How Air Traffic Control Works

During peak air travel times in the United States, there are about 5,000 airplanes in the sky every hour. This translates to approximately 50,000 aircraft operating in our skies each day. How do these aircraft keep from colliding with each other? How does air traffic move into and out of an airport or across the country?

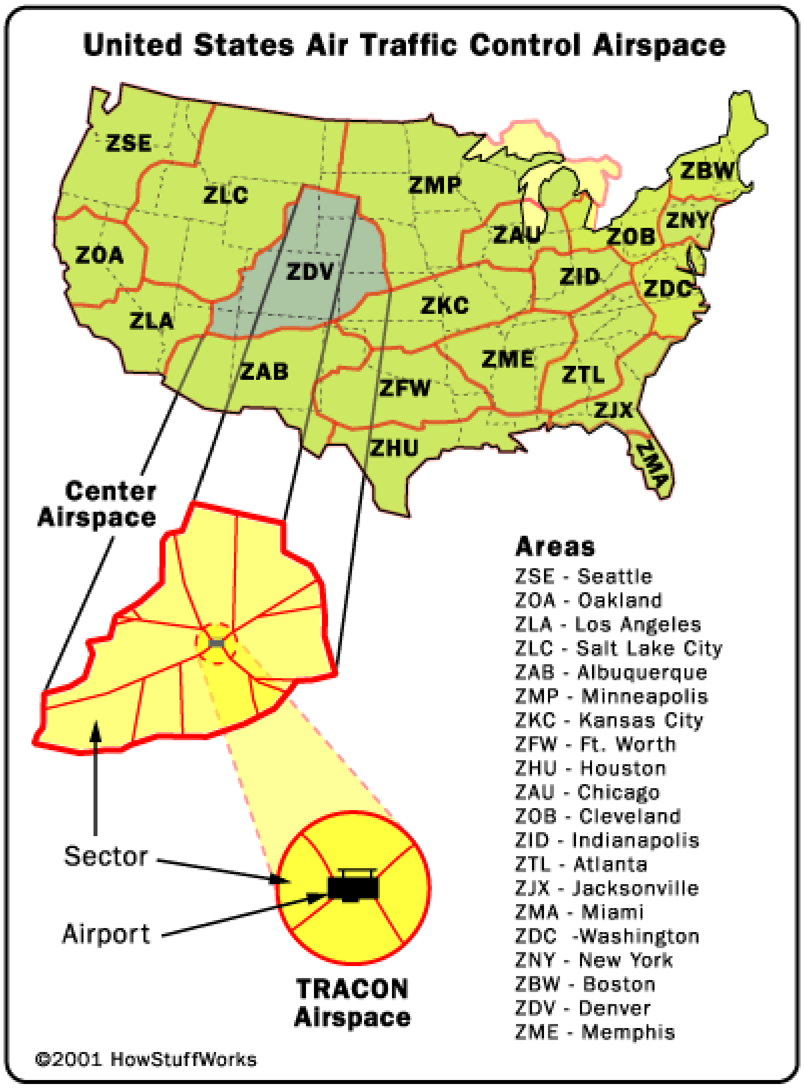
The task of ensuring safe operations of commercial and private aircraft falls on air traffic controllers. They must coordinate the movements of thousands of aircraft, keep them at safe distances from each other, direct them during takeoff and landing from airports, direct them around bad weather and ensure that traffic flows smoothly with minimal delays.

Photo courtesy Federal Aviation Administration (FAA)
Air traffic controllers in an airport tower

When you think about air traffic control, the image of men and women in the tower of an airport probably comes to mind. However, the air traffic control system is much more complex than that. In this article, we will examine air traffic control in the United States. We'll follow a flight from departure to arrival, looking at the various controllers involved, what each one does, the equipment they use and how they are trained.

Airspace and Air Traffic Control

The United States airspace is divided into 21 zones (**centers**), and each zone is divided into sectors. Also within each zone are portions of airspace, about 50 miles (80.5 km) in diameter, called **TRACON** (**T**erminal **R**adar **A**pproach **CON**trol) airspaces. Within each TRACON airspace are a number of airports, each of which has its own airspace with a 5-mile (8-km) radius.



Some pilots of small aircraft fly by vision only (**visual flight rules**, or VFR). These pilots are not required by the FAA to file flight plans and, except for FSS and local towers, are not serviced by the mainstream air traffic control system. Pilots of large commercial flights use instruments to fly (**instrument flight rules**, or IFR), so they can fly in all sorts of weather. They must file flight plans and are serviced by the mainstream air traffic control system.

The air traffic control system, which is run by the Federal Aviation Administration (FAA), has been designed around these airspace divisions. The air traffic control system divisions are:

- **Air Traffic Control System Command Center** (ATCSCC) - The **ATCSCC** oversees all air traffic control. It also manages air traffic control within centers where there are problems (bad weather, traffic overloads, inoperative runways).
- **Air route traffic control centers** (ARTCC) - There is one
- **ARTCC** for each center. Each ARTCC manages traffic within all sectors of its center except for TRACON airspace and local-airport airspace.
- **Terminal radar approach control** - **TRACON** handles departing and approaching aircraft within its space.
- **Air traffic control tower** (ATCT) - An **ATCT** is located at every airport that has regularly scheduled flights. Towers handle all takeoff, landing, and ground traffic.

- **Flight service station** (FSS) - The **FSS** provides information (weather, route, terrain, flight plan) for private pilots flying into and out of small airports and rural areas. It assists pilots in emergencies and coordinates search-and-rescue operations for missing or overdue aircraft.

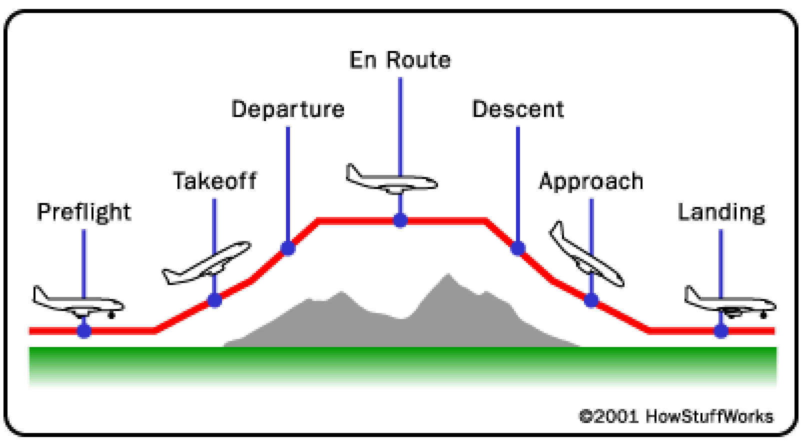
The movement of aircraft through the various airspace divisions is much like players moving through a "zone" defense that a basketball or football team might use. As an aircraft travels through a given airspace division, it is monitored by the one or more air traffic controllers responsible for that division. The controllers monitor this plane and give instructions to the pilot. As the plane leaves that airspace division and enters another, the air traffic controller passes it off to the controllers responsible for the new airspace division.

Let's follow a flight to demonstrate this system.

Flight Profile and Preflight

Suppose you are flying across the United States, perhaps from New York to San Francisco. Your flight, like every other commercial airline flight, follows a typical profile:

1. **Preflight** -This portion of the flight starts on the ground and includes flight checks, push-back from the gate and taxi to the runway.
2. **Takeoff** - The pilot powers up the aircraft and speeds down the runway.
3. **Departure** - The plane lifts off the ground and climbs to a cruising altitude.
4. **En route** - The aircraft travels through one or more center airspaces and nears the destination airport.
5. **Descent** - The pilot descends and maneuvers the aircraft to the destination airport.
6. **Approach** - The pilot aligns the aircraft with the designated landing runway.
7. **Landing** - The aircraft lands on the designated runway, taxis to the destination gate and parks at the terminal.



Profile of a typical commercial flight

Preflight

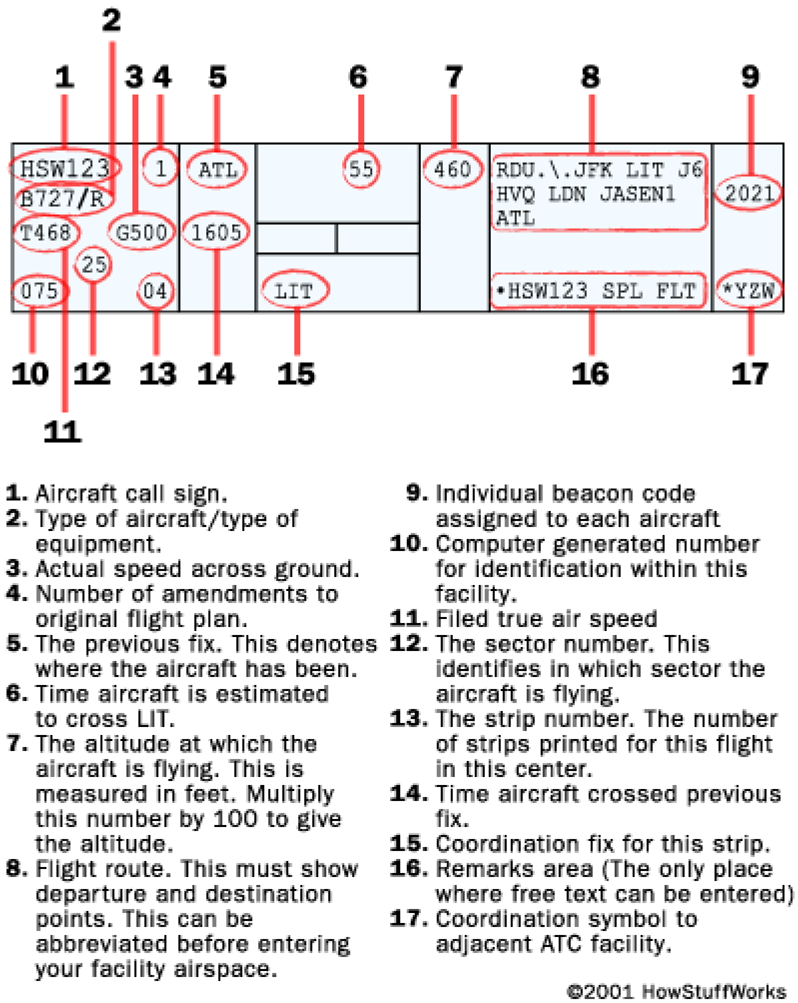
While you prepare for your flight by checking your bags and walking to the gate, your pilot inspects your plane and files a flight plan with the tower -- all IFR pilots must file a flight plan at least 30 minutes prior to pushing back from the gate. Your pilot reviews the weather along the intended route, maps the route and files the plan. The flight plan includes:

- Airline name and flight number

- Type of aircraft and equipment
- Intended airspeed and cruising altitude
- Route of flight (departure airport, centers that will be crossed and destination airport)

Your pilot transmits this data to the tower.

In the tower, a controller called a **flight data person** reviews the weather and flight-plan information and enters the flight plan into the FAA host computer. The computer generates a **flight progress strip** that will be passed from controller to controller throughout your flight. The flight progress strip contains all of the necessary data for tracking your plane during its flight and is constantly updated.



Example of a flight progress strip

Once the flight plan has been approved, the flight data person gives clearance to your pilot (**clearance delivery**) and passes the strip to the ground controller in the tower.

The **ground controller** is responsible for all ground traffic, which includes aircraft taxiing from the gates to takeoff runways and from landing runways to the gates. When the ground controller determines that it is safe, he or she directs your pilot to push the plane back from the gate (airline personnel operate the tugs that actually push the aircraft back and direct the plane out of the gate area). As your plane taxis to the runway, the ground controller watches all of the airport's taxiways and uses ground radar to track all of the aircraft (especially useful in bad weather), ensuring that your plane does not cross an active runway or interfere with ground vehicles. The ground controller talks with your pilot by radio and gives him instructions, such as which way to taxi and which runway to go to for takeoff. Once your plane reaches the designated takeoff runway, the ground controller passes the strip to the local controller.

Photo courtesy British Airways

An airplane taxis to the runway under instructions from the ground controller.

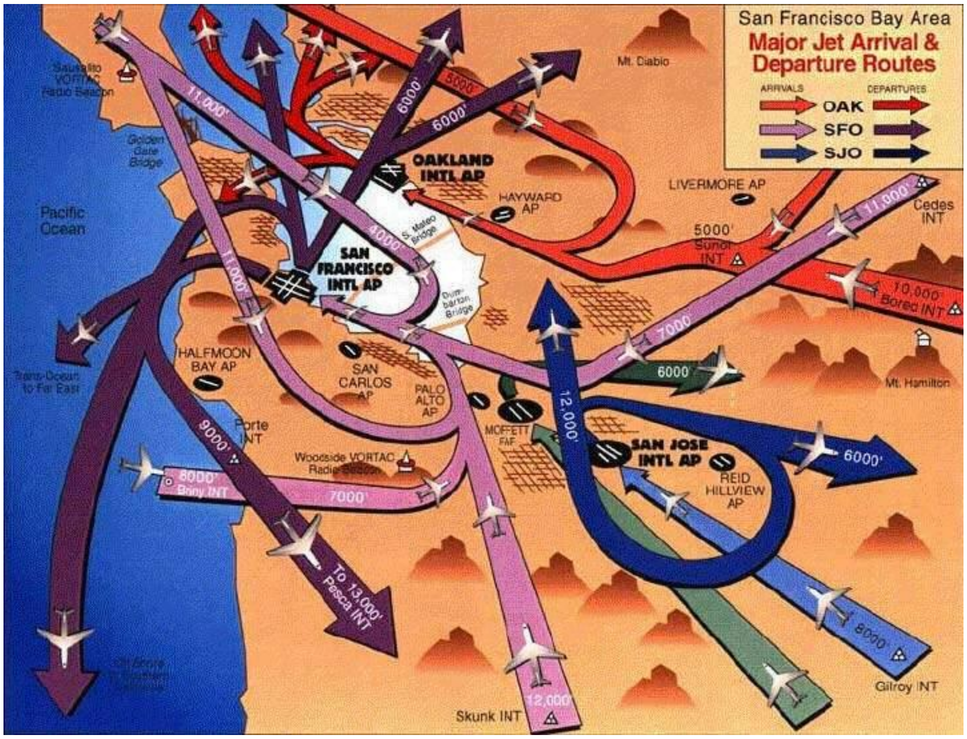
The **local controller** in the tower watches the skies above the airfield and uses surface radar to track aircraft. He or she is responsible for maintaining safe distances between planes as they take off. The local controller gives your pilot final clearance for takeoff when it is deemed safe, and provides the new radio frequency for the departure controller. Once clearance is given, your pilot must decide if it is safe to takeoff. If it is safe, he accelerates the plane down the runway. As you leave the ground, the local controller hands your plane off electronically to the departure controller at the TRACON facility that services your departure airport, but still monitors the plane until it is 5 miles from the airport. Your pilot now talks with the departure controller.

Departure

Once your plane takes off, your pilot activates a transponder device inside the aircraft. The **transponder** detects incoming radar signals and broadcasts an amplified, encoded radio signal in the direction of the detected radar wave. The transponder signal provides the controller with your aircraft's flight number, altitude, airspeed and destination. A blip representing the airplane appears on the controller's radar screen with this information beside it. The controller can now follow your plane.

An airplane's transponder transmits flight data to incoming radar signals.

The **departure controller** is located in the TRACON facility, which may have several airports within its airspace (50-mile/80-km radius). He or she uses radar to monitor the aircraft and must maintain safe distances between ascending aircraft. The departure controller gives instructions to your pilot (heading, speed, rate of ascent) to follow regular **ascent corridors** through the TRACON airspace.



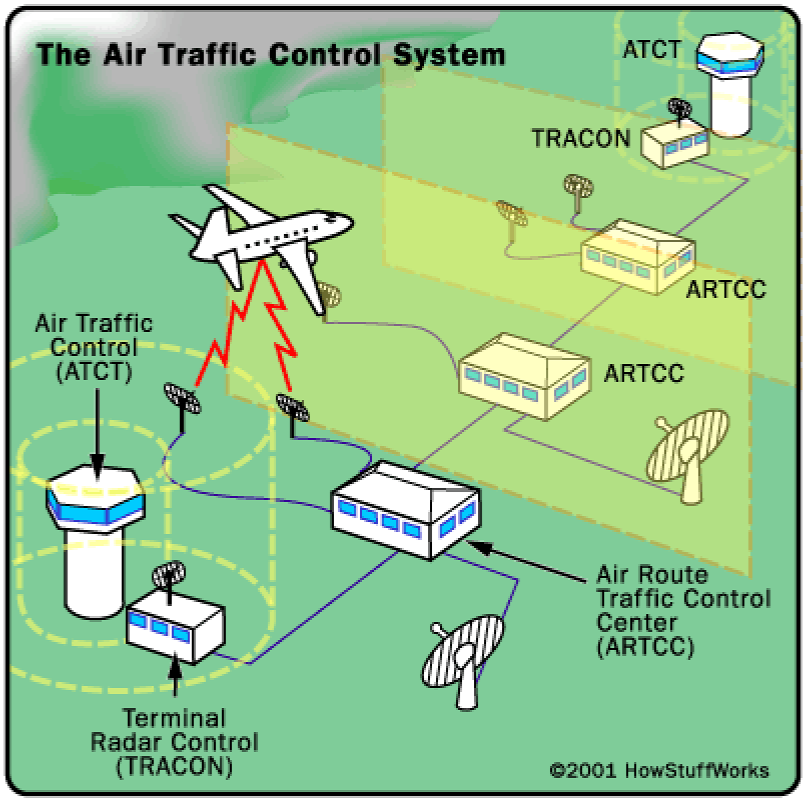
Departure and approach corridors for westward air traffic to and from airports in the San Francisco Bay Area TRACON airspace.

The departure controller monitors your flight during ascent to the en route portion. When your plane leaves TRACON airspace, the departure controller passes your plane off to the **center controller** (ARTCC controller). Every time your plane gets passed between controllers, an updated flight progress slip gets printed and distributed to the new controller.

En Route and Descent

Safe vertical separation between aircraft is considered to be 1,000 ft (305 m) at altitudes below 29,000 ft (8845 m) and 2,000 ft (610 m) at altitudes above that. When aircraft are at the same altitude, safe horizontal separation is considered to be 5 miles (8 km). The Air Transport Association has recommended that these separations be reduced to use airspace more efficiently and reduce airport delays.

Once your plane has left TRACON airspace, it enters a sector of the ARTCC airspace, where it is monitored by at least two air traffic controllers. The **radar associate controller** receives the flight-plan information anywhere from five to 30 minutes prior to your plane entering that sector. The associate controller works with the radar controller in charge of that sector. The **radar controller** is in charge of all air-to-ground communication, maintains safe separation of aircraft within the sector and coordinates activities with other sectors and/or centers. The controllers must monitor the airspace at high altitude (above 24,000 ft/7320 m) and low altitude (below 24,000 ft). The center controllers provide your pilot with updated weather and air-traffic information. They also give directions to your pilot regarding such aspects as speed and altitude to maintain a safe separation between aircraft within their sector. They monitor your plane until it leaves their sector. Then they pass it off to another sector's controller.



The various air traffic control facilities encountered by a plane during its flight

Another controller, called the **radar hand-off controller**, assists the radar and associate radar controllers during times of heavy traffic, watching the radar screen and helping to maintain smooth air-traffic flow.

Photo courtesy NASA
ARTCC, showing various controllers

While you are enjoying your meal, snack, in-flight movie or the view outside the window, your plane gets passed from sector to sector and center to center. In each sector, center controllers radio instructions to the pilots. The path of your plane may have to be changed from the original flight plan to move around bad weather or avoid a congested sector. Your pilots may request a change in altitude to avoid or reduce turbulence. This back and forth between pilots and center controllers continues until you are about 150 miles (241 km) from San Francisco (your destination). At this point, the center controller directs all planes flying into San Francisco to move from high altitudes to low altitudes and merges the descending aircraft into a single file line toward the airport. The controller gives instructions to your pilot, such as changes in heading, speed and altitude, to place your plane in line with these other aircraft. Depending on traffic conditions, the controller may have to place your plane into a holding pattern, which is a standard route around each airport, where you wait until the airport can handle your arrival. The controller continues to give directions to your pilot until your plane is within TRACON airspace.

Traffic Management Advisor

To assist the center controllers in scheduling descents to airports within their airspace, the FAA uses Traffic Management Advisor (TMA) software developed by NASA and the Federal Aviation Administration (FAA). TMA assists the center coordinator in scheduling when each plane should arrive and what order it should be placed in for descent.

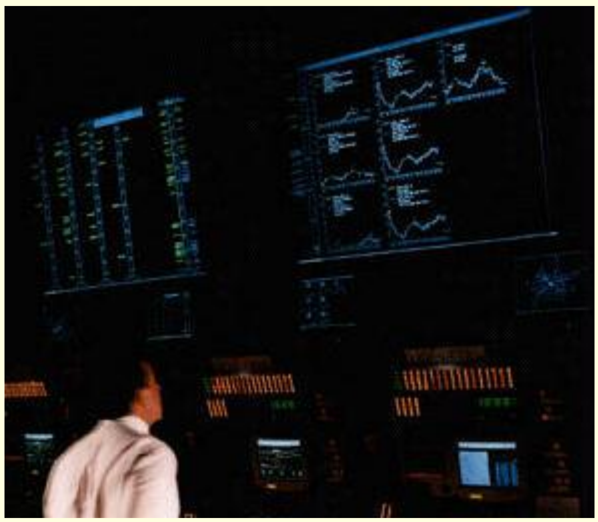


Photo courtesy NASA

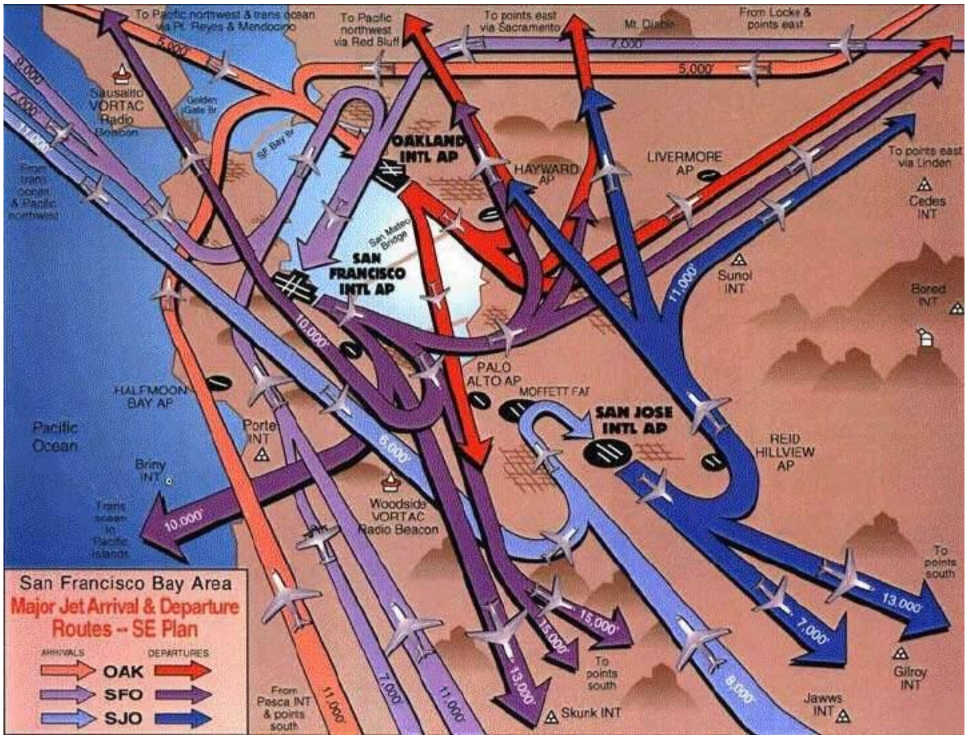
A center coordinator consults the TMA displays.

TMA uses flight-plan information, aircraft performance data and wind predictions to compute, predict and schedule when a particular airplane should reach its destination. It also looks at the number of planes allowed to land within a given period of time at an airport (the airport's capacity) and compares it to the number of planes scheduled. If the scheduled number exceeds the capacity (**rush alert**), it calculates the number that can be landed safely and makes recommendations to the coordinator for adjustments in the air-traffic pattern. This information is passed on to the controllers, who then give appropriate directions to the pilots.

Approach

When your descending plane is 50 miles from the San Francisco airport, it is within TRACON airspace. An **approach controller** directs your pilot to adjust the aircraft's heading, speed and altitude to line up and prepare to land along standard approach corridors. Your pilot then aligns your plane with the runway. When you are 10 miles (16 km) from the runway, the approach controller passes your plane off to the local controller in the airport tower.

Departure and approach corridors for eastward air traffic to and from airports in the San Francisco Bay Area TRACON airspace.



FAST Software

The approach controller uses another software program developed by NASA and the FAA called the **final approach spacing tool** (FAST). The FAST program assists controllers in choosing the landing order and runway for each approaching aircraft. The program does the following:

- Projects each aircraft's flight path based on flight plan and radar tracking
- Predicts arrival time
- Suggests landing order and runway assignment based on calculations that take into account aircraft size, aircraft performance capability and wind directions

The FAST software helps to ensure that no single runway or controller gets overloaded with planes, helping to minimize unnecessary delays.

Landing

The local controller in the airport tower checks the runways and the skies above the runways with binoculars and surface radar (local and ground controllers are the only controllers licensed to use visual information in performing their duties). When the local controller determines that it is safe, he or she gives your pilot clearance to land. The local controller also updates weather conditions for your pilot and monitors the spacing between your plane and other landing aircraft.

Photo courtesy NASA
Air traffic controllers in the tower monitor takeoffs, landings and ground traffic with visual and radar tools.

Once you've landed, the local controller directs your plane to an exit taxiway, tells your pilot the new radio frequency for the ground controller and passes your plane off to the ground controller.

The ground controller watches the runways and taxiways and uses ground radar information to ensure that your taxiing aircraft does not cross active runways or interfere with ground vehicles. He or she directs your plane to the appropriate terminal gate. Ground personnel from the airline use hand signals to assist your pilot in parking the airplane at the gate.

Career Training

What does it take to be an air traffic controller? To be a ground controller, you have to memorize the position of aircraft on the runways and taxiways with a single, short glance. Local, TRACON and ARTCC controllers must be able to think and visualize in three dimensions. All controllers must be able to gather information from what they hear, make decisions quickly and know the geography of their own airspace, as well as that of others. They must be able to read and interpret symbols as well as predict the whereabouts of aircraft from course headings and speeds, and they must be able to concentrate intensely. To test your skills as an air traffic controller, see pages 17 through 67 of the "Gate to Gate" CD ROM: Student Activity and Career Guidance Package.

Air traffic controllers at all levels are employed by the FAA. To become an air traffic controller, you must apply through the federal civil-service system and pass a written test that assesses your abilities to perform a controller's duties. Abstract reasoning and 3-D spatial visualization are tested on the exam. Applicants must have three years of work experience, a four-year college degree or some combination of the two.

If you are accepted into the training program, you will attend the FAA Academy in Oklahoma City, Oklahoma, for seven months of training. While there, you will learn the air traffic control system, equipment, regulations, procedures and about aircraft performance. You will need to pass a final examination before you graduate.

Photo courtesy NASA

Air traffic controller training on TRACON systems

After graduation, you will accumulate work experience at various sites across the country, from airport towers to ARTCCs. You must be certified for various positions, such as ground controller, associate radar controller and radar hand-off controller. You will be required to pass annual physical examinations, semi-annual performance examinations and periodic drug screenings. Air traffic control positions are highly competitive jobs, and the controller workforce is relatively young (most were hired after the air traffic controller strike in the 1980s, when President Ronald Reagan ordered that all striking controllers be fired).

Gate to Gate CD-ROM

NASA Ames Research Center and the FAA have released an excellent, educational, multi-media CD-ROM entitled **"Gate to Gate"** that explains modern air traffic control. There is also an accompanying **Student Activity and Career Guidance Package** that teachers can use. You can request the free CD-ROM by contacting Karen Stewart at the FAA.

Air Traffic Control Problems

Air travel has increased dramatically since the U.S. federal government deregulated the airline industry in the 1970s. However, the construction of new airports and runways has not kept pace with the increase in air traffic. This has put excessive pressure on the air traffic control system to handle the nearly 50,000 flights per day, a number projected to increase in the near future. To handle these flights and avoid delays and collisions, the FAA and NASA have developed modern software, upgraded existing host computers and voice communications systems and instituted full-scale GPS (global positioning system) capabilities to help air traffic controllers track and communicate with aircraft. The FAA is currently redesigning U.S. airspace to make more room for increased traffic. For example, the U.S. military has freed previously restricted airspace off the coast of North Carolina for use by commercial aircraft. These efforts should help ease traffic and minimize delays in the short term; however, increasing airport capacity by building new runways and airports is ultimately the way to handle the problem. For more information, see Airlines Announce "Top Ten" Air Traffic Control Priorities.

Air Crash

In the event of an air crash or runway incursion (two planes on a collision course), the National Transportation Safety Board (NTSB) investigates. The NTSB team reconstructs the air-traffic services given to the plane, examines radar tracking data and studies transcripts of the controller-pilot conversations. See NTSB: The Investigative Process for details.

For more information about air traffic control and related topics, check out the links on the next page.

Lots More Information

Related HowStuffWorks Articles

- How Airports Work
- How Airport Security Works
- How Black Boxes Work
- How Baggage Handling Works
- How Airlines Work
- How Becoming An Airline Pilot Works
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- How Airline Freight Works
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- How Oil Refining Works
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- How Helicopters Work
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- Do commercial jumbo-jets have locks on the doors and ignition keys?
- I've noticed that I am not allowed to use my cell phone in airplanes or in hospitals. Why are these prohibitions in place?
- When an aerobatic plane flies upside down, how does the fuel get to the engine?
- How does a speedometer in an airplane work?

- What causes a sonic boom?
- Can you explain pressurized airplane cabins?
- How does an oxygen canister on an airplane or a spacecraft work? How can heat generate oxygen?
- Why do those long white clouds form behind jets flying high overhead?
- How much fuel does an international plane use for a trip?
- How does an EPIRB distress radio work?
- How do they start jet engines on airplanes?

More Great Links

General Information

- Airline Handbook: Air Traffic Control
- Air Traffic Cafe'
- Air Traffic Control Network
- National Air Traffic Controllers Association Home Page
- NASA Ames: Center-TRACON Automation System
- Air Transport Association: Airlines Announce "Top Ten" Air Traffic Control Priorities
- UK Air Traffic Control
- U.S. Dept. of Labor Occupational Outlook Handbook: Air Traffic Controllers
- NTSB: The Investigative Process

Federal Aviation Administration (FAA)

- FAA Home Page
- FAA Air Traffic Services: About Air Traffic
- FAA Air Traffic Training Division
- Air Traffic Control System Command Center (ATCSCC)
- ATCSCC Virtual Tour
- "Gate to Gate" Educational CD-ROM - PDF