled Airspace (Class A and B Airspace)</b>
VFR flight operations	<p>Must remain in VMC (VMC minima are fairly low, typically clear of clouds and one mile visibility)</p> <p>If VMC conditions exist, VFR operations are permitted and no ATC clearance is required</p> <p>If IMC conditions exist, VFR operations are not authorized</p> <p>No ATC separation services are provided</p> <p>Pilots responsibility to see and avoid both IFR and VFR aircraft</p>	<p>Must remain in VMC (VMC minima are higher, typically a specified distance from clouds and three to five miles visibility)</p> <p>If VMC conditions exist, VFR operations are permitted but an ATC clearance may be required to operate in certain areas</p> <p>If IMC conditions exist, VFR operations are not authorized</p> <p>No ATC separation services are provided to VFR aircraft</p> <p>Pilot’s responsibility to see and avoid both IFR and other VFR aircraft</p> <p>VFR aircraft operating in controlled airspace may be required to meet additional, class-specific operating rules and procedures</p>	<p>VFR flight operations might not be permitted</p> <p>If permitted, VFR aircraft must remain in VMC (VMC minima are higher, typically a specified distance from clouds and three to five miles visibility)</p> <p>If VMC conditions exist, VFR operations may be permitted but an ATC clearance would be required</p> <p>If IMC conditions exist, VFR operations are not authorized</p> <p>Separation services are provided to all aircraft</p> <p>All aircraft will be separated by ATC</p> <p>VFR aircraft operating in positive controlled airspace may be required to meet additional, class-specific operating rules and procedures</p>
IFR flight operations	<p>IFR operations permitted with no ATC clearance required, nor will it be issued</p> <p>ATC separation services not provided</p> <p>Pilots responsibility to see and avoid both IFR and VFR aircraft</p>	<p>ATC clearance required</p> <p>ATC separation will be provided between IFR aircraft; IFR pilots must see and avoid VFR aircraft while in VMC</p> <p>IFR aircraft operating in controlled airspace may be required to meet additional, class-specific operating rules and procedures</p>	<p>ATC clearance required</p> <p>ATC separation will be provided between all aircraft</p> <p>All aircraft operating in positive controlled airspace may be required to meet additional, class-specific operating rules and procedures</p>

In positive controlled airspace, all aircraft, whether IFR or VFR, are separated by ATC. All aircraft operations require an ATC clearance. VFR pilots must remain in VMC conditions but are separated by ATC from both VFR and IFR aircraft. IFR aircraft are also separated from both IFR and VFR aircraft. [Table 3.1](#) describes the general rules that both IFR and VFR pilots must comply with when operating in these three classes of airspace.

**AIR TRAFFIC CONTROL PROVIDERS**

In most countries, a branch of the national government normally provides ATC services. The ATC provider may be a civilian, military, or a combination of both. Some national ATC services are now being operated by private corporations funded primarily by user fees. Other governments are experimenting with ATC system privatization. Some of these initiatives purpose to transfer all ATC responsibility to private agencies, whereas other propose to transfer only certain

functions, such as weather dissemination and the operation of low-activity control towers, to private or semipublic entities.

Privatized ATC is a fairly recent historical development with roots tracing back to the 1930s. When an ATC system was first started in the United States, control towers were operated by the municipalities that owned the airports. Enrooted ATC was provided through a consortium of airlines. Only in the 1940s was ATC taken over and operated by the national government.

The concept behind privatized ATC is that if freed from cumbersome government procurement requirements, employment regulations, and legislative pressures, private corporations might provide service at less cost, be more efficient, and be more responsive to users' needs because they would be funded and controlled by the users. Possible disadvantages of such a system include lack of governmental oversight and responsibility, possible conflict of interest between system users and operators, little incentive to assist military aviation activities, and restricted access to the capital funding needed to upgrade and operate such a complex system.

### **AIR TRAFFIC CONTROL ASSIGNMENTS**

Every nation is responsible for providing ATC services within its national borders. To provide for a common method of ATC, ICAO promulgates standardized procedures that most countries generally adhere to. These standards include universally accepted navigation systems, a common ATC language (English), and general ATC separation standards. ICAO is a voluntary organization of which most countries are members. Every ICAO signatory nation agrees to provide ATC services to all aircraft operating within its boundaries and agrees to accept that their pilots abide by other national ATC systems when operating within foreign countries.

Every nation's ATC procedures can and do occasionally deviate from ICAO recommended practices. Each operational procedure that deviates from ICAO standards is published by the national ATC service provider in the Aeronautical Information Publication.

ICAO has been granted the responsibility for providing ATC services in international airspace, which mostly comprises oceanic and polar airspace. ICAO has assigned separation responsibility in those areas to individual states both willing and able to accept that responsibility. Some countries that have accepted this responsibility include the United States, the United Kingdom, Canada, Australia, Japan, Portugal, and the Philippines.

### **AIR TRAFFIC CONTROL SERVICES**

Airspace with little or no potential traffic conflicts requires little in the way of sophisticated ATC systems. If air traffic density increases, if aircraft operations increase in complexity, or if special, more hazardous operations are routinely conducted; additional control of aircraft is usually required to maintain an acceptable level of safety. The easiest method of defining these increasing ATC system requirements and their associated operating rules is to define different classes of airspace within which different ATC services and requirements exist.

Standard ICAO airspace classifications include classes labeled A, B, C, D, E, F, and G. In general, Class A airspace is positive controlled, in which ATC services are mandatory for all aircraft. Class G is uncontrolled airspace in which no ATC services are provided to either IFR or VFR aircraft. Classes B, C, D, E, and F provide declining levels of ATC services and requirements.

It is each nation's responsibility to describe, define, explain, and chart the various areas of airspace within their respective boundaries. In general, areas with either high-density traffic or a mix of different aircraft operations are classified as class A, B, or C airspace. Areas of low traffic density are usually designated as class D, E, F, or G.

## AIR TRAFFIC CONTROL SERVICES OFFERED WITHIN EACH TYPE OF AIRSPACE

The requirements to enter each airspace classification and the level of ATC services offered within each area are listed here:

*Class A airspace:* All operations must be conducted under IFR and are subject to ATC clearances and instructions. ATC separation is provided to all aircraft. Radar surveillance of aircraft is usually provided.

*Class B airspace:* Operations may be conducted under IFR or VFR. However, all aircraft are subject to ATC clearances and instructions. ATC separation is provided to all aircraft. Radar surveillance of aircraft is usually provided.

*Class C airspace:* Operations may be conducted under IFR or VFR; however, all aircraft are subject to ATC clearances and instructions. ATC separation is provided to all aircraft operating under IFR and, as necessary, to any aircraft operating under VFR when any aircraft operating under IFR is involved. All VFR operations will be provided with safety alerts and, on request, conflict resolution instructions. Radar surveillance of aircraft is usually provided.

*Class D airspace:* Operations may be conducted under IFR or VFR; however, all aircraft are subject to ATC clearances and instructions. ATC separation is provided to aircraft operating under IFR. All aircraft receive safety alerts and, on pilot request, conflict resolution instructions. Radar surveillance of aircraft is not normally provided.

*Class E airspace:* Operations may be conducted under IFR or VFR. ATC separation is provided only to aircraft operating under IFR within a surface area. As far as practical, ATC may provide safety alerts to aircraft operating under VFR. Radar surveillance of aircraft may be provided if available.

*Class F airspace:* Operations may be conducted under IFR or VFR. ATC separation will be provided, so far as practical, to aircraft operating under IFR. Radar surveillance of aircraft is not normally provided.

*Class G airspace:* Operations may be conducted under IFR or VFR. Radar surveillance of aircraft is not normally provided.

## AERONAUTICAL NAVIGATION AIDS

Air traffic separation can only be accomplished if the location of an aircraft can be accurately determined. Therefore, an ATC system is only as accurate as its ability to determine an aircraft's position. The navigation systems currently in use were developed in the 1950s but are undergoing a rapid change in both technology and cost. As integrated circuitry and computer technology continue to become more robust and inexpensive, the newly certified global navigation satellite system (GNSS), global positioning system, promises unprecedented navigational performance at a relatively low cost. ICAO has just recently affirmed its preference for GNSS as the future primary international navigation standard. Various experts predict that existing navigation systems will be either decommissioned or relegated to a GNSS backup role by the turn of the century.

In general, the accuracy of existing navigation aids is a function of system cost and/or aircraft distance from the transmitter. Relatively inexpensive navigation systems are generally fairly inaccurate. The most accurate systems tend to be the most expensive. [Table 3.2](#) describes the type, general cost, advantages, and disadvantages of many common aeronautical navigation systems.

**TABLE 3.2**  
**Navigation System Capabilities, Advantages, and Disadvantages**

System	General Cost	Effective Range	Accuracy	Ease of Use	Advantages	Disadvantages
Nondirectional beacon	Inexpensive transmitter. Inexpensive receiver	50–1,000 nautical miles	Fairly inaccurate	Somewhat difficult to use	Inexpensive and easy transmitter installation	Susceptible to atmospheric interference. No data transmission capability
VORTAC	Moderately expensive transmitter. Fairly inexpensive receiver	25–200 nautical miles	Fairly accurate	Fairly easy to use	Current enroute international standard. Can provide distance information if aircraft suitably equipped	Large number of transmitters required to provide adequate coverage. Primarily a point-to-point navigation system
Inertial Navigation Systems (INS)	No transmitters required. Very expensive receivers	Unlimited	Fairly accurate	Fairly easy to use	Very independent operation as no ground transmitters required	Expensive. Needs to be programmed. Accuracy deteriorates over time without external input
Global Navigation Satellite system	Extremely expensive, space-based transmitters. Inexpensive receivers	Worldwide	Very accurate. Can be made more accurate with augmentation	Fairly easy to use	Inexpensive, world-wide coverage with point-to-point navigation capability	Only one or two independent systems currently available, other countries considering systems but very expensive to create, operate and maintain
Instrument Landing System (ILS)	Expensive transmitter. Fairly inexpensive receiver	10–30 nautical miles	Fairly accurate	Fairly easy to use	Current world-wide standard for precision approaches	Limited frequencies available. Only one approach path provided by each transmitter. Extensive and expensive site preparation might be required



## GLOBAL NAVIGATION SATELLITE SYSTEM

GNSSs have just recently been adopted as the future navigation standard by ICAO. Currently, GNSS systems are as accurate as most current enroute navigation systems. Inherent inaccuracies (and some intentional signal degradation) require that GNSS be augmented if it is to replace instrument landing system (ILS) and/or microwave landing system (MLS) as a precision navigation system. Satellite accuracy augmentation (both space and ground based) has been proposed as one method to provide general improvements to accuracy that may permit GNSS to replace ILS as the precision approach standard. Ground-based augmentation may be required before GNSS will be sufficiently accurate for all-weather automatic landings. Which system or combination of systems will be eventually used is still undermined.

## RADAR SURVEILLANCE IN AIR TRAFFIC CONTROL

Radar is used by air traffic controllers to monitor aircraft position, detect navigational blunders, reduce separation if possible, and make more efficient use of airspace. Controllers can utilize radar to provide aircraft navigational assistance during both the enroute and approach phases of flight. If radar is able to provide more accurate aircraft positional information than existing navigation systems can provide, it may be possible to reduce the required separation between aircraft.

Three different types of radar are used in ATC systems. Primary surveillance radar was first developed during World War II and can detect aircraft without requiring onboard aircraft equipment. Secondary surveillance radar (SSR) requires an interrogator on the ground and an airborne transponder in each aircraft. SSR provides more accurate aircraft identification and position, and can transmit aircraft altitude to the controller. Mode-S secondary radar is a recent improvement to secondary radar systems that will provide unique aircraft identification and the ability to transmit flight information to the controller, and ATC instruction and other information directly to the aircraft. [Table 3.3](#) lists the functional advantages and disadvantages of each radar surveillance system.

Automatic dependent surveillance (ADS) is a scheme whereby GPS-derived position data are transmitted to the ground (and eventually nearby aircraft) using a discreet frequency. ADS data can be used in lieu of or in combination with radar-derived position data to accurately locate aircraft.

## AIRCRAFT SEPARATION IN AN AIR TRAFFIC CONTROL SYSTEM

The airspace within which ATC services are provided is normally divided into three-dimensional blocks of airspace known as sectors. Sectors have well-defined lateral and vertical limits and normally are shaped according to traffic flow and airspace structure. Only one controller has ultimate responsibility for the separation of aircraft within a particular sector. The controller may be assisted by other controllers, but is the one person who makes the decisions (in accordance with approved procedures), concerning the separation of aircraft within that particular sector.

If pilots of participating aircraft within the sector can see other nearby aircraft, the pilots can simply *see and avoid* nearby aircraft. Or if a controller can see one or both aircraft, the controller may issue heading and/or altitude instructions that will keep the aircraft separated. This informal but effective method of aircraft separation is known as visual separation. Although a simple concept, it is very effective and efficient when properly used. As long as aircraft can be spotted and remain identified, the use of visual separation permits aircraft to operate in much closer proximity than if the aircraft cannot be seen. Most airports utilize visual separation and visual approaches during busy traffic periods. If weather conditions permit visual separation to be applied, the capacity of most major airports can be significantly increased.

Visual separation can only be employed if one pilot sees the other aircraft, or if the controller can see both aircraft. The primary disadvantage of visual separation is that it can only be employed when aircraft are flying fairly slowly. It would be next to impossible to utilize visual separation



**TABLE 3.3**  
**Air Traffic Control Radar Systems**

<b>Radar System</b>	<b>Operational Theory</b>	<b>Information Provided</b>	<b>Advantages</b>	<b>Disadvantages</b>
Primary surveillance radar	Very powerful electrical transmission is reflected by aircraft back to radar receiver which is then displayed to ATC personnel	Range and azimuth	Detects all aircraft within range regardless of aircraft equipment	Also detects unwanted objects. Weather and terrain can reflect and block signal. System prone to numerous false targets
Secondary surveillance radar, (also known as the Air Traffic Control Radar Beacon System or ATCRBS)	Low powered electrical signal transmitted from ground station triggers response from airborne equipment	Range and azimuth, assigned aircraft code and altitude	Detects only aircraft. If ground system is properly equipped, aircraft identity and altitude can be displayed to ATC	System requires aircraft to be equipped with operable transponder. Operation restricted to common frequency which can be overwhelmed if too many aircraft respond
Mode S	Selective low-powered signal transmitted from ground triggers response from individual aircraft	Range, azimuth, aircraft identity and altitude. Capability exists to transmit additional data both to and from aircraft	Detects only those aircraft specifically interrogated by the ground equipment	Requires all aircraft to be equipped with Mode-S capable transponder
Automatic Dependent Surveillance (ADS)	Signal transmitted from ground triggers response from individual aircraft. ADS does permit aircraft-to-aircraft communication	ADS signals include aircraft identity and altitude. Future iterations could include aircraft flight data and ATC clearances	Identification signal is unique to each aircraft. Much greater bandwidth for data transmission than other data schemes	Requires all aircraft to be equipped with ADS equipment. Mode-S is compatible with ADS systems

during high-altitude, high-speed cruising conditions common to modern aircraft. Visual separation can therefore only be effectively employed within the immediate vicinity of airports. The use of visual separation near airports requires that aircraft remain continuously in sight of one another. This is a difficult proposition at best during the approach to landing or departure phase of flight because these are two of the busiest times for pilots.

## NONRADAR SEPARATION

When visual separation cannot be employed, controllers must use either radar or nonradar separation techniques. Due to range and curvature of the earth limitations inherent to radar, there are many situations in which radar cannot be used to identify and separate aircraft. Radar coverage exists near most medium- and high-density airports, and at altitudes of 5,000 feet or above in the continental United States and Europe. Outside of these areas, and over the ocean, radar surveillance may not exist, and the controller must employ some form of nonradar separation to provide ATC.

Nonradar separation depends on accurate position determination and the transmittal of that information to the controller. Due to navigation and communication system limitations, ATC is unable to precisely plot the position of each aircraft in real time. As navigation systems have inherent inaccuracies, it is impossible to know exactly where each aircraft is at any given time. Nonradar separation therefore assumes that every aircraft is located within a three-dimensional block of airspace. The dimensions of the airspace are predicated on the speed of the aircraft and the accuracy of the navigation system being used. In general, if VHF (very high frequency) omnidirectional range is being utilized for aircraft navigation, the airspace assigned to each aircraft may have lateral width of about eight nautical miles, vertical height of 1,000 feet (2,000 feet when operating above 29,000 feet), and a longitudinal length that varies depending upon the speed of the aircraft. In general, the longitudinal extent of the airspace box extends about 10 nautical miles of flight time in front of the aircraft. Depending on the speed of the aircraft, this longitudinal dimension could extend from 10 to 100 miles in front of the aircraft.

As neither the controller nor the pilot knows exactly where within the assigned airspace box each aircraft is actually located, the controller must assume that aircraft might be located anywhere within the box. The only way to insure that aircraft do not collide is to insure that airspace boxes assigned to different aircraft never overlap. Airspace boxes are permitted to get close to one another, but as long as they never overlap, aircraft separation is assured.

Nonradar separation is accomplished by assigning aircraft either different altitudes or nonoverlapping routes. If aircraft need to operate on the same route at the same altitude, they must be spaced accordingly to prevent longitudinal overlap. Controllers may separate potentially conflicting aircraft either through the use of nonoverlapping holding patterns, or by delaying departing aircraft on the ground. If there is a sufficient speed differential between two conflicting aircraft, the controller can normally permit the faster aircraft to lead the slower aircraft using the same route and the same altitude. Depending on the speed difference between the aircraft, the longitudinal separation criteria can normally be reduced.

The controller uses flight progress strips to visualize the aircraft's position and therefore effect nonradar separation. Pertinent data are written on a flight strip as the aircraft progresses through each controller's sector. The controller may request that the pilot make various position and altitude reports, and these reports are written on the flight strip.

The primary disadvantage of nonradar separation is that its application depends on the pilot's ability to accurately determine and promptly report the aircraft's position, and the controller's ability to accurately visualize each aircraft's position. To reduce the probability of an in-flight collision occurring to an acceptably low level, the separation criteria must take into account these inherent inaccuracies and built-in communication delays. This requires that fairly large areas of airspace be assigned to each aircraft. An aircraft traveling at 500 knots might be assigned a block of airspace 1,000 feet in height, covering close to 400 square miles. This is hardly an efficient use of airspace.

## RADAR SEPARATION

Radar can be utilized in ATC to augment nonradar separation, possibly reducing the expanse of airspace assigned to each aircraft. Radar's design history causes it to operate in ways that are not always advantageous to ATC, however. Primary radar was developed during World War II as a defensive, antiaerial invasion system. It was also used to locate enemy aircraft and direct friendly aircraft on an intercept course. It was essentially designed to bring aircraft together, not to keep them apart.

Primary radar is a system that transmits high-intensity electromagnetic pulses focused along a narrow path. If the pulse is reflected off an aircraft, the position of the aircraft is displayed as a bright blip, or target, on a display screen known as a plan position indicator. This system is known as primary surveillance radar.

The radar antenna rotates slowly to scan in all directions around the radar site. Most radars require 5 to 15 seconds to make one revolution. This means that once an aircraft's position has been plotted by radar, it will not be updated until the radar completes another revolution. If an aircraft is moving at 600 knots, it might move two to three miles before it is replotted on the radar display.

Primary radar is limited in a range based on the curvature of the earth, the antenna rotational speed, and the power level of the radar pulse. Radars used by approach control facilities have an effective range of about 75 nautical miles. Radars utilized to separate enroute aircraft have a range of about 300 nautical miles.

SSR is a direct descendent of a system also developed in World War II known as identification friend or foe. Secondary radar enhances the radar target and can be integrated with a ground-based computer to display the aircraft's identity, altitude, and ground speed. This alleviates the need for the controller to constantly refer to flight progress strips to correlate this information. However, flight progress strips are still used by radar controllers to maintain other information, and as a backup system utilized in the case of radar system failure.

Although one might think that radar dramatically reduces aircraft separation, in fact it only normally significantly reduces the longitudinal size of the airspace box assigned to each aircraft. The vertical dimension of the airspace box remains 1,000 feet, the lateral dimension may be reduced from eight to five nautical miles (sometimes three miles), but longitudinal separation is reduced from 10 flying minutes, to three to five nautical miles.

## RADAR SYSTEM LIMITATIONS

There are various physical phenomena that hamper primary radar effectiveness. Weather and terrain can block radar waves, and natural weather conditions such as temperature inversions can cause fake or false targets to be displayed by the system. Radar also tracks all moving targets near the airport, which may include highway, train, and in some cases, ship traffic. While controlling air traffic, the controller can be distracted and even momentarily confused when nonaircraft targets such as these are displayed on the radar. It is difficult for the controller to quickly determine whether a displayed target is a *false target* or an actual aircraft.

Another major limitation of radar is its positional accuracy. As the radar beam is angular in nature (usually about ½-degree wide), the beam widens as it travels away from the transmitter. At extreme ranges, the radar beam can be miles wide. This makes it difficult to accurately position aircraft located far from the antenna and makes it impossible to differentiate between two aircraft operating close to one another. As radar system accuracy decreases as the aircraft distance from the radar antenna increases, aircraft close to the radar antenna (less than about 40 miles) can be laterally or longitudinally separated by three miles. Once the aircraft is greater than 40 miles from the radar antenna, five nautical miles of separation must be used. The size of the airspace box using radar is still not reduced vertically but can now be as little as nine square miles (compared with 600 when using nonradar separations).

## ADDITIONAL RADAR SERVICES

Radar can also be used by the controller to navigate aircraft to provide a more efficient flow of traffic. During the terminal phase of flight, as the aircraft align themselves with the runway for landing, radar can be used by the controller to provide navigational commands (vectors) that position each aircraft at the optimal distance from one another, something impossible to do if radar surveillance is not available. This capability of radar is at least as important as the ability to reduce the airspace box assigned to each aircraft.

Air-traffic controllers can also utilize radar to assist the pilot to avoid severe weather, although the radar used in ATC does not optimally display weather. The controller can also advise the pilot of nearby aircraft or terrain. In an emergency, the controller can guide an aircraft to the nearest airport and can guide the pilot through an instrument approach. All these services are secondary to the primary purpose of radar, which is to safely separate aircraft participating in the ATC system.

## RADAR IDENTIFICATION OF AIRCRAFT

Before controllers can utilize radar for ATC separation, they must positively identify the target on the radar. Due to possible false target generation, unknown aircraft in the vicinity, and weather-induced false targets, it is possible for a controller to be unsure of the identity of any particular radar target. Therefore, the controller must use one or more techniques to positively verify the identity of any target before radar-separation criteria can be utilized. If positive identity cannot be ascertained, nonradar separation techniques must be utilized.

Controllers can verify the identity of a particular target using either primary or secondary radar. Primary methods require that the controller correlate the pilot's reported position with a target on the radar, or by asking the pilot to make a series of turns and watching for a target to make similar turns. Secondary radar identification can be established by asking the pilot to transmit an IDENT signal (which causes a distinct blossoming of the radar target), or, if the radar equipment is so equipped, asking the pilot to set the transponder to a particular code, and verifying that the radar displays that code (or the aircraft identification) next to the target symbol on the radar.

None of these methods are foolproof, and all have the potential for aircraft misidentification. During the identification process, the wrong pilot may respond to a controller's request, equipment may malfunction, or multiple aircraft may follow the controller's instruction. If an aircraft is flying too low or is outside the limits of the radar display, the target may not even show up on the radar scope. Once identified, the controller may rely completely on radar positioning information when applying separation, so multiple methods of radar identification are usually utilized to insure that a potentially disastrous misidentification does not occur and that the aircraft remains identified. If positive radar identification or detection is lost at any time, the controller must immediately revert to nonradar separation rules and procedures until aircraft identify can be reestablished.

## RADAR SEPARATION CRITERIA

Radar accuracy is inversely proportional to the aircraft's distance from the radar antenna. The further away an aircraft is, the less accurate is the radar positioning of that aircraft. Radar separation criteria have been developed with this limitation in mind. One set of criteria has been developed for aircraft that are less than 40 nautical miles from the radar site. An additional set of criteria has been developed for aircraft 40 or more nautical miles from the antenna. As the display system used in air route traffic control centers uses multiple radar sites, controllers using this equipment must always assume that aircraft might be 40 miles or farther from the radar site when applying separation criteria. [Table 3.4](#) describes the separation criteria utilized by air-traffic controllers when using radar. The controller must utilize at least one form of separation.

**TABLE 3.4**  
**Radar Separation Criteria**

Aircraft Distance from Radar Antenna	Vertical Separation	Lateral Separation	Longitudinal Separation
Less than 40 nautical miles	1,000 feet	Three nautical miles	Three nautical miles. Additional separation may be required for wake turbulence avoidance
40 nautical miles or greater	1,000 feet	Five nautical miles	Five nautical miles. Additional separation may be required for wake turbulence avoidance

As stated previously, radar serves only to reduce the nonradar-separation criteria previously described. It does nothing to reduce the vertical separation between aircraft. Radar primarily serves to reduce lateral and longitudinal separation. Nonradar lateral separation is normally eight nautical miles, but the use of radar permits lateral separation to be reduced to three to five nautical miles. Radar is especially effective when reducing longitudinal separation, however. Nonradar longitudinal separation requires 5–100 nautical miles, whereas radar longitudinal separation is three to five nautical miles. It is this separation reduction that is most effective in maximizing the efficiency of the ATC system. Instead of lining up aircraft on airways 10–50 miles in trail, controllers using radar can reduce the separation to three to five miles, therefore increasing the airway capacity 200%–500%. While under radar surveillance, pilots are relieved of the responsibility of making routine position and altitude reports. This dramatically reduces frequency congestion and pilot–controller miscommunications.

Another advantage of radar is that controllers are no longer restricted to assigning fixed, inflexible routes to aircraft. As aircraft position can be accurately determined in near real time, controllers can assign new routes to aircraft that may shorten the pilot’s flight, using the surrounding airspace more efficiently.

Radar vectors such as these are most effective in a terminal environment in which aircraft are converging on one or more major airports and are in a flight transitional mode in which they are constantly changing altitude and airspeed. A controller using radar is in a position to monitor the aircraft in the terminal airspace and can make overall adjustments to traffic flow by vectoring aircraft for better spacing, or by issuing speed instructions to pilots to close or widen gaps between aircraft. It is because of these advantages that most national ATC organizations first install radar in the vicinity of busy terminals. Only later (if at all) are enroute navigation route provided by radar monitoring.

## CURRENT TRENDS IN AUTOMATION

Early forms of radar provided a display of all moving targets within the radar’s area of coverage. This included not only aircraft, but weather, birds, vehicular traffic, and other atmospheric anomalies. By using technology developed in World War II, air traffic controllers have been able to track and identify aircraft using the ATC radar beacon system (ATCRBS). ATCRBS, sometimes known as SSR, or simply secondary radar, requires a ground-based interrogator and an airborne transponder installed in each aircraft. When interrogated by the ground station, the transponder replies with a unique code that can be used to identify the aircraft, and if so equipped, it can also transmit the aircraft’s altitude to the controller.

This system is tremendously beneficial to the controller because all aircraft can easily be identified. Nonpertinent aircraft and other phenomena observed by the radar can be ignored by the controller. If the ground-based radar is properly equipped, aircraft identity and altitude can also be constantly displayed on the radar screen, relieving the controller of mentally trying to keep each radar target properly identified.

The ground-based component of the secondary radar system has since been modified to perform additional tasks that benefit the air traffic controller. If the ground radar is properly equipped, and the computer knows the transponder code that a particular aircraft is using, the aircraft can be tracked and flight information can be computer processed and disseminated. As the radar system tracks each aircraft, basic flight information can be transmitted to subsequent controllers automatically as the aircraft nears each controller's airspace boundary. Future aircraft position can also be projected on the basis of past performance, and possible conflicts with other aircraft and with the ground can be predicted and prevented. These last two systems (known as conflict alert for aircraft–aircraft conflicts and minimum safe altitude warning for aircraft–terrain conflicts) only provide the controller with a warning when aircraft are projected to be in danger. The system does not provide the controller with any possible remediation of the impending problem. Future enhancements to the computer system should provide the controller with options that can be selected to resolve the problem. This future system is to be known as conflict resolution advisories.

## **AIRBORNE SYSTEMS**

Engineers and researchers have experimented with aircraft-based traffic avoidance systems since the 1960s. These prototype systems were not designed to replace but rather to augment and back up the current ground-based ATC system. This device is known as threat collision and avoidance system (TCAS). TCAS was developed with three different levels of service and capabilities.

TCAS is an aircraft-based system that monitors and tracks nearby transponder-equipped aircraft. This position and relative altitude of nearby aircraft are constantly displayed on a TCAS display located in the cockpit of each aircraft. TCAS I provides proximity warning only to assist the pilot in the visual acquisition of intruder aircraft. No recommended avoidance maneuvers are provided nor authorized as a direct result of a TCAS I warning. It is intended for use by smaller commuter aircraft holding 10 to 30 passenger seats, and general aviation aircraft. TCAS II provides traffic advisories and resolution advisories. Resolution advisories provide recommended maneuvers in a vertical direction (climb or descent only) to avoid conflicting traffic. Airline aircraft, and larger commuter and business aircraft holding 31 passenger seats or more, use TCAS II equipment. TCAS III provides all the capabilities of TCAS II but adds the capability to provide horizontal maneuver commands. All three versions of TCAS monitor the location of nearby transponder-equipped aircraft. Current technology does not permit TCAS to monitor aircraft not transponder equipped.

## **CONFLICT ALERT/VISUAL FLIGHT RULES INTRUDER**

The ATCRBS has recently been enhanced with a new conflict alert program known as conflict alert/VFR intruder. The old conflict alert program only advised the controller of impending collisions between participating IFR aircraft. It did not track nonparticipating aircraft such as those operating under VFR. Conflict alert/VFR intruder tracks all IFR and VFR aircraft equipped with transponders and alerts the controller if a separation error between the VFR and a participating IFR aircraft is predicted. The controller can then advise the pilot of the IFR aircraft and suggest alternatives to reduce the risk of collision.

## **TRAFFIC MANAGEMENT SYSTEMS**

It has become recently apparent that the current ATC system may not be able to handle peak traffic created in a hub-and-spoke airline system. Much of this is due to inherent limitations of the ATC system. ATC system expansion is planned in many countries, but until it is completed, other methods of ensuring aircraft safety have been developed. To preserve an acceptable level of safety, special traffic management programs have been developed to assist the controllers in their primary function, the safe separation of aircraft.



### AIRPORT CAPACITY RESTRICTIONS

During hub-and-spoke airport operations, traffic can become intense for fairly short periods of time. During these intense traffic periods, if optimal weather and/or airport conditions do not exist, more aircraft may be scheduled to arrive than the airport and airspace can safely handle. In the past, this traffic overload would be handled through the use of airborne holding of aircraft. Controllers would try to land as many aircraft as possible, with all excess aircraft assigned to nearby holding patterns until space became available.

This method of smoothing out the traffic flow has many disadvantages. The primary disadvantage is that while holding, aircraft consume airspace and fuel. In today's highly competitive marketplace, airlines can ill afford to have aircraft circle an airport for an extended period of time.

In an attempt to reduce the amount of airborne holding, the Federal Aviation Administration (FAA) has instituted a number of new traffic management programs. One program seeks to predict near-term airport acceptance rates (AARs) and match arriving aircraft to that number. One program in use is the controlled departure program. This program predicts an airport's acceptance rate over the next 6–12 hours and matches the inbound flow of aircraft to that rate. Aircraft flow is adjusted through the delaying of departures at remote airports.

Overall delay factors are calculated, and every affected aircraft is issued a delayed departure time that will coordinate its arrival to the airport's acceptance rate.

The primary disadvantage of such a system is twofold. First, it is very difficult to predict 6–12 hours in advance conditions that will affect a particular airport's acceptance rate. These conditions include runway closures, adverse weather, and so on. As unforeseen events occur that require short-term traffic adjustments, many inbound aircraft are already airborne and therefore cannot be delayed on the ground. This means that the only aircraft that can be delayed are those that have not yet departed and are still on the ground at nearby airports. This system inadvertently penalizes airports located close to hub airports because they absorb the brunt of these unpredictable delays. In other situations, traffic managers may delay aircraft due to forecasted circumstances that do not develop. In these situations, aircraft end up being delayed unnecessarily. On the contrary, once an aircraft has been delayed, that time can never be made up.

Once aircraft are airborne, newer traffic flow management programs attempt to match real-time airport arrivals to the AAR. These programs are known as aircraft metering. Metering is a dynamic attempt to make short-term adjustments to the inbound traffic flow to match the AAR. In general terms, a metering program determines the number of aircraft that can land at an airport during a 5- to 10-minute period, and it also determines and then applies a delay factor to each inbound aircraft so that they land in sequence with proper spacing. The metering program dynamically calculates the appropriate delay factor and reports this to the controller as a specific time that each aircraft should cross a specific airway intersection. The controller monitors the progress of each flight and issues speed restrictions to ensure that every aircraft crosses the appropriate metering fix at the computer-specified time. This should, in theory, ensure that aircraft arrive at the arrival airport in proper order and sequence.

### AIR TRAFFIC CONTROL SYSTEM OVERLOADS

Due to the procedural limitations placed upon aircraft participating in the ATC system, many ATC sectors far away from major airports can become temporarily overloaded with aircraft. In these situations, controllers would be required to separate more aircraft than they could mentally handle. This is a major limitation to the expansion of many ATC systems.

Various programs are being researched to counteract this problem. A prototype system has been developed in the United States known as enroute sector loading. The enroute sector loading



computer program calculates every sector's current and predicted traffic load and alerts ATC personnel whenever it predicts that a particular sector may become overloaded. When this occurs, management personnel determine whether traffic should be rerouted around the affected sector. This particular program is successful at predicting both systemic overloads and transient overloads due to adverse weather and traffic conditions.

## PILOT/CONTROLLER COMMUNICATIONS-RADIO SYSTEMS

Most ATC instructions, pilot acknowledgments, and requests are transmitted via voice-radio communications. By international agreement, voice communication in ATC is usually conducted in the English language using standardized phraseology. This phraseology is specified in ICAO documents and is designed to formalize phrases used by all pilots and controllers, regardless of the native language. This agreement permits pilots from the international community to be able to fly to and from virtually any airport in the world with few communication problems.

Voice communications between pilots and controllers are accomplished using two different formats and multiple frequency bands. The most common form of voice communication in ATC is simplex communications, in which the controller talks to the pilot and vice versa utilizing a single radio frequency. This method makes more efficient use of the narrow radio frequency bands assigned to aviation but has many inherent disadvantages. As one frequency is used for both sides of the conversation, when one person is transmitting, the frequency is unavailable to others for use. To prevent radio system overload, simplex radios are designed to turn off their receiver whenever transmitting.

These conditions make it difficult for a controller to issue instructions in a timely manner when using simplex communications. If the frequency is in use, the controller must wait until a break in communications occurs. More problematic is the occasion when two or more people transmit at the same time or if someone's transmitter is inadvertently stuck on. Due to the way radios operate, if two people try to transmit at the same time, no one will be able to understand the transmission, and neither of the individuals transmitting would be aware of the problem, because their receivers are turned off when transmitting.

Duplex transmission utilizes two frequencies—one for controller-to-pilot communications and the other for pilot-to-controller communications. This communication method is similar to that utilized during telephone conversations. Both individuals can communicate simultaneously and independently are able to interrupt one another and can listen while talking. Duplex transmission schemes have one major disadvantage, however. To prevent signal overlap, two discrete frequencies must be assigned to every controller-pilot communication. This essentially requires that double the number of communications frequencies be made available for ATC. Due to the limited frequencies available for aeronautical communications, duplex transmissions can seldom be used in ATC.

Most short-range communications in ATC utilize the VHF radio band located just above those used by commercial FM radio stations. Just as FM radio stations, aeronautical VHF is not affected by lightning and other electrical distortion, but it is known as a line-of-sight frequency band, which means that the radio signal travels in a straight line and does not follow the curvature of the Earth.

Airborne VHF radios must be above the horizon line if they are to receive any ground-based transmissions. If an aircraft is below the horizon, it will be unable to receive transmissions from the controller and vice versa.

This problem is solved in the ATC system through the use of remote communications outlets (RCOs). RCOs are transmitter/receivers located some distance from the ATC facility. Whenever a controller transmits, the transmission is first sent to the RCO using land-based telephone lines, and then it is transmitted to the aircraft. Aircraft transmissions are relayed from the RCO to the

controller in the same manner. Each RCO is assigned a separate frequency to prevent signal interference. This system permits a single controller to communicate with aircraft over a wide area but requires the controller to monitor and operate multiple radio frequencies. The use of RCOs not only extends the controller's communications range but also makes the ATC communications system vulnerable to ground-based telephone systems that may malfunction or be damaged, thereby causing serious ATC communication problems.

Most civil aircraft utilize VHF communications equipment. Military aircraft utilize ultra-high-frequency (UHF) band transmitters. UHF is located above the VHF band. UHF communications systems are preferred by most military organizations because UHF antennas and radios can be made smaller and more compact than those utilized for VHF. UHF is also a line-of-sight communications system. Most ATC facilities are equipped with both VHF and UHF radio communications systems.

Extended-range communication is not possible with VHF/UHF transmitters. RCOs can help one extend the range of the controller but need solid ground on which to be installed. VHF/UHF radios are unusable over the ocean, the poles, or in sparsely populated areas. For long-range, over-ocean radio communications, high-frequency (HF) radios are used. HF uses radio frequencies just above the medium-wave or AM radio band. HF radios can communicate with line-of-sight limitations, as far as 3,000 miles in some instances, but can be greatly affected by sunspots, atmospheric conditions, and thunderstorm activities. This interference is hard to predict and depends on the time of day, season, sunspot activity, local and distant weather, and the specific frequency in use. HF radio communication requires the use of multiple frequencies, with the hope that at least one interference-free frequency can be found for communications at any particular time. If controllers cannot directly communicate with aircraft, they may be required to use alternate means of communications, such as using the airline operations offices to act as communication intermediaries. This limitation requires that controllers who rely on HF communications not place the aircraft in a position where immediate communications may be required.

Experiments have been conducted using satellite transmitters and receivers to try to overcome the limitations of HF/VHF/UHF transmission systems. Satellite transmitters utilize frequencies located well above UHF and are also line-of-sight. But if sufficient satellites can be placed in orbit, communications anywhere in the world will be virtually assured. Satellite communications have already been successfully tested on overseas flights and should become commonplace within a few years.

## VOICE COMMUNICATION PROCEDURES

As previously stated, virtually every ATC communication is currently conducted by voice. Initial clearances, taxi and runway instructions, pilot requests, and controller instructions are all primarily conducted utilizing voice. This type of communication is fairly unreliable due to both the previously mentioned technical complications and communications problems inherent in the use of one common language in ATC. Although every air traffic controller utilizes English, they may not be conversationally fluent in the language. In addition, different cultures pronounce words and letters in different ways. Many languages do not even use the English alphabet. Moreover, every controller has idioms and accents peculiar to their own language and culture. All these factors inhibit communications and add uncertainty to ATC communications.

When using voice-radio communications, it can be very difficult for a controller to insure that correct and accurate communication with the pilot has occurred. Pilots normally read back all instructions, but this does not solve miscommunication problem. Informal and formal surveys lead experts to believe that there are literally millions of miscommunications worldwide in ATC every year. Obviously, most of these are immediately identified and corrected, but some are not, leading to potential problems in the ATC system.

## ELECTRONIC DATA COMMUNICATIONS

In an attempt to minimize many of these communication problems, various schemes of nonvoice data transmission have been tried in ATC. The most rudimentary method still in use is the ATCRBS transponder. If the aircraft is properly equipped, its identity and altitude will be transmitted to the ground station. Existing ATCRBS equipment is currently incapable of transmitting information from the controller to the aircraft. The new Mode-S transponder system will be able to transmit more information in both directions. This information might include aircraft heading, rate of climb/descent, airspeed, and rate of turn, for example. Mode-S should also be able to transmit pilot requests and controller instructions. Mode-S is slowly being installed on the ground, and airborne equipment is gradually being upgraded. Until a sufficient number of aircraft have Mode-S capability, the ATCRBS system will still be utilized. Full Mode-S implementation will probably be completed sometime after the year 2000.

An intra-airline data-communications system known as the aircraft communications addressing and reporting system (ACARS) has been utilized by the airlines for years to send information to and from properly equipped aircraft. ACARS essentially consists of a keyboard and printer located on the aircraft and corresponding equipment in the airline's flight operations center. ACARS is currently used by the airlines to transmit flight planning and load information. A few ATC facilities are now equipped to transmit initial ATC clearances to aircraft using ACARS. This limited service will probably be expanded until Mode-S becomes widespread.

## CONTROLLER COORDINATION

As controllers are responsible for the separation of aircraft within their own sector, they must coordinate the transfer of aircraft as they pass from one sector to another. In most situations, this coordination is accomplished using voice communications between controllers. In most cases, unless the controllers are sitting next to each other within the same facility, coordination is accomplished using the telephone.

*Hand-offs* are one form of coordination and consist of the transfer of identification, communications, and control from one controller to the next. During a hand-off, the controller with responsibility for the aircraft contacts the next controller, identifies the aircraft, and negotiates permission for the aircraft to cross the sector boundary at a specific location and altitude. This is known as the transfer of identification. Once this has been accomplished, and all traffic conflicts are resolved, the first controller advises the pilot to contact the receiving controller on a specific radio frequency. This is known as the transfer of communication. Separation responsibility still remains with the first controller until the aircraft crosses the sector boundary. Once the aircraft crosses the boundary, separation becomes the responsibility of the receiving controller. This is known as the transfer of control.

To simplify hand-offs, standardized procedures and predefined altitudes and routes are published in a document known as a *letter of agreement* (LOA). LOAs simplify the coordination process because both controllers already know what altitude and route the aircraft will be utilizing. If the controllers wish to deviate from these procedures, they must agree to an *approval request* (*appreq*).

The transferring controller usually initiates an *appreq* verbally, requesting a different route and/or altitude for the aircraft to cross the boundary. If the receiving controller approves the *appreq*, the transferring controller may deviate from the procedures outlined in the LOA. If the receiving controller does not approve the deviation, the transferring controller must amend the aircraft's route/altitude to conform to those specified in the LOA.

There are many problems inherent in this system of verbal communication/coordination. When both controllers are busy, it is very difficult to find a time when both are not communicating with aircraft. Controllers are also creatures of habit and may sometimes *hear* things that were not said. There are many situations in ATC in which aircraft are delayed or rerouted, not due to conflicting traffic, but because the required coordination could not be accomplished in a timely manner.

Automated hand-offs have been developed in an attempt to reduce these communication/coordination problems. An automated hand-off can be accomplished if the two sectors are connected by computer, and the routes, altitudes, and procedures specified in the LOA can be complied with. During an automated hand-off, as the aircraft nears the sector boundary, the transferring controller initiates a computer program that causes the aircraft information to be transferred and start to flash on the receiving controller's radar display. This is a request for a hand-off and implies that all LOA procedures will be complied with. If the receiving controller determines that the hand-off can be accepted, computer commands are entered that cause the radar target to flash on the transferring controller's display.

This implies that the hand-off has been accepted, and the first controller then advises the pilot to contact the next controller on the appropriate frequency. Although this procedure may seem quite complex, in reality it is very simple, efficient, and reduces voice coordination between controllers significantly. Its primary disadvantage is that the route and altitudes permissible are reduced, and the ATC system becomes less flexible overall.

**FLIGHT PROGRESS STRIPS**

Virtually, all verbal communications are written down for reference on paper flight progress strips. Flight strips contain most of the pertinent information concerning each aircraft. When a controller verbally issues or amends a clearance or appreqs a procedural change with another controller, this information is hand written on the appropriate flight progress strip. Flight progress strips are utilized so that controllers do not need to rely on their own memory for critical information. Flight strips also make it easier for other controllers to ascertain aircraft information if the working controller needs assistance or when a new controller comes on duty. Due to differences in each controller's handwriting, very specific symbology is used to delineate this information. [Figure 3.1](#) contains examples of some common flight strip symbologies.

3	1	2	11	15	16	20	21	25	27
4			12				22		28
5			13						
6			14				23		
7	8			17	18				
	9			19		20a	24	26	
		10	14a						29 30
DAL542			1	7HQ	30	330		FLLJ14 ENO 000212	2675
H/B753/A				1827				COD PHL	
T468 G555									
16 16									
486 09				PXT		RA ↑1828			*ZCN

**FIGURE 3.1** Flight strip symbology.

## FLIGHT INFORMATION AUTOMATION

The constant updating of flight progress strips and the manual transferring of information consume much of a controller's time and may necessitate the addition of another controller to the sector to keep up with this essential paperwork. This process is forecast to become somewhat more automated in the future. Future ATC systems have been designed with flight strips displayed on video screens. It is theoretically possible that as controllers issue verbal commands, these commands will be automatically interpreted and the electronic flight strips will be updated. Future enhancements may make it possible for the controller to update an electronic flight strip, and that information might be automatically and electronically transmitted to the pilot or even to the aircraft's flight control system.

## CONTROLLER RESPONSIBILITIES IN THE AIR TRAFFIC CONTROL SYSTEM

Controllers are responsible for the separation of participating aircraft within their own sector. They also provide additional services to aircraft, such as navigational assistance and providing weather advisories. Additional responsibilities placed on the controller include maximizing the use of the airspace and complying with air traffic management procedures.

To accomplish these tasks, the controller must constantly monitor both actual and predicted aircraft positions. Due to rapidly changing conditions, a controller's plan of action must remain flexible and subject to constant change. The controller must continuously evaluate traffic flow, plan for the future, evaluate the problems that may occur, determine appropriate corrective action, and implement this plan of action. In the recent past, when traffic moved relatively slowly and the airspace was not quite as crowded, a controller might have minutes to evaluate situations and decide on a plan of action. As aircraft speeds have increased, and the airspace has become more congested, controllers must now make these decisions in seconds. As in many other career fields, experts feel that the current system may have reached its effective limit and increased ATC system expansion will not be possible until many of the previously mentioned tasks become automated.

## FUTURE ENHANCEMENTS TO AIR TRAFFIC CONTROL SYSTEMS

ICAO has agreed that GNSS should become the primary aircraft-positioning system. It appears at this time that uncorrected GNSS systems should supplant VORTAC as both an enroute and non-precision instrument approach aid. Space-based augmentation should permit GNSS to be used as a CAT I precision approach replacement for ILS. Ground-based augmentation should correct GNSS to meet CAT II and possibly CAT III ILS standards.

The GNSS system can be modified to permit the retransmission of aircraft position back to ATC facilities. This system, known as ADS, should supplant radar as a primary aircraft surveillance tool. Not only is this system more accurate than radar surveillance, but also it does not have the range and altitude limitations of radar and is able to transmit additional data both to and from the controller. This might include pilot requests, weather information, traffic information, and more.

Many other changes are planned. ICAO has completed a future air navigation system (FANS) that defines changes to navigation, communication, and surveillance systems. FANS is a blueprint for the future of international aviation and ATC. [Table 3.5](#) summarizes FANS.

Once these improvements have taken place, automated ATC systems can be introduced. Various research programs into automation have been initiated by many ATC organizations, with the eventual goal of developing an air traffic management system called *free flight*.

The concept of free flight has been discussed since the early 1980s. Free flight proposes to change ATC separation standards from a static, fixed set of standards to dynamic separation that takes into

**TABLE 3.5**  
**Future ATC and Navigation System Improvements**

Function	Type	Current Standard	Future Standard
Navigation	Enroute	VORTAC	Skeleton VORTAC and ILS backup system
	Approach	ILS GNSS	Augmented GNSS
Communication	Short-range	VHF and UHF	VHF and UHF
	Long-range	HF	Satellite
Surveillance		Radar and ADS	Radar and automatic dependent surveillance
Datalink		ATCRBS	Mode-S and ADSs

account aircraft speed, navigational capability, and nearby traffic. Based on these parameters, each aircraft will be assigned a *protected* zone that will extend ahead, to the sides and above and below the aircraft. This zone will be the only separation area protected for each aircraft. This differs from the current system that assigns fixed airway dimensions and routes for separation.

Assuming that each aircraft is equipped with an accurate flight management system, free flight proposes that each aircraft transmit to ground controllers its flight management system–derived position. On the ground, computer workstations will evaluate the positional data to determine whether any aircraft conflicts are predicted to exist, and if so, offer a resolution instruction to the air traffic controller. The controller may then evaluate this information and pass along appropriate separation instructions to the aircraft involved.

The free flight concept is still being developed, but if found feasible, will soon be implemented at high altitudes within the U.S. airspace structure. As confidence in the system is gained, it will likely be extended overseas and into the low-altitude flight structure.

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