Chapter 3

THE NATIONAL AIRSPACE SYSTEM

Photo credit U S Department of Transportation

Contents

List of Tables

List of Figures

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THE NATIONAL AIRSPACE SYSTEM

The National Airspace System (NAS) is a large and complex network of airports, airways, and air traffic control (ATC) facilities that exists to support the commercial, private, and military use of aircraft in the United States. This chapter examines the major parts of the system, both to see how the system operates and to identify factors that may shape its future development. For explanatory purposes, it first considers the goals of the system and then describes the system under three major headings: airports, air traffic services, and airspace users.

GOALS

NAS is designed and operated to accomplish three goals with respect to civil aviation:

1. safety of flight;
2. expeditious movement of aircraft; and
3. efficient operation.

These goals are related hierarchically, with safety of flight the primary concern. The use of airport facilities, the design and operation of the ATC system, the flight rules and procedures employed, and the conduct of operations are all guided by the principle that safety is the first consideration.

Without compromising safety, the second goal is to permit aircraft to move from origin to destination as promptly and with as little interference as possible. This involves preventing conflicts between flights, avoiding delays at airports or en route, and eliminating inefficient or circuitous flight paths. It also entails making maximum use of airport and airway capacity in order to satisfy demand, so long as safety is not compromised. If safety and capacity utilization are in conflict, the Federal Aviation Adminstration's (FAA) operating rules require that the volume of traffic using the system be reduced to a level consistent with safety.

The third goal is to provide airport and ATC services at low cost. This entails minimizing the costs to users—not only monetary costs but also the penalties of delay, inconvenience, or undue restriction. It also entails operating the system as efficiently as possible so as to reduce transaction costs and to increase productivity, i.e., to handle more aircraft or to provide better service to those aircraft with a given combination of runways, controllers, and ATC facilities.

Whereas safety cannot be compromised in the interest of cutting costs, capacity and cost may be traded off for the sake of safety. The special measures adopted to deal with disruption of the system as a result of the air traffic controllers' strike in August 1981 illustrate the hierarchal relationship of safety, capacity, and efficiency. In order to continue safe operation in the face of work force reductions, the number of aircraft allowed to use certain crowded airports and air ways at peak demand hours was reduced to a level that could be handled safely. These measures reduced capacity (the number of aircraft that the system could accommodate) and increased cost (delays, canceled flights, adherence to quotas), but an effort was made to allow the remaining capacity to be used effectively and keep costs within reasonable limits. For example, limits on the number of air carrier flights were imposed only at the 22 busiest airports, and restrictions were later eased at those airports where more operations could be accommodated. Airlines were allowed to use larger aircraft so as to provide as much seat capacity as possible but with fewer flights, and wherever possible flow control procedures were employed to ensure that aircraft were delayed on the ground rather than in flight, so as to minimize waste of fuel. Other restrictive measures were applied to cut back on general aviation (GA) flights. The military services voluntarily reduced flight operations.

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The anticipated growth of air traffic and the demand for ATC services over the next two decades poses several problems, and the need to maintain a dynamic balance among system goals motivates the search for improved methods of ATC and better utilization of airway and airport capacity. Before turning to examination of these problems, however, it is first necessary to look at the major parts of the NAS and to consider the factors that could shape their course of revelopment.

AIRPORTS

Airports are the first major part of NAS. They are any place designed, equipped, or commonly used for the landing and takeoff of aircraft. This definition covers a broad variety of sites: many of the sites designated as airports by the FAA are merely dirt strips or seaplane moorings near open water; at the opposite end of the spectrum are complex air terminals serving major metropolitan areas, like the 5,000-acre JFK International Airport in New York. About 60 percent of the 15,000 U.S. airports are private or military fields and not available for public use. Of the roughly 6,500 civil airports open to the public, almost 90 percent are used exclusively by small GA aircraft. The remaining 780 airports (about 5 percent of all U.S. airports) are served either by scheduled air carriers or by commuter and air taxi operators (see table 1).

FAA, in compliance with the Airport and Airway Development Act of 1970, maintains a master list of airport development needs for the next decade. This compilation, which is periodically revised, is known as the National Airport System Plan (NASP). It identifies categories of airports that are of Federal interest and that are eligible for Federal funds under the Airport Development Aid Program (ADAP), and the Planning Grant Program administered by FAA. NASP categorizes public use airports according to the type of aviation activity they accommodate: international, domestic air carrier, commuter, reliever, and general aviation. This does not imply that GA aircraft use only GA airports; in fact, there are GA operations at all categories of airports. Rather, the GA classification denotes that such airports serve only GA and not other types of users.

International Airports

An international airport regularly serves air carrier flights operating between the United States and foreign countries. International airports tend to be among the best equipped airports in terms of runways, landing aids, and ATC facilities. In 1980 there were 76 such airports.

Table 1 .–Airports Included in National Airport System Plan, 1980[a]

Type of service	Conventional	Heliport	Seaplane	Total
Air carrier[b]	603	1	31	635
Commuter	139	—	6	145
Reliever	155	—		155
General aviation	2,198	4	22	2,224
Total NASP airports	3,095	5	59	3,159
Total public-use airports not in NASP[c]				3,360
Total				6.519

[a] Includes airports in Hawaii and Alaska.
[b] Includes 76 airports designated as ports of entrY.
[c] Entirely general aviation.

SOURCE: Federal Aviation Administration, *National Airport System Plan*, 1980-89, 1980,

Domestic Air Carrier Airports

In 1980, NASP included 603 airports served by domestic air carriers, a figure that includes all of the international airports described above but excludes 1 heliport and 31 seaplane facilities served by scheduled air carriers. These airports are classified by FAA according to the size of the traffic hub they serve, where a hub is defined as a Standard Metropolitan Statistical Area (SMSA) requiring air service. The hub classifications are:

Hub classification:	*Percentage of total airline passengers **
Large (L)	1.00 or more
Medium (M)	0.25 to 0.99
Small (S)	0.05 to 0.24
Nonhub (N)	less than 0.05

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*Passengers eplaned by domestic and foreign carriers at U S airports

A hub may have more than one air carrier airport, and the 25 SMSAs presently designated as large hubs are served by a total of 38 air carrier airports. The distribution of aviation activity at domestic air carrier airports is highly skewed, with progressively greater percentages of flights and passengers concentrated at fewer and fewer airports. In 1980, for example, the 486 nonhubs handled only 3 percent of all passenger enplanements; the 76 small hubs handled 8 percent; the 41 medium hubs handled 18 percent; and the 25 large hubs handled 70 percent. To carry this point one step further, the top five air carrier airports (Chicago, Atlanta, Los Angeles, Denver, and Dallas/Fort Worth) handled about one-quarter of all passenger enplanements and one-fifth of all airline departures. This means that air traffic congestion tends to center at a very small fraction of airports; but because of the volume of traffic handled at these airports, it affects a large percentage of all aircraft and passengers.


Photo credit: Federal Aviation Administration

All filled up


Photo credit: Federal Aviation Administration

Room to grow

Commuter Airports

Until the Airline Deregulation Act of 1978, many commuter and air taxi airlines were not certificated as scheduled air carriers by the Civil Aeronautics Board (CAB), and NASP classified airports served exclusively by commuter and air taxi in a separate category. Since airline deregulation, the number of airports in this category has fluctuated widely, showing sharp increases in 1979 and 1980 as commuter airlines sought to open up new markets and an almost equally sharp drop in 1981 as these markets failed to materialize. Commuter airports, typically located in small communities, handle a very low volume of traffic, 2,500 to 5,000 passenger enplanements per year. The major concern about this category is not capacity but keeping the airport in operation so as to provide essential air service for the small communities in which they are located.

Reliever Airports

Reliever airports are a special category of GA airport whose primary purpose is to reduce congestion at air carrier airports in large and mediurn hubs by providing GA users with alternative operational facilities and aircraft services of roughly similar quality to those available at hub airports. The criteria for classification as a reliever airport in NASP are 25,000 itinerant operations or 35,000 local operations annually, either at present or within the last 2 years. The reliever airport must also be situated in a SMSA with a population of at least 500,000 or where passenger enplanements by scheduled airlines are at least 250,000 annually. There were 155 airports designated as relievers in the 1980-89 NASP.

General Aviation

GA airports are either private use or public use, but only the latter are eligible for Federal development or improvement funds under NASP. There were approximately 2,200 GA public-use airports in the 1980 NASP. Capacity is usually not a concern except at the largest GA airports, such as Long Beach, Van Nuys, Teterboro, or Opa-Locka, which may require improvements similar to those contemplated at major hub airports. For most GA airports the chief concern is upgrading and extending airport facilities and ATC services so as to accommodate larger and more sophisticated aircraft and to allow operation under adverse conditions. These improvements are being sought both to support the expected growth of GA and to provide facilities comparable to air carrier airports, thereby permitting diversion of some GA operations from congested hubs.

AIR TRAFFIC SERVICES

The ATC system—the second major part of the National Airspace System—offers three basic forms of service: navigation aid (including landing), flight planning and in-flight advisory information, and air traffic control.

Navigation

Aid to navigation was the first service provided to civil aviation by the Federal Government. At the end of World War I, the Post Office undertook to set up a system of beacons along the original airmail routes to guide aviators at night and in times of poor visibility. By 1927, this airway extended from New ‘fork to San Francisco, with branches to other major cities.

In the 1930’s, ground beacons for visual guidance were replaced by two types of low-frequency radio navigation aids—nondirectional beacons and four-course radio range stations. The nondirectional beacon emitted a continuous signal that allowed the pilot to navigate, in a manner analogous to using a light ground beacon, by homing on the signal with an airborne direction finder. The radio range station was a further improvement in that it emitted a directional signal, forming four beacons alined with respect to the compass, each defining a course. Pilots listened to a radio receiver and followed these radio beams from station to station along the route. The four-course radio range system was phased out beginning in 1950, after reaching a maximum deployment of 378 stations. Low-frequency nondirectional radio beacons are still in limited use in the United States and widespread use in other parts of the world.[*]

The technology that supplanted the low-frequency four-course range as the basic navigation system for civil aviation was very high frequency omnirange (VOR) transmitters, which were first put in service in 1950. This system had several advantages over low-frequency radio. VOR is less subject to interference and aberrations due to weather; it is omnidirectional, permitting the pilot to fly on any chosen radial rather than only the four courses possible with the radio range station; and the addition of a cockpit display freed the pilot from the need to listen to radio signals continuously. The major disadvantage of VOR is that signals are blocked

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[*] In 1981, there were 1,095, nondirectional radio beacons in service in the United States, including 54 military and 734 non-Federal installations.

at the horizon, and navigational signals from a station can be received over a much smaller area than low-frequency radio. To provide the same geographical coverage as the older low-frequency radio system, therefore, a great many more VOR stations were required. At present, there are 1,039 VOR stations in operation (930 FAA, 42 military, 67 non-Federal), providing extensive but not complete coverage of the contiguous 48 States and Hawaii and limited coverage of Alaska.

In the 1960's, the basic VOR system was supplemented by distance measuring equipment (DME) that permitted measurement of range as well as direction to a station. The DME used the distance-measuring portion of a military Tactical Control and Navigation System (TACAN), colocated with a VOR station to create what is called a VORTAC. This is the standard airway navigation aid in use today, and at present all commercial air carriers have VOR/DME equipment. ’ Over 80 percent of GA aircraft are also equipped with VOR receivers, and over one-third of these also have DME. In addition to the Federal investment in VORTAC facilities (on the order of $250 million), there is a very large private investment (roughly $300 million) in airborne navigation equipment to use the present VORTAC technology. As a result, both the Federal Government and the aviation community have a strong incentive to protect this investment by prolonging the operational life of their VORTAC equipment and the airway route structure based on it.

Nevertheless, VOR—which relies on 30- or 40-year-old technology-has some inherent disadvantages. Because it is a ground-based system, it does not provide coverage of oceanic areas. Because it is a line-of-sight system, VOR is of limited usefulness at low altitudes or in mountainous areas. The VOR route structure concentrates traffic along rather narrow channels and produces a potential for conflict at intersections where airways cross. Further, navigation from one fix (intersection) to the next does not always produce the most direct routing from origin to destination.

Several alternative navigational systems (developed principally for military aviation) are available, and some are already used in auxiliary applications by civil aviation. The *Omega system*, developed by the U.S. Navy, is a low-frequency radio system that provides global coverage. It has been purchased by some airlines for transoceanic flights. *Loran-C* (also low-frequency radio), operated by the Coast Guard, is a maritime navigation system that also covers most of the continental United States; it affords very good accuracy and low-altitude coverage, even in mountainous areas. Some airline and corporate jet aircraft have self-contained airborne navigation systems such as *Doppler radar or Inertial Navigation System (INS),* which are accurate and are usable worldwide. All of these new systems permit *"area navigation" (RNAV),* whereby the pilot can fly directly between any two points without restriction to a VOR airway. There are also available RNAV systems that permit the aircraft to follow direct routings using VOR as a reference.

Many commercial air carriers and more than 7 percent of GA aircraft (largely business and corporate aircraft) have RNAV capability. Since 1973, FAA has been gradually implementing RNAV routes in the upper airspace and instituting approach procedures at selected airports to accommodate aircraft equipped with such systems. Phasing out the current airways structure and converting to a more flexible system of area navigation is a process that will require many years to complete. At present, FAA is committed to upgrading VORTAC stations to solid-state equipment at a cost of roughly $210 million (fiscal year 1980 dollars) over the next 10 years. At the same time, FAA must face the question of adopting new navigation technology to conform to new international standards scheduled for consideration by the International Civil Aviation Organization in 1984. The issue is not so much selection of a single new navigation system to replace VORTAC as it is a question of adopting procedures for worldwide navigation

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● Military aircraft are equipped with TACAN, VOR/DME, or both.

(especially RNAV) that will be compatible with several possible technologies.

Landing Aids

A guidance system for approach and landing is simply a precise, low-altitude form of navigation aid with the additional accuracy and reliability needed for landing aircraft in conditions of reduced visibility. The standard system now in use, the Instrument Landing System (ILS), was first deployed in the early **1940's although a prototype** system was **first demonstrated** by James Doolittle in 1929.

ILS provides guidance for approach and landing by two radio beams transmitted from equipment located near the runway. One transmitter, known as the localizer, emits **a** narrow beam alined with the runway centerline. The other transmitter, the glide slope, provides vertical guidance along a fixed approach angle of about 3°. These two beams define a sloping approach path with which the pilot alines the aircraft, starting at a point 4 to 7 miles from the runway. Because the ILS is generally not accurate or reliable enough to bring the aircraft all the way onto the runway surface by instrument reference alone, the pilot makes a transition to external visual reference before reaching a prescribed minimum altitude on the glide slope (the decision height). The decision height varies according to the airport and the type of ILS installation: 200 feet for most airports (category I), but 100 feet on certain runways at some airports (category II). At present there are 708 category I and 44 category II ILS installations in commission in the United States. * FAA plans call for installation of ILS at additional sites, primarily commuter airports, and for modernization of some 250 existing sites by converting to solid-state equipment and, in the process, upgrading 69 of them to category II capability.

ILS has two major limitations, both of which affect airport capacity. First, since the ILS does not provide reliable guidance all the way to touchdown, there are times and conditions when the airport must be closed. Such severely reduced visibility occurs less than 1 percent of the time for U.S. airports as a whole, but when this happens at a busy airport, traffic can be backed up not only at the affected airport but also at alternate landing sites and at airports where traffic originates. The other limitation is that it provides only a single fixed path to the runway—in effect, a conduit extending 4 to 7 miles from the runway threshold through which all traffic must flow. This has an even greater affect on capacity. When visibility is such that the ILS approach must be used, traffic must be strung out along a single path and the rate at which landings can be effected is constrained by the speed and spacing of aircraft in single file.

The Microwave Landing System (MLS), which has been under development by FAA for several years and is now ready for initial deployment, could overcome these limitations of ILS, which in turn could help improve the flow of traffic in terminal areas by allowing more flexibility in segregating and sequencing the arrival of aircraft on the runway. The magnitude of the resulting capacity gains is subject to some dispute, however, and not all agree that MLS would play a major part in reducing terminal airspace congestion. The MLS is discussed further in chapter 5.'

Flight Planning and Advisory Information

Timely and accurate information about weather and flight conditions is vital to airmen, and FAA perceives this aspect of system operation to be a prime benefit, particularly to the GA community. Flight planning and information services take several forms and are provided partly by FAA and partly by the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce. NOAA publishes maps, aeronautical charts, and related documents from information furnished by the FAA. The National Weather Service of NOAA provides weather maps and reports. FAA pub-

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* In addition, there are 48 non-FAA facilities that have category I ILS installations.

'*Microwave Landing Transition Plan, APO-81-1* (Washington, D. C.: Federal Aviation Administration, 1981).

lishes manuals, instructions, and notices to airmen (NOTAMs) to help pilots in planning and executing flights. FAA operates a national weather teletype network, disseminates weather information by radio broadcast and recorded telephone messages, and provides weather briefings. FAA also disseminates to airmen, both preflight and in flight, information concerning the status of navigation aids, airport conditions, hazards to flight, and air traffic conditions. FAA personnel are also available to help pilots in preparing and filing flight plans and to disseminate these flight plans to other ATC facilities along the intended route and at the destination.

All of these planning and advisory services are intended to guide the airman in making use of the airspace under either of two basic sets of rules—Visual Flight Rules (VFR) and Instrument Flight Rules (IFR)—which govern the movement of all aircraft in the United States. * In general, a pilot choosing to fly VFR may navigate by any means available to him: visible landmarks, dead reckoning, electronic aids (such as VORTAC), or self-contained systems on board the aircraft. If he intends to fly at altitudes below 18,000 ft, he need not file a flight plan or follow prescribed VOR airways, although many pilots do both for reasons of convenience. The basic responsibility for avoiding other aircraft rests with the pilot, who must rely on visual observation and alertness (the "see and avoid" concept).

In conditions of poor visibility or at altitudes above 18,000 ft, pilots must fly under IFR. Many also choose to fly IFR in good visibility because they feel it affords a higher level of safety and access to a wider range of ATC services. Under IFR, the pilot navigates the aircraft by referring to cockpit instruments and by following instructions from air traffic controllers on the ground. The pilot is still responsible for seeing and avoiding VFR traffic, when visibility permits, but the ATC system will provide separation assurance from other IFR aircraft and, to the extent practical, alert the IFR pilot to threatening VFR aircraft.

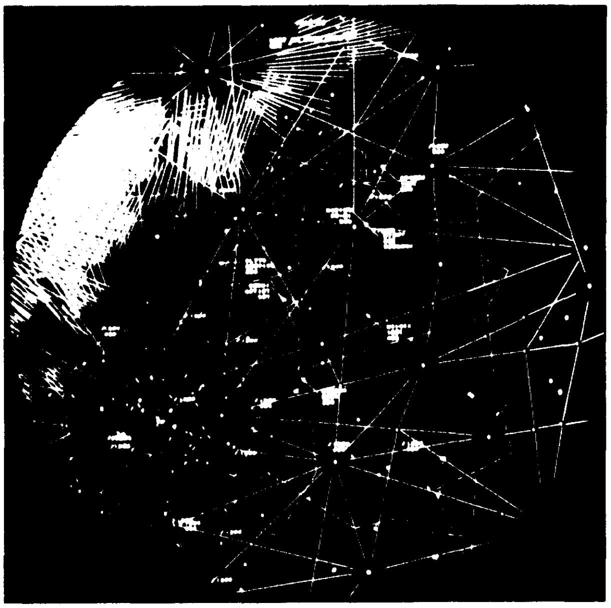

Photo credit Federal Aviation Administration

A display of air traffic as **it** appears to a controller

The distinction between VFR and IFR is basic to ATC and to the safe and efficient use of airspace, since it not only defines the services provided to airmen but also structures the airspace according to pilot qualifications and the equipment their aircraft must carry. VFR flights over the contiguous 48 States may not operate at altitudes above 18,000 ft, which are reserved for IFR flights. The altitudes between 18,000 and *60,000* ft are designated as positive control airspace; flights at these levels must have an approved IFR flight plan and be under control of an ATC facility. Airspace above 60,000 ft is rarely used by any but military aircraft. Most of the airspace below 18,000 ft is controlled, but both VFR and IFR flights are permitted.

The airspace around and above the busiest airports is designated as a terminal control area (TCA) and only transponder-equipped aircraft with specific clearances may operate in it regardless of whether operating under VFR or IFR. All airports with towers have controlled airspace to regulate traffic movement. At small airports without towers, all aircraft operate by the see-and-avoid principle except under instrument weather conditions. Figure 3 is a schematic rep-

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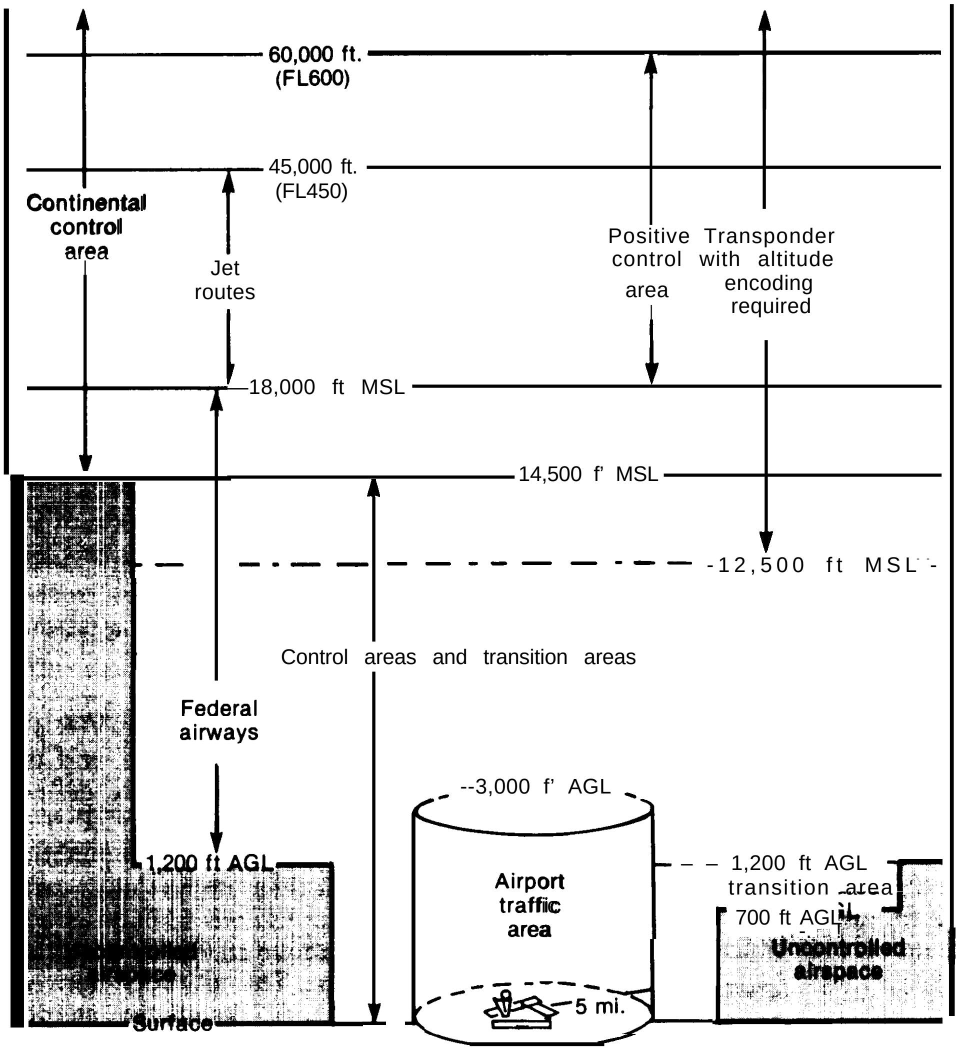
● Similar visual and instrument flight rules are in force in foreign countries that are ***members*** of the International Civil Aviation Organization (ICAO). In many cases, ICAO rules are patterned on the U.S. model,

Figure 3.—Airspace Structure



AGL - Above ground level
MSL - Mean sea level
FL - Flight level

SOURCE: Federal Aviation Administration.

resentation of the resulting airspace structure; as the general rule, VFR flights are permitted everywhere except in positive control airspace although clearances are required to operate within TCAs and at airports with control towers.

The IFR/VFR distinction also governs avionics and pilot qualifications. A VFR flight taking off and landing at a small private field and flying only in uncontrolled airspace needs little or no avionic equipment, although a pilot must have a radio if he elects to file a VFR flight plan or land at an airport with a control tower. Aircraft flying under IFR, on the other hand, are required to have radio and avionics equipment that will allow them to communicate with all ATC facilities that will handle the flight from origin to destination. They must also be instrumented to navigate along airways and to execute an IFR approach at the destination airport. These requirements apply to all IFR aircraft, and Federal Air Regulations also specify additional equipment requirements and pilot qualifications for various classes of air carrier aircraft. In addition, both IFR and VFR aircraft must have transponders that automatically transmit their identity and altitude when they are in TCAs* or at altitudes above 12,500 feet.

The VFR/IFR distinction also determines the type of ATC facility that will provide service to airspace users. There are three general types of facilities operated by FAA: air route traffic control center (ARTCC), which serve primarily IFR traffic; airport traffic control towers, which serve both IFR and VFR aircraft; and flight service stations (FSS), which primarily serve VFR traffic.

FSS serves three primary purposes: flight planning and advisory information for all GA aircraft; the dissemination of flight plans (VFR and IFR) to other facilities along the intended route; and operation of teletype networks to furnish information on weather and facility status to civil and military users. FAA encourages but does not require pilots flying VFR to file a flight plan; IFR flights must file a flight plan and obtain clearance to use the airspace. Personnel are on duty to provide direct briefings and assistance in filing flight plans (counter service), but most FSS contacts are by telephone or by radio. If a VFR flight encounters weather or restricted visibility en route, the pilot (provided he is rated for instrument flight) can change to an IFR flight plan while in the air and be placed in contact with the ATC system. The FSS handles these requests and coordinates changes with towers or ARTCCs. * *

FSS personnel are also ready to aid VFR pilots who experience in-flight emergencies. If a pilot is lost, the FSS will assist him by means of direction-finding equipment or arranging for tracking by an ATC radar facility. FSS personnel provide weather reports to pilots aloft and receive and relay pilot reports on weather and flight conditions. In more serious cases, such as engine trouble or forced landing, the FSS will attempt to pinpoint the location and coordinate search and rescue operations. Flight service stations also make periodic weather observations and transmit this information by teletype network to other ATC facilities and U.S. weather reporting services. Thus, FSS is essentially a communications center, serving general aviation directly but also providing information services for all airspace users. Figure 4 illustrates the communication links and the types of facilities that are in contact with a typical FSS.

FAA operates 317 FSSs, mostly at airports with VORTAC installations. Since traffic operates out of thousands of airports, much of FSS's work is done by means of transcribed messages and standardized briefings. The importance of FSS as an onsite facility at airports may thus be diminishing, and FAA has plans to consolidate FSSs into about 60 centralized locations. Concurrent with the reduction in the number of FSSs, FAA plans to increase the amount and type of on-call and remote services, including methods for semiautomatic filing of flight plans. FSS personnel would, however, be available—but usually at a remote location—to provide emergency services or to provide direct assistance to airmen. This proposed consolidation of FSS facilities has been the subject of controversy in the aviation community because it is feared that the quality and extent of services might be diminished and that observations for the National Weather Service might be curtailed.

Air Traffic Control

The essential feature of air traffic control service to airspace users is separation. The need for this service derives from the simple fact that, under IFR conditions, the pilot may not be able to see other aircraft in the surrounding airspace and will therefore need assistance to maintain safe separation and reach his destination. Historically, this need came about gradually with the increasing use of the airspace as the airlines began to operate under instrument flight conditions in the 1930's. In 1934 and 1935, the airlines organized a system for controlling traffic within roughly 100 miles of Newark, Chicago, and

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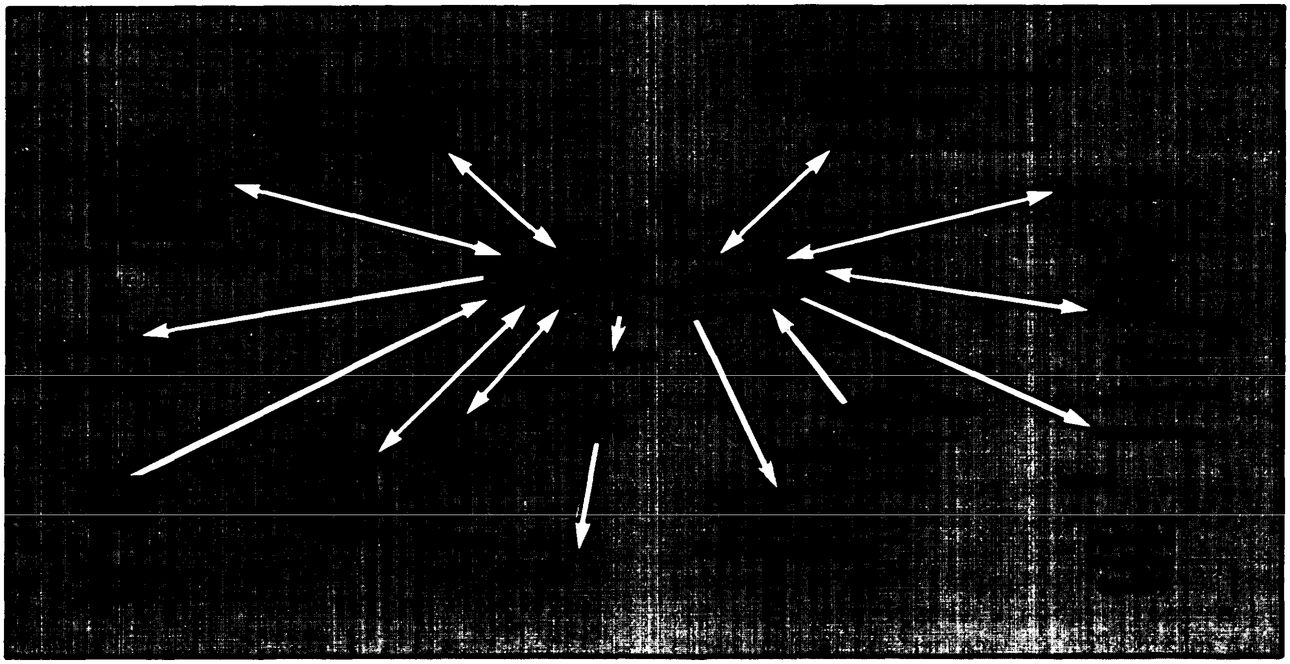
*Altitude-encoding transponders (Mode C) are required only in Group I TCAs, of which there are nine at present.

**In the interest of reducing controller workload, this service was suspended following the controllers' strike in August 1981.

Figure 4 Typical Flight Service Station Communication Links



SOURCE: Federal Aviation Administration.

Cleveland. In 1936, the U.S. Government assumed responsibility for these centers and established five more "airway" centers within the following year.

This "first generation" of separation service relied solely on radio and telephone communication. At established points along the airways, pilots were expected to report their time of arrival and altitude and their estimated time of arrival over the next checkpoint. In the ATC center controllers wrote the message on a blackboard and tracked flights by moving a marker on a tabletop map. In a later improvement, paper strips marked with flight data were posted in the order of their estimated arrival at each reporting point or airway intersection. This flight-strip system is still available as a backup system in the event of radar surveillance equipment failure, since it requires only radio communication between the pilot and the controller. To provide direct pilot-controller contact, especially as traffic density grew, it became necessary in the 1950's to establish remote communication air-ground stations at distances over 100 miles from ATC centers to relay messages from pilots to the controller handling their flights. This greatly improved the safety, capacity, and efficiency of the control process. In the first generation system, aircraft flying in the same direction and altitude were kept 15 minutes apart in their estimated arrival times at reporting points. This separation standard depended on the accuracy of position information and—equally important—on the speed and reliability of communicating instructions to resolve potential conflicts. Since the capacity of the ATC system increases as separation standards are reduced, progress therefore depended on further improvements in both communications and surveillance equipment as the ATC system developed.

The second generation of separation service came with the introduction of radar after World War II. In the 1950's, airport surveillance radars (ASRs) were introduced at major airports to provide data on arriving and departing aircraft within roughly 50 miles* At about the same time, the Civil Aeronautics Authority (predeces-

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● FAA now operates 195 ASRs.

sor to FAA), in coordination with the Air Force, began purchasing long-range (200-mile) radars for the en route centers with a view to establishing complete radar coverage of the continental United States. This was completed in *1965*, with the exception of some gaps in low-altitude coverages, and today data from multiple radar sites are relayed to ATC centers, so that radar contact can be kept with almost every IFR flight. The introduction of radar allowed continuous monitoring of actual aircraft progress and the detection of potential conflicts or hazard situations. The controller, under a process known as "radar vectoring, " could direct aircraft away from thunderstorms, around slower aircraft or downwind for spacing in the approach area. In so doing, however, the controller began to preempt control of heading and altitude from the pilot for short periods of time. Radar separation standards were greatly reduced from those of the first generation: 3 miles on approach or about 2 minutes at piston aircraft speeds.

Despite these improvements, there were still two major deficiencies in a surveillance system that relied on raw radar return: the altitude of the aircraft was not measured; and the identity of the aircraft could not be established from radar return alone. In 1958, the newly formed FAA began development of a so-called "secondary" radar surveillance system in which the radar beam, as it rotated in the scan of azimuth, triggered a positive, pulsed-code reply from a "transponder" (or beacon) on board the aircraft. This pulse contained information on the identity and altitude of the aircraft which could be correlated with primary radar return. This development program, known as Project Beacon, led to adoption of the secondary radar system in 1961, and it is the standard surveillance method in use today for separation assurance. All commercial air carriers and about two-thirds of GA aircraft are now equipped with transponders* and the primary radar system has become a backup for use in the event of equipment malfunction. The introduction of transponders and the simultaneous development of digitized information systems and computer-driven traffic displays led to a reduction of controller workload. Automated flight plan processing and dissemination, introduced at about the same time, further reduced controller workload by facilitating handoffs of aircraft from one en route sector to another and between en route and terminal area controllers. Collectively, these technological changes constitute the third generation of air traffic control.

All of these improvements have simplified and speeded up the acquisition of information needed to provide separation service, but they have not substantially altered the decisionmaking process itself, which still depends upon the controller's skill and judgment in directing aircraft to avoid conflicts. In recent years, attempts have been made to automate the decisionmaking aspects of separation assurance or to provide a backup to the controller in the form of computer-derived conflict alerts. Computers can now perform a simplistic conflict alert function by making short-term projections of aircraft tracks and detecting potential conflicts that the controller may have missed. Since the technique depends upon all aircraft being equipped with transponders, however, it does not provide separation assurance between unequipped aircraft.

The introduction of two-way digital communication rather than voice would mark the beginning of a new generation of separation service. In 1969, the Air Traffic Control Advisory Committee recommended the introduction of an improved form of radar known as the Discrete Address Beacon System (DABS). This system provides selective identification and address and a two-way, digital data link that allows improved transmission of data between ground and aircraft, so that much of the routine ATC information can be displayed in the cockpit for the pilot. DABS would thus provide more complete and rapid exchange of information than the present voice radio method. DABS would improve separation service in other ways as well. It could provide more accurate position and track data and could lead to more comprehensive forms of automated conflict detection and resolution. Further, because DABS can interrogate aircraft selectively it can avoid the overlap of signals in areas of high traffic density.

● Slightly less than 30 percent of GA aircraft have altitude-encoding (Mode C) transponders.

Another method for providing improved separation assurance is by means of collision avoidance systems on board the aircraft, which would alert the pilot to converging aircraft and direct an avoidance maneuver. Airborne collision avoidance systems, while conceived as a backup to ground-based separation service, would effectively transfer back to the IFR pilot some of the see-and-avoid responsibility that now governs VFR flight. Still another approach to separation assurance is the use of techniques to meter or space the movement of aircraft traffic into terminal areas from the en route portion of the system. These are strategic rather than tactical measures, in that they are directed not at avoiding conflicts per se but at preventing the congested conditions in which conflicts are more likely to occur. Traffic metering, spacing, and sequencing techniques are now used by controllers to prevent traffic buildup or undesirable mixes of aircraft, but for some time FAA has been seeking to develop automated methods that will accomplish this smoothing and sorting of traffic flow without intervention by controllers. Success of these efforts will depend upon development of computer prediction and resolution routines that will detect conflicts among flight plans (rather than flight paths) and issue appropriate instructions before actual conflict occurrs.

SYSTEM ORGANIZATION AND OPERATION

The third major part of the National Airspace System is the facilities and operational procedures for managing air traffic.

ATC Sectors

From the controller's viewpoint, the ATC system is made up of many small sectors of airspace, each defined in its horizontal and vertical extent and each manned by a controller with one or more assistants. Each sector has one or more assigned radio frequencies used by aircraft operating in the sector. As the flight moves from sector to sector, the pilot is instructed to change radio frequencies and establish contact with the next controller. On the ground, the controller must perform this "hand off" according to strict procedures whereby the next controller must indicate willingness to accept the incoming aircraft and establish positive control when the pilot makes radio contact before relieving the first controller of responsibility for the flight.

Since the number of aircraft that can be under control on a single radio frequency at any one time is limited to roughly a dozen, sector boundaries must be readjusted to make the sectors smaller as traffic density grows. At some point, however, resectorization becomes inefficient; the activity associated with handing off and receiving aircraft begins to interfere with the routine workload of controlling traffic within the sector. To help manage this workload, the sectors around busy airports are designed in such a way that arriving or departing traffic is channeled into airspace corridors, in which aircraft are spaced so as to arrive at sector boundaries at regular intervals. While this procedure facilitates the task of air traffic control, it results in longer and more fuel-consuming paths for aircraft, which have to follow climb and descent paths that are less than optimal. To this extent, the performance characteristics of the ATC system aggravate the effects of congestion in busy airspace and detract from the overall efficiency of airspace use.

ATC Facilities

Organizationally, the facilities that control air traffic are of three types: en route centers, terminal area facilities (approach / departure control and airport towers), and flight service stations. The first handles primarily IFR traffic; terminal area facilities and flight service stations handle both IFR and VFR flights. In addition, flight service stations perform information collection and dissemination activities that are of systemwide benefit.

The en route portion of the ATC system consists of 20 ARTCCs, * each reponsible for **a** major geographic region of the continental United States (see figs. 5 and 6). An ARTCC contains between 12 and 25 sectors which control traffic on the airways within the region, and ARTCC airspace is further divided into low-altitude sectors primarily used by propeller aircraft and high-altitude jet sectors. When aircraft are in level cruise, management of traffic is relatively simple and problems are infrequent. The sectors that are difficult to control are those where flights are climbing or descending around a major airport. Since these en route sectors are feeding aircraft into and out of terminal areas, the task of control also becomes complicated if the airport is operating near capacity. En route controllers may be required to delay the passage of aircraft out of their sector in order to meter traffic flow into terminal areas.

At smaller airports, aircraft leaving control of an ARTCC pass directly to control by the airport tower. At major hubs, however, there is an intermediate ATC facility called terminal radar approach control (TRACON) located at the airport. The TRACON (or "IFR room") handles arriving and departing traffic within roughly *40* miles of the airport—sequencing and spacing arrivals for landing on one or more runways, and sometimes at more than one airport. The TRACON also vectors departing aircraft along climbout corridors into en route airspace. The approach and departure controllers at a TRACON exercise a high degree of control over aircraft and must monitor the progress of each aircraft closely, as well as coordinate their activities with the ARTCCs from which they are receiving traffic and with the towers that are handling the takeoffs and landings at the airport itself.

Tower personnel control the flow of traffic to and from the runways and on ramps and taxiways connecting to the terminal. Tower controllers are the only ATC personnel that actually have aircraft under visual observation, although at larger airports they rely heavily on radar for surveillance. Figure 7 illustrates the activities of

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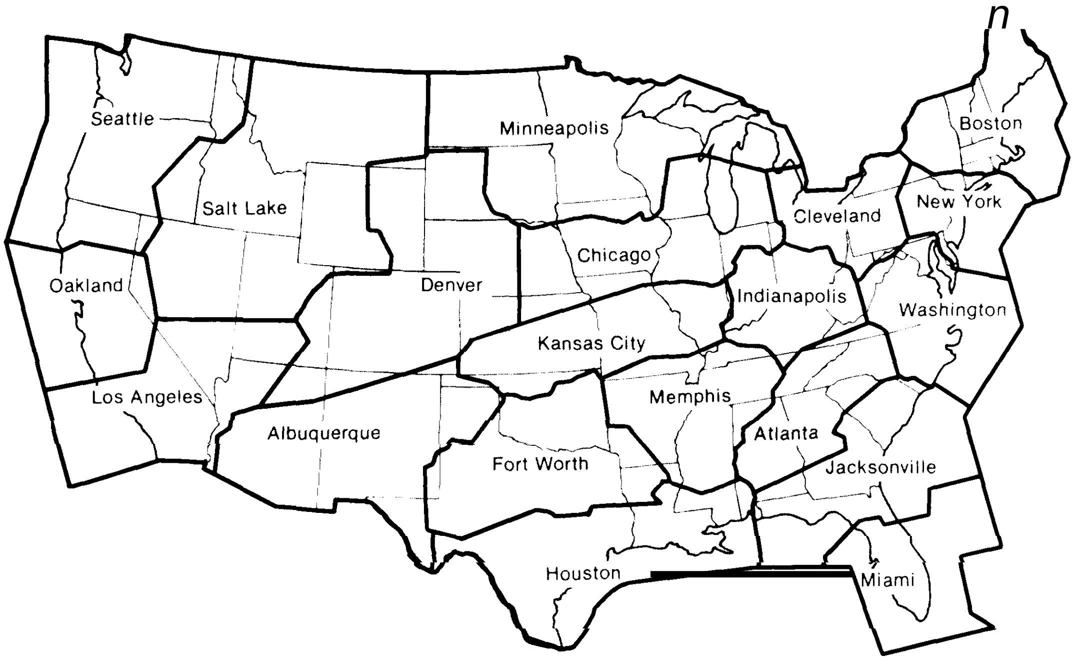
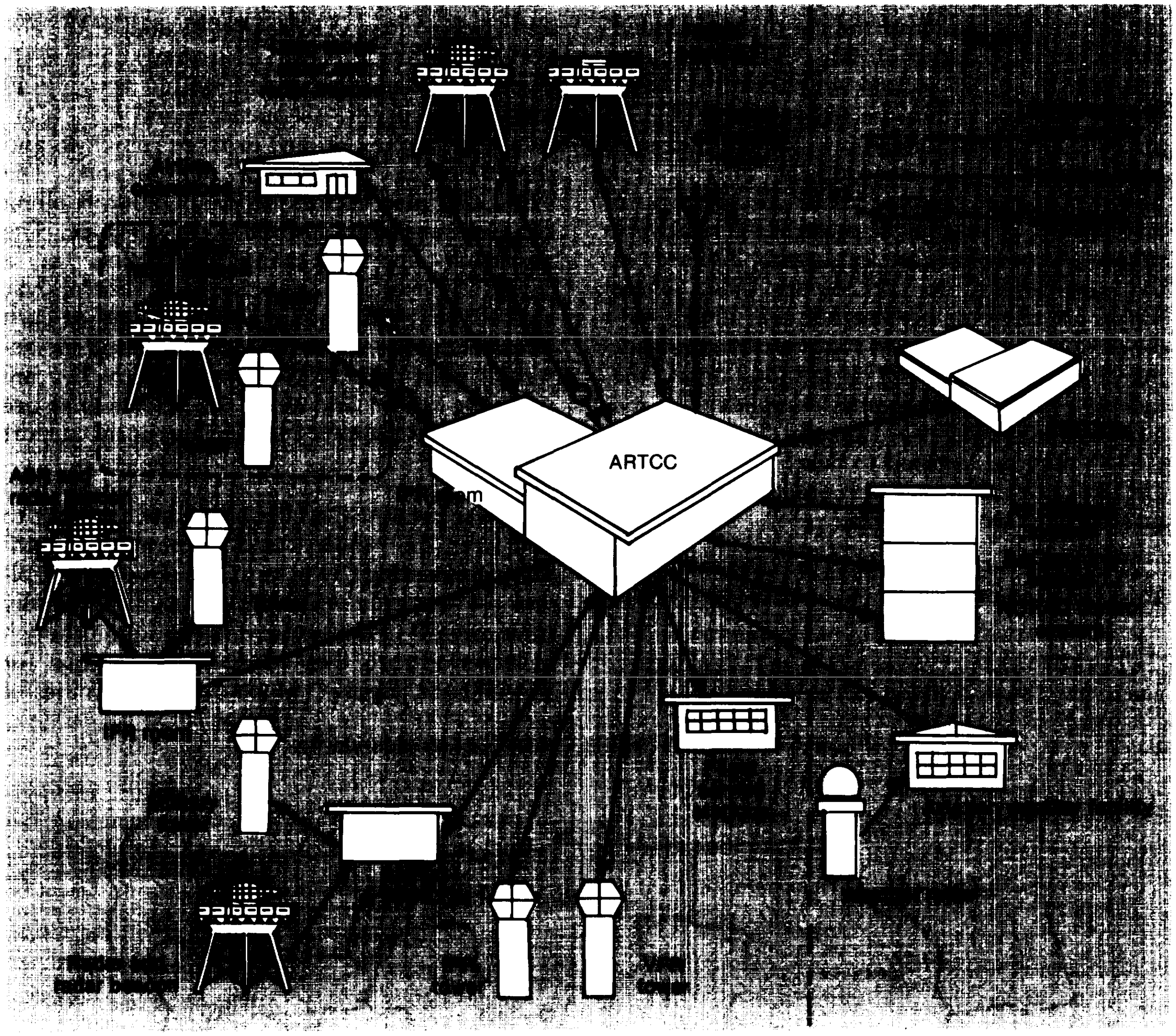
*In addition, there are two ARTCCs located outside the continental United States, in Hawaii and Puerto Rico.

Figure 5.—Air Route Traffic Control Center Boundaries



SOURCE: Federal Aviation Administration.

Figure 6.—Connections of a Typical ARTCC With Other Facilities



SOURCE: Federal Aviation Administration.

ATC terminal and en route facilities handling a typical IFR flight.

There are currently 431 airports with towers operated by FAA, of which 234 are approach control towers and the remainder are nonapproach control towers. An approach control tower, with its associated TRACON, provides separation and instrument landing services for IFR traffic and is also responsible for integrating VFR traffic into the approach Pattern. Figure 8 illustrates the equipment and facilities typically available at a large airport with an approach control tower. A nonapproach control tower is responsible for assisting traffic by providing weather, traffic, and runway information for all arrivals (VFR or IFR), but does not provide ILS or separation assurance.

Airspace Users

The users are the fourth major part of the National Airspace System. They cover a wide spectrum in skill and experience, types of aircraft

Figure 7.—ATC Activities for a Typical IFR Flight

At the departure gate, pilot confirms altitude, speed, route and estimated flight time with controller in the Chicago tower at O'Hare. After flight clearance, pilot contacts Chicago ground control for taxiing instructions and proceeds to runway.

When ready for takeoff, pilot once again contacts controller in the Chicago tower who, using radar and his own view from the tower, clears airplane for takeoff.

One mile away from takeoff point, the controller in the Chicago tower transfers responsibility for the fright to a departure controller, also at O'Hare airport, who directs the pilot to the proper course for the first leg of the flight.

Thirty miles farther in the flight, the departure controller transfers responsibility by instructing the pilot to contact a particular controller at the en-route Chicago Center, located in Aurora, Ill.

The controller at Chicago Center tracks the plane as it climbs to approximately 23,000 feet, then hands over the flight to another controller at the center who handles flights above that height. The airplane reaches cruising altitude of 33,000 feet about 100 miles east of Chicago.

The next handoff takes place as Chicago Center passes responsibility to the en-route Cleveland Center in Oberlin, Ohio. One controller tracks the airplane and transfers responsibility to a colleague as the fright passes from one sector to another.

Cleveland Center instructs the pilot to begin descent procedures as aircraft is over western Pennsylvania. The next handoff, to en-route New York Center in Ronkonkoma, N.Y., takes place as the plane is about 75 miles east of La Guardia Airport, New York City.

The plane continues its descent and New York Center hands off responsibility for the flight to the local New York approach-control facility at Garden City, N. Y., where a controller lines up the plane for its final approach to La Guardia Airport.

About 6 miles from the runway, responsibility passes to the tower at La Guardia, where a controller monitors the aircraft's instrument landing. The last handoff of the flight is made from tower to ground control, which directs the plane to its assigned gate.

SOURCE Newsweek

flown, and demands for air traffic services. They can be grouped in three categories—commercial, GA, and military—with GA exhibiting the greatest diversity. Table 2 is a summary of the U.S. pilot population in 1980 according to the type of license held and the percentage with instrument ratings, i.e., those qualified to use the airspace under IFR. The table shows that about *42* percent of all pilots are now IFR qualified; 10 years ago the percentage was about 30 percent. Almost all of this growth has occurred in the private (GA) category.

Table 3, which is a breakdown of aviation activity according to type of aircraft and hours

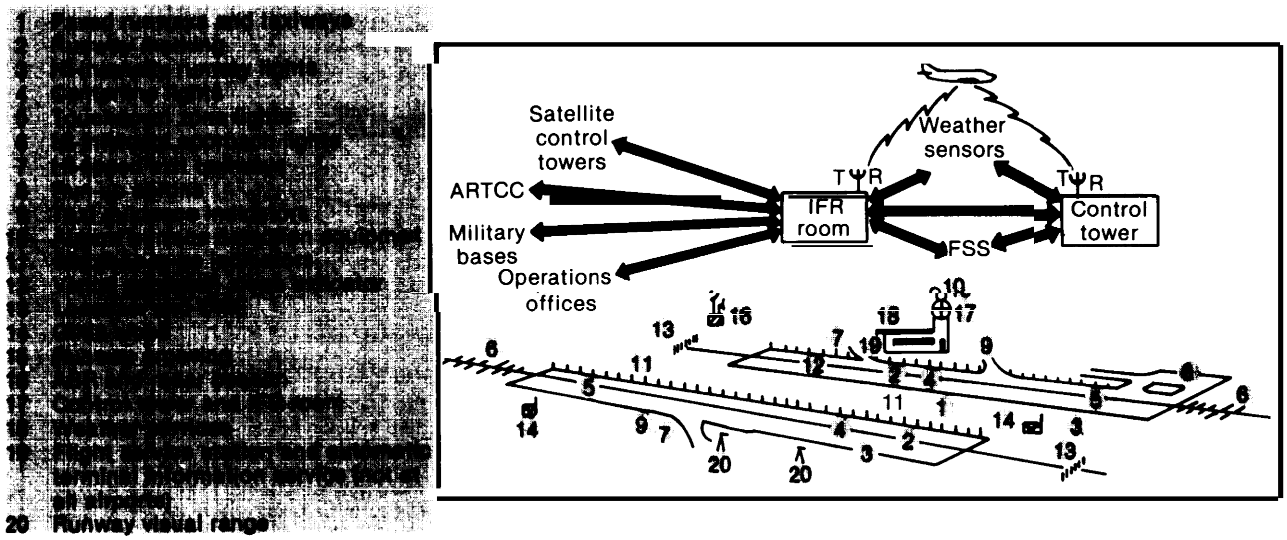
Table 2.-U.S. Pilot Population, 1980

Pilot group	Number	Instrument rated	Percent
Private (GA):			
Student.	199,833	0	0
Private license ... , .	357,479	39,347	11
Commercial:			
Commercial[a].	183,422	147,741	81
Airline transport license[b].	69,569	69,569	100
Total (excluding students)	610,490	256,547	42

[a] A commercial license allows the holder to work as a pilot and operate on air craft providing passenger service for hire.
[b] A more advanced rating required of pilots for air Carrier airlines.

SOURCE: FAA *Statistical Handbook of* Aviation, 7980.

Figure 8.—ATC Facilities and Equipment at a Typical Large Airport



SOURCE: Federal Aviation Administration.

Table 3.–Summary of Aviation Activity, 1980

User group	Number of aircraft	Percent IFR-equipped [a]	Estimated hours flown (millions)		
			Total	IFR[a]	Percent IFR[a]
Commercial air carrier:					
Piston.	595	100	0.48	0.48	100
Turboprop	682	100	1.11	1.11	100
Turbojet	2,526	100	6.63	6.63	100
Rotorcraft	2	100	<.01	<.01	100
Total	3,805	100	8.22	8.22[b]	100
General aviation:					
Piston (single-engine). . . .	168,435	34	28.34	2.83	10
Piston (multiengined)	24,578	91	6.41	2.82	44
Turboprop	4,090	99	2.24	1.66	74
Turbojet	2,992	100	1.33	1.22	92
Rotorcraft	6,001	2	2.34	<.01	0
Total	206,096	42	40.66	8.53	21
Military (all types)	18,969	N.A.	5.26	N.A.	N.A.

[a] Estimates based on 1979 survey of general aviation aircraft.

[b] Includes 7.00 million hours for air carriers (all classes); 0.09 million hours for air taxi; 0.99 million hours for commuters; and 0.14 million hours for air cargo.

SOURCES: *FAA Statistical Handbook of Aviation, 1980; General Aviation Activity and Avionics Survey, 1979,* FAA-MS-B1-1, January 1981.

flown, indicates the relative airspace use and demand for IFR services among user categories. Commercial air carrier aircraft (including commuters and air taxis) make up less than 2 percent of the civil aviation fleet, but they account for about 17 percent of hours flown and almost half of the total IFR hours flown in civil aviation. As a class, general aviation aircraft (98 percent of the civil fleet) fly only about 1 hour in 5 under IFR, but this figure is deceptive. Turboprop and turbojet GA aircraft (those with performance characteristics and usage most like air carrier aircraft) are virtually all IFR-equipped and log a very high percentage of their flight hours under

IFR. The growing numbers and increasing tendency of these more sophisticated GA aircraft to operate under IFR has caused the general increase in ATC system workload over the past 10 years. At present, GA aircraft account for 51 percent of all IFR flight hours, 30 percent of IFR aircraft handled by ARTCCs and 45 percent of instrument approaches at FAA control facilities.

Commercial air carriers are the most homogeneous category of airspace users, although there are some differences between trunkline operators and commuter or air taxi operators in terms of demand for ATC services. Certificated route air carriers follow established schedules and operate in and out of larger and better equipped airports. They have large, high-performance aircraft that operate at altitudes above 18,000 feet en route, where they have only minimal contact with aircraft not under the positive control of the ATC system. In terminal areas, however, they share the airspace and facilities with all types of traffic and must compete for airport access with other users. Airline pilots are highly proficient and thoroughly familiar with the rules and procedures under which they must operate. All air carrier flights are conducted under IFR, regardless of visibility, in order to avail themselves of the full range of services, especially separation assurance.

Commuter airlines also follow established schedules and are crewed by professional pilots. However, they characteristically operate smaller and lower performance aircraft in airspace that must often be shared with GA aircraft, including those operating under VFR. As commuter operations have grown in volume, they have created extra demands on the airport and ATC systems. At one end of their flight they use hub airports along with other commercial carriers and so may contribute to the growing congestion at major air traffic nodes. Their aircraft are IFR-equipped and can operate under IFR plans like other scheduled air carriers, but this capability cannot be used to full advantage unless the airport at the other end of the flight, typically a small community airport, is also capable of IFR operation. Thus, the growth of commuter air service creates pressure on FAA to install instrument landing aids and control facilities towers at more smaller airports.

GA aircraft include virtually all types, ranging from jet aircraft like those used by scheduled air carriers to small single-engine planes that are used only for recreation. Most are small, low-performance aircraft that operate only at low altitudes under VFR, and many use only GA airports and never come into contact with the en route and terminal control facilities of the ATC system. However, there is increasing use of more sophisticated, IFR-equipped aircraft by businesses and corporations, many of whom operate their fleets in a way that approximates that of small airlines. By using larger aircraft and equipping them with the latest avionics, the business portion of the GA fleet creates demands for ATC services that are indistinguishable from commercial airspace users.

It is the disparate nature of GA that makes it increasingly difficult to accommodate this class of users in NAS. The tendency of GA aircraft owners at the upper end of the spectrum to upgrade the performance and avionic equipment of their aircraft increases the demand for IFR services and for terminal airspace at major airports. In response, FAA finds it necessary to increase the extent of controlled airspace and to improve ATC facilities at major airports. These actions, however, tend to crowd out other types of GA, typically VFR users who would prefer not to participate in the IFR system but are forced to do so or forego access to high-density terminal areas. The safety of mixed IFR-VFR traffic is the major concern, but in imposing measures to separate and control this traffic, the ATC system creates more restrictions on airspace use and raises the level of aircraft equippage and pilot qualification necessary for access to the airspace.

Military operations can be placed in two broad categories. Many operations are similar to GA, but others involve high-performance aircraft operating in airspace where they are subject to control by the ATC system. Front an operational point of view, military flight activities comprise a subsystem that must be fully integrated within NAS; but military aviation has unique requirements that must also be met, and these requirements sometimes conflict with civil aviation uses. Training areas and low-level routes that are used for training by military aircraft are set aside and clearly indicated on the standard navigation charts. The military services would like to have ranges located near their bases in order to cut down transit time and maximize the time aircrews spend in operational exercises. Civilian users, on the other hand, are forced to detour around these areas at considerable expense in both time and fuel. FAA is charged with coordinating the development of ATC systems and services with the armed forces, so that a maximum degree of compatibility between the civil and military aviation can be achieved.