AIR TRAFFIC

In today's world, air travel is a primary mode of transportation. During 1996, nearly 575 million passengers boarded scheduled air carrier flights in the United States. Over the next 10 years, air carrier traffic is expected to increase by more than 50%. Air travel also includes air taxi, general aviation, and military traffic. Safety is an issue when airspace capacity becomes saturated. To guarantee a safe environment, the Federal Aviation Administration (FAA) operates the Air Traffic Control (ATC) system to coordinate and control air traffic. To prepare for the future traffic increase, the FAA is redesigning the National Airspace System (NAS).

Air carrier operations are those scheduled flights that carry passengers or cargo for a fee. More than 8 million air carrier departures were recorded in 1996. Air carrier operations include the major airlines, national carriers, smaller regional (or commuter) airlines, and cargo carriers. Airlines with annual revenues of $1 billion or more in scheduled service are called majors. There were nine major U.S. passenger airlines in 1994: America West, American, Continental, Delta, Northwest, Southwest, TWA, United, and US Airways. Two cargo carriers were classified as majors: Federal Express and United Parcel Service (1).

National carriers are scheduled airlines with annual revenues between $100 million and $1 billion. National carriers often serve particular regions of the nation. Like the majors, nationals operate mostly medium-sized and large jets. In the third category are regional carriers that serve a single region of the country, transporting travelers between the major cities of their region and smaller, surrounding communities. Regional carriers are one of the fastest growing and most profitable segments of the industry. Large and medium-sized regional carriers often use aircraft that seat more than 60 passengers. Small regional, or commuter, airlines represent the biggest segment of the regional airline business. Most of the aircraft used by small regionals have less than 30 seats (1).

Air taxi operations include those operations involved with charters, air ambulance service, air tours, and other unscheduled air service. General aviation operations are those flights serving individuals and organizations using self-owned or leased aircraft. Pleasure, business, and flight training trips are typical general aviation activities.

Military air traffic from all defense organizations also uses the civilian air traffic control system. The intermixture of civilian and military traffic needs to be controlled by a single system to ensure safe operations.

The percentage of air carrier, air taxi, general aviation, and military aircraft operating in U.S. airspace in 1996 is shown in Fig. 1. The statistics in Fig. 1 reflect the operations that were controlled by the FAA's Air Route Traffic Control Centers (ARTCC), or Centers. The total number of Center operations was 40.7 million in 1996. The largest percentage of Center traffic is from air carrier operations. Air carriers domi-

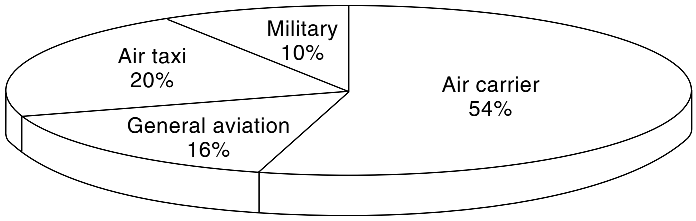

Figure 1. Types of air traffic operations controlled at ARTCC Centers in 1996. Total number of operations was 40.7 million.

nate Center traffic because each flight has an instrument flight plan filed with air traffic control for the possibility of encountering instrument meteorological conditions (IMC). An instrument flight plan requires interaction with the air traffic control system. The general aviation percentage may seem small considering the number of general aviation aircraft. General aviation aircraft are not required to communicate with ATC provided that they maintain visual meteorological conditions (VMC) and avoid controlled airspace. Visual flight rules (VFR) are used for flight in VMC that requires vertical separation from clouds and a minimum visibility (2).

AIR TRAFFIC CONTROL

To handle the volume of air traffic, the FAA has established the Air Traffic Control system. The ATC system includes air traffic control towers (ATCT), terminal radar approach control (TRACON), Air Route Traffic Control Center (ARTCC), and flight service stations (FSS). The tower controls the airspace around an airport. The airspace typically extends 5 statute miles horizontally and 3000 feet vertically above ground level (AGL) (10). Aircraft operating in this area must contact the tower even if the aircraft is passing through this airspace or is landing at a "satellite" airport that lies in the area. There are 352 FAA-controlled towers in the United States. In 1995, there were more than 26 million operations at the 100 busiest airports in the United States. The 10 busiest airports (1995) are shown in Table 1.

A TRACON is the radar facility that handles arrivals and departures in a high-traffic area. A TRACON usually controls aircraft within a 30- to 40-mile radius of the principal airport in the area. Controllers in the TRACON help arriving aircraft transition from en route to the airport tower. Aircraft arriving from all quadrants must be funneled to the active runway's final approach fix before the TRACON hands the aircraft to the tower controller. Minimum separation between aircraft must be maintained to ensure safety from wake vortex turbulence. The TRACON also handles the transition from Tower to Center for departing aircraft.

The ARTCC or Center handles aircraft during their en route phase between departure and arrival airports. Aircraft typically fly along predefined airways, or highways in the sky. Each airway is defined as a path between navigation aids on the ground. Under the current air traffic system, aircraft are frequently restricted to ATC-preferred routes, which are not necessarily the routes preferred by the pilot or airline. Air traffic controllers instruct pilots when to change their direction, speed, or altitude to avoid storms or to maintain traffic separation. Not all aircraft follow the airway system. Depending on traffic load, weather, and aircraft equipment, it is possible for the controller to clear the aircraft on a direct route. Of the 20 ARTCCs in the continental United States, the five busiest in 1995 were Chicago, Cleveland, Atlanta, Washington, and Indianapolis (3).

Table 1. Ten Busiest US Airports Based on 1995 Statistics

Rank	City–Airport	1995 Enplanements	1995 Operations
1.	Chicago O'Hare	31,255,738	892,330
2.	Atlanta Hartsfield	27,350,320	747,105
3.	Dallas–Fort Worth	26,612,579	873,510
4.	Los Angeles	25,851,031	716,293
5.	San Francisco	16,700,975	436,907
6.	Miami	16,242,081	576,609
7.	Denver	14,818,822	487,225
8.	New York JFK	14,782,367	345,263
9.	Detroit Metropolitan	13,810,517	498,887
10.	Phoenix Sky Harbor	13,472,480	522,634

The FAA's Air Traffic Control System Command Center (ATCSCC) is responsible for managing traffic flow across the United States. The ATCSCC is located in Herndon, Virginia. The command center oversees the entire ATC system and provides flow information to the other ATC components. If an area is expecting delays due to weather or airport construction, the command center issues instructions to reduce traffic congestion by slowing or holding other traffic arriving at the trouble area.

The FAA operates numerous navigation aids (NAVAID) to assist aircraft operations. En route navigation primarily uses the VORTAC or VOR/DME system. A VOR/DME system consists of a network of VOR/DME radio navigation stations on the ground that provide bearing and distance information. An aircraft must have the proper radio equipment to receive the signals from these systems. Civilian traffic obtains bearings from the VOR (very high frequency, or VHF, omnidirectional range) component and distance from the DME (Distance Measuring Equipment). Military traffic uses the TAC or TACAN (Tactical Airborne Navigation) signal. The VOR/DME system is the NAVAID that defines the airways.

Instrument approaches to an airport runway require electronic guidance signals generated by transmitters located near the runway. Precision approaches use the Instrument Landing System (ILS). The ILS provides horizontal (localizer) and vertical guidance (glideslope). A Category I ILS approach typically allows an aircraft to descend to 200 feet AGL without seeing the runway environment. Continued descent requires that the runway environment be in view. Each airport runway with a precision approach typically requires dedicated ILS equipment installed and certified for that runway. Nonprecision approaches are commonly defined using VOR/DMEs, nondirectional beacons (NDB), and localizers. A nonprecision approach does not provide glide slope guidance and, therefore, limits the minimum altitude allowed without visual contact with the runway.

AIRSPACE CAPACITY

The number of aircraft operations, both civilian and military, continues to grow, which strains the capacity of the airspace system. Over the period 1980 to 1992, traffic in the United States grew at an average annual rate that was 0.4 percentage point faster than the increase in capacity (3). By 2005, the number of air carrier passengers is expected to grow from 550 million (1995) to 800 million. During the same period, the number of air carrier domestic departures is expected to grow from 7.6 million to 8.9 million. Today's restricted airspace system will not be able to accommodate the rapid growth in aviation (3).

Delay in air carrier operations is one method of measuring system capacity. From 1991 to 1995, the number of air carrier operations increased more than 18% while the number of air

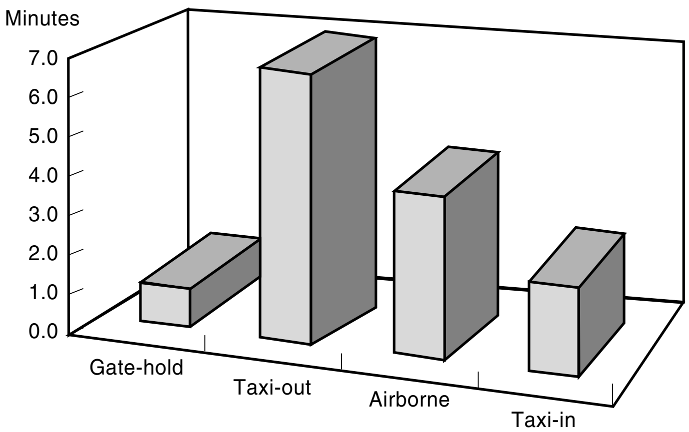

Figure 2. The average delay per flight phase (in minutes) during an air carrier's scheduled revenue flight.

carrier operations delayed 15 min or more fell from 298,000 to 237,000. The average delay per flight held steady at 7.1 min during this period (3).

Figure 2 highlights taxi-out as the flight phase with the largest average delay. Taxi-out, the time from push-back at the gate until takeoff, is susceptible to delay from airport surface traffic. Aircraft that are taxiing in are expedited to make room for more arrivals and other surface traffic. During a departure push, many aircraft are departing the airport at approximately the same time. Aircraft taxiing out are coming from numerous gates scattered across the airport and channeled to one or two active departure runways. The departing aircraft will often form long lines as they inch toward the runway. For airport operations using the same runway for arrivals and departures, the departing aircraft must wait for an arrival gap before entering the runway and taking off. When a runway is dedicated for departures, aircraft separation requirements slow the departure process (3).

To reinforce the effects of flight delay, consider its economic impact. Heavy aircraft of 300,000 lb or more cost $4575 per hour of delay; large aircraft less than 300,000 lb and small jets cost $1607 per hour. Single-engine and twin-engine aircraft under 12,500 lb cost $42 and $124 per hour, respectively. With approximately 6.2 million air carrier flights in 1995 and an average airborne delay of 4.1 min per aircraft, 424,000 hours of airborne delay occurred that year. At the average operating cost of approximately $1600 (1987 dollars) per hour, the delay cost the airlines $678 million (3).

Poor weather was attributed as the primary cause of 72% of operations delayed by 15 min or more in 1995. Weather-related delays are largely the result of instrument approach procedures, which are much more restrictive than the visual procedures used during better weather conditions (3). Figure 3 shows that weather followed by airport terminal congestion were the leading causes of delay from 1991 to 1995. Closed runways/taxiways and ATC equipment, the third and fourth largest causes, had smaller effects on annual delay.

Delays will become worse as air traffic levels climb. The number of airports in the United States, where cumulative annual delays are expected to exceed 20,000 hours per year, is predicted to increase from 23 in 1991 to at least 33 by the year 2002 (4).

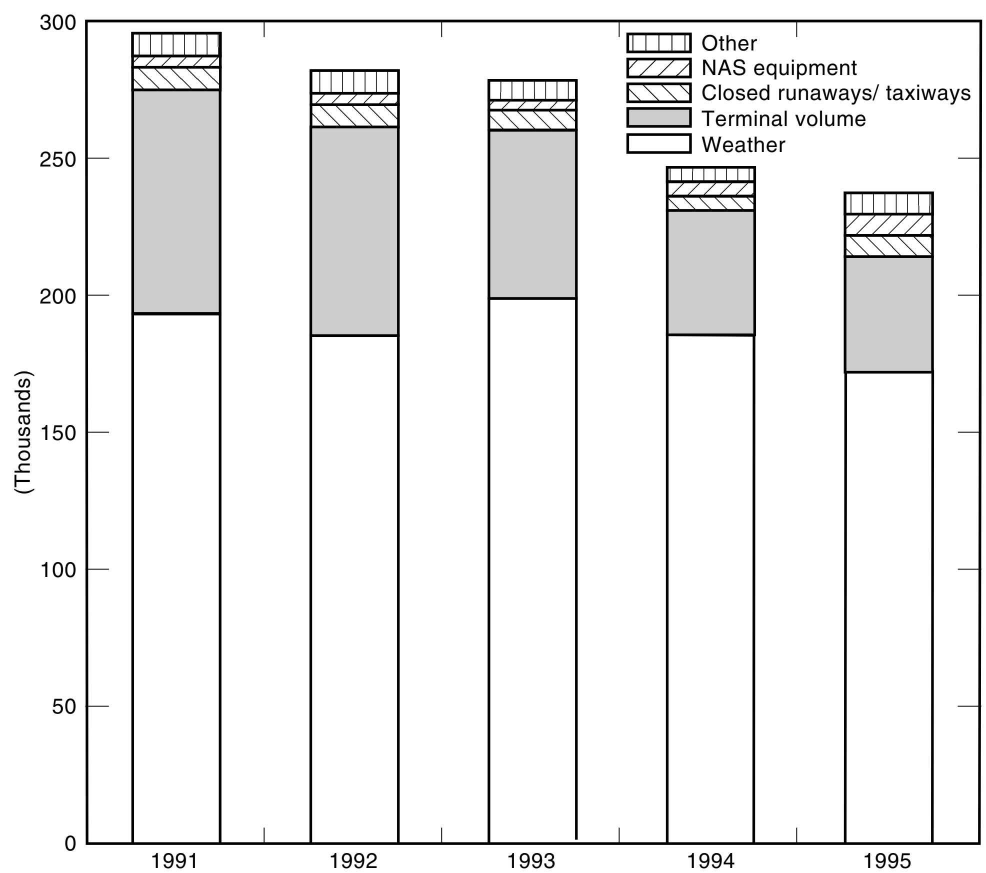

Figure 3. The number of delayed air carrier flights (in thousands) for the period 1991 to 1995. The reasons for the delay are shown.

INCREASED AIR TRAFFIC LEVELS

The FAA, air carriers, and general aviation organizations are all forecasting increased air traffic for the coming decades. The FAA predicts that by 2007, operations from all air traffic, including air carriers, regionals, air taxi, general aviation, and military aircraft, are expected to increase to 74.5 million (a 19% increase over 1995). The number of passenger enplanements on international and domestic flights, both air carrier and regional/ commuter, is expected to grow to 953.6 million by 2007 (a 59% increase over 1995). The growth rate of enplanements exceeds the growth rate of operations due to the use of larger aircraft and a higher occupancy rate on each flight (3).

The FAA numbers count all activity at a U.S. airport regardless of whether the air carrier is U.S flagged or international. Figure 4 shows similar numbers for U.S. air carriers as forecast by the Air Transport Association (1).

The forecast for the next decade projects that the busiest airport facilities are going to become busier. The top 100 airports in 1991 had 408.8 million revenue passengers depart, which accounted for over 94% of all passengers in the United States. From 1991 to 1995, the number of air carrier and regional/commuter enplanements increased by 32.9% (from 408.8 million to 543.4 million). By 2010, passenger boardings at the top 100 airports will increase by 69.1% (to 919.1 million) and aircraft operations are projected to increase by 27.6% (to 33.7 million) (3).

The 10 busiest airports in 2010 based on operations and their percentage growth from 1995 are shown in Table 2. A comparable ranking of the 10 busiest airports as a function of passenger departures is shown in Table 3. Chicago O'Hare, Dallas–Fort Worth, Atlanta Hartsfield, and Los Angeles International are forecast to be the busiest airports by 2010 in both operations and passenger enplanements.

While the air transportation industry in the United States continues to grow, it is important to remember that North America traditionally represents only about 40% of the world's total air traffic (4). In the next decade, international air travel is expected to continue its significant increase. Passenger traffic on world air carriers has shown an annual growth rate of 5.0% over the last decade. Forecasts for the coming decade are predicting that the growth rate will increase slightly to 5.5% annually. The number of passenger enplanements worldwide would grow from 1285 million in 1995 to 2010 million in 2005 (56% growth). The fastest growing international route groups for passenger traffic are forecast to be in Transpacific and Europe–Asia/Pacific route groups (5).

By the year 2010, the International Air Transport Association (IATA) predicts that the number of international passengers traveling to and from the United States will reach 226 million, an increase of 187% over the 1993 figure of 78.8 million (4). The majority of these are expected to travel on U.S. carriers.

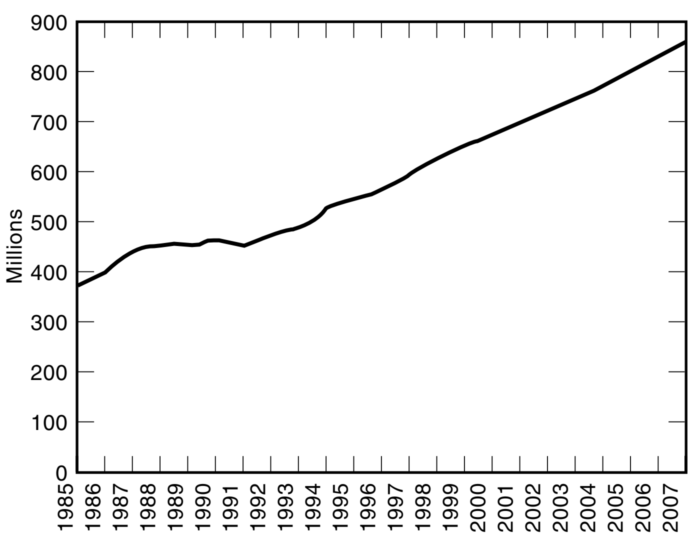

Figure 4. The number of revenue passengers on US air carriers grew from 382 million in 1985 to 547 million in 1995. The growth is forecast to climb to 857 million revenue passengers by 2007.

Table 2. Forecast Departures at the 10 Busiest US Airports

Rank	City–Airport	1995 Operations	2010 Operations	% Growth
1.	Chicago O'Hare	892,330	1,168,000	30.9
2.	Dallas–Fort Worth	873,510	1,221,000	39.8
3.	Atlanta Hartsfield	747,105	1,056,000	41.3
4.	Los Angeles	716,293	987,000	37.8
5.	Miami	576,609	930,000	61.3
6.	Phoenix Sky Harbor	522,634	736,000	40.8
7.	St. Louis Lambert	516,021	645,000	25.0
8.	Las Vegas McCarran	508,077	682,000	34.2
9.	Oakland Metropolitan	502,952	573,000	13.9
10.	Detroit Metropolitan	498,887	675,000	35.3
Total for top 100 airports		26,407,065	33,706,000	27.6

AIRCRAFT FLEET

To handle the swelling number of air travelers, the air carrier fleets need to be upgraded with larger aircraft. Most of the growth in fleet size of the major U.S. carriers will occur after 2000, when aging aircraft are replaced with newer, more efficient aircraft. The fleet size, with its upswing after 2000, is shown in Fig. 5 (1).

Table 3. Forecast Passenger Enplanements at the 10 Busiest US Airports

Rank	City–Airport	1995 Enplanements	2010 Enplanements	% Growth
1.	Chicago O'Hare	31,255,738	50,133,000	60.4
2.	Atlanta Hartsfield	27,350,320	46,416,000	69.7
3.	Dallas–Fort Worth	26,612,579	46,553,000	74.9
4.	Los Angeles	25,851,031	45,189,000	74.8
5.	San Francisco	16,700,975	28,791,000	72.4
6.	Miami	16,242,081	34,932,000	115.1
7.	Denver	14,818,822	22,751,000	53.5
8.	New York JFK	14,782,367	21,139,000	43.0
9.	Detroit Metropolitan	13,810,517	24,220,000	75.4
10.	Phoenix Sky Harbor	13,472,480	25,408,000	88.6
Total for top 100 airports		543,439,185	919,145,000	69.1

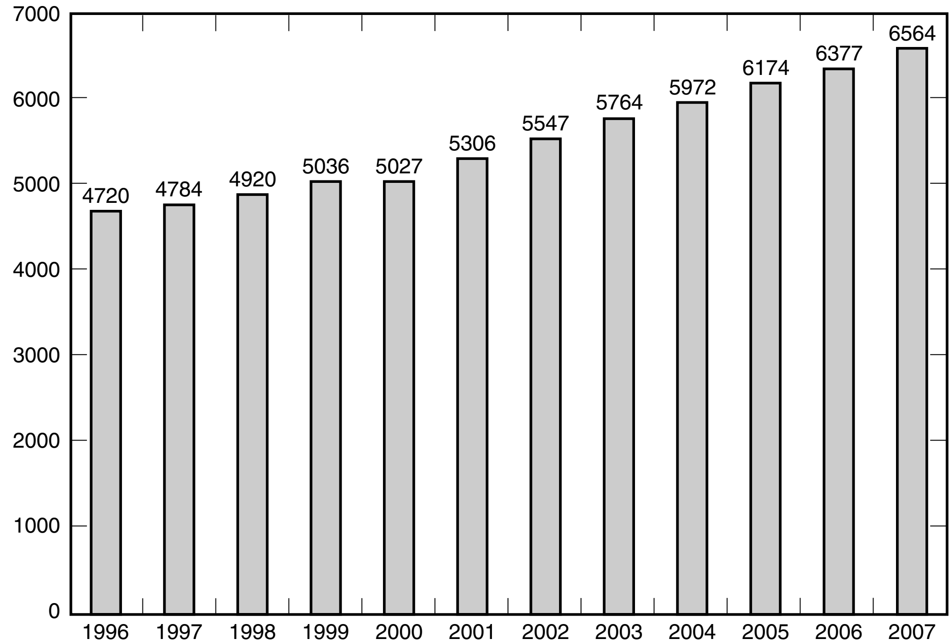

Figure 5. Jet aircraft forecast to be in service by US air carriers.

At the end of 1995, U.S. air carriers had firm orders placed for 604 new aircraft and options on an additional 799 aircraft. The price tag for the firm orders was $35.5 billion. The firm orders were distributed among aircraft from Airbus Industries, Boeing Commercial Aircraft Company, McDonnell-Douglas Aircraft Company, and the Canadian Regional Jet. The most popular aircraft on order was the Boeing 737, with 218 firm orders and 260 options.

FREE FLIGHT

In April 1995, the FAA asked RTCA, Inc., an independent aviation advisory group, to develop a plan for air traffic management called Free Flight (6). Free Flight hopes to extend airspace capacity by providing traffic flow management to aircraft during their en route phase. By October 1995, RTCA had defined Free Flight and outlined a plan for its implementation (7).

The Free Flight system requires changes in the current method of air traffic control. Today, controllers provide positive control to aircraft in controlled airspace. Free Flight will allow air carrier crews and dispatchers to choose a route of flight that is optimum in terms of time and economy. Economic savings will be beneficial both to the air carriers and to the passengers. Collaboration between flight crews and air traffic managers will be encouraged to provide flight planning that is beneficial to the aircraft and to the NAS. User flexibility may be reduced to avoid poor weather along the route, to avoid special-use airspace, or to ensure safety as aircraft enter a high-density traffic area such as airports. The new system will offer the user fewer delays from congestion and greater flexibility in route determination (3).

Flights transitioning the airspace in Free Flight will have two zones surrounding the aircraft. A protected and an alert zone are used to provide safety for the flight. The size and shape of the zones depend on the size and speed of the aircraft. The goal is that the protected (or inner) zones of two aircraft will never touch. The aircraft may maneuver freely as long as its alert zone does not come in contact with another aircraft's alert zone. When a conflict occurs between two aircraft alert zones, changes in speed, direction, or altitude must be made to resolve the conflict. The conflict resolution may be made by the air traffic manager or from the airborne collision avoidance system, TCAS (Traffic Alert and Collision Avoidance System).

The FAA and airspace users must invest in new technology to implement Free Flight. New communication, navigation, and surveillance systems are required to maintain situational awareness for both the air traffic manager and the flight crew. The FAA and aviation community are working together to phase in Free Flight over the next 10 years (8).

NATIONAL AIRSPACE SYSTEM

In parallel with RTCA's development of the Free Flight concept, the FAA began to develop a new architecture for the NAS that would support future aviation needs and Free Flight. The new NAS architecture transitions from air traffic control to air traffic management. The new NAS architecture is focused on the implementation of Free Flight to handle aircraft traffic and routing. The FAA's Pilot/Controller Glossary defines the NAS as "the common network of U.S. airspace; air navigation facilities, equipment and services; airports or landing areas; aeronautical charts, information and services; rules, regulations and procedures; technical information; and manpower and material. Included are system components shared jointly with the military" (9).

The new NAS architecture and Free Flight require a change from the old system of air traffic control to a new air traffic management system. The air traffic managers will now be responsible for monitoring/managing an aircraft's flight along its route. In the new system, an aircraft's route will primarily be the responsibility of the aircraft crew instead of ATC. The air traffic manager will need to intervene only to provide conflict resolution and route planning in high-density traffic areas.

The new NAS architecture recommends new communications, navigation and landing, surveillance, and weather systems for the next 20 years. Major NAS plans in the communications, navigation, and surveillance (CNS) are as follows (9):

- Use satellite-based (Global Positioning System, or GPS) landing and navigation systems while decommissioning ground-based facilities.
- Use automatic GPS-derived position reports as air traffic management's surveillance system.
- Use digital air/ground communications instead of today's analog radios.

Major changes in the ATC decision support systems include the following:

- A common air traffic management platform
- A new conflict detection/resolution and collaborative decision-making tool
- A new integrated display/ controller workstation for ATC towers

A new NAS Infrastructure Management System (NIMS) provides centralized monitoring and control to NAS facilities from operational control centers (OCC) (9).

The NAS architecture defines changes to aircraft avionics, ground-based ATC equipment, ground-based navigation and landing aids, and the airport environment. A summary of the changes in each area is provided.

Airborne Equipment

Implementation of the NAS requires several new avionics advancements. The avionics systems that are being defined for NAS are in communications, navigation, surveillance (CNS), and cockpit displays.

Global Positioning System. The Global Positioning System (GPS) is proposed as the primary navigation aid in the new NAS. GPS uses Department of Defense (DoD) satellites to derive the present position and velocity of the user vehicle. A GPS receiver has a position accuracy within 100 m, 95% of the time. This accuracy is sufficient for en route and oceanic navigation.

To navigate in the airport terminal area or to perform an approach in instrument weather, the aircraft needs the increased accuracy of a differential GPS (DGPS) system. A stand-alone GPS has position error due to clock error, atmospheric effects, and DoD-induced noise. Differential GPS can effectively remove these errors by adding a differential correction signal. The NAS defines two types of differential GPS systems: wide-area augmentation system (WAAS) and local-area augmentation system (LAAS) (9).

The WAAS uses a network of GPS base stations to determine the GPS errors. The differential correction signal is uplinked to geostationary WAAS satellites. The aircraft receives the correction signal from the WAAS satellite and corrects its GPS position. Position accuracy with WAAS DGPS is within 7.6 m 95% of the time. The WAAS DGPS will provide sufficient accuracy for an aircraft to make a Category I instrument approach (200 ft ceiling/1800 ft visibility) (9).

The LAAS is dedicated to a single airport or airports in the same area. A GPS base station is located at or near the airport. The differential correction signal is broadcast to all aircraft within a 30 mile region using an RF datalink. The LAAS is more accurate than the WAAS since the aircraft are in closer proximity to the base station providing the corrections. The LAAS DGPS can be used for Category II approaches (100 ft ceiling/1200 ft visibility) and Category III approaches (0 ft ceiling). Category III has three subcategories (A, B, C) with visibility minimums of 700 ft, 150 ft, and 0 ft, respectively (10).

The LAAS DGPS is also useful for ground navigation. Accurate positioning on the airport surface increases the pilot's situational awareness during taxi operations. It also provides ATC with an accurate knowledge of all ground traffic.

Automatic Dependent Surveillance-Broadcast. An ATC radar screen displays aircraft position using the airport surveillance radar (ASR) and the secondary surveillance radar (SSR). The ASR transmits a radar signal that reflects from the aircraft skin. The SSR interrogates an aircraft's transponder, which returns the aircraft's transponder code and its altitude. Aircraft equipped with a newer Mode-S transponder can return additional data, such as heading and velocity.

The proposed NAS architecture phases out the SSR system. It will be replaced with Automatic Dependent Surveillance-Broadcast (ADS-B). At approximately twice per second, the aircraft's on-board ADS-B broadcasts aircraft position (latitude/longitude/altitude) and status information using the Mode-S transponder. The ADS-B periodically broadcasts the flight identification and the aircraft's ICAO (International Civil Aviation Organization) address. For air carriers, the flight identification is the flight number (for example, NW132) that passengers, pilots, and controllers use to identify a particular flight. The ICAO address is a unique number that is assigned to an aircraft when it is manufactured.

ADS-B provides controllers with the accurate aircraft identification and position needed to implement Free Flight. ADS-B also provides information to the ground controller during airport surface operations. Positive identification and accurate position (using LAAS DGPS) during taxi-in and taxi-out operations are especially important for safe and timely operations in low-visibility conditions (11).

Traffic Alert and Collision Avoidance System (TCAS). TCAS is an airborne surveillance system that monitors nearby aircraft and detects impending collisions. The position and altitude of nearby traffic are shown on a cockpit display. TCAS transmits transponder interrogation signals similar to the SSR ground-based system. Aircraft receiving the signal respond with a normal transponder reply that includes altitude. The TCAS can determine the bearing to the aircraft using a multielement antenna.

TCAS protects a safety zone around the aircraft. A track is started for every traffic target detected by TCAS. The collision avoidance logic calculates the time to a possible conflict with each of the traffic targets. If the time to a collision or near-miss counts down to 45 s, a traffic advisory is generated informing the pilot of the situation. If the time gets to 25 s, a resolution advisory is issued. A resolution advisory commands the pilot to climb, descend, or maintain the current altitude to avoid a collision. When both aircraft are TCAS equipped, the TCAS systems communicate the resolution advisory to prevent both aircraft from taking the same avoidance maneuver (12).

Datalink Communications. Communication frequencies at airports are congested with radio chatter. A flight crew may have to wait for an opening to make a request of ATC. There can also be confusion over which aircraft was given an ATC command. The congestion can cause delays and impact safety. Many of the voice communications are routine and could be handled by digital datalink. Digital datalink communications are routed between ATC and aircraft computer systems. The data are processed and presented to the controller or pilot as needed.

Controller-pilot data link communications (CPDLC) use a two-way datalink. Controller commands and instructions are relayed to the aircraft using an addressed datalink. Only the intended aircraft receives the instruction. The ATC command is processed on the aircraft and presented to the flight crew. The flight crew performs the command. Acknowledgment back to the controller can either be pilot initiated or automatically generated when the crew complies with the instruction (13). Flight Information Service (FIS) data can also be accessed via datalink. FIS contains aeronautical information that the pilot uses in flight planning. Without the FIS datalink, the pilot must access the information by request over a voice channel.

Datalinks are to be used for navigation and surveillance data as well as communications. A one-way datalink is used for ADS-B, DGPS, and Terminal Information Service (TIS). An aircraft broadcasts its ADS-B position using a one-way datalink. Other aircraft and ATC can receive the ADS-B report and track the aircraft position. A one-way broadcast uplinks the LAAS DGPS differential corrections to aircraft in the airport area. The TIS system is a one-way broadcast of airport traffic to aircraft on the ground. Weather data can be transmitted between the aircraft and ground across a datalink (9).

Many of the datalink services will initially use the Mode-S transponder datalink. With the development of VHF data radios and satellite service, the NAS architecture may change the primary datalink provider for these services.

Cockpit Displays. Cockpit displays are used in the NAS architecture to display air traffic management information that is transferred to the aircraft. Moving map navigation displays using GPS position will assist the pilot both in the air and on the ground. While airborne, the navigation display can display the desired route, possible weather, and other traffic. Suggested route changes from air traffic management to avoid congestion or special-use areas can be displayed on the moving map. The pilot can negotiate the route change with ATC. Terrain data can be incorporated into the moving map to ensure safe clearance of all terrain features.

The moving map display is very beneficial during airport surface operations. At night or in low-visibility conditions, the airport surface is very confusing to aircrews that are not familiar with the airport. A joint NASA/FAA experiment has shown that a taximap displaying airport layout, taxi routes, and other traffic can improve safety and efficiency. The taximap display can also reduce runway incursions that occur when a taxiing aircraft enters an active runway with an arrival or departure in progress (11).

ATC commands transmitted via the CPDLC datalink can be shown both graphically on the moving taximap and textually for clarification. Aircrew acknowledgments can be displayed as well.

Ground-Based NAS Equipment

The ground-based equipment needed for the NAS architecture involves improvements and development at all NAS facilities. Traffic flow management and air traffic control tools are improved at the ARTCCs (Centers), the TRACONs (Approach Control), and the ATCT (Towers).

En Route ARTCC Equipment. The new NAS architecture upgrades the existing ARTCC Center equipment. New display systems, surveillance data processors (SDP), and flight data processors (FDP) are improvements to existing systems. The SDP system will collect information from the surveillance systems such as the ADS-B reports. The SDP will provide aircraft tracking and conflict detection/resolution. The FDP will correlate aircraft tracks with flight plan information. The FDP will also communicate with other ARTCC Centers and terminals to ensure that all air traffic management units have the same flight plan information for an aircraft (9).

Air Traffic Management Decision Support Services. Air traffic management (ATM) combines the ATC and traffic flow management (TFM) functions. ATM support tools are called decision support services. The TFM decision support services function includes the collaborative decision-making tool that aids the pilot/controller interaction in flight planning (9).

The decision support services for the ATC function involves conflict detection/resolution and Center/TRACON Automation System (CTAS). The Center/TRACON Automation System is a tool developed by NASA to support air traffic management. CTAS computes an aircraft's route and intentions 40 min into the future. The aircraft destination, as filed in the flight plan, and aircraft type are considered in the calculations. CTAS examines the aircraft mix that is arriving at an airport and provides the arrival sequencing and separation for efficient operation (8).

Ground Controller Equipment. Sensors and conflict detection/resolution equipment dominate enhancements to the ground controller equipment. At a large, busy airport, the number of aircraft taxiing can be significant. During arrival and departure pushes, in good and bad weather, it is difficult to manage the position of each aircraft and its intentions. Three systems that will help the ground controller manage the traffic safely and efficiently are the Airport Surface Detection Equipment (ASDE), the Airport Target Identification System (ATIDS), and the Airport Movement Area Safety System (AMASS) (9).

Airport Surface Detection Equipment (ASDE) is a radar system that detects aircraft and other vehicles moving on the airport surface. The ASDE antenna is a large rotodome that typically mounts on top of the control tower. The rotodome physically spins at 60 revolutions per minute. The ASDE system "paints" surface traffic using the radar reflection from the

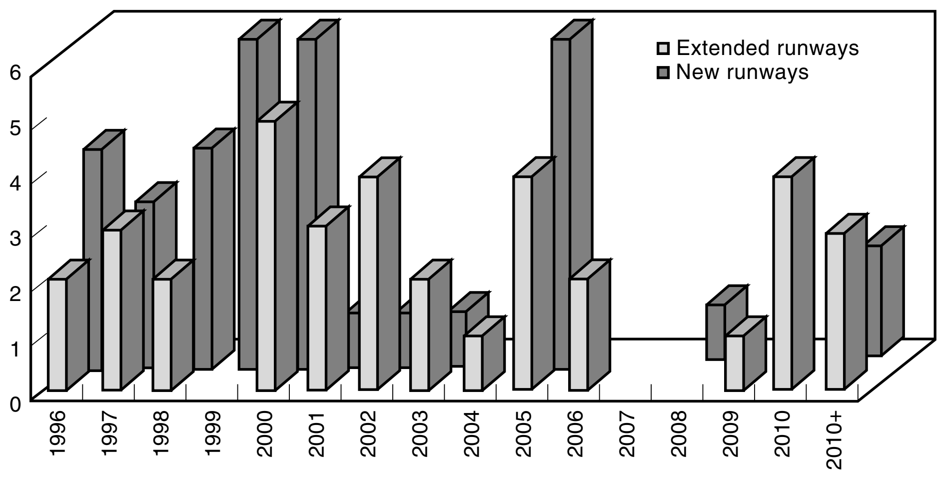

Figure 6. The number of new runways and runway extensions being planned for US airports.

target. The ASDE system is already installed at numerous airports. A large ASDE monitor is mounted in the control tower to display traffic.

One drawback with the ASDE system is that traffic appears as "blips" on the monitor with no flight identification tags. The ATIDS solves that problem by applying tags to the ASDE targets. ATIDS is a multilateration system that listens to the Mode-S transmissions from aircraft. By timing the arrival of the transmission at multiple sites, it is possible to determine the aircraft location through triangulation. The ATIDS system uses flight plan information to correlate the aircraft's transponder code with the flight number (14).

AMASS tracks ASDE targets and performs collision detection analysis on airport traffic. AMASS alerts the ground controller of possible conflicts. AMASS also alerts the controller to possible runway incursion incidents where a taxiing aircraft is entering an active runway incorrectly. AMASS correlates position information from the ASDE and ATIDS systems and applies the ATIDS identification tag to the targets on the ASDE display.

Airport Facilities and Procedures. To increase capacity, the nation's airports have been building new runways and extending existing runways. Extending the length of the runways can help increase capacity by making general aviation runways into air-carrier-length runways. New procedures are also being defined for parallel approaches and reduced separation standards.

Adding new runways and extending existing runways adds capacity without the cost of adding new airports. By 1997, 64 of the top 100 airports had recently completed, or were in the process of developing, new runways or runway extensions to increase airport capacity. Many of these are at the busiest airports that are forecast to have more than 20,000 h of annual air carrier delay in 2005 (3).

Figure 6 lists the number of new runways and runway extensions that are currently planned. There are 17 new runways and 10 runway extensions not shown on the figure because they are planned but have not been assigned a firm completion date (3).

The largest capacity gains result from the construction of new airports. Considering that the new Denver International Airport, which opened in 1995, cost more than $4 billion, building new airports is not always feasible. Only one new airport was under construction in 1997. The new airport is being created from the conversion of Bergstrom Air Force Base in Austin, Texas to a civilian facility. The closed military base was to be open for passenger service by 1999. The new facility will add capacity to the system at a reduced cost from building a new airport (3).

Terminal area capacity can be increased by redesigning terminal and en route airspace. Relocating arrival fixes, creating new arrival and departure routes, modifying ARTCC traffic flows, and redefining TRACON boundaries can all increase capacity. Improvements to en route airspace must be coordinated with terminal area improvements to avoid a decrease in terminal capacity. If the en route structure is improved to deliver more aircraft to the terminal area, then additional delays would decrease the terminal capacity (3).

Instrument Approach Procedures. Instrument approach procedures can improve capacity by reducing the separation standards for independent (simultaneous) instrument approaches to dual and triple parallel runways. Landing and hold short operations for intersecting runways and simultaneous approaches to converging runways can also increase capacity.

Simultaneous instrument approaches to dual parallel runways are authorized when the minimum spacing between runways is 4300 ft. The spacing minimum has been reduced to 3000 ft when the airport has a parallel runway monitor, one localizer is offset by 2.5°, and the radar has a 1.0 s update. Airport capacity is expected to increase by 15 to 17 arrivals per hour (3).

Simultaneous arrivals to three parallel runways are also authorized. Spacing requirements state that two runways are a minimum of 4000 ft apart. The third runway must be separated by a minimum 5300 ft. Radar with a 1.0 s update rate must also be used (3).

Land and hold short operations (LAHSO) allow simultaneous arrivals to intersecting runways. Land and hold short operations require that arriving aircraft land and then must hold short of the intersecting runway. Current regulations define land and hold short operations only for dry runways. Special criteria for wet operations are being developed and should be implemented by early 1997. During tests at Chicago O'Hare, a 25% increase in capacity was achieved during wet operations using land and hold short operations on intersecting runways (3).

Simultaneous approaches can be performed on runways that are not parallel provided that VFR conditions exist. VFR conditions require a minimum ceiling of 1000 ft and minimum visibility of 3 miles. The VFR requirement decreases runway capacity in IFR (Instrument Flight Rules) conditions and causes weather-related delays. Simultaneous instrument approaches to converging runways are being studied. A minimum ceiling of 650 ft is required. The largest safety issue is the occurrence of a missed approach (go-around) by both aircraft. An increase in system capacity of 30 arrivals per hour is expected (3).

Reduced Separation Standards. A large factor in airport capacity is separation distance between two aircraft. The main factor in aircraft separation is generation of wake vortexes. Wake vortexes are like horizontal tornadoes created from an aircraft wing as it generates lift. Wake vortex separation standards are based on the class of the leading and trailing aircraft. Small aircraft must keep a 4 nautical mile (nm) separation when trailing behind large aircraft. If the lead aircraft is a Boeing 757, then a small aircraft must trail by 5 nm. Large aircraft only need to trail other large aircraft by 3 nm. The FAA and NASA are studying methods of reducing the wake vortex separation standards to increase capacity. Any reduction in the spacing standards must ensure that safety is preserved (3).

EMERGING TECHNOLOGIES

Several new technologies are being developed that are not specifically defined in the NAS. One technology that will increase system capacity is the roll-out and turn-off (ROTO) system. The ROTO system reduces runway occupancy time for arrivals by providing guidance cues to high-speed exits. The ROTO system with a heads-up display gives steering and braking cues to the pilot. The pilot is able to adjust braking and engine reversers to maintain a high roll-out speed while reaching the exit speed at the appropriate time. In low visibility, ROTO outlines the exit and displays a turn indicator. Present ROTO development uses steering cues to exit the runway; future systems could provide automatic steering capability (11).

BIBLIOGRAPHY

1. *The Airline Handbook,* Air Transport Association, 1995.
2. *Air Traffic, FAA Administrators Fact Book,* April 30, 1997, http://www.tc.faa.gov//ZDV/FAA/administrator/airtraffic.html
3. *1996 Airport Capacity Enhancement Plan,* Federal Aviation Administration, Department of Transportation. (http://www.bts.gov/NTL/data/96_ace.pdf)
4. *North American Traffic Forecasts 1980–2010: Executive Summary,* International Air Transport Association (IATA), 1994 edition. (http://www.atag.org/NATF/Index.html)
5. *Growth in Air Traffic To Continue: ICAO Releases Long-Term Forecasts,* press release, International Civil Aviation Organization, Montreal, Canada, March 1997.
6. *FAA and Aviation Community to Implement Free Flight,* press release, *FAA News,* Washington, DC, March 15, 1996.
7. *Free Flight Implementation,* Final Report of RTCA Task Force 3 RTCA, Inc. October 31, 1995.
8. T. S. Perry, In search of the future of air traffic control, *IEEE Spectrum,* **34** (8): 18–35, 1997.
9. *National Airspace System (NAS) Architecture,* version 2.0, Federal Aviation Administration, Department of Transportation, October 21, 1996.
10. *Federal Aviation Regulations / Airmen's Information Manual 1998,* Jeppesen-Sanderson, Inc., 1998.
11. S. Young and D. Jones, Flight testing of an airport surface movement guidance, navigation, and control system, *Proc. Inst. Navigation's Tech. Meet.,* Jan. 21–23, 1998.
12. M. Kayton and W. Fried, *Avionics Navigation Systems,* 2nd ed., New York: Wiley, 1997.
13. J. Rankin and P. Mattson, Controller interface for controller-pilot data link communications, *Proc. 16th Dig. Avionics Syst. Conf.,* October 1997.
14. R. Castaldo, C. Evers, and A. Smith, Positive identification of aircraft on airport movement area—results of FAA trials, *IEEE J. Aerosp. Electron. Systems,* **11** (6): 35–40, 1996.

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