Chapter 4

TECHNOLOGY

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TECHNOLOGY[1]

The airport system in place in the United States today is extensive and highly developed; in general, it serves the Nation well. Still, there are problems of congestion and delay at the busiest airports, where facilities are not adequate to accommodate demand at all times and in all conditions of weather and visibility. The Federal Aviation Administration (FAA) forecasts that growth of commercial and private aviation could be constrained by lack of airport capacity, which it considers to be the most serious problem facing civil aviation through the remainder of this century.[2]

Recent policy statements by FAA acknowledge that, with a few exceptions, the direct solution of building new airports and expanding existing ones may not be practical due to lack of suitable new airport sites, physical limitations of present facilities, and concerns about environmental impacts of aviation on surrounding communities.[3] Similar views have been expressed in two recent studies of airport capacity,[4,5] and there is a widely held opinion that, while the airport system is expandable in the broad sense, there is little hope of creating major new facilities in those key metropolitan areas where air travel demand and aviation activity continue to outstrip available airport capacity unless airport planners can persuade surrounding communities that airports can be good neighbors.

For this reason, the aviation community and FAA have sought technological solutions that will ease congestion by allowing fuller and more efficient use of the airports we already have. This technology includes new equipment for surveillance, navigation, and communication and revised procedures for using the airspace and airport facilities. In this way, it is hoped that additional demand can be absorbed within the infrastructure now in place, without adversely affecting surrounding communities.

This chapter examines technological measures, either currently available or under development, that could be employed to relieve congestion and delay. It consists of a survey of possible improvements in airport technology, with emphasis on the circumstances in which this technology would be applicable, the extent to which it could increase the amount of traffic handled, and the prospects for development and deployment over the coming years.

In aviation, the term technology typically brings to mind sophisticated electronic and mechanical devices used for navigation, surveillance, communication, and flight control. Such devices are clearly of interest, but for the purposes of this report, technology is interpreted in a broader sense. As used here, technology refers not only to new devices and equipment but also to new operational concepts and procedures that they make possible. Also, many in the aviation community draw a distinction between technology (meaning equipment and sometimes procedures) and civil engineering (referring to the design and construction of physical components of the airport—the concrete, so to speak). While recognizing that different engineering disciplines and techniques are involved, this report does not make such a ciistinction and considers the design and construction of improved physical components such as runways, taxiways, and terminal buildings as simply one more form of technology that will add to airport capacity or permit more effective and economical use of the airport as a whole.

[1]This chapter is based on material prepared for OTA by Landrum & Brown, Inc.

[2]*National Airspace System Plan,* revised edition (Washington, DC: Federal Aviation Administration, April 1983), p. 11-10.

[3]Ibid., p. I-5.

[4]*Report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction* (Washington, DC: Airport Operators Council International, September 1982).

[5]*Report and Recommendations of the Airport Access Task Force* (Washington, DC: Civil Aeronautics Board, March 1983).

THE AIRPORT AND ITS COMPONENTS

The airport is a complex transportation hub serving aircraft, passengers, cargo, and surface vehicles. It is customary to classify the several components of an airport in three major categories: airside facilities; landside facilities; and the terminal building, which serves as the interchange between the two' (see fig. 7).

Airside components, sometimes called the aeronautical surfaces, or more simply the airfield, are those on which aircraft operate. Principally, they are the runways where aircraft take off and land, the taxiways used for movement between the runway and the terminal, and the apron and gate areas where passengers embark and debark and where aircraft are parked. Because the airspace containing the approach and departure paths for the airfield has an important effect on runway utilization, it is also customary to include terminal area airspace as part of the airside.

The terminal consists primarily of the buildings serving passengers and is made up of passenger loading and waiting areas, ticket counters, baggage handling facilities, restaurants, shops, car rental facilities, and the like. Loading, handling, and storage areas for air cargo and mail, often separately located, are also part of the terminal complex.

6 Some experts do not employ this tripartite classification. For example, R. Horonjeff and F. X. McKelvey, Planning and ***Design of Airports*** (***New*** York: McGraw Hill, 3d cd., 1983), distinguish only between the airside and the landside, making the division at the passenger loading gates and including the terminal as part of the landside.

The landside is essentially that part of the airport devoted to surface transportation. It begins at the curbside of the terminal building and includes roadways, parking facilities, and—in some cases—rail rapid transit lines and stations that are part of a larger urban mass transit system. Customarily, only roadways and transportation facilities on the airport property are considered part of the landside, even though they are actually extensions of, and integral with, the urban and regional transportation network.

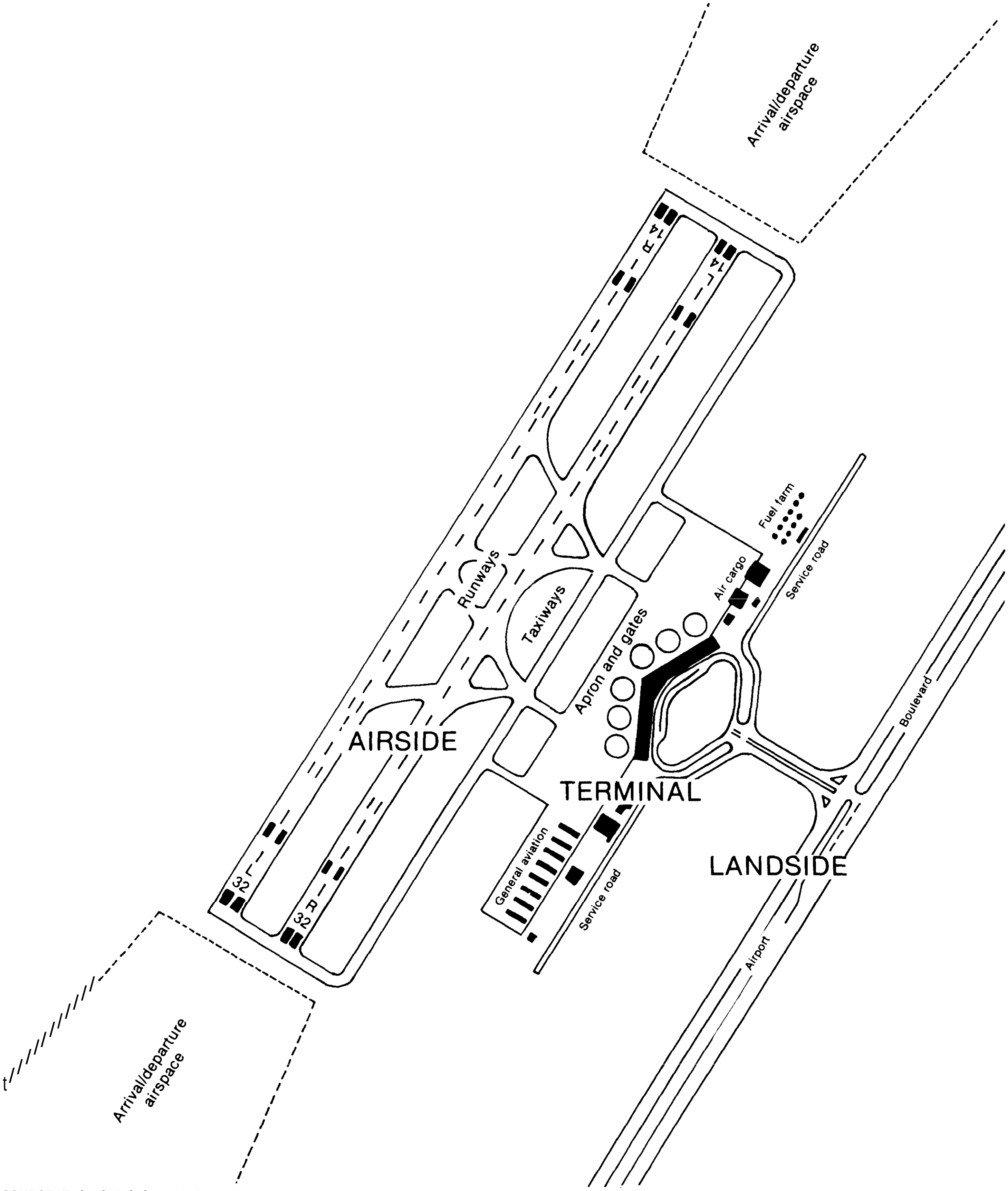
In the discussion that follows, attention is focused initially on those airside components where capacity and delay problems tend to be severe. The landside and terminal areas are not trouble-free, however, and congestion of these facilities can have an important effect on the overall capacity of the airport. An examination of possible technological improvements in terminals and landside access is included at the end of this chapter.

AIRPORT AND AIRSPACE TECHNOLOGY

Technological approaches to expanding airport capacity or reducing delay fall into three broad categories. First, there are improved devices and procedures that will expedite the flow of air traffic into and out of the airport—i.e., techniques that will augment airside capacity or mitigate ***aircraft*** delay by increasing the runway operation rate. The second category includes techniques to facilitate movement of aircraft on the airport surface. The purpose of these technologies is to move aircraft from the runway to the passenger loading gates and back again as expeditiously as possible, thereby shortening the taxi-in and taxi-out components of delay and easing congestion on taxiways, aprons, and loading ramps. The third category embraces techniques that can be used to aid the transit of ***passengers*** through the terminal building and the flow of ***vehicles*** on airport circulation and access roads. In contrast with the first two categories, where the aim is to alleviate aircraft delay, the third category is intended to facilitate the movement of people and to reduce that part of delay incurred in getting to and from aircraft.

Thus, the survey that follows addresses the broad question of *airport* capacity, not just airside capacity or aircraft delay. The intent is to examine ways to improve the overall adequacy and efficiency of the airport as a transportation hub. The underlying proposition is that delay–any form of delay—ultimately affects the passenger through loss of time and increased cost of air transportation service. In this sense, it is parochial

Figure 7.—Airport Components



SOURCE Federal Avlatlon Admlnlstratlon

to speak only of aircraft delay since the basic purpose of the air transportation system is to move people from origin to destination, in safety, with minimum expenditure of time and money. All measures taken at airports to shorten travel time, to lower travel cost, or to lessen inconvenience are of equal importance, regardless of whether they apply to the airside, the landside, or passage through the terminal.

The scheme of organization for this survey is outlined in table 13, which lists various forms of technological improvements and identifies the area of the airport where they could be applied and the purpose they could achieve. Discussion of specific technologies listed in table 13 is presented in the sections that follow, which make up the bulk of this chapter. In the concluding part of the chapter is a survey of the capacity and delay problems at a representative sample of airports and a tabulation of possible forms of technological relief.

GUIDANCE, SURVEILLANCE, AND CONTROL

The position and spacing of aircraft in the airborne traffic stream is a key factor in determining airfield capacity. For the pilot, it is vital to know where the aircraft is in relation to the runway and the airspace corridors around the airport. This is accomplished by ground-based navigation equipment and airborne receivers. The air traffic controller uses surveillance radar to monitor the position of the aircraft on approach and departure paths and in relation to other aircraft using the airport. The success of these activities—navigation by the pilot and surveillance by the controller—is affected by the inherent accuracy of the equipment used. (Is the aircraft in fact where the pilot and controller think it is?) The data update rate is also important. (How recent is this information and what may have happened since the last position reading?)[7]

In conditions of good visibility, when visual cues can be used by the pilot to confirm the position of the aircraft and to supplement guidance systems, the spacing between aircraft can be reduced to the minimum permitted by safe operating procedures. When visibility is lessened by darkness, rain, or fog, the pilot must rely on instruments and the controller on radar. In such circumstances, a margin of safety must be added to the interval between aircraft, in effect increasing the time that must be allowed for each to use an assigned portion of the airspace or to occupy the runway, and correspondingly lowering the throughput rate. If the accuracy of navigation and surveillance devices could be improved, the capacity of the airfield under Instrument Meteorological Conditions (IMC) could be closer to that attainable under Visual Meteorological Conditions (VMC).

Three technologies that could improve aircraft guidance, surveillance, and control are planned for deployment in the next few years. They are the Microwave Landing System, improved surveillance radar, and automated traffic-management systems for the air traffic controller.

Microwave Landing System

The guidance system for approach and landing now in use is the Instrument Landing System (ILS), which has been the standard system in this country since 1941 and is widely used by civil aviation throughout the world. ILS provides guidance by radio beams that define a straight-line path to the runway at a fixed slope of approximately 30 and extending 5 to 7 miles from the runway threshold. All aircraft approaching the airport under ILS guidance must follow this path in single file, spaced at intervals dictated by standards for safe longitudinal separation and the need to avoid wake vortex. This long, straight-in approach is a bottleneck that reduces the runway utilization rate, especially when fast and slow aircraft are mixed in the approach stream or when arrivals from different directions must be merged

‘To appreciate the magnitude of this uncertainty, consider that at typical jet approach speeds, an aircraft can travel almost 1,000 ft horizontally and descend 50 to 60 ft in the 4 seconds between successive scans of the radar presently used for air traffic control at airports.

Table 13.–Technology To Increase Airport Capacity and Reduce Delay

Technology	Area of application	Purpose	Benefit
Aircraft guidance, surveillance, and control:			
Microwave Landing System	Airspace	Improve precision of navigation; make more flexible use of airspace	Increased capacity; reduced delay; less noise impact
Surveillance radar	Airspace	Improve surveillance; reduce separation	Improved safety; increased capacity
Traffic management techniques	Airspace	Improve traffic flow	Reduced delay
Airspace use procedures:			
Reduced lateral separation for parallel and converging runways	Airspace	Increase utilization of multiple runways in IMC	Increased capacity
Reduced longitudinal separation	Airspace	Reduce in-trail separation	Increased capacity
Separate short runways for small aircraft	Airspace	Segregate air traffic by size and speed	Increased capacity; reduced delay
Weather and atmospheric effects:			
Wake vortex detection	Airspace	Reduce in-trail separation	Increased capacity
Wind shear detection	Airspace	Alert pilots to wind shear	Improved safety; reduced delay
Noise control and abatement:			
Control of aircraft noise	Airspace	Reduce aircraft noise	Increased capacity; reduced delay
Aircraft operating procedures	Airspace	Lessen or distribute noise impacts	Increased capacity: reduced delay
Airport surface utilization:			
Surveillance and control	Taxi ways	Improve surveillance, control, and guidance of aircraft on ground	Increased capacity; reduced delav; improved safety
High-speed turnoffs and improved taxiways.	Runway	Reduce runway occupancy time	Increased capacity
Taxiway marking and lighting	Taxi ways	Increase efficiency of taxiway use	Reduced delay
Apron and gate facilities	Ramps and aprons	Improve docking at gate; improve aircraft maintenance and servicing	Increased capacity; reduced delay
Terminal facilities and services:			
Terminal building design	Terminal	Increase utility and efficiency of terminal building	Increased capacity; reduced delay
Passenger movers	Terminal	Improve circulation in terminal; reduce walking distance	Reduced delay; greater passenger convenience
Ticketing	Terminal	Expedite ticket purchase and passenger check-in	Reduced delay
Baggage handling	Terminal	Expedite baggage check-in, transfer, and pickup	Reduced delay
Passenger security screening	Terminal	Make screening faster and more reliable	Reduced delay; improved security
Federal Inspection Service	Terminal	Expedite customs and immigration clearance	Reduced delay
Airport access:			
Terminal curbfront design	Terminal; landside	Facilitate airport entrance and exit	Reduced delay
Airport circulation roads	Landside	Facilitate automobile traffic flow	Reduced delay
Airport ground access	Land side	Reduce access time; lessen road congestion	Reduced delay

SOURCE Office of Technology Assessment

on the common final approach path. As a result, the capacity of the airfield under IMC, when the long ILS common approach path must be used, is usually less than under VMC.

The runway utilization rate under IMC could come closer to that attainable under VMC if aircraft could follow multiple approach paths, descend at different approach angles, or aim at different touchdown points on the runway—none of which is practical with ILS. If this flexibility were possible, as it is under VMC, airfield capacity would be less affected by weather conditions, and throughput would be governed almost exclusively by runway geometry and aircraft performance characteristics.

The Microwave Landing System (MLS), which has been under development by FAA for over a decade, would overcome some of the disadvantages inherent in the ILS. Because MLS uses a beam that scans a wide volume of airspace, rather than the pencil beam of ILS, it permits aircraft to fly any of several approach angles (including two-step glide slopes) and, in the horizontal plane, to approach along curving paths that intersect the extension of the runway centerline at any chosen point. In effect, MLS offers a degree of freedom in using the airspace that is closer to that enjoyed under conditions of good visibility (see fig. 8).

The chief motive for FAA in seeking to develop and deploy the MLS is not the potential capacity benefits, however, but its operational advantages —more precise guidance, ease of installation, improved reliability, less susceptibility to electromagnetic interference, and greater number of transmission channels. The capacity benefits are secondary but still of great importance at some airports where the present ILS acts to constrain capacity in adverse weather conditions. In terms of its effect on capacity, the chief advantage of MLS is that, in IMC, it allows pilots and controllers greater flexibility in selecting an approach path so as to shorten the approach time, to avoid air turbulence generated in the wake of preceding aircraft, or to avoid noise-sensitive areas. Another advantage is that MLS can provide guidance for the aircraft during missed approach, allowing a safe exit from the terminal airspace and smooth reentry into the approach pattern. The availability of missed approach guidance could have a significant capacity benefit at those airports with parallel or converging runways that cannot now be used in IMC. A third advantage is that MLS can be installed on runways where ILS is not possible due to siting problems and on short auxiliary runways reserved for commuter and small general aviation (GA) aircraft.[8] On some runways, MLS can increase capacity during IMC by providing lower landing minimums than ILS and thereby allowing the airport to remain open in marginal weather conditions. A fourth advantage of MLS is its capability to provide nonconflicting routes into closely situated airports, where approach or departure paths may mutually interfere and limit capacity utilization.

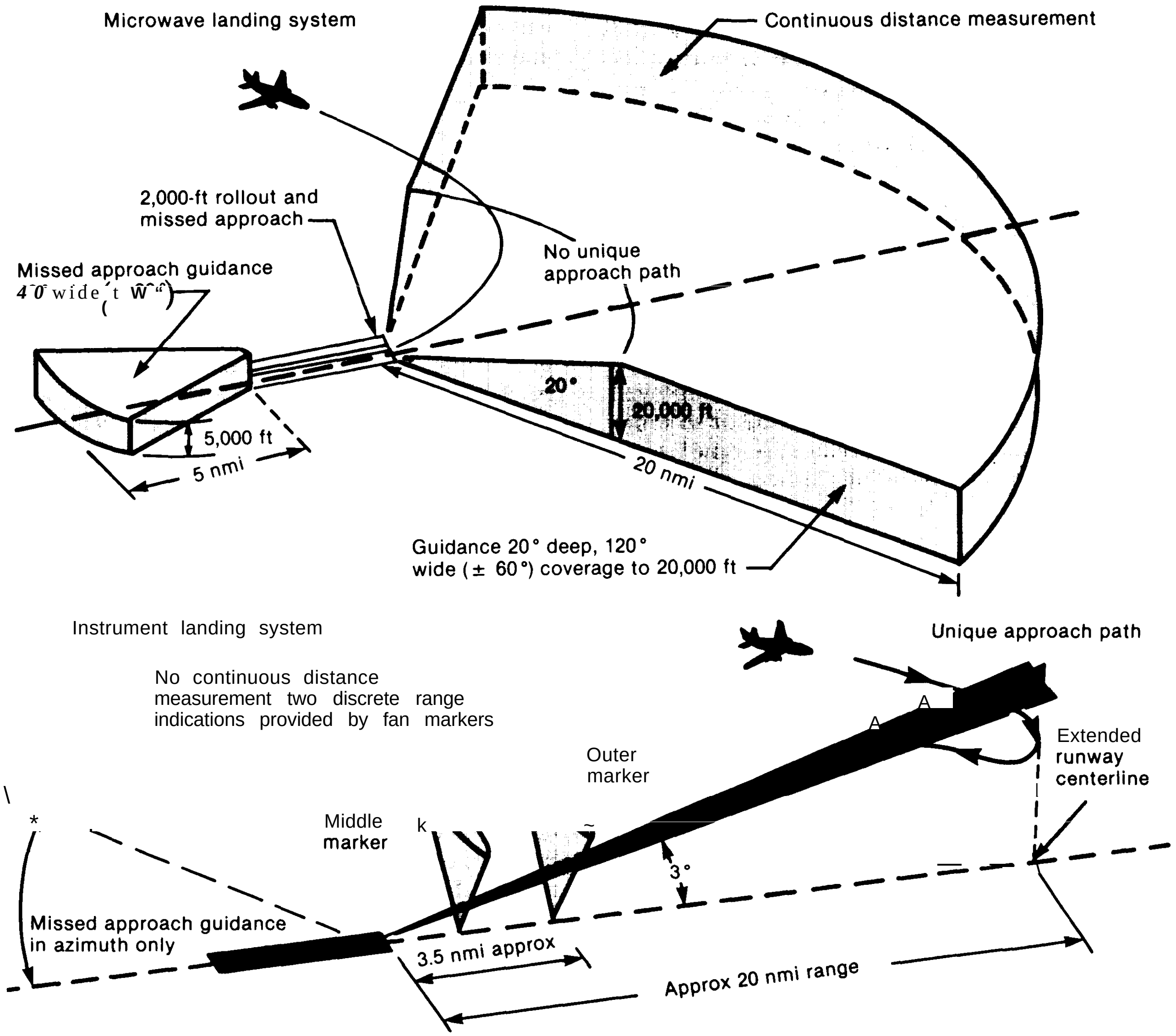
The capacity benefits of MLS are highly site-specific—depending on the runway configuration, the prevalence of adverse weather, the mix of aircraft using the airport, and the extent to which these aircraft are equipped with MLS receivers. Estimates by FAA indicate that the benefits could range up to 10 or 15 percent greater capacity at some airports under IMC. The overall effects on capacity at these airports would be somewhat smaller since they depend on how often Instrument Meteorological Conditions occur. The net economic benefits are estimated by FAA to be $500 million over a 20-year period (1976 dollars), principally to air carriers and commuter airlines in the form of reduced delay costs and savings of passenger time.[9]

This estimate has been challenged in a recent report by the Industry Task Force on Airport Capacity Improvement and Delay Reduction. The Task Force found that the chief advantages were at small or remote airports served by helicopters and commuter airlines and in high-density traffic areas where MLS could permit commuter aircraft to approach and land on separate short run-

[8]For a further discussion of MLS technology and its benefits, see ***Airport and Air Traffic Control System*** (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-STI-175, January 1982), pp. 92-96, 117; and ***Improving the Air Traffic Control System: An Assessment of the National Airspace System Plan*** (Washington, DC: Congressional Budget Office, August 1983), pp. 9-18.

[9]***An Analysis of the Requirements for, and the Benefits and Costs of the National Microwave Landing System (MLS),*** FAA-EM-80-7 (Washington, DC: Federal Aviation Administration, June 1980).

Figure 8.—Comparison of Microwave Landing System and Instrument Landing System



SOURCE: Federal Aviation Administration

ways.[10] The direct benefits to major air carriers are much less clear, according to the Task Force, because they depend on use of curved or segmented approaches and multiple glide paths—procedures that have not yet been tested and proven in an operational environment.[11]

FAA is now proceeding with MLS implementation. A contract for production and installation of 172 units was let in late 1983, with follow-on

[10] For instance, a study conducted at Denver showed that when commuter and GA aircraft make use of separate short runways, the delay to air carrier using the long runways could be reduced significantly.

[11] *Report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction*, op. cit., pp. 9-10.

procurements planned for 1985-95 (900 units) and 1996-2000 (350 units), making a total of approximately 1,425 installations by the beginning of the next century. Priority will be given to large and medium hub airports and to those airports now lacking ILS because of siting restrictions or lack of available transmission channels.[12] FAA estimates the total cost of ground equipment to be $1.33 billion. User costs for MLS receivers are estimated to be an additional $1.63 billion, bringing the total cost for full deployment of MLS to nearly $3 billion over the coming 20 years.[13] [14]

Replacement of the existing ILS poses two problems that may complicate the transition to MLS and delay realization of the full benefits. There are at present about 650 ILS units in commission at some 460 airports and another 150 or so units in various stages of procurement—some as replacements for existing units, others as new installations. The MLS transition plan calls for these ILS units to remain in service for many years to come, until at least 60 percent of the aircraft routinely using the ILS / MLS runway are equipped with MLS. While ILS and MLS can be colocated and operated simultaneously without signal interference, there may be procedural difficulties in blending aircraft equipped with ILS (and therefore capable of only straight-in approaches) into a traffic stream with MLS-equipped aircraft flying curved or segmented approaches. Thus, the full capacity benefits of MLS may not be attainable at a given airport until all or nearly all aircraft are MLS-equipped and the ILS can be decommissioned.

A second factor that may delay taking full advantage of MLS at specific sites is the agreement with the International Civil Aviation Organization whereby the United States is committed to retaining ILS service at international gateway airports until 1995. There are 75 such airports, generally the busiest U.S. airports and those most prone to capacity and delay problems. Retaining ILS service at these airports may influence some users to defer purchasing MLS equipment for another 10 years or more.

While the capacity gains attributable to MLS may be rather small for the airport system as a whole, MLS does appear to offer promise at those airports where it could be used to create a more flexible traffic pattern or to provide commuter and small GA aircraft access to an alternate runway in IMC, thereby relieving pressure on the main runway used by large air carrier aircraft. Beyond these direct benefits, moreover, MLS may permit procedural changes that could also increase capacity or reduce delay. These potential benefits of MLS are discussed in a later section on airspace use procedures.

Surveillance Radar

Surveillance is accomplished by radar and associated electronic and computer systems that locate, identify, and display the position of aircraft in the airspace. In terminal areas, two types of radar are presently used for this purpose: search radar (technically termed “primary radar”) and the radar beacon system (sometimes called “secondary radar”). Search radar emits signals and displays the returns reflected from the body of the aircraft, objects on the ground, and precipitation or weather fronts, thereby providing a basic two-dimensional map of the airspace. The beacon system, known as the Air Traffic Control Radar Beacon System or ATCRBS, displays only replies from aircraft equipped with electronic devices, called transponders, that send out a coded signal when interrogated by the radar beacon. This signal indicates not only the position of the aircraft but also its identity (flight number) and altitude (if the aircraft is equipped with an altitude-encoding transponder). The beacon system is presently the main source of surveillance information for air traffic control (ATC).

This radar-derived information is correlated and presented to the air traffic controller on one of four different types of display systems: TPX-42, ARTS II, ARTS III, or ARTS 111A. The TPX-42 is the least sophisticated equipment. It is a non-

12 The aviation industry has voiced strong opposition to the Proposal for installing MLS at large and medium airports first, and in May 1984 FAA agreed to a complete review of the deployment strategy. Depending on the outcome of this review, the early stages of the MLS program schedule might be set back a year or more.

13 Microwave Landing *System Transition Plan, APO-81-1* (Washington, DC: Federal Aviation Administration, May 1981).

14 Preliminary Analysis of *the Benefits and Costs To Implement the National Airspace System Plan, DO~/~AAIEM-82-2?2* (Washington, DC: Federal Aviation Administration, June 1982).

programmable device that correlates and displays search radar data and beacon returns on each successive sweep of the antenna. The TPX-42 is used at airports with little traffic. The Automated Radar Terminal System (ARTS II) is a programmable data processor that displays primary and secondary radar data on the controller's scope but does not track aircraft or predict their position. It is used at airports with low to medium levels of activity.

ARTS III detects, tracks, and predicts the position of aircraft. This information is presented on the controller's display as computer-generated symbols (denoting altitude, ground speed, and identity) positioned alongside the secondary radar return. ARTS 111 also incorporates features that alert the controller when aircraft descend below minimum safe altitude or when two aircraft are approaching too closely and require action to assure safe separation—a feature known as conflict alert. ARTS 111A is a refinement of ARTS 111 that is capable of tracking aircraft detected by search radar alone—i.e., aircraft not equipped with an ATCRBS transponder. ARTS 111 and ARTS 111A equipment is installed at the 62 busiest air traffic hubs.

FAA is now in the process of replacing much of the primary radar and display equipment. The existing primary surveillance radars used at airports (ASR-4, ASR-5, and ASR-6) are based on vacuum tube technology that suffers from reliability problems and maintenance difficulties. Newer solid-state equipment (ASR-7 and ASR-8) has been installed at some locations, but these radars, like earlier versions of ASR, are adversely affected by ground clutter, false targets generated by flocks of birds, propagation anomalies, and masking of aircraft returns by weather. Of these shortcomings, weather masking is perhaps the most severe operational problem. The strong return from storms conceals the weaker return from aircraft detected on primary radar alone. To compensate, controllers alter the polarization of the radar to reduce weather echoes and make the aircraft return stand out more clearly, but this lessens the apparent severity of weather fronts and precipitation.

Between 1986 and 1990, FAA plans to install a new primary radar system (ASR-9) which will have a separate weather channel allowing the controller to assess the severity of storms while retaining the ability to detect small aircraft without transponders. The ASR-9 will also incorporate an improvement called Moving Target Detection to overcome the problems of ground clutter and spurious targets. These improvements in primary radar information, when coupled with the present radar beacon display, will provide the controller with a clearer and more accurate picture of the airspace—thereby lessening workload and creating a better basis for decisionmaking about aircraft movement around the airport. The estimated cost of installing 105 ASR-9 systems is $480 million, with the option of adding 35 more in the 1990s at a cost of roughly $125 million.[15]

As radar systems are being upgraded, FAA also plans to improve the data processing and display equipment used by air traffic controllers. Initially, the TP)(-42 system will be replaced by a new version of ARTS II, designated ARTS 11A, which will incorporate minimum safe altitude warning and conflict alert features like the present ARTS III. The ARTS III equipment will also be enhanced with greater memory to handle heavier traffic loads and improved software that will reduce the number of false conflict alerts. In the period 1990-95, ARTS II and III will be replaced by new data processing and display consoles, called sector suites, that will provide improved presentation of surveillance and weather data, display of traffic management and planning information, and automated assistance to the controller in separating and routing traffic in terminal airspace.[16]

The immediate capacity benefit of the ASR-9 radars will be surveillance information of improved reliability and accuracy, which will provide the controller with a better picture of the airspace situation. Of even greater importance, the improved ASR-9 radar, the upgraded ARTS II and III, and the eventual installation of new sector suites will support changes in traffic management techniques that will help the controller make

[15] *National Airspace System Plan* (Washington, DC: Federal Aviation Administration, April 1983), ch. IV.
[16] Ibid., ch. III.

more efficient use of the airspace. These prospects are discussed next.

Traffic Management Techniques

A major task of the air traffic controller is management of traffic so as to maintain a smooth flow of aircraft to and from the airport with minimum delay. This is done by the techniques of metering, sequencing, and spacing.[17] With current technology, these are largely matters of controller art that depend heavily on the individual's skill and experience. On a typical day, the controller must make literally hundreds of related decisions about the order and timing of aircraft movements in the traffic pattern under the prevailing conditions of wind and weather. The chief problems that the controller must deal with in performing these activities are randomness in the arrival and departure streams and differences in the speed and flight characteristics of successive aircraft using the airspace. The extent to which the controller is successful in applying the techniques of traffic management has a significant influence on delay and efficient use of airport capacity.

It has long been recognized by ATC experts that the key to more effective traffic management, especially in circumstances of heavy demand, is to involve computers in the decisionmaking process. In some instances, this means providing the controller with computerized aids to decision-making—devices to collect, integrate, and display information that will give a better picture of the traffic situation and help in executing a control strategy. In other instances—particularly where decisionmaking is routine, repetitive, and reducible to unambiguous rules—the approach is to substitute the computer for the human operator, thus relieving him of workload and guarding against human error and inconsistency.

As part of the planned modernization of the ATC system, FAA is developing new software packages that will assist in traffic management at and around airports. Known under the collective designation of Traffic Management System (TMS),[18] this new software will perform several important functions to increase the efficiency of airport and airspace utilization: airspace configuration management, dynamic planning and computation of acceptance rate, tactical execution of control strategy, runway configuration management, and departure flow metering.

For incoming flights, TMS will establish an acceptance rate and order of landing based on estimated arrival time and predetermined flight paths. As aircraft progress toward the runway, TMS will adjust landing time and spacing between aircraft as necessary to eliminate gaps or surges in the traffic stream and to make efficient use of airspace and runways. In the earlier stages of implementation, the computer will generate recommended instructions and command messages for the controller to relay to pilots by voice radio. In later stages, the computer will transmit commands directly to individual aircraft by the Mode S data link.[19]

17' Metering is regulating th, arrival time of aircraft in the terminal area so as not to exceed a given acceptance rate. Sequencing entails specifying the exact order in which aircraft will take off or land. Spacing involves establishing and maintaining the appropriate interval between successive aircraft, as dictated by considerations of safety, uniformity of traffic flow, and efficiency of runway use.

18TMS is a relatively new term for a concept that was originally called Integrated Flow Management.

19Mode S (for selective) is a proposed addition to the ATCRBS transponder that will permit direct, automatic exchange of digitally encoded information between the ground controller and individual aircraft.

Photo credit: Federal Aviation Administration

Traffic management can smooth the flow

Other components of TMS will contribute to more efficient traffic management in other ways. Runway configuration management, a software program that has been under development at Chicago O'Hare since 1980, will assist controllers in establishing the most efficient combination of arrival and departure runways for given conditions of weather and demand. Departure flow metering will help assure an appropriate blend of takeoffs and landings and will feed aircraft out of the terminal area and into en route airspace.

FAA plans do not call for implementation of TMS all at once, nor at all airports. The components are being developed separately and will be tested and put in place as ready and where needed. The overall timetable is contingent on the development and installation of new computers and sector suites in terminal area control centers and on the development of companion software packages for the en route ATC system—the Advanced En Route Automation (AERA) program. Full implementation of TMS, AERA, and related technological changes will not occur until 1995 or later.

TMS and AERA are tied together because FAA's long-term response to air traffic growth involves a general application of the flow management concept so as to provide strategic and tactical planning, continuous performance monitoring, and flexible and adaptive exercise of control for the airspace as a whole. For example, en route metering—which is a feature of AERA-will contribute to efficient runway use by treating all arrivals along all routes as a single traffic pattern and adjusting in-trail separation so as to achieve a steady rate of delivery into the terminal area. The present method of flow management, which uses uniform, preestablished in-trail separation, can result in inefficient runway utilization (surges and gaps in the traffic flow) because it cannot adapt readily when flow along arrival routes does not exactly match the nominal rate used as the basis for selecting in-trail spacing.

The capacity benefits of TMS are difficult to estimate on a systemwide basis. The anticipated benefits are highly specific to conditions at the airport site and particular patterns of demand. Further, it is not always possible to distinguish between the benefits of TMS and those that would result from other planned improvements in the ATC system. Estimates published by FAA as part of an analysis of overall benefits and costs of the National Airspace System Plan (NAS Plan) suggest that the benefits arising from improved traffic management and flow planning in terminal areas could be fuel savings on the order of 0.75 to 1.25 percent. FAA calculates the value of these savings to be between $165 million and $280 million per year (1982 dollars) for the period 1993-2005. Of these savings, about 60 percent would accrue to air carriers, with the remainder about equally distributed between business and private general aviation.[20]

The FAA report does not provide a projected cost for TMS alone, but lumps these costs with those of AERA and other airport and airspace programs in the NAS Plan (see table 14). The total

[20] *Preliminary Analysis of the Benefits and Costs To Implement the National Airspace System Plan*, op. cit.

Table 14.-Summary of NAS Plan Benefits and Costs (billions, 1982 dollars)

	20-year totals			Present (discounted) values[a]		
	Benefits	costs	Net	Benefits	costs	Net
Aviation users:						
Microwave Landing System Program	2.6	1.6	1.0	1.0	0.2	0.8
Airport Throughput Improvement Program	5.7	b	5.7	1.7	b	1.7
Increased fuel efficiency[c]	16.4	2.4	14.0	4.1	0.9	3.2
Total for aviation users	24.7	4.0	20.7	6.8	1.1	5.7
Federal Aviation Administration	24.3	8.0	16.3	9.0	5.0	4.0
Total	49.0	12.0	37.0	15.8	6.1	9.7

[a]10-percent discount rate.
[b]Avionic costs for this program are included in the costs shown for other programs.
[c]Chiefly AERA program benefits.

SOURCE: Federal Aviation Administration, *Preliminary Analysis of the Benefits and Costs To Implement the National Airspace System Plan*, DOT/FAA/EM-82-22, June 1982 costs are estimated to be $12 billion ($4 billion to aviation users and $8 billion to FAA) over the next 20 years; the associated 20-year benefits are calculated to be $24.7 billion to users, primarily in fuel savings attributable to AERA and $24.3 billion to FAA in operating cost savings. (All estimates in 1982 dollars.)

Supporting Technologies

In addition to programs aimed specifically at reducing delay and increasing the throughput of major airports, FAA is pursuing other technological developments that will either facilitate the ATC process or provide greater assurance of safety. Three particularly important developments of this sort are the Mode S data link, the Cockpit Display of Terminal Information (CDTI), and the Traffic Alert and Collision Avoidance System (TCAS). These technologies will not, by themselves, provide relief to the problems of congestion and delay in terminal areas, but they could make possible other technological improvements or procedural changes to improve the flow of traffic.21

The addition of Mode S to the present ATCRBS transponder has perhaps the most far-reaching implications for air traffic control. Mode S will allow the air traffic controller to interrogate aircraft individually and will make possible direct and selective two-way digital communication between air and ground. Mode S thus will form the basis for the more automated forms of air traffic control envisioned in the TMS and AERA programs. Equally important, Mode S will open up a new, high-capacity channel of communication that will provide more complete and rapid exchange of information and greatly reduce controller and aircrew workload by relieving them of the time-consuming process of transmitting, receiving, and acknowledging messages by voice radio. A third benefit of Mode S is that it can enhance the surveillance function by reducing interference among transponder replies of aircraft operating close together in terminal airspace.

An important potential application of the Mode S data link is that it could be used to improve the quantity and quality of information available in the cockpit by providing a display of traffic in the surrounding airspace. This display, CDTI, has been under development for several years and has been recommended by pilots and ATC experts as a valuable new tool to enhance safety and to aid maneuver in terminal airspace. The CDTI, by showing the location and path of nearby aircraft, could give the pilot an overall view of the traffic pattern and could provide an additional source of information under conditions of reduced visibility.

The CDTI is not envisioned as a substitute for ground-based air traffic control nor as the basis for independent maneuver to avoid collision or to assure safe separation. Rather, it is intended as a supplemental display that will allow the pilot to “read” the air traffic pattern and to cooperate more effectively and confidently with the ground-based controller in congested airspace. FAA, in cooperation with the National Aeronautics and Space Administration (NASA), is currently exploring roles for a CDTI. The focus of this effort is to develop CDTI system requirements and to determine the compatibility of these requirements with Mode S and TCAS data sources.

The overriding concern in seeking ways to increase airport throughput and runway acceptance rates is maintaining safe separation among aircraft. Basic separation assurance is provided in two ways: by application of the “see-and-avoid” principle in Visual Flight Rules (VFR) and by ATC procedures and ground-based surveillance in Instrument Flight Rules (IFR). Pilots and others concerned with aviation safety have long advocated additional assurance in the form of an airborne (i.e., ground-independent) collision avoidance system. The system currently proposed by F&l—Traffic Alert and Collision Avoidance System—is an independent airborne device designed to use ATCRBS (or Mode S) transponder information for generating a warning to the pilot that an approaching aircraft is a threat and that evasive maneuver may be called for.

TCAS is in the development stage at present and may not be ready for operational use until the late 1980s. The availability of TCAS, or an equivalent system of airborne collision avoidance,

“*See **Airport and Air Traffic Control System,*** op. cit., for more detailed discussion of these technologies.

will be an important factor in the decision to adopt revised procedures for increasing the efficiency of airspace use. Without assurance that safe separation can be maintained and that there is a backup to ground-based air traffic control, neither airspace users nor FAA are likely to have the confidence to proceed with revision of present longitudinal and horizontal separation standards.

AIRSPACE USE PROCEDURES

Procedures governing the use of terminal airspace and airport runways, which are designed primarily to assure safety, sometimes slow or disrupt the flow of traffic. In general, these procedures consist of rules and standards pertaining to the permissible distances between aircraft in various weather conditions and approach patterns. Actually, there are two sets of procedures: one for use in Visual Meteorological Conditions (VMC) and another, more stringent, set for use in Instrument Meteorological Conditions (IMC). Instrument Flight Rules—which are largely determined by available navigation, communication, and surveillance technology—often cause delays at busy airports because of the increased separation standards and special safeguards that must be applied in restricted visibility.

There is a widely held, but not unanimous, view among airspace users that revisions of the existing instrument flight procedures are practical and that they would be warranted in the interest of reducing delay. While these revisions are sometimes spoken of as capacity improvements, they would not in most cases actually increase the capacity of airports. Instead, they would allow existing capacity to be used more fully or with greater efficiency and would bring the throughput attainable under IMC closer to that which prevails under VMC.

In response to urging from airspace users, FAA instituted a comprehensive examination of airspace use procedures in October 1981. This effort, known as the National Airspace Review (NAR) is a 42-month joint undertaking by FAA and the aviation industry "to identify and implement changes which will promote greater efficiency for all airspace users and simplify [the ATC] system. Additionally, the NAR will match airspace allocations and air traffic procedures to technological improvements and fuel efficiency programs."[22] The portion of NAR concerned specifically with terminal area ATC procedures was completed in July 1984.

Many of the procedural changes sought by airspace users and under study by FAA in NAR were also examined by a special aviation industry task force convened at the request of FAA under the auspices of the Airport Operators Council International. The task force report, issued in September 1982, strongly urged FAA to revise present airspace use procedures, especially those pertaining to the use of multiple runways under Instrument Meteorological Conditions.[23]

Reduced Lateral Separation

Several of the proposed revisions would permit changes in the standards for lateral separation of aircraft under instrument flight conditions. The present standards often severely restrict throughput because they preclude use of all the available runways when visibility is reduced. If the airport could continue to operate these runways, the disparity between IMC and VMC acceptance rates could be substantially narrowed. The following are the major capacity-related changes under consideration.

Converging Runways

Converging runways are those whose extended centerlines meet at a point beyond the runways themselves. Simultaneous approaches to converging runways are presently authorized only during VMC. The proposed procedure would ex-

[22] *Federal Register*, vol. 48, No. 153, Aug. 10, 1981, p. 40654.

[23] *Report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction*, op. cit. In a subsequent letter to FAA Administrater Helms, dated Dec. 9, 1983, the Task Force put forth proposals for simulation and demonstration of IFR approaches to converging and independent parallel runways. The Task Force also endorsed studies to evaluate reduced longitudinal separation in certain circumstances.

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tend this authorization to IMC in certain circumstances. The major problem to be overcome in using converging runways under instrument conditions is development of procedures to assure separation in the event of a blunder by one of the aircraft during the approach or in case both aircraft must execute a missed approach at the same time. These procedures, in turn, depend on the availability of improved surveillance radar, MLS to provide missed approach guidance, and perhaps automated aids for the controller to coordinate simultaneous approaches to two runways.

In time, it maybe possible to extend these procedures to the case of intersecting runways-those whose surfaces actually cross at some point. In addition to the problems of blunder protection and separation assurance during missed approaches, this configuration poses the risk of collision between two aircraft on the ground, and there must be adequate safeguards that aircraft on both runways can stop or turn off before reaching the intersection. Because of the inherent safety problems, most observers are skeptical about the feasibility of using this type of runway layout for instrument operations.

Dependent Parallel Runways

At present, instrument approaches maybe conducted on parallel runways that are as close as 3000 ft apart so long as a diagonal separation of 2 nautical miles (nmi) is maintained between adjacent aircraft. For parallel runways separated by 2,500 ft, the diagonal spacing requirement is 2.5 nmi. In addition, aircraft must be separated by 1,000 ft vertically or 3 nmi horizontally as they turn onto their parallel approach paths. These runways are termed dependent because the approaches to each must be coordinated to maintain the prescribed diagonal spacing. Hence, the operational rate attainable on either is constrained by the movement of aircraft on the other.

FAA studies suggest that the diagonal spacing requirements for IFR operation on dependent parallel runways could be reduced. For runways separated by 2,500 ft, the standard could be reduced from the present 2.5 nmi to 2 nmi with current technology and no other changes in existing procedures.[24] Reducing the spacing requirements for approaches to parallel runways less than 2,500 ft apart requires: 1) that the pilot be able to confirm that he is, in fact, on approach to the proper runway since radar surveillance would no longer be sufficient; and 2) that wake vortices from aircraft approaching one runway do not interfere with operations on the other. Because of wake vortex, current procedures require that aircraft approaches to closely spaced parallel runways (less than 2,500 ft apart) be treated as approaches to a single runway and separated accordingly.

An operational solution to the wake vortex problem on closely spaced parallel runways entails that the following additional conditions be met:

- there must be a steady crosswind to diminish the effects of wake vortex, but the wind velocity must be less than maximum crosswind limitation;
- small aircraft that are vulnerable to wake vortices must use the upwind runway of the closely spaced pair;
- the threshold of the upwind runway must be displaced from that of the downwind runway;
- the upwind runway must have a high-angle glide slope to allow for a steeper descent by vulnerable aircraft so that they can remain above, and hence avoid, wake vortices; and
- wind monitors must be set up along the approach path to ascertain that conditions are favorable for the dissipation of wake vortices.

Satisfying these requirements may be difficult at airports that do not have runways with suitably staggered thresholds and a sufficiently large number of aircraft that can approach at a steeper than normal glide slope to avoid wake turbulence. In addition, there are operational difficulties that may limit the applicability or the capacity benefits of this procedure. First, the wake vortex generated by a heavy aircraft carrying out a missed

[24] A. L. Haines and W. J. Swedish, *Requirements for Independent and Dependent Parallel Instrument Approaches at Reduced Runway Spacing*, FAA-EM-81-8 (Washington, DC: Federal Aviation Administration, Office of Systems Engineering Management, May 1981).

approach could interfere with operations on the other runway. One possible solution would be to require that both the leading and trailing aircraft execute missed approaches along diverging paths whenever the leading heavy aircraft misses the approach. Second, interference from departures could limit capacity gains since it may be necessary to retain present longitudinal separation standards between heavy aircraft departing on one runway and small aircraft landing on the other in order to avoid wake turbulence. Finally, as the distance between parallel approaches is reduced, there will be a need for more accurate surveillance to verify that aircraft are on approach to the proper runway. The radar now in use, which has a 5-milliradian accuracy and a 4-second update rate, is probably not adequate for this purpose and may have to be replaced with new radar capable of l-milliradian accuracy and 1-second update .25 Such radar performance has been achieved in the Precision Approach Radar system formerly installed at some airports but now decommissioned. Military radar also has this capability but would have to be adapted and tested before use in civil aviation.

Independent Parallel Runways

Independent instrument approaches to parallel runways separated by at least 4,300 ft are presently authorized under the following conditions: 1) when aircraft are turned onto the approach path, they must be separated vertically by at least 1,000 ft or laterally by 3 nmi from aircraft turning on approach to the other runway; and 2) a “No Transgression Zone, ” at least 2,000 ft wide, must be maintained between the approaches, with a separate controller assigned to monitor this zone. A study by FAA indicates that, as with dependent parallel runways, reducing lateral spacing for independent parallel runways from 4,300 to 3000 ft would require installation of more accurate radar but no other changes in current procedures. 26

[25] 1bid.
[26] Ibid.

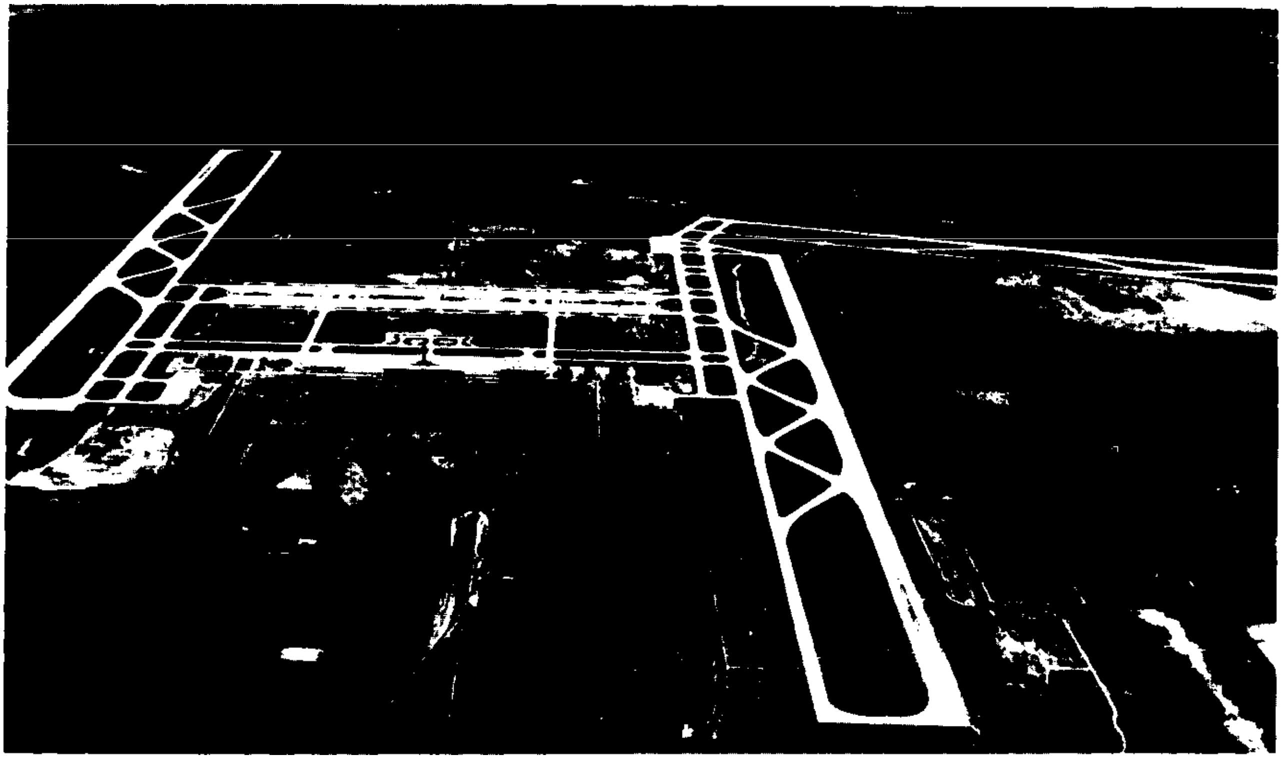
Triple Parallel Runways

Demand at some of the busier airports, such as O’Hare, Atlanta, Dallas/Fort Worth, Pittsburgh, and Detroit, sometimes exceeds the capacity of the runway system in IMC, and addition of a third approach stream would be desirable. Current ATC procedures allow approaches to triple parallel runways only during VMC. Revision of separation standards to permit their use during IMC would significantly expand the time that maximum airfield capacity is available at these few very busy airports.

While the requirements for three parallel approaches are similar to those for two parallel approaches, the addition of a third runway complicates the approach procedures and limits possible gains in capacity utilization. To be most effective, at least the outside pair of approaches should be independent from each other, although both may be dependent on the middle runway. If all three parallel runways were dependent, there would be only a minor increase in throughput compared to that attainable with two dependent runways. Also, since a blunder ***on*** one of the outside approaches could affect more than one other aircraft, establishment of triple independent parallel approaches necessitates two “No Transgression Zones, ” with a separate controller assigned to monitor each. Because the l, 000-ft vertical separation rule for aircraft turning onto parallel approach paths still apply, final approach courses, particularly for the center runway, would be longer–thereby diminishing somewhat the throughput gain attainable with the triple parallel configuration.

A few airports have runway layouts that allow a converging approach to be added to two existing parallel approaches. This third approach is used during VMC, but in IMC the converging runway must be closed because separation between aircraft executing missed approaches cannot be assured visually.

The requirements for three approaches, one of which is converging, are similar to those for two converging approaches. However, establishing the third converging approach for use with a parallel pair involves additional safeguards because a blunder by an aircraft on one of the outside ap-



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preaches affects more than one other aircraft. The missed approach path for the converging runway must be coordinated with those of the other two runways—a procedure that is quite complex and cannot be implemented without further research and evaluation. In particular, FAA is studying whether MLS will be required to provide non-conflicting missed approach paths .27

Reduced Longitudinal Separation on Final Approach

Current procedures require longitudinal (in-trail) separation of 3 nmi between aircraft conducting instrument approaches to the same runway In VMC, in-trail separations of 2.5 nmi and even 2 nmi are not uncommon depending on the runway geometry, the observed runway occupancy time, and the mix of aircraft. Proposals have been advanced to reduce the IMC standard to 2.5 nmi immediately, and perhaps to 2 nmi eventually for certain airports and runway configurations.[29]

One determinant of the longitudinal separation standard is the length of time needed for aircraft to leave the runway after landing (runway occupancy time). As a safety measure, current ATC procedures do not permit two aircraft to occupy a runway at the same time. FAA studies have shown that runway occupancy time at many major airports averages between 41 and 63 seconds.[30]

[27] *Response to the Industry Task Force on Airport Capacity Improvement and Delay Reduction* (Washington, DC: Federal Aviation Administration, FAA Management Steering Group, May 25, 1983), p. 6.

[28] When there is a hazard of wake turbulence, these longitudinal separation standards are increased to 4 to 6 nmi depending on the size of the leading and following aircraft.

[29] See, for example, *Report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction*, op. cit., pp. 6-7; and letter from the Task Force Chairman to the FAA Administrator, Dec. 9, 1983.

[30] *Analysis of Runway Occupancy Times at Major Airports*, FAA-EM-78-9 (Washington, DC: Federal Aviation Administration, May 1978); and W. J. Swedish, *Evaluation of the Potential for Reduced Longitudinal Spacing on Final Approach*, FAA-EM-79-7 (Washington, DC: Federal Aviation Administration, August 1979).

For those airports where runway occupancy time averages so seconds *or less,* FAA studies indicate that minimum in-trail separation of 2.5 nmi could be allowed in circumstances where wake vortex and ATC workload permit. Flight tests conducted by the U.S. Air Force have demonstrated the feasibility of 2.5-mile separation for military use. However, safety standards for commercial operations are different than those for military operations, and analysis of radar accuracy and update rates, controller and pilot response times, and aircraft performance characteristics will be needed to determine whether 2.5-mile separation during IMC is safe for civil aviation. Since there is a direct relationship between in-trail separation and throughput, this procedural change would be a very effective method to reduce delay under instrument flight conditions.

Present ATC procedures specify that the nominal longitudinal separation standards for VMC or IMC be adjusted to compensate for the possible effects of wake turbulence. These separation standards, shown in figure 9, are based on a three-way classification of aircraft according to gross takeoff weight and attempt to account for the wake-turbulence characteristics of aircraft and their vulnerability to wake vortex encounters:

- heavy ah-craft—maximum gross takeoff weight (GTW) in excess of 300,000 lb,
- ***large*** aircraft—maximum GTW between 12,500 and 300,000 lb, and
- ***small*** aircraft—maximum GTW less than 12,500 lb.

Definition of aircraft categories based on GTW alone is not an accurate index of of wake vortex generation for all aircraft, notably those aircraft whose GTW is slightly over 300,000 lb such as the DC-8 and B-767. As the number of B-767 aircraft in the fleet grows and as the re-engining program for DC-8S proceeds, aircraft whose GTW ***is*** roughly 300,000 lb will become an increasingly large proportion of the commercial aircraft fleet. If these aircraft continue to be classified as "heavy," greater arrival separations will be required, with adverse effects on capacity and delay.

If aircraft were classified on the basis of more precise analytical or empirical data concerning their specific aerodynamic and wake-vortex characteristics, it might be possible to reduce the in-trail separation rules for some types. As a minimum, the use of approach weight rather than maximum GTW as the basis for separation criteria could be considered. To be even more pre-

Figure 9.—Arrival and Departure Separations

Minimum Arrival Separations—Nautical Miles

Visual Flight Rules*

Lead \ Trail	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

Instrument Flight Rules

Lead \ Trail	S	L	H
S	3	3	3
L	4	3	3
H	6	5	4

Minimum Departure Separations—Seconds

Visual Flight Rules*

Lead \ Trail	S	L	H
S	35	45	50
L	50	60	60
H	120	120	90

Instrument Flight Rules

Lead \ Trail	S	L	H
S	60	60	60
L	60	60	60
H	120	120	90

*VFR separations are not operational minima but rather reflect what field data show under saturated condition

KEY: S = Small, L = Large, H = Heavy (see text.)

SOURCE: Adapted from *Parameters of Future ATC Systems Relating to Airport Capacity/Delay* (Washington, D.C.: Federal Aviation Administration, June 1978), pp. 3.3, 3.5.

cise, wingspan, approach speed, and engine and flap configurations should also be taken into account. A recommendation to this effect was made in the report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction and is now under consideration by FAA.[31]

Separate Short Runways for Small Aircraft

The current practice in air traffic control is to organize aircraft on approach according to time of arrival, not type of aircraft. So long as the traffic mix is reasonably uniform, this practice has a minor effect on throughput. At many airports, however, small aircraft represent a significant portion of traffic. To avoid wake turbulence generated by the heavy and large classes of transports, these small aircraft are required to follow in trail at distances of 4 to 6 nmi from the larger aircraft. Since many of these small aircraft operate at slow speeds, safety requires that larger and faster aircraft be spaced more than 3 nmi behind so that the leading small aircraft are not overtaken on approach. One way to overcome these operational penalties would be to segregate small general aviation and some commuter aircraft into a separate traffic stream using a different (short) runway. At some airports such a runway is already available but not usable for instrument approaches because of inadequate instrumentation; at others, new runways would have to be built and equipped with MLS.

There is some disadvantage to separate short runways in that they do not provide as much operational flexibility as a full-length additional air carrier runway. However, the separate short runway can be built at a fraction of the cost of an air carrier runway, and runway siting problems as well as local environmental issues may be easier to resolve.

Ideally, the separate short runways for small aircraft should be parallel to and operate independently from the main runway used by large air carrier traffic. A short runway that is not parallel to the main runway would not be available for use in IMC unless revised procedures for converging instrument approaches are also implemented; but even so, dependency on the main runway would limit the throughput gain because of the need to coordinate the two traffic streams. If the procedures described above to reduce spacing requirements for independent and dependent parallel approaches prove feasible, the siting of these short secondary runways could become easier. Another development that would facilitate siting of short runways and broaden the applicability of the concept would be installation of MLS to allow curved approaches and steeper glide slopes by small aircraft, not only to alleviate wake turbulence problems but also to achieve a greater rate of runway use.

[31] *Report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction,* op. cit., pp. 3-4.

WEATHER AND ATMOSPHERIC EFFECTS

Perhaps the single greatest technological need in relieving delay at airports, aside from improved radar to monitor aircraft more closely spaced in terminal airspace, is development of techniques to improve the detection and prediction of weather and atmospheric effects. Weather-related technologies are typically viewed as safety improvements rather than capacity improvements, but there are significant exceptions—notably methods to protect from wake vortices. Current aircraft arrival and departure separations are predicated in large part on avoidance of wake vortices, and the key to many of the revised approach procedures described above is a better method to detect or to predict the occurrence of wake turbulence.

Beyond this, improvement in the ability to prediet weather and atmospheric phenomena could lead to general reductions in delay. Present technology does not always permit sufficiently accurate prediction of the time and magnitude of adverse weather conditions, making it necessary to increase safety margins and thereby reduce throughput. The ability to foresee disruptions due to weather would permit planning to compensate fer the impacts on traffic flow.

Wake Vortex

Wake vortex is an aerodynamic disturbance that originates at the wingtips and trails in corkscrew fashion behind the aircraft. Since the strength of the turbulence increases with lift, the strongest vortices occur behind heavy aircraft. These vortices spread downward and outward in the wake of the aircraft and may persist along the flight path for as long as 2 or 3 minutes in still air. When the aircraft *is* within 300 ft of the ground, the vortices can bounce off terrain and rise back toward the flight path, creating even more disturbance. Wake turbulence can be of such strength and duration that it poses a hazard to following aircraft (especially smaller aircraft), and present procedures require separation of 3 to 6 nmi depending on the size of the leading and following aircraft and the movement of the airmass.[32]

Alternatives to the present procedural method of avoiding wake turbulence are being sought both in the interest of safety and for the capacity benefits that could be realized through closer spacing of aircraft in the approach zone. Two avenues are being taken. FAA has concentrated on development of techniques to detect wake vortex and to predict its movement and persistence. NASA has focused on aerodynamic research to provide better understanding of the mechanics and causes of wake vortex and to develop designs to alleviate it at the source. NASA research indicates that certain combinations of flaps, spoilers, and protrusions on wing surfaces can reduce turbulence or cause it to dissipate more quickly. Unfortunately, many of these techniques also tend to increase noise and reduce energy efficiency. Work is continuing on ways to minimize wake vortex at an acceptable price in terms of noise and fuel consumption, but no ready solution is in sight. This *is* an important area of research and development since the alternative—wake vortex detection and avoidance—has not been perfected to the point that pilots have confidence in its reliability.

FAA has sought to develop equipment and a concept of operation that provide real-time vortex sensing capability and to devise a predictive algorithm that will warn pilots and controllers. An experimental device, known as Vortex Advisory System (VAS), was installed and tested at O'Hare in 1978. VAS is made up of wind sensors mounted on towers along the approach path, a central computer to process wind data and predict the strength and movement of wake turbulence, and a display to alert the controller when a hazardous condition exists. VAS has not yet proven operationally acceptable, and FAA plans further development and test.

The disadvantage of VAS is that it does not detect wake vortices; it only measures wind direction and velocity, from which an inference can be made about the presence and strength of wake turbulence. This deficiency is particularly evident further out on the approach path (beyond the middle marker) and in crosswind conditions where turbulence on one approach path may migrate to a parallel approach. To overcome these limitations, FAA is also investigating other technological approaches such as short-wave radar, lasers, and infrared devices that could provide better long-range sensing and wider coverage.

No practical solution is now in view, and it seems likely that procedural methods to avoid wake turbulence will continue to be employed. So long as wake vortices cannot be reliably detected and predicted, the present separation standards (perhaps with some modification to account for the aerodynamic characteristics of specific types of aircraft) will remain in force and preclude any throughput gains that might be achieved through reduced in-trail spacing.

Wind Shear

Wind shear is any sudden change in wind velocity or direction. It may be associated with warm and cold fronts, low-level jet streams, or mountainous terrain. One of the most dangerous types of wind shear is a downward surge of air striking the ground and spreading out in all directions. This kind of wind shear is often associated with thunderstorms, but it may occur in other weather conditions. These downdrafts, called microbursts, are difficult to predict because they are small and

[32] J. N. Barrer, "Operational Concepts for Reducing Vortex Spacings on Closely Spaced Parallel IFR Approaches, " The MITRE Corp., WP-81W520, September 1981.

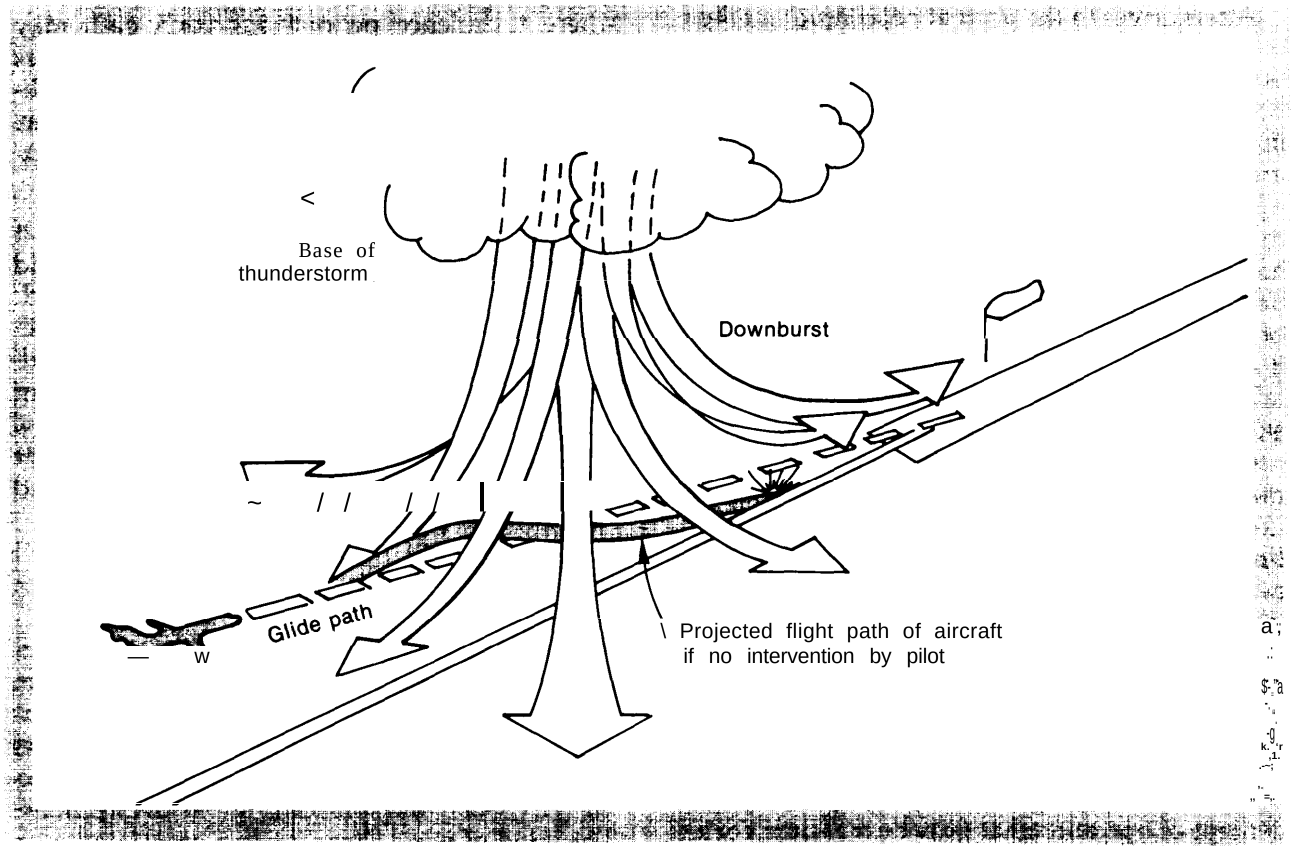
localized, extending only 2 or 3 miles and often lasting less than 5 minutes.

For the pilot of an aircraft, wind shear is experienced as an abrupt increase or decrease of lift (or often one rapidly followed by the other) caused by a sudden shift in the relative wind. In this condition, the aircraft may gain or lose altitude unexpectedly and become difficult to control in angle of attack and flight path (see fig. **10).** If this occurs near the ground on takeoff or landing, there can be extreme hazard.[33] While the primary concern is safety of flight, wind shear also disrupts airport activities and can cause suspension of operations until the condition abates.

In **1982,** The Federal Government undertook a project known as Joint Airport Weather Studies (JAWS) to provide a better understanding of wind shear, thunderstorms, and related weather hazards and to identify weather conditions that could be warning signs to pilots. A multi-agency effort involving the National Science Foundation, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and the Federal Aviation Administration, JAWS collected data on downbursts at Denver Stapleton airport during a 3-month period in the summer of **1982.** The knowledge of wind shear

[33] On July 8, 1982, a Pan American World Airways Boeing 727 crashed at Kenner, LA, near New Orleans International Airport, shortly after taking off in a thunderstorm. Wind shear was determined to have been the cause.

Figure 10.—Effects of Low=Aititude Wind Shear



The downburst spreads out as it nears the ground. The aircraft, instead of following a straight path to the runway, encounters first an abrupt increase in headwind which lifts the nose, and then a sudden strong tailwind, which forces the nose down. If the pilot cannot compensate for these wind changes at low altitude, the aircraft may crash.

SOURCE: ICAO Bulletin

gained through JAWS will contribute to the Low Level Wind Shear Alert System (LLWSAS) which provides the air traffic control tower with information on wind conditions near the runway. LLWSAS consists of an array of anemometers that read wind velocity and direction around the airport and signal the sudden changes that indicate wind shear. LLWSAS is now installed at *60* airports, and FAA plans to deploy *50* more by **1985.**

Over the longer term, FAA is developing other systems intended to provide better and more timely weather information at airports, both to improve safety and to help in traffic management. The Automated Weather Observing System (AWOS) will gather weather data from urtrnanned sensors, automatically formulate weather reports, and distribute them to airport control towers. AWOS will also broadcast this information to pilots as voice synthesized messages over VHF radio. Implementation of the system, scheduled for the period *1983-90,* began with a l-year demonstration program in June 1983, when 21 units were put into operation at towered and non-towered airports in various locations. Full deployment at 745 airports is scheduled to begin in 1986.[34] A similar system, Joint Automated Weather Observation System (JAWOS), is planned for installation at *some* medium and large hub airports. JAWOS will automatically gather local weather data and distribute it to other air traffic control facilities and to the National Weather Service.

In cooperation with the Department of Defense and the National Oceanic and Atmospheric Administration, FAA is also developing a next generation nationwide weather network based on pulsed Doppler radar (NEXRAD). This network will provide more accurate information on precipitation, reflectivity, wind velocity, and turbulence. NEXRAD will probably not provide the minute-to-minute observations needed to detect small localized downbursts that produce wind shear, nor will it be able to detect wind shear in the absence of precipitation. Still, NEXRAD will greatly improve the quality and comprehensiveness of the weather information available to air traffic controllers and will be a significant aid in managing traffic to compensate for adverse weather conditions. A total procurement of *160* units is planned, with the last scheduled to be in place and the system fully operational by 1992.

“Several GA user groups have argued that the AWOS timetable could be accelerated by a year or more and have asked FAA to reconsider the deployment schedule.

NOISE CONTROL AND ABATEMENT

Aircraft noise, especially the noise of jet aircraft, is one of the greatest barriers to airport utilization and expansion, and it is the most common subject of complaint by airport neighbors. The areas of severest noise impact are just beyond the ends of runways, but noise levels can be unacceptably high elsewhere along approach and departure paths where aircraft are close to the ground. In legal actions brought by airport neighbors, the courts have generally found that the airport operator is responsible for injury due to reduced property value or nuisance and have awarded damages to property owners and others affected by noise.

There are two ways to reduce noise. One is to quiet the aircraft themselves, notably the engines, and FAA has imposed progressively stricter noise standards for aircraft in FAR *36* and FAR 91E.[35] As a result, new aircraft entering service are much quieter than earlier models, and some older aircraft have been equipped with new, quieter engines. While research is continuing on aircraft noise, airframe and engine manufacturers tend to the view that large-scale and cost-effective advances in the technology of noise suppression will be increasingly difficult to find.

35FAR part 36 defines noise requirements for certification of new aircraft and engines. FAR Part 91 Subpart E sets the timetable for compliance and calls for retirement or retrofit of aircraft (both foreign and domestic) that do not comply with FAR Part 36 by 1985. To protect air service to small communities, FAR Part **91** Subpart E allows three additional years (until 1988) for twin-engine aircraft with 100 or fewer seats to achieve compliance.

The other approach has been to impose operational restrictions on airports—principally in the form of limits on the hours of use, frequency of flights, and the approach and departure routes that may be taken. Airport operators and airlines have resisted these measures since they reduce the capacity of the airport overall or at peak times and because noise abatement flight procedures often result in lengthier, less fuel-efficient paths to and from the airport. Two studies of airport capacity published recently have stressed the need to lessen some of these restrictions in the interest of increasing airport capacity and making more efficient utilization of aircraft.[3b] 37

The discussion that follows addresses first prospective improvements in aircraft technology that might lessen noise, and then procedural solutions to alleviate the noise problem.

Aircraft Noise

Aircraft noise has two components: engine noise produced by moving engine parts and by air flow through the engine, and airframe noise caused by the passage of air over aircraft surfaces. In early jet aircraft, the engine was the predominant noise source. Advances in engine technology over the past 20 years have reduced engine noise to the point where the engine and the airframe are now about equal contributors to aircraft noise on landing. The engine is still the major noise source on takeoff.

Engine Noise

The principal sources of noise in a jet engine are: 1) the fan, 2) the compressor and turbine, and 3) the exhaust. The relative importance of these sources varies somewhat with the design of the engine and the operating regime, but exhaust noise is generally the greatest of the three.

Efforts to reduce fan noise have centered on altering the design of the fan blades and incorporating sound absorbing material in the fan case and the inlet and discharge ducts. Typically, this sound absorption is accomplished by a liner of porous material backed by cavities to trap sound. The newer aircraft engines now in service incorporate these design concepts, but further, small noise reductions may still be achieved.

Compressor and turbine noise are generated inside the engine by the compression, heating, and expansion of the air passing through. Methods for reducing compressor and turbine noise have included redesign of compressor parts and turbine blades to modify their sound characteristics, and use of sound absorbing material. Since the ability to alter the design or configuration of the compressor or turbine is limited by mechanical and aerodynamic considerations and engine load requirements, it is expected that the principal method to attain further reductions in compressor and turbine noise will be acoustic treatment in the intake ducts. Research is now aimed at development of improved acoustic material capable of withstanding the hot and cold environment of the compressor and turbine, and at reducing the cost of these noise suppression treatments.

Exhaust noise results from the turbulent mixing of hot, high-speed exhaust gases with the ambient air. The way to reduce this noise is through techniques that lower the temperature and velocity differential between the exhaust and the outside air, but without loss of engine efficiency and thrust. In the early, pure turbojet engines, all of the intake air was passed through the hot section of the engine, from which it exited at high velocity. These engines were very noisy. A later development diverted some of the air from the compressor around the combustion chamber and turbine and merged it with the exhaust stream—thus shielding the high-velocity exhaust with a cooler, slower moving sheath of air from the compressor. These low bypass ratio engines were more efficient and proved, on average, to be about 8 decibels (dB) quieter than pure turbojets.[38] Engines introduced in the ***1970s*** made use of an even higher bypass ratio to achieve both greater fuel efficiency and a further 8- to 10-dB reduction of noise .39

36 Report and Recommendations of ***the Airport Access Tskk Force*** (Washington, DC: Civil Aeronautics Board, March 1983).
37 Report of the Industry Task ***Force on Airport*** Capacity ***Improvement and Delay Reduction,*** op. cit.

38 The bypass ratio is the amount of air diverted around the combustor relative to that which passes through it.
39 For reference, a change of 3 dB is just perceptible to the human ear. A reduction of about 10 dB is perceived as halving the amoyance of a sound source.

Engine manufacturers are continuing to explore techniques such as high-pressure turbines, exhaust diffusers, and improved internal cooling methods–principally to increase engine efficiency but also for their potential to reduce noise. They are also evaluating internal flow mixers to combine low-velocity bypass air with higher velocity engine flow to produce an exhaust stream with less turbulence and a more uniform exit velocity. These efforts are yielding diminishing returns since further noise reduction involves very tightly coupled tradeoffs with fuel efficiency, production techniques, and maintenance costs. Attainment of noise levels significantly lower than those of FAR Part *36* appears to be very difficult without a sacrifice of fuel efficiency or a large cost penalty.

Airframe Noise

Airframe noise stems primarily from turbulent air flow past the undercarriage, leading and trailing edges of high-lift devices, aircraft cavities, and projections from the aircraft surface. For an aircraft in flight, these noises intermingle and are not usually distinguishable as to source. The principal methods available to reduce aerodynamic noise are wing design, high lift systems, and aircraft streamlining.

Recent exploratory development in aircraft wing design has included supercritical airfoil sections and winglets. Aircraft using these wing design features are currently being flight tested. Fundamentally, the supercritical airfoil and winglets would reduce drag and provide additional lift, but they also serve to reduce aerodynamic noise somewhat. Drag is exhibited as turbulence in the wake of aircraft, and turbulence produces noise. Further, insofar as reduced drag and increased lift permit the aircraft to be operated at lower power settings on takeoff and landing, these aerodynamic improvements might provide a secondary benefit of reduced engine noise.

Advanced high-lift systems make use of two-segment trailing edge flaps and a variable camber on the leading edge of the wing. High-lift devices of this sort are currently used on Short Takeoff and Landing (STOL) aircraft such as the deHavilland DHC 7. They have also been incorporated in some large transport aircraft. The 747 and later model *727* aircraft have triple-slotted flaps, and the *767* has both variable camber leading-edge flaps and double-slotted trailing edge flaps. These systems do not necessarily produce quieter aircraft; in fact, they may be noisier. However, high-lift devices permit steeper approach and takeoff paths, thereby reducing the size and severity of the aircraft noise footprint on the ground and leading—in effect—to less aircraft noise overall.

Techniques to streamline aircraft include placement of fairings around extended landing gear and other projections from the aircraft surface and enclosure of wing and body cavities. Such features are intended primarily to improve the aerodynamic performance of the aircraft, but they could also lessen aerodynamic noise. Another streamlining technique involves strategic placement of the engines at locations where the airframe can act as a shield for engine noise. There are critical tradeoffs between engine placement and aircraft performance and safety that need to be treated carefully. There is also a need for additional research to improve the understanding of how the engines and airframe interact in the production and suppression of noise.

Many of the techniques described above might lessen aerodynamic noise, but the overall reduction would probably be rather small. There is a widely held view among aircraft designers that the newest aircraft are close to the practical lower limit of aerodynamic noise and that further reductions will be technically difficult, prohibitively costly, and perhaps disadvantageous for other aspects of aircraft performance. While some of these techniques will be pursued and might be incorporated in future aircraft, the general opinion is that there are no aerodynamic solutions that will lead to large-scale reductions in aircraft noise.

Aircraft Operating Procedures

In addition to technological measures to reduce noise at the source, there is the the procedural solution of operating aircraft in a way that alleviates the effect on noise-sensitive areas. Many such measures have already been adopted—some locally, some more generally—and work is continuing to improve these procedures, to devise new ones, or to extend their application more widely.

Procedures in use today are limited, in some cases, by safety and capacity considerations and by the capabilities of the ATC system. The ability to apply these procedures is also affected by conditions of wind, weather, and visibility. Perhaps the greatest deficiency, however, is that restrictions are applied airport by airport—often as a result of local ordinance—in a fashion that is fragmentary, confusing, and inefficient. Aircraft operators complain that both airport capacity and aircraft utility are wasted and that market opportunities are lost. The Airport Access Task Force of the Civil Aeronautics Board (CAB) devoted major attention to the question of noise abatement procedures and urged the Federal Government to reduce the number of locally imposed aircraft operating restrictions and to develop nationally applicable procedures that would appropriately balance public concerns about noise with the interests of air commerce.[40]

Prospective advances in technology might make some of the procedures in use today more effective or less onerous to aircraft operators. One such procedure is departure thrust management, which necessitates adjustments in power settings during climbout and exit from the terminal area. As newer aircraft with better performance characteristics and quieter engines come to predominate in the fleet, these departure practices may be easier to implement, or—in some instances—they may not be required as often. The CAB Airport Access Task Force estimated that phasing out aircraft with low bypass engines (from 94 percent of the fleet in 1980-81 to 10 percent by 2000) would produce an average noise reduction of almost 6 dB systemwide, even if operations were to increase by 50 percent.[41]

Preferential runway use is another method for reducing the extent or severity of noise impact on the surrounding community. This involves using, whenever possible, those runways that minimize the number of people or the area exposed to aircraft noise. The effectiveness of preferential runway use is site-specific since it depends on the runway layout in relation to land use patterns, the prevailing wind and weather, and the installation of navigation and landing aids. Implementation of the Traffic Management System and deployment of MLS might make it possible to extend this practice to other airports or allow it to be used in a wider spectrum of weather conditions.

On the other hand, preferential runway use has the effect of exposing the unfortunate few who live or work in affected areas to more unremitting noise than might be considered their "fair share." For this reason, it may be more equitable to temper preferential runway use with some variation of runway use patterns. Distributing noise more uniformly among areas surrounding the airport would lessen the impact on some, but at the risk of antagonizing perhaps far more who are not presently exposed to aircraft noise.[42]

Preferential flight paths are prescribed routings for arriving and departing aircraft to avoid overflight of noise-sensitive areas. This procedure is frequently combined with preferential runway use, but may be used even where the airport has only a simple runway layout. At some airports

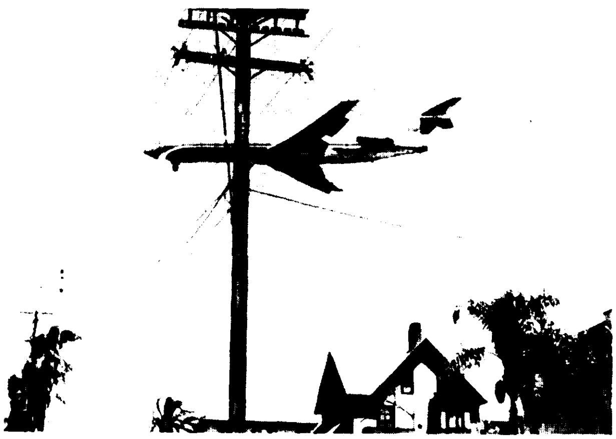


Photo credit: Dom McGrath, Jr.

Houses under the approach path to San Diego airport

[40] *Report and Recommendations of the Airport Access Task Force*, op. cit.

[41] Ibid., p. 17.

[42] The controversy over the scatter plan tested at Washington National Airport in early 1984 is a classic illustration of how attempts to distribute aircraft noise more uniformly simply engender new opposition, chiefly from those who find their previously quiet areas subjected to noise.

the use of preferential flight paths is limited by the availability or capability of the installed landing and navigation aids. It is expected that MLS will enhance the ability to use noise-avoidance flight paths since it provides more precise and flexible approach guidance with a wider range of coverage than the existing ILS. MLS would permit multiple final approach paths, including curved approaches. The ability to fly curved approach paths will enable aircraft to avoid noise-sensitive areas in IMC much as they do now in VMC and will aid in the reduction of noise levels for airports with noise-sensitive land uses located under the straight-in approach path. MLS would also allow some aircraft to fly steeper approach paths, which—by keeping aircraft higher as they pass over development around the airport-will reduce the area of high noise impact. In FAA studies of the application of MLS to specific sites, it was found that the use of curved and segmented IMC approaches made possible by installation of MLS at airports such as La Guardia, Minneapolis, San Francisco, Seattle, and Washington National could lead to significant noise reductions.

AIRPORT SURFACE UTILIZATION

An airport is an interconnected set of physical facilities and components. For it to function efficiently, the capacities of each of these elements must be matched. Relief of a bottleneck in one part of the airport will not have the desired effect on overall throughput unless other parts are capable of absorbing a greater influx of traffic. Indeed, a common experience is that enlargement of one part of the airport complex simply shifts the delay elsewhere, to the next most constraining element.

Nowhere is this more evident than on the airport surface. Measures to augment runway capacity or to increase the flow of traffic through the airspace may be of little practical benefit unless aircraft are able to move expeditiously on and off runways and to and from the terminal building. It is on airport taxiways and aprons that aircraft are closest together and that their speed is lowest. If the movement of aircraft on the airport surface is constrained by runway and taxiway design and layout, by operational procedures, or by poor visibility, the effect ripples throughout the airport and airspace, and delays accumulate.

This section examines three types of technology deployed on the airport surface: surveillance and control systems, taxiway design and lighting, and equipment used at parking aprons and gates. In general, new airport surface utilization technologies will not lead to major increases of airside capacity, which is largely determined by available runways and airspace use procedures. The primary capacity benefits are indirect—increased safety, especially during inclement weather, and relief of operational impediments to making efficient use of the airside.

Surveillance and Control

Surveillance and control of aircraft movement on the airport surface is accomplished largely by visual means. In darkness or fog—and even in good visibility at large, complex airports-Airport Surface Detection Equipment (ASDE) is used by air traffic controllers to augment and confirm information obtained from visual surveillance of the airport surface. Used primarily at high activity airports, ASDE allows controllers to locate and monitor the movement of aircraft and ground equipment on runways, taxiways, and apron areas.

The existing equipment, designated ASDE-2, utilizes tube technology, which presents reliability and maintenance problems. In addition, utility of ASDE-2 is limited by display resolution, brightness, airport map definition, and poor weather penetration capability. The last is particularly significant under conditions of precipitation or fog, when the system is needed the most. Under these conditions, visual surveillance is virtually impossible, and ASDE is the controller's primary means to obtain the necessary information.

A new system utilizing solid state technology is programmed for deployment by ***1986-89.*** This system, ASDE-3, is expected to increase reliability and reduce system maintenance, in addition to improving display resolution and weather penetration. More accurate information on the specific location and movement of aircraft and ground equipment on the airport surface provided by ASDE-3 might allow reductions in safety-dictated separation of aircraft and promote more efficient utilization of runways and taxiways. Ultimately, small gains in airfield capacity could result.

Research and development on more advanced systems will be needed since even ASDE-3 cannot identify aircraft and surface vehicles under all weather conditions or be used by the controller to guide them to their destinations. At present, the capability of navigation systems to help aircraft land in very low visibility (Category IIIC operations) exceeds that of surveillance and control systems to guide them after they are on the airport surface.

The Tower Automated Ground Surveillance System (TAGS) is a display enhancement intended for use in conjunction with ASDE at major airports. The ASDE-3 search radar provides a map of the airport and the location of aircraft on the airport surface, which are shown graphically on the ASDE display. TAGS will provide, for transponder-equipped aircraft, a flight identification label alongside the position indicator on the ASDE display. Since TAGS operates by receiving a signal transmitted directly by aircraft equipment, the system would be virtually immune to weather. Presentation of flight identity by TAGS would also improve ground control capability in good visibility. TAGS is presently in the exploratory phase of development and probably will not be ready for deployment until the 1990s.

Taxiways

The design and layout of taxiways, particularly those that provide egress from runways, have an important effect on runway occupancy time (ROT).[43] The placement of exit taxiways, where landing aircraft turn off the runways, and the angle at which these taxiways intersect the runways can be crucial. Poorly placed exit taxiways prolong runway occupancy by forcing incoming aircraft to taxi at low speed for some distance before clearing the runway. Taxiways that leave the runway at right angles force the aircraft to come almost to a complete stop before turning. Since the runway occupancy rule (with a few exceptions in VMC) does not allow an approaching aircraft to cross the runway threshold while the preceding aircraft remains on the runway, longer runway occupancy either forces the air traffic controller to increase arrival spacing or causes some approaching aircraft to execute a go-around—both of which are disruptive of throughput.

At some airports, relocating taxiways so that aircraft with shorter stopping distances can leave the runway sooner would lower ROT by as much as 20 to 30 percent. At others, providing a drift-off area alongside the runway or redesigning taxiways so that they diverge from the runway gradually and allow aircraft to turn off at higher speeds (i.e., sooner after landing) would have much the same effect. However, translating reduced ROT into a corresponding throughput gain is not straightforward since it depends on whether the runway layout, the airspace geometry, and the ATC procedures will permit closer arrival spacing to take advantage of the shorter runway occupancy. Still, it is an avenue to be explored, and among the recommendations of the Industry Task Force on Airport Capacity Increase and Delay Reduction were several that urged FAA and airport operators to adopt measures that would assist faster exit from runways.[44] One of these was to adopt procedures and rules that would increase the motivation of pilots to use specified rapid exits and improve the coordination between controllers and pilots in minimizing ROT.

Marking and lighting of taxiways can be as important as their design and physical layout in expediting ground movement of aircraft. For runway exits to be used to their full potential, pilots must be able to detect their location and identify the one they are to use with ample leadtime. This is especially critical at night and during periods of poor visibility. A taxiway marking and lighting system that conveys the necessary information to

[43] Runway occupancy is measured from the time an approaching aircraft crosses the threshold until it turns off the runway or from the time a departing aircraft takes the active runway until it clears the departure end. Current ATC rules prohibit two aircraft from occupying the runway at the same time.

[44] Report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction, op. cit., pp. 11-14.

pilots in a clearly understandable fashion will promote more efficient utilization of airfield pavements.

Research and development are in progress on several aspects of marking and lighting. For exit taxiways, the major efforts are to improve the lighting pattern and the configuration, spacing, and orientation of components in a way that promotes ready identification of the exit and provides visual guidance for safe and prompt transition from the runway to the taxiway. Among the areas under study are improved lighting and signing for taxiway intersections, traffic control signals and lighting systems for ground guidance, and methods for controlling lighting patterns and intensity from the tower. Development is also proceeding on new lighting techniques such as lights that use low voltage electricity, light-emitting diodes, and electroluminescent components to relieve some of the deficiencies of present lighting, which pilots characterize as "the blueberry pie maze. "

To optimize the use of airport pavements and to make proper decisions related to safety, pilots and controllers must have accurate and up-to-date information on surface conditions that affect aircraft ground movement and stopping characteristics. Perhaps the most noticeable changes in these characteristics are aircraft braking and stopping distance on wet or icy pavement, which are important not only from a safety standpoint but also because of the effect on capacity.

One major effort is to devise pavement designs and surface treatments that will improve traction. Research is also being conducted on means to provide information that will allow pilots and controllers to predict aircraft stopping capability and skid risk more accurately under various runway surface conditions. Items such as pavement sensors that continuously monitor pavement condition and coefficients of friction are being examined. Attention is also directed at development of better methods to convey this information to the pilot and, ideally, to provide braking guidance or warning of specific hazardous conditions and locations. The primary concern is safety, but better information about pavement condition and aircraft performance when traction is reduced would also yield a capacity benefit in that a more accurate delineation of safety limits might make

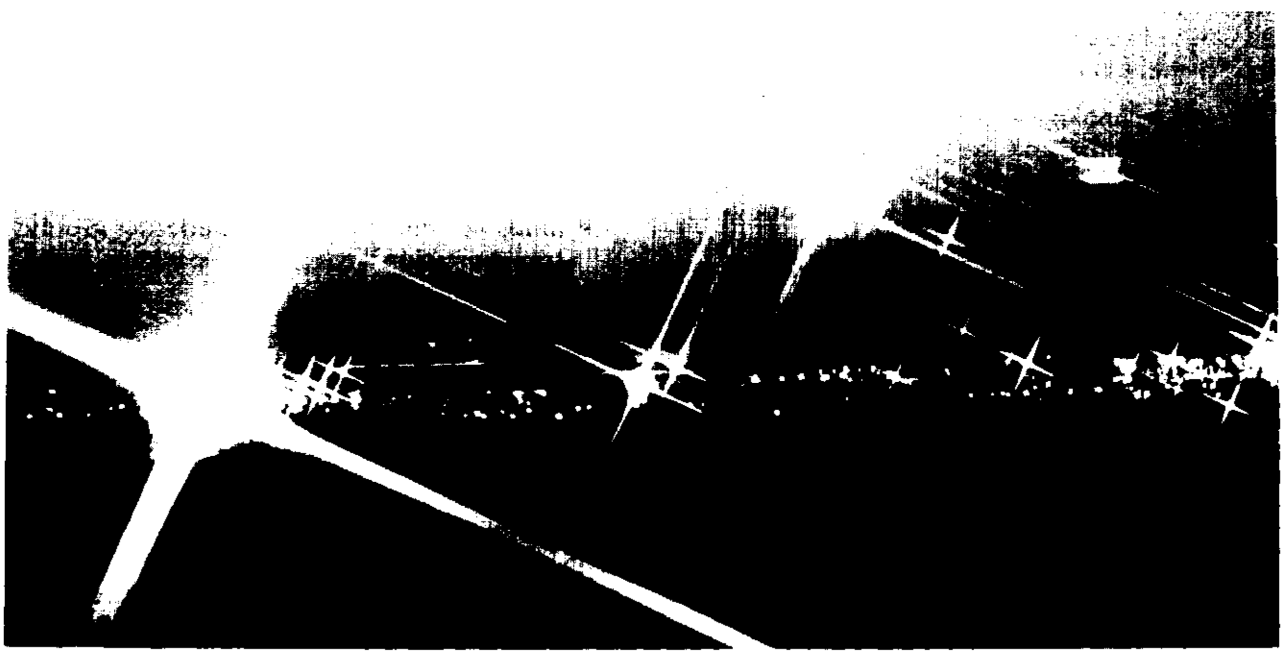


Photo credit' **Federal Aviation Administration**

Night life at Chicago O'Hare

it possible to relax some of the present conservative rules governing aircraft movement on the surface in slippery conditions.

Apron and Gate Facilities

Opportunities to relieve airport surface congestion extend up to the parking spaces at the gates. Aircraft docking is typically accomplished by a ramp agent with flashlights and hand signals guiding the flight crew for proper parking of the aircraft and assuring that the wing tips have safe clearance from buildings, ground equipment, and other aircraft. New optical, electrical, electronic, and mechanical devices are being developed to provide flight crews with positive visual guidance that will permit more rapid and accurate docking. This technology will allow apron space to be used more efficiently and help prevent the delays that arise when aircraft must be repositioned in order to mate with fixed ground support systems and passenger loading bridges.

While needs and procedures vary by airline and by airport, the aircraft servicing functions commonly performed at an airport include fueling, engine start, galley and cabin service, electrical ground power, towing, passenger stair or loading bridge operation, and handling of baggage, mail, and cargo. In addition, various routine or special aircraft maintenance functions are conducted.

Several technological advances offer reductions in servicing time and cost. At some airports, ground power is now being provided by fixed systems mounted on the passenger loading bridge or in underground pits. Similarly, fixed pneumatic systems are being developed to provide ground power and aircraft engine start. These installations ease the congestion caused by mobile units clustered around aircraft on the ramp and provide for a more efficient servicing operation. Auxiliary power units now provided on most newer aircraft alleviate congestion by replacing ground equipment needed for electric service, air start, and air-conditioning. These self-contained units also assist in quick turnaround, thereby reducing gate occupancy time. Special pallets and handling equipment provide for efficient transfer and loading of bags and cargo. While use of this technology saves time at the gate, the loading and unloading of the pallets themselves can sometimes be time-consuming due to mechanical problems and alignment difficulties.

These improvements in technology help ease surface congestion in two ways, Those that speed turnaround lessen gate delays and enhance throughput. Those that reduce the apron space needed for service vehicles and equipment allow more aircraft to be parked in a given area, thereby directly increasing apron capacity and helping to ease airport surface congestion in general.

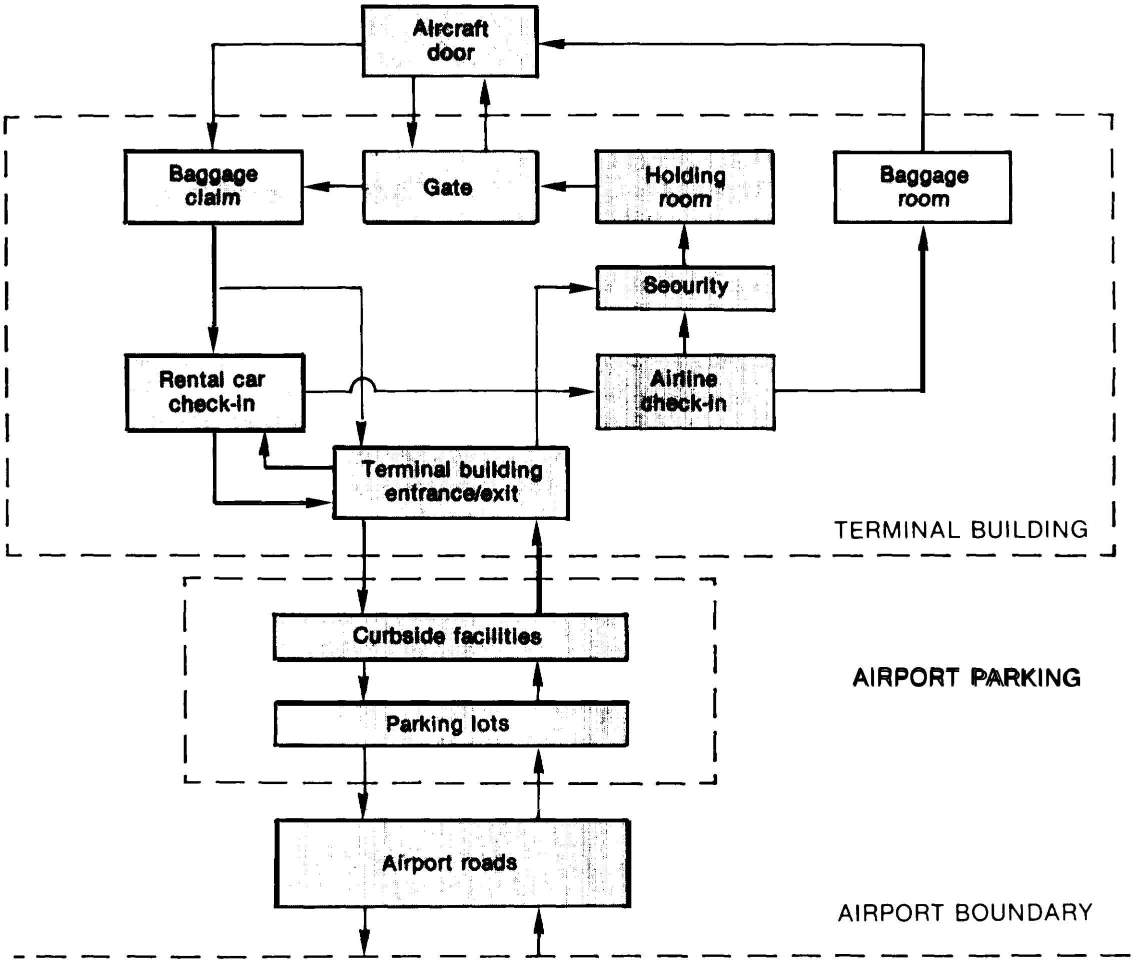
Terminal Facilities and Services

The airport terminal-the building itself and the paved areas surrounding it on the airside and the landside—is the zone of transition for passengers, providing the link between surface and air transportation. Design and operation of the terminal have an influence on both airside capacity and ground access and on overall throughput of the airport complex. This basic relationship, illustrated in figure 11, dictates that the design of the terminal complex must reconcile the requirements of three operational areas:

- airside—where aircraft are serviced and passengers board,
- ***terminal*** building—the collection point containing facilities for passenger processing and services during transfer between airside and landside, and
- landside—the area accommodating ground transportation (roadways, parking areas, etc.).

Basically, the terminal and associated landside facilities are long-term installations with relatively stable patterns of use. They are largely independent of the specialized aircraft and airline passenger processing functions that occur on the airside. In contrast, the airside is characterized by short-term, impermanent use which is closely tied to changing aircraft technology with a useful life of about 10 to 15 years. The essence of airport terminal design is to strike an appropriate balance

Figure 11.—Airport Landside Functional Flow



SOURCE: L. McCabe and T. Carberry, "Simulation Methods for Airport Facilities," in *Airport Landside Capacity*, Transportation Research Board, Spec!al Report 159, 1975"

between these somewhat contradictory requirements.[45]

The principal effect of the terminal on the airside is through the design of aprons and gates, which determines the number of aircraft that can be accommodated at one time and the turnaround time for passenger boarding and aircraft servicing. As seen in the previous section, gate and apron operations can also have a wider—though not major—effect on airside throughput. The impacts of terminal design usually do not extend beyond the apron and gate area, and terminal building characteristics have scant influence on the design of other airside components such as taxiways and runways.

Overall, the influence of the terminal on the functional requirements and performance of airside facilities is relatively small compared with the inverse effect that the airside exerts on the terminal.[4b] The primary purpose of the terminal is to transfer passengers and their baggage between surface and air transportation with minimum time, confusion, and inconvenience. The func-

[45]Leigh Fisher Associates, Inc., "Recommended Planning Criteria for New Passenger Terminal Facilities at Tampa International Airport," July 1963; cited in R. E. Horn and J. C. Orman, "Airport Airside and Landside Interaction," in *Airport Landside Capacity*, Transportation Research Board, Special Report 159, 1975.

[4']Horn and Orman, op. cit.

tional requirements and choice of design for a terminal complex must take into account the passenger and baggage flows resulting from aircraft size, traffic mix, schedules of operation, and type of service provided (origin-destination or connecting flights). As a design task, this involves the integration of three major parts of the terminal: airside gates, passenger collection and service areas, and landside access and egress. Since these parts are highly interactive, it is important that the separation between them be kept to a minimum and that traffic flow smoothly among the parts.

This would be a fairly straightforward task were it not for the need to design the airside interface so that it can be adapted to accommodate continually changing aircraft technology, airline service patterns, and traffic volumes. At some large hubs, the steadily increasing size of aircraft and their fixed-point servicing requirements, when coupled with growing passenger and automobile traffic, have led to terminal complexes of a size that imposes inconvenience and delay on passengers. In response, airport designers have been forced to add an intermediate transportation mode within the terminal itself (moving sidewalks, transport buses, fixed rail systems, and other such people movers) to aid passengers in transferring between the airside and the landside.[47]

The discussion that follows touches first on general questions of terminal building design and then on technology of specific features that might be improved to facilitate passenger movement or to reduce passenger inconvenience and delay. It should be recognized that these aspects of design and operation will have little, if any, effect on airside capacity and throughput even though they might lead to substantial reductions in the overall trip time for air travel. It should also be recognized that such matters have been of little interest to FAA or to policymakers in the Federal Government. They are, of course, keenly important to airport operators and—to a lesser extent—airlines because they constitute investment needs that must be balanced against airside capacity expansion in the overall program of capital improvement for airports. Recent estimates indicate that over half of the large hub airports are experiencing congestion and delay within terminal buildings and that over *30* large and medium hubs are contemplating investments in terminal expansion or improvement, with a total cost of $4 billion.[48 49]

Terminal Building Design

Airport terminals can be grouped into four categories according to their basic design concept:

- ***centralized with finger piers—a*** common hall with branching corridors leading to aircraft gates;
- ***centralized with satellites—a*** central concourse surrounded by small, separate clusters of gates and waiting areas, each connected to the concourse by walkways or people movers;
- ***linear or gate arrival***—usually semicircular buildings with ground access on one side and aircraft gates on the other, designed so as to minimize walking distance through the terminal; and
- ***transporter***—a compact passenger facility with buses or special vehicles used for transport to a remote aircraft parking apron.

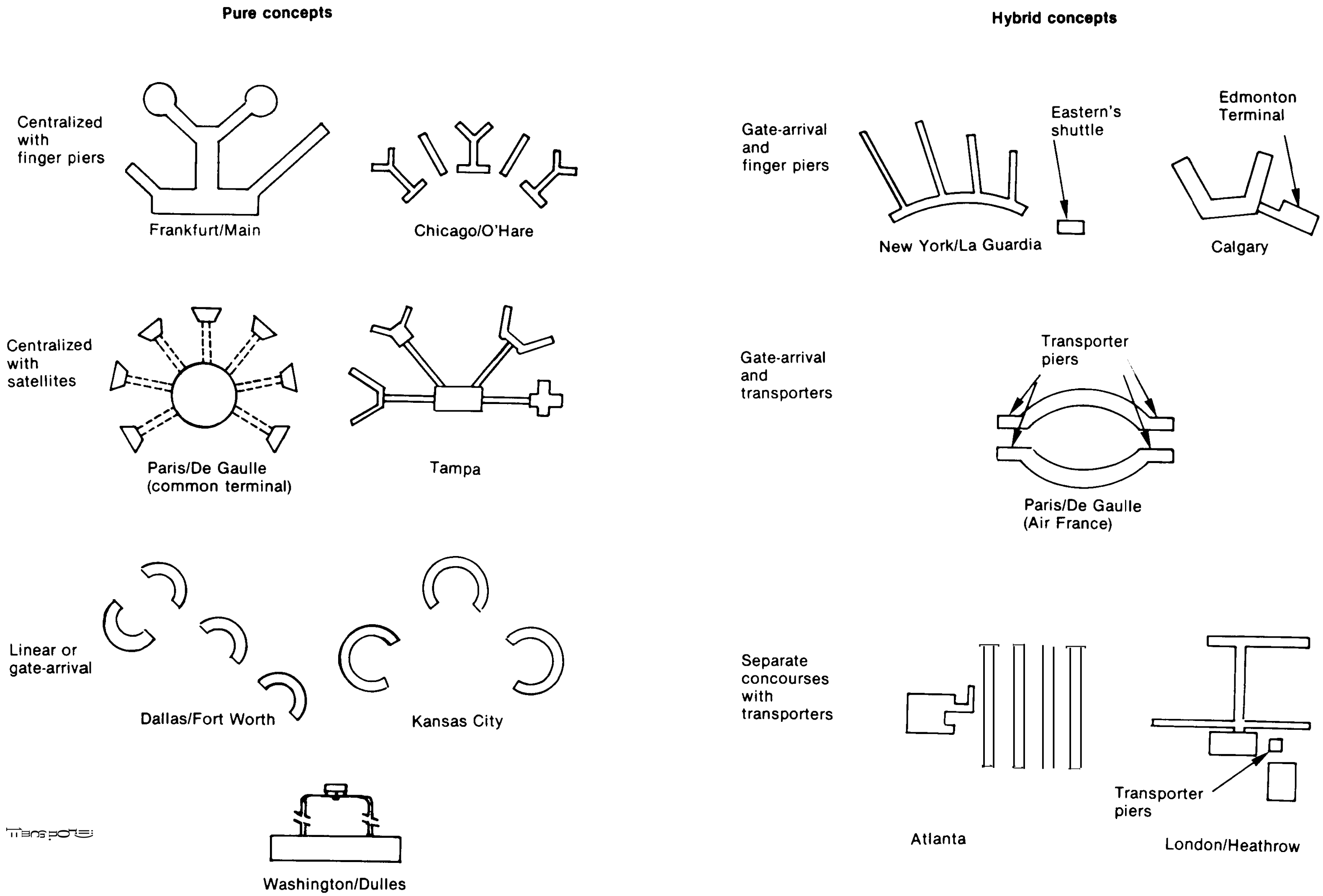
These concepts are embodied in pure form only at a few airports which have been built on entirely new sites. At most airports the design of the terminal building has evolved and been modified in response to traffic growth and local conditions, giving rise to a hybrid that incorporates features of two or more of the basic concepts (fig. 12). At airports with land available adjacent to the existing facility, the design has tended to evolve into a finger pier arrangement, sometimes with separate unit terminals for commuter airlines or groups of new air carriers for whom there is not room in the main terminal. At airports where the terminal has grown to the limits of available land area, satellite terminals and remote hardstand parking have typically developed. Transporter and satellite terminal concepts utilizing people-

“M. Brink and D. Maddison, “Identification and Measurement of Capacity and Levels of Service of Landside Elements of the Airport,” in ***Airport Landside*** Capacity, op. cit.

[48] *Report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction,* op. cit.

[49] *Metropolitan Area Assessment Report* (Washington, DC: Federal Aviation Administration, Office of Airport Planning and Programming, April 1982).

Figure 12.—Airport Terminal Design Concepts



SOURCE: R. De Neufville, *Airport Systems Planning* (London: MacMillan, 1975).

moving equipment have been adopted at some airports to enhance the attractiveness of the terminal for passengers since they eliminate the extreme walking distances associated with long piers extending from central terminals. The transporter concept has the additional advantage of allowing a small terminal building, free of the constraints imposed by aircraft parking gates.

At a new site, the choice of terminal design is largely dependent on the volume and type of traffic expected. Centralized terminals are best for airports with a high proportion of transferring passengers, especially those changing from one airline to another. The gate-arrival design works well for origin-destination passengers and commuter airlines since it shortens the transit from the curbfront to the aircraft gate. The unit terminal with passenger transporters can handle peaks of traffic efficiently, but only if the traffic is made up largely of origin-destination passengers. In the expansion of existing terminals, these same considerations come into play, but the choice may be constrained by the design of the existing structure, the available land, and the on-airport road net.

Misestimation of traffic volume or the type of service to be provided can sometimes render even a well-conceived design inefficient or inappropriate. Dallas-Fort Worth Airport, for example, was planned with the expectation that origin-destination traffic would predominate. Since airline deregulation, the growth of hubbing—which typically requires passengers to change planes at the airport—has thwarted the effectiveness and convenience of the design. At O'Hare, the need to adapt the concourses for passenger security screening has created long and circuitous routes for transferring passengers. Efforts to encourage greater use of Dunes Airport for short and medium-length domestic flights have been hindered by the design of the terminal since the need to go from apron to terminal and back again by mobile lounges greatly increases the time and inconvenience of interline connection. Kennedy Airport, planned with separate terminals for major airlines, is well-suited for origin-destination passengers and for transfers to flights on the same airline, but very inconvenient for interlining domestic passengers and those coming in on international flights and continuing to other U.S. destinations.

Clearly, no single design is best for all circumstances. Traffic patterns, traffic volume and flow characteristics (e.g., peaking), the policies of individual carriers using the airport, and local considerations (e.g., esthetics and civic pride) dictate different choices from airport to airport and from one time to another. The airport planner, who is required to anticipate conditions 10 to 15 years in the future, must often resort to guesswork. Even if the guess is right initially, conditions change—as the above examples illustrate—and result in a mismatch between terminal architecture and the traffic to be served. To guard against this, airport planners now tend to favor flexible designs that can be expanded modularly or offer the opportunity for low-cost, simple modification as future circumstances may demand.

Terminal Services

These precautions, of course, are of little help in terminals that have already been built for one type of traffic but forced to accommodate another, or where demand outstrips capacity. Many airports will continue to suffer from inappropriate or outdated designs that lead to congestion and delay in passenger areas and diminish the overall utility of the airport as a transportation hub. For such airports, an alternative to a new or expanded terminal as an avenue of relief from congestion is to correct specific features that cause bottlenecks by applying improved technology that will compensate for design inadequacies. Some of these partial technological remedies are discussed next.

Passenger Movers

To speed passenger movement through the terminal and to lessen the inconvenience of walking long distances to board flights or to reach landside exits, some airports have turned to passenger movers.[50] Several technologies are available, covering a broad spectrum of cost. They in-

[50]At airports designed as unit terminals with remote aircraft parking, some form of passenger mover is, of course, a necessity.

elude buses, mobile lounges, moving sidewalks, and automated guideway systems. The choice of any of these involves a tradeoff between their service characteristics and cost (capital and operating) against those of adding new gates or terminal wings. This tradeoff is very sensitive to the rate of use, the specific vehicle chosen, and the cost of gate construction. Passenger movers tend to be more cost effective than gates if the rate of use is high. Variation in traffic load is also important, and analysis indicates that passenger movers are best suited to serving those locations and intraterrninal trips where there is a great fluctuation in demand. 5l

Buses and mobile lounges add to airside surface traffic; they are also labor-intensive and therefore costly to operate. For these reasons, airports with finger piers or satellite terminals have sometimes opted for automated vehicles such as moving sidewalks or guideway transit systems. Moving sidewalks are not an entirely satisfactory option. They are costly to operate and maintain, and their speed must be slow to allow passengers to board and descend safely. Thus, they provide only a marginal decrease in passenger movement time, although they greatly reduce the effort of long passages through the terminal complex. There is some experimentation with accelerating devices and transition techniques that would permit greater line speeds and still afford comfortable and safe boarding and descent. If these experiments are successful, the utility of moving sidewalks will be greatly increased.

For longer distances or where the volume of traffic is large, automated guideway systems are sometimes practical. Several different types are available, varying principally in terms of propulsion, vehicle size, and complexity of the guideway network and control system. Reliability and train control system design were problems in the first systems installed at airports (Dallas-Fort Worth, for example), but the technology has improved rapidly and now appears to give good service at airports such as Atlanta and Orlando. Capital costs of vehicles and guideway construction remain high, and they are still difficult and expensive to maintain. The view of airport designers is that these systems are cost effective only at a few very large airports, and there is reluctance to utilize this technology except as a last resort.

51 R. De Neufville, Airport Systems Planning (London: Macmillan, 1976); pp. 118 ff.

Ticketing

The ticket counter serves three major functions: ticket transactions, baggage check-in, and flight information. Of these, the most time-consuming are ticket transactions (which often include baggage check-in for the individual passenger). Technologies to speed ticket counter operations or to eliminate them altogether are being explored, both to reduce delays in the terminal and to cut airline personnel costs. Computerized ticket systems available today offer passengers advance reservations and sales, preassignment of seats, and automatic tagging of baggage. They will probably be used more widely by the major air carriers, some of whom may also offer them to small carriers under a service contract. A companion development is the computerized aircraft manifest that has been implemented by some airlines. These systems typically produce aircraft load sheets, passenger manifests, and automatic telex reservations. They greatly reduce the administrative work at the counter and expedite airline dispatch from the gate.

Ticket dispensing machines similar to those used for banking are now in limited use by some airlines at a few locations and for selected routes. Improvement of these machines so that they can handle a larger number of routes and fare structures could promote wider use, with corresponding reduction in the amount of activity that must be conducted at the ticket counter. This technology could also be extended to sale of tickets off the airport property. With the deregulation of travel agencies, the range of services provided by these firms has expanded, offering passengers an alternative to purchasing tickets at the airport. Travel agents now account for more than ***60*** percent of airline ticket sales in the United States. The entry of mass-marketing firms such as Sears and Ticketron into the air travel field may further decrease the need for ticketing at airport terminals, reducing airline personnel and equipment requirements, and alleviating congestion at terminal ticket counters.

Baggage Handling

The handling of baggage, especially baggage claim at the end of a flight, is a common and= for passengers—particularly onerous form of delay in terminals. At most airports, baggage handling is the responsibility of the individual air carriers, but some airports operate a consolidated baggage service—either with airport personnel or on a contract basis—in the interest of speeding the process and reducing the cost. Reduction of the delays and passenger inconvenience associated with baggage handling has been approached in three ways: more efficient procedures for check-in and claim, automated handling and sorting, and elimination of some baggage handling by encouraging carry-on luggage.

One of the simplest and most widely applied methods to expedite baggage handling is curbside check-in. This separates baggage handling from other ticket counter and gate activities, thereby disencumbering those locations and allowing baggage to be consolidated and moved to aircraft more directly. Another method is replacement of the baggage claim carrousel with loop conveyor belts that allow passengers greater access to their luggage without increasing the size of the claim area.

Sorting baggage, moving it to and from the apron, and aircraft loading and unloading are time-critical and labor-intensive operations. Technologies to improve this process include high-speed conveyors to transport baggage between the terminal and the flight line, often used in conjunction with pallets or containers that can be put on and taken off aircraft with labor-saving equipment. Computerized sorting equipment, capable " of distributing bags with machine-readable tags, has been installed at some airports. These devices are not yet fully satisfactory since the encoding and reading of tags are time-consuming and somewhat unreliable.

To handle peak loads, automated systems must have a larger capacity because they are less flexible than manual systems. Redundancy is a must with an automated system, which increases the capital cost. As these automated systems improve and come into wider use, **a** further step is to install self-service systems that allow passengers to check and claim luggage either in the terminal, at the curbside, or at remote locations on or off the airport property. While such a development would be primarily a labor-saving measure by airlines and airport operators, it might also speed transit through the airport for many passengers.

The functional equivalent of automated, self-service baggage handling systems—and one that may be cheaper and more reliable—is expanded capacity within the aircraft for carry-on luggage. With the advent of stronger and lighter materials, aircraft designers have been able to reconfigure cabins to provide larger and more secure storage space on board. New aircraft universally contain such overhead storage bins, and many airlines have converted older aircraft to incorporate similar enclosed overhead storage. A further development might be provision of a common baggage space either within the cabin or in a special module that could be transferred to the cargo bay. Passengers entering and leaving the aircraft would pass through this space and handle their own baggage.

Passenger Security Screening

To deter aircraft hijacking, the Federal Government has established regulations to ensure safe passage for the traveling public. These regulations, implemented in January 1973, require security screening of passengers and carry-on articles. Over the past decade, security screening has become an accepted fact of life for air travelers and a problem for airport designers and operators since the security checkpoints tend to disrupt passenger flow and—in some instances—force remodeling of the terminal.

The equipment used today consists of X-ray machines with moving belts and magnetometers for metal detection. This system, which replaced manual search, significantly increased the capacity and capability of the screening process. The chief drawback of the existing equipment is that, while effective in detecting metal, it has limited capability to detect explosives and volatile substances.

New technology for screening cargo and baggage is being investigated. The aim is both to speed the screening process and to increase the thoroughness and reliability of detection. The new

Photo credit' Los Angeles Department of Airpofls

Customs and immigration: once gracious . . .

systems under development make use of improved bomb and explosive sensing techniques such as vapor detection, bulk detection, and computerized tomography.

Federal Inspection Service

The United States has ***24*** airports of foreign entry where Federal Inspection Service (FIS) for clearing passengers and cargo is provided by Customs, Immigration, and Agriculture officials. Clearance procedures are rigid and time-consuming, and FIS processing has been a major cause of delay at high-volume ports of entry.

The U.S. Department of State is now issuing machine-readable passports that may help expedite FIS clearance. Additional procedures and technologies are being investigated to achieve greater capacity, reduced clearance time, and higher agent productivity. Alternative procedures and physical arrangement of facilities are the principal areas of concentration.

The system employed at most airports of entry today is the Customs Accelerated Passenger Inspection Service (CAPIS), which provides separate immigration and customs checkpoints. CAPIS is highly time-consuming for passengers and labor-intensive to operate. A new system, referred to as One Stop, combines immigration and customs functions at a single station. Although promising, this system has not yet achieved its expected capacity in tests and demonstrations. Chicago O'Hare and Houston Intercontinental Airport are experimenting with another approach that uses a modified version of the standard European system known as "Red-Green," where travelers who do not have goods to declare are separated from those who do, with only the latter passing through a secondary inspection station. Also under study are hybrid systems that combine features of CAPIS, One-Stop, and the "Red-Green" concepts.

Photo credit: U.S. Depatiment of Transportation

. . . now streamlined

LANDSIDE ACCESS

It is a truism that nearly every airplane trip begins and ends with an automobile ride, and there is no clearer manifestation of our dependence on the automobile than at the terminal curbside and on the access roads to the airport. While the figures vary among airports, it is generally estimated that over 90 percent of all airline passenger trips to and from airports are by private automobile or taxi. At medium and small airports, the figure is probably close to 100 percent since these communities tend not to have well-developed public transit providing a practical alternative to the automobile.

A further indication of the symbiosis between the airplane and the automobile is the emergence and growth of the car rental industry. This business has its origin in the need for air travelers to have transportation to and from airports in cities away from home. While many car rental firms have since branched out into other markets, the bulk of their business is still rentals to airline passengers, and revenues from this activity are a major source of income for airport operators.

Not all trips to the airport are made by airline passengers or those who come to meet travelers or drop them off. For airport workers (accounting for perhaps one-third of all access trips) and calls by delivery vans, service representatives, and others with business on the airport property (also about one-third of all access trips), the automobile likewise predominates. Some (especially airport workers) come at times when public transit is not available or when service is infrequent, and they have almost no alternative but to drive to the airport and park.

At many airports, automobile traffic is a principal source of landside congestion and delay. Of the 33 major airports surveyed by the Industry Task Force on Airport Capacity Improvement and Delay Reduction, the most common problem areas were at the curbside (20 airports) and on airport circulation and access roads (11 airports) .52 Similar findings were obtained in a survey of airports performed for this assessment. Of the 39 large, medium, and small hubs and commuter airports sampled, 23 indicated present or anticipated problems with parking, curbfront circulation, on-airport roads, or access routes. A recent review of airport problems by FAA found that 23 of 41 major metropolitan area airports are suffering from capacity constraints imposed by landside congestion or lack of adequate access.[53]

Perhaps the best known example of the effect that landside access can have on airport operations is at Los Angeles International Airport (LAX). Because of limited capacity of airport circulation roads and the inability of the freeways and city streets near the airport to absorb a greater volume of automobile traffic, regional transportation authorities imposed a capon aircraft operations and annual passenger volume permitted at the airport. Much of the impetus for the recent expansion at LAX was to relieve this landside constraint, and a large share of the $700 million modernization program now nearing completion there was expended to double-deck roads leading to and from the terminal and to remodel the terminal complex so as to segregate arriving and departing automobile traffic .54

LAX is not an isolated example. Chicago O'Hare is proposing a $1 billion program of airport modernization, a large share of which will be to "bring aging and congested terminal and roadway facilities into balance with underutilized airside capacity. "5[5] St. Louis spent $78 million of the total ***$273*** million in funds programmed through 1983 on highways and airport frontage roads on or adjacent to the airport property.[sb] The Port Authority of New York and New Jersey has launched a $1.5 billion modernization plan for the three New York airports. Important parts of this plan are new roadways and local transportation to improve airport access and additional parking space around the terminals. [s']

Only a few landside improvements and airport access projects are eligible for Federal aid from the Airport and Airway Trust Fund. The Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (UMTA) also provide funds for landside development, and the airport operator or local airport authority contributes an important share through retained earnings and revenue bonds. Funding of landside investments is a complex multijurisdictional arrangement with wide variation from airport to air-

52 Report of the Industry Task *Force on Airport Capacity* Improve*ment and Delay Reduction,* op. cit.

53 Metropolitan Area ***Assessment Report,*** op. cit.

54B. Sweetman, "The New LAX Prepares 1984," *hteravia,* July 1983, pp. 724-725.

55 J. Ott, "$1 Billion Upgrade Planned at O'Hare," ***Aviation Week & Space Technology,*** Aug. 8, 1983, pp. 35-36.

"J. Ott, "Expansion Eases St. Louis Congestion," ***Aviation Week & Space Technology,*** May 23, 1983, pp. 35-36.

"E. Kozicharow, "New York Port Authority Boosting Airport Capacity," ***Aviation Week & Space Technology,*** May 9, 1983, pp. 33-34.

port. The capital improvements sponsored by FAA are limited to on-airport roadways, guideways, and walkways. Off the airport property, projects to improve landside access may receive FHWA and UMTA grants or be supported by State and local funds[58] (see fig. 13).

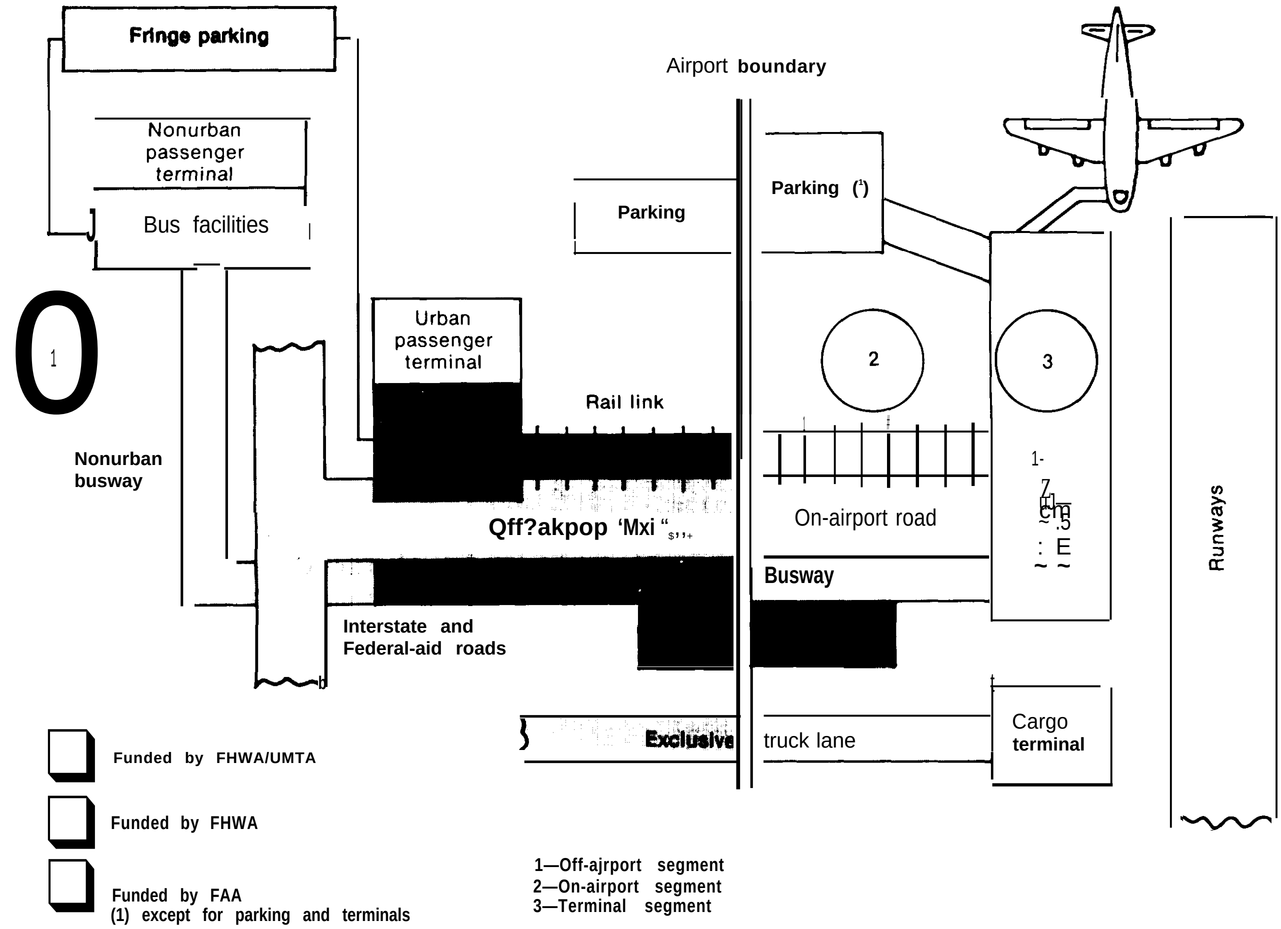
In general, the solution to landside problems does not appear to be *new* technology, but application of management techniques to make better use of the facilities available and construction of new facilities (based on existing technology) to add to landside capacity. In a larger sense, there is also a need to look at the question of airport access from the perspective of the regional transportation system and to find ways to integrate the airport more effectively into the urban area it serves. The sections that follow focus on approaches that can be taken or applied more widely to alleviate the problems of traffic flow on the airport property and to reduce the cost and inconvenience of access from the surrounding metropolitan area.

Terminal Curbfront

The terminal curbfront provides temporary vehicle storage during passengers' transition between the terminal and the landside, and it *is* at the curbside that all passengers, except those using nearby parking or transit facilities, either enter or leave some form of ground transportation.

58A. J. Negrette, "Airport Landside and Off-Airport Interaction, " in ***Airport Landside Capacity,*** op. cit.

Figure 13.—Federal Capital Funding of Airports and Related Facilities



SOURCE: Transportation Research Board, *Airporf Landslde* Capacity, Special Report 159, 1975.

Curbfront congestion is a particularly difficult problem to solve because the facilities there are intimately tied to the design of the terminal building and airport characteristics such as activity level (peak passenger volume), user characteristics (mode of transportation, mix of passengers and well-wishers, and number of bags), and vehicle characteristics (type, number of passengers, and dwell time at the curb). The most practical approaches are physical expansion or modification of facilities and procedural changes to improve passenger and vehicle flow.

The most common forms of physical improvement are additional curbfrontage, bypass lanes, multiple entry and exit points in the terminal building, remote park and ride facilities, and pedestrian overpasses or underpasses. These improvements are intended to increase the utilization of curbfrontage by vehicular traffic or, in the case of park and ride, to reduce demand on the curbfront by diverting passengers from private cars to high-volume vehicles. Walkways to segregate foot and vehicular traffic promote pedestrian safety and facilitate roadway traffic by eliminating conflicts between pedestrians and vehicles.

In some cases, procedural changes—either alone or in conjunction with low-cost physical modifications such as signing or lane dividers—are an effective alternative to expensive construction or remodeling of the curbfront. For example, parking restrictions combined with strict enforcement will reduce curbside congestion and dwell time in discharging and boarding passengers. Short-term parking islands or reserved sections along the curbfront, defined by roadway marking or simple dividers, may segregate vehicles picking up or discharging passengers from those that must handle baggage or enter the terminal for brief errands. Similarly, separation of private cars from taxis, buses, and limousines can diminish conflicts among these kinds of traffic and improve the flow to and from the curbfront. An effective approach at some airports has been provision of bus service from remote parking to the terminal and regulations to discourage bringing private automobiles to the terminal building. None of these measures is a substitute for adequate curbside capacity, but they can lead to more efficient use of the facilities available and perhaps compensate for deficiencies in terminal and curbfront design.

Airport Ground Access

Aside from expansion or improvement of the road network leading to the airport, most effort to facilitate airport ground access has focused on substitutes for the automobile. Bus or airline limousine service has proved workable in some cities, but patronage is generally low because of the infrequency of service or the inconvenience of getting between origin or destination and a centrally located bus terminal. Helicopter shuttle between the airport and city center has been tried; but it is expensive, unreliable because of weather, and objectionable to the community because of noise.

A solution that has been advocated by many planners is a rail rapid transit system, either operated exclusively to and from the airport or as part of a regional network. Cleveland, for example, built a rapid transit extension to Hopkins International Airport in 1968; and the Washington, DC, Metro system includes a station near, but not at, the main terminal at National Airport. Proposals to provide such service-either by construction of a new line to the airport or by linking an existing line to the airport by a feeder bus—have been advanced for several other cities.[59]

In part, this interest has been stimulated by examples in foreign countries, which either have or are planning rail service to airports. Paris Charles de Gaulle Airport has a rail station a little over a mile from the terminal with connection provided by shuttle bus. Amsterdam (Schiphol), Birmingham, Dusseldorf, Frankfurt, Gatwick, Heathrow, Orly, Vienna, and Zurich already have rail stations in or immediately adjacent to the airport terminal. Cologne and Munich 2 will have such service by 1985. Haneda Airport in Japan has a monorail

59 A survey by the U.S. Aviation Industry Working Group in 1979 found that eight U.S. airports-Atlanta, Baltimore-Washington International, Kennedy, Los Angeles International, Oakland, Miami, Ontario (California), and San Francisco—were considering some form of rail link. Of these, Kennedy and Oakland have established such service, but in both cases it is by a bus connection with transit station off the airport property.

line from the center of Tokyo to the terminal, which brings passengers to within 300 ft of check-in counters. Toronto and Montreal (Dorval) in Canada have rail lines that are close by but not integral with the terminal (a connecting bus or taxi trip is needed to complete the link), and Montreal International (Mirabel) will soon have direct service from the airport to the downtown area with 13 intermediate stops. Figure 14, a cutaway drawing of the Zurich airport, illustrates the concept of the integrated airport-rail complex.

De Neufville points out that rail transit is not a universal solution to the airport access problem.[60] In most major U.S. cities, there is not a regional rail network to be tied into the airport; and, without it, there is little prospect that an exclusive line between downtown and the airport would be viable. Few passengers want to travel between the airport and the central business district, and even fewer want to go during rush hour. Rail transit, with its fixed routes and corridor structure, does not serve well in the U.S. setting, where there is wide dispersion of origins and destinations for airport passengers. The capital costs of such systems are likely to be high, and it is doubtful that operating expenses could be covered from the fare box, necessitating subsidy from the municipality or the airport. There may be public resistance to building a system to serve airport users exclusively when other parts of the metropolitan area could profit perhaps more from rail rapid transit service. Finally, the service characteristics of rail transit do not lend themselves particularly well to airport trips. Passengers encumbered by baggage find rail transit inconvenient because there is no storage space on trains and narrow aisles may be difficult to negotiate with luggage in hand. If there are intermediate stops—as there almost certainly would be if the rail line attempts to serve more than a few who want to travel from city center to the airport—the trip is prolonged, and trains may be crowded with passengers riding for other purposes.

60 De Neufville, op. cit., p. 7.

These arguments do not necessarily deny the validity of foreign experience, but they raise doubts about the viability of rail transit access to airports in this country—where we do not have the population densities, the existing urban rail network, and the tradition of public transit that are characteristic of Europe and Japan.

An alternative to rail transit, which accomplishes the same purpose but with greater flexibility and somewhat lower cost, ***is*** the remote airline terminal (fig. 15). This is a facility for processing arriving and departing passengers at a site off the airport property and transferring them to the terminal by group transportation. The off-airport terminal may include facilities for ticketing, baggage handling, and parking. Connection with the airport can be provided by public transit, special airport bus, or helicopter shuttle. The technology to implement this concept exists, and it has been tried in several cities.

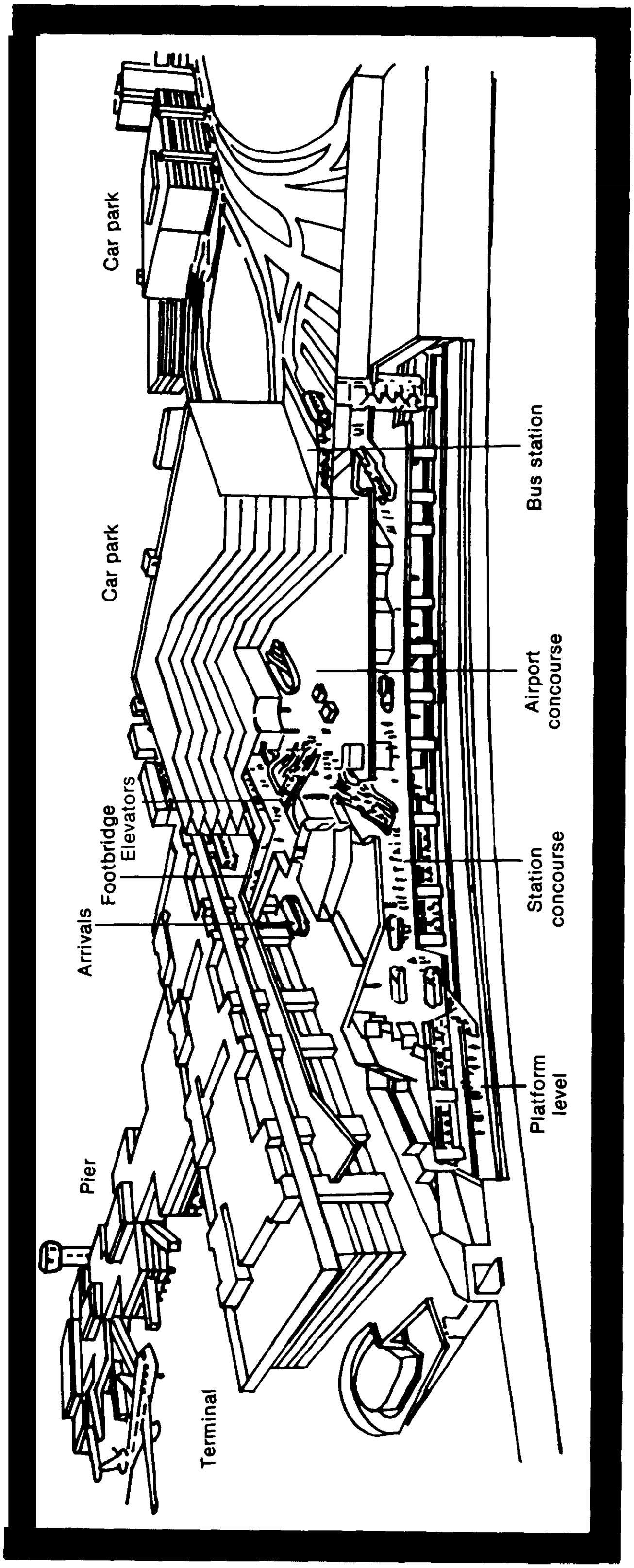
The popularity of the remote terminal concept has waned in recent years, largely because indirect costs tend to offset the benefits. Trip origins and destinations are becoming more and more scattered throughout the urban area, to the extent that trips to and from the city center now account for less than a quarter of airport patronage. On the other hand, the increasingly tighter restrictions on airport terminal and landside expansion may make this concept worth reexamining, particularly if a way can be found to build and operate a network of small dispersed facilities adapted to the urban-suburban pattern of business and residence in major metropolitan areas.

APPLICATIONS OF TECHNOLOGY TO AIRPORT PROBLEMS

In the search for solutions to capacity and delay problems, the value of new technology is typically measured by its ability to achieve one or more of the following results:

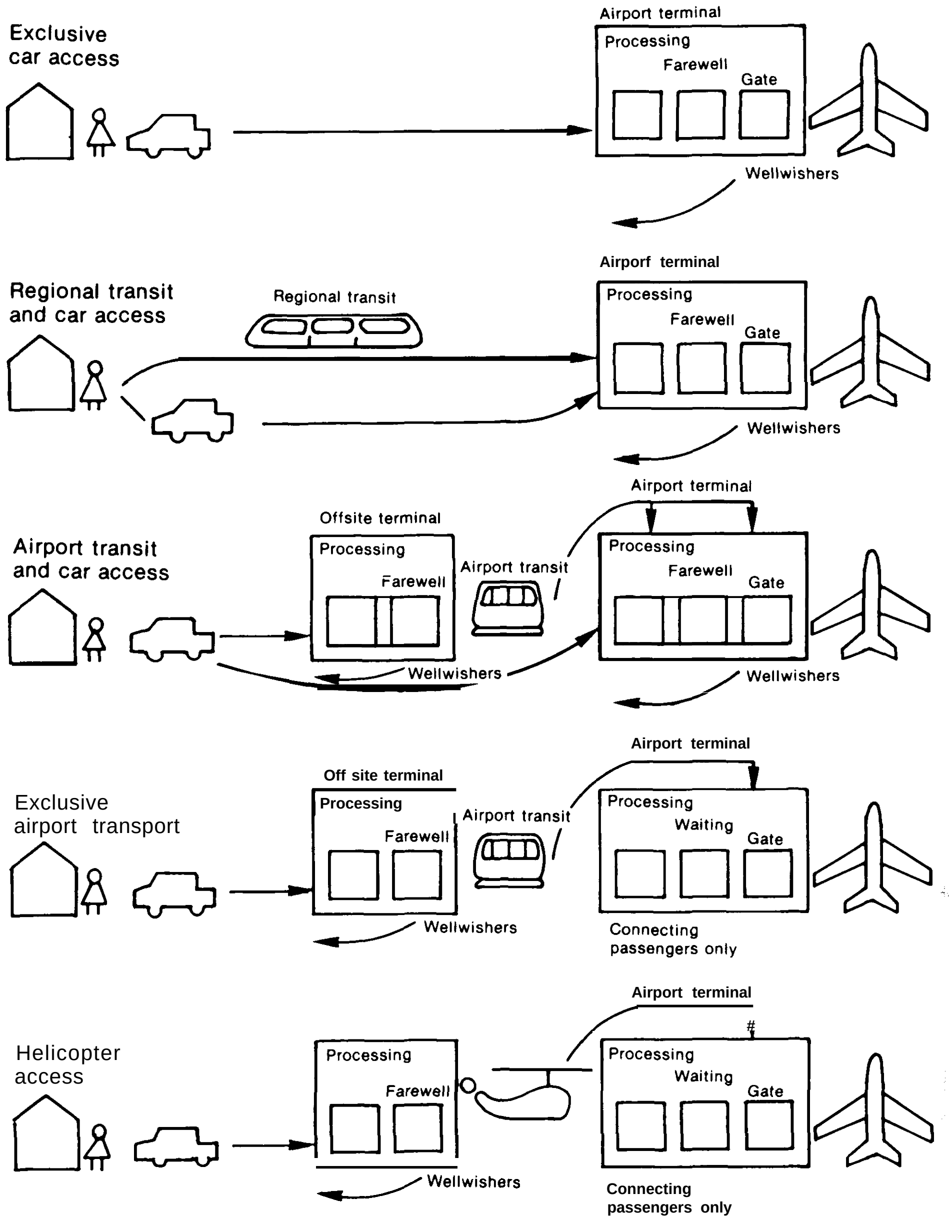
- increased capacity,
- higher efficiency (or throughput),
- greater safety,
- improved reliability,

Figure 14.—Zurich Airport and Rail Terminal Complex



SOURCE: European Conference of Ministers of Transport, *The Interface Between Air and Land Transport in Europe*, OECD Seminar Report, 1983.

Figure 15.—Off-Site Passenger Terminal Concepts



SOURCE: *Airpoti Landside Capacity,* **Transportation Research Board, Special Report 159, 1975.**

- greater accuracy,
- lower cost, and
- greater convenience.

The first two are direct benefits; they constitute relief of the problem of how to accommodate a higher level of demand. Safety is of prime importance, but it has little relationship to capacity and delay unless—as is often the case with procedures and rules—the requirement for safety precludes some measure for increasing capacity or throughput. Thus, if some new method of assuring safety is found and it also allows a subsequent change in procedures or utilization of airport facilities, safety improvements may give rise to a secondary capacity-related benefit. Reliability, accuracy, cost, and convenience are operational benefits. They are worth seeking in and of themselves, but they have little direct relation to capacity except insofar as they are attributes that lead to adoption of new technology or hasten its implementation.

The description of airside, terminal, and landside technologies presented in the first part of this chapter has touched on all of these prospective benefits. The emphasis has been on their potential to relieve capacity and delay problems, but other attributes have been cited where they appear relevant either to the future use of the technology or to the choice of one form of technology over another.

To provide additional perspective on the value of new and emerging technologies from the standpoint of capacity and efficiency, OTA surveyed a sample of 54 airports to determine the nature of the capacity and delay problems they now face or expect to face within 10 years. The survey also examined specific technological remedies that might be applied at each airport. The results of this survey, presented below, should not be interpreted as a prescription for planning and implementation of new technology at these airports or for the airport system as a whole. Rather, the survey attempts to show the general extent to which technology can improve the capabilities of the airport system and relieve congestion and delay.

No attempt is made to quantify the systemwide capacity increase or delay reduction that might result from application of new technology. These benefits are highly dependent on the operational conditions and physical characteristics of the individual airport. Although certain airports may be similar in some respects, there is little basis for concluding that what works at one will necessarily be of the same benefit to others. Thus, the tabulation of technological measures considered appropriate to the airports surveyed should be viewed simply as a general map of the forms of relief available and their possible application to the problems at representative airports.

Capacity and Delay Problems at Selected Airports

The airports surveyed consist primarily of large, medium, and small hubs, cross-categorized by the predominant type of traffic—long-, medium-, and short-haul. Also included are a few commuter service, reliever, and general aviation airports. The sample was not scientifically drawn and stratified to represent the airport system as a whole. In choosing these 54 airports, the intent was to include as many types as possible so as to indicate the general problems that airports face, but the focus was on those where congestion and delay tend to be greatest and have the more pronounced effect on air transportation—hence, the predominance of large and medium hubs in the sample.

Another consideration governing the choice of airports was other recent studies of airport capacity and delay. The report of the Industry Task Force on Airport Capacity Improvement and Delay Reduction contained a survey of 33 major airports; 19 of these are included in the OTA sample. A study of capacity and delay performed by FAA in **1981,** examined *19* large airports, of which the OTA 'sample includes **13.**[61] Another FAA study described airport problems in 41 metropolitan areas.[62] The OTA sample includes airports in *27* of these metropolitan areas, although not always the major airport or all the airports that FAA examined in their survey of the region. By overlapping the OTA sample with these other studies, the intent was to provide a cross-reference to these reports and an indication of the similarity of findings.

Table 15 indicates the nature of the capacity and delay problems found in the OTA survey. For each of the airports, deficiencies and bottlenecks in the following areas were identified:

- airspace,
- airfield,
- taxiway,
- apron,

[61] *Airfield and Airspace Capacity/Delay Policy Analysis*, FAA-APO-81-14 (Washington, DC: Federal Aviation Administration, Office of Aviation Policy and Plans, December 1981).
[62] *Metropolitan Area Assessment Report*, op. cit.

- gates,
- terminal building,
- parking,
- curbfront,
- on-airport roads,
- off-airport roads, and
- environment and noise.

Entries in the table indicate whether problems or limitations exist now (E) or are expected in the future (F). The most severe problem area is identified by a dagger. In all cases, this information was obtained from published sources (FAA reports, airport master plans, regional transportation studies, and the like), supplemented with telephone interviews to confirm the findings or to resolve differences among the source documents.

One of the highlights of this survey is that airspace and airfield problems are widespread and affect airports of all sizes. Of the 30 large and medium hub airports, 23 reported existing or future airside limitations. So, too, did 17 of the 24 smaller airports—an indication that this form of capacity limitation is not solely a function of the size of the airport. Gate and terminal problems, not surprisingly, are confined almost exclusively to larger airports served by major air carriers.

Perhaps the most striking result of the survey is that landside congestion and delay at the curbfront, in parking areas, and on circulation and access roads are of equal rank with airside problems at large and medium hub airports. The same number of airports—*23* large and medium hubs—cited the landside and the airside as problem areas. For 10 of these airports, the airside is or will be the most severe problem; for 8 it is the landside. This suggests that efforts to relieve congestion and delay should not focus entirely on the airfield and airspace. Landside access is also a pressing concern. The point is even stronger if the terminal building is grouped with the landside. The airside is the most severe problem area at 10 large and medium airports, while at 15 the problem is in nonaeronautical areas.

Prospective Technological Solutions

To complete the analysis, an assessment was made of the various forms of technology that might be applied to remedy problems at the sample airports. Table ***16*** lists the results. The specific problem areas cited earlier in table 15 have been combined into four general categories: airside, airport terminal, surface access, and environment and noise. Listed under these headings are technologies that have the potential to relieve or mitigate capacity and delay problems at the ***54*** sample airports.

Table ***16*** does not constitute a comprehensive list of all technologies that might be applied, only OTA'S estimate of those that offer the greatest promise or would be the most practical to implement. Identification of a technology as applicable to a given airport does not necessarily imply that FAA or the airport operator plans to implement it, nor that capacity and delay problems would thereby be "solved. " In some cases, the capacity gains provided by these technologies will be small, or they may provide benefits only in certain weather conditions or for a small part of the day. Thus, table **16** should be interpreted simply as a general indication of how the technologies described here can be related to a set of typical airports. For those familiar with conditions at these particular airports, table 16 may also provide insights on the relationships among various measures to increase capacity or to reduce delay and on the dynamics of airside, terminal, and landside interactions.

Table 5.—Airport Capacity Survey

Airport	Airspace	Airfield	Taxiway	Apron	Gates	Terminal	Auto parking	Curbfront	On-airport roads	Off-airport roads	Environ/ noise	Comments
Large hub:												
Long haul:												
Atlanta, GA	E,F	E,F†	—	—	—	—	—	—	—	—	E,F	Airfield saturation by 1987-90
Chicago O'Hare, IL	E,F	F	—	—	E†	E	[illegible]	E	E	E,F	E,F	Terminal expansion being initiated
Dallas-Fort Worth, [illegible]	E,F	E†	E	—	E	E		E	E	—	E,F	Early arrivals and schedule banking congests airfield
[illegible]	—	E,F	—	—	E,F	E,F	[illegible]	E,F	—	E,F†	E,F	Many interim improvements to be made
[illegible] Metropolitan, MI	—	F	—	—	E,F†	F	[illegible]	F	E,F	E,F	E,F	New South Terminal would solve most problems
Houston Intercontinental, TX	E	E†	—	—	—	E	—	—	—	—	E,F	Needs new runway
Las Vegas McCarran, NV	—	F	—	—	E	E†	[illegible]	E	E	E	—	Terminal expansion being started
Los Angeles, CA	E,F†	—	E	—	E	E	—	E	—	E,F	E,F	Annual passenger cap; terminal and access road expansion just completed
Philadelphia, PA	[illegible]	—	E	—	—	—	—	—	—	E†	E,F	Tie-in to I-95 needed; regional air traffic problem with New York and Cleveland
St. Louis Lambert, MO	—	—	—	[illegible]	[illegible]	[illegible]	[illegible]	—	E	—	E,F	Terminal expansion under way; roadway construction started
Medium haul:												
La Guardia, NY	[illegible]	F	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	E†	E,F†	E,F	Limitation on type of aircraft that can use airport
Santa Ana, CA	[illegible]	E,F	[illegible]	[illegible]	[illegible]	[illegible]		E,F	E	—	E,F	Curfew; departure quotas; large number of GA operations
Washington National, [illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	E	E,F	E,F	E,F†	Annual passenger cap; curfew; and limitation on type of aircraf that can use airport
Short haul:												
Chicago Mid[illegible]	[illegible]	[illegible]	E	—	[illegible]	E	[illegible]	F	[illegible]	E	[illegible]	Terminal and airfield improvements planned
Detroit City, MI	—	[illegible]	—	[illegible]	[illegible]	—	[illegible]	—	[illegible]	—	—	Severe noise problem; landlocked
Houston Hobby, TX	E	[illegible]	F	[illegible]	[illegible]	E	[illegible]	E		E,F†	E,F	Airside, terminal, and parking construction under way
Long Beach, CA	[illegible]	—	—	—	—	—	—	—	—	—	E,F	Annual passenger cap
Medium hub:												
Long haul:												
Baltimore-Washington International, MD	[illegible]	—	—	—	—	—	[illegible]	—	—	—		Airfield and terminal expansion under way
Memphis, TN	—	[illegible]	—	—	—	—	—	—	—	—	—	Closely spaced runways constrain IFR operations
Milwaukee Mitchell, WI	—	—	—	—	—	[illegible]	[illegible]	—	—	—	—	Terminal expansion under way
Orlando, FL							[illegible]	—	—	—	—	Expansion planned to meet future needs

†Most severe problem.
E = Problems or limitations are now being experienced in this area.
F = Problems or limitations are anticipated for the future in this area.
SOURCE: Office of Technology Assessment.

Table 15.—Airport Capacity Survey (continued)

Airport	Airspace	Airfield	Taxiway	Apron	Gates	Terminal	Auto parking	Curbfront	On-airport roads	Off-airport roads	Environ/ noise	Comments
Reno, NV	—	[illegible]	—	—	—	—	[illegible]	—	—	E	—	New runway to be built; terminal recently expanded
Salt Lake City, UT	—	[illegible]	—	[illegible]	[illegible]	E	—	—	—	[illegible]	—	Expansion program started
San Diego, CA	E	—	—	—	—	—	[illegible]	—	—	[illegible]	—	No tie to Interstate; backup from LAX and Denver flow control
San Jose, CA	—	—	—	E	E	E	—	—	—	—	[illegible]	Expansion under way; curfew in effect 11:30 p.m.-7:30 a.m.
West Palm Beach, FL	—	[illegible]+	E	[illegible]	E	[illegible]	[illegible]	E	[illegible]	[illegible]	[illegible]	Expansion planned; GA reliever needed
Medium haul:												
Buffalo, NY	—	—	—	—	—	[illegible]	E	—	[illegible]	—	—	Master plan being prepared
Charlotte, NC	—	—	E	E†	E	—	—	—	—	—	E,F	Apron, taxiway, and concourse expansion under way; noise abatement plan in effect
San Antonio, TX	[illegible]+	—	—	—	—	—	—	—	—	—	—	Airspace conflicts with military bases; new terminal being built
T ^Z	—	—	—	—	—	E	—	—	—	[illegible]	—	Terminal expansion started
Small hub:												
Daytona Beach, FL	[illegible]	—					—	—	—	—	—	Converging approaches; separate short runways; reduced separation; MLS
Ontario, CA	—	—	—	[illegible]	—	[illegible]	—	—	—	—	E,F	Annual passenger cap; terminal expansion planned
Commuter service:												
Anchorage Merrill, AK	[illegible]	—	—	E	—	—	—	—	[illegible]	—	—	Complex VFR airspace; other airports in proximity
Chicago Meigs, IL	E,F†	E,F	—	—	—	—	—	—	—	—	—	Closes at 9:00 p.m.
Farmingdale Republic, NY	E,F†	E,F	E	[illegible]	—	—	[illegible]	—	—	—	[illegible]	Saturated airspace; heavily peaked demand; landlocked
For Worth Meecham	—	—	—	[illegible]+	—	—	—	—	—	—	—	Airport near capacity; shortage of hangars and tie-downs
[illegible]	[illegible]	[illegible]	—	[illegible]	—	—	—	—	—	—	—	Landlocked; limited expansion planned
Houma, LA	—	—	E†	E	—	—	—	—	—	—	—	Needs new parallel taxiway
Reliever:												
Arapahoe County, CO	F	E,F	—	[illegible]	—	[illegible]	[illegible]	—	—	[illegible]	—	Available land and ground access are biggest problems
Baltimore Glenn L. Martin, MD	—	[illegible]	E	[illegible]	—	—	—	—	—	—	—	
Crystal, MN	E		—		—	—	—	—	—	—	—	
Dallas Addison, TX	E	[illegible]	—	[illegible]	—	—	—	—	—	—	—	Regional IFR problem; affected by DFW operation
[illegible]	E,F		—	[illegible]	—	—	—	—	—	—	—	Landlocked; no expansion possible
Fort Lauderdale Executive, FL	—	F	—	E,F†	—	—	—	—	—	—	E,F	

†Most severe problem.
E = Problems or limitations are now being experienced in this area.
F = Problems or limitations are anticipated for the future in this area.
SOURCE: Office of Technology Assessment.

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Table 15.—Airport Capacity Survey (continued)

Airport	Airspace	Airfield	Taxiway	Apron	Gates	Terminal	Auto parking	Curbfront	On-airport roads	Off-airport roads	Environ/ noise	Comments
Hartford Brainard, CT	E,F	E,F	–	E,F	–	–	–	–	—	—	E,Ft	Severe noise problems; landlocked
Kansas City Downtown, MO.	—	—	—	—	—	—	—	—	—	—	—	Ample capacity
Mesa Falcon, AZ	—	Et	–	E	–	E	E	–	·	—		New runway to be built; hangar facilities and fixed base operator space needed
Novato, CA	E,F	E,F	E,F	E,Ft	–	–	–	–	—	E,F		Landlocked; adjacent land is too expensive; wetlands laws may preclude further expansion
Van Nuys, CA	—	—	—	—	—	—	—	—	—	—	E	Airport saturated; no further growth is projected; 74 dBA noise limit
General aviation:												
Aurora, OR.	—	—	—	—		—	—	—	—	—		
Carlsbad, CA	E,F	E,F	E,F	E,Ft	=	–	–	–	—	—	E,F	Landlocked; local ordinance prohibits airport expansion
Cincinnati Lunken, OH	—	F	E	E,F	–	–	E,Ft	–	—	—	—	Landlocked
Greeley-Weld County, CO	E,F	E,Ft	–	E,F	–	–	E,F	–	—	·	—	Needs parallel runway and additional land; constrained by two other airports
Vero Beach, FL.	—	E,Ft	E,F	E,F	–	E,F	E,F	E,F	E,F	E,F	E,F	Maior expansion ~roaram needed

tMost severe problem.
E = Problems or limitations are now being experienced in this area.
F = Problems or limitations are anticipated for the future in this area.

SOURCE: Office of Technology Assessment.

Table 16.—Airport Technology Summary

Airport	Rank order by operatlons[a]	Airside	Airport termmal	Surface access	Environmental/no6e
Large hub:					
Long haul:					
Atlanta Hartsfield, GA	2	E,F† Reduced separation, aircraft reclassification, TMS, ASR-9, WVAS, ASDE-3, TAGS	—	—	E,F Departure thrust management, preferential flight paths
Chicago, O'Hare, IL	1	E,F Converging approaches, triple approaches, separate short runways, reduced separation, aircraft reclassification, runway configuration management, MLS, TMS, ASR-9, ASDE-3, TAGS, airport surface condition information, WVAS	Et Curbfront improvements, termmal conftguratlon, FIS procedures	E,F Roadways, mass transportation, helicopter shuttle	E,F Departure thrust management, preferential runway use, preferential fllght paths
Dallas-Fort Worth, TX	7	E,F† Triple approaches, reduced separation, aircraft reclassification, separate short runway, WVAS	E Curbfront Improvements, termmal configuration	E Roadways, mass transportahon	E,F Preferenhal runway use, departure thrust management, preferenhal flight paths
Denver Stapleton, CO	6	E,F Converging approaches, dependent parallel approaches (with operational solution to wake vortex), MLS, TMS, ASR-9, ASDE-3, TAGS, WVAS	E,F Curbfront Improvements, terminal configuration	E,Ft Roadways, mass transportation	E,F Departure thrust management, preferential runway use, preferential flight paths

[a]Federal Aviation Administration, *FAA Air Traffic Activity, FY 1982*.
†—Most severe problem.

SOURCE: Office of Technology Assessment.

Table 16.—Airport Technology Summary (continued)

Airport	Rank order by operations[a]		Airside		Airport terminal		Surface access		Environmental/noise
Detroit Metropolitan Wayne, MI	39	F	Independent parallel approaches, reduced separation, aircraft reclassification, triple approaches, TMS, ASR-9, WVAS	E,F†	Curbfront improvements, terminal configuration	[illegible]	Roadways, mass transportation	E,F	Departure thrust management, preferential flight paths
Houston Intercontinental, [illegible]	15	E†	Converging approaches, reduced separation, aircraft reclassification, MLS, TMS, ASDE-3, TAGS, WVAS	E	FIS procedures, terminal configuration		—	E,F	Departure thrust management, preferential flight paths
Las Vegas McCarran, NV	29	[illegible]	Reduced separation, aircraft reclassification, WVAS	E†	Curbfront improvements, terminal configuration	E	Roadway, mass transportation		—
Los Angeles, CA	5	[illegible]	Reduced separation, aircraft reclassification, TMS, ASR-9, ASDE-3, TAGS, WVAS	E	Terminal configuration, curbfront improvements	E,F	Roadways, mass transportation, helicopter shuttle	E,F	Departure thrust management, preferential flight paths
Philadelphia, PA	17	[illegible]	Converging approaches (with runway extension), reduced separation, aircraft reclassification, MLS, TMS, ASR-9, ASDE-3, TAGS, WVAS		—	E†	Roadways	E,F	Departure thrust management, preferential flight paths, preferential runway use
St. Louis Lambert, MO	32	[illegible]	Reduced separation, aircraft reclassification, MLS, TMS, ASR-9, ASDE-3, TAGS, WVAS	[illegible]	Terminal configuration, FIS procedures	E,F	Roadways, mass transportation	E,F	Departure thrust management preferential runway use, preferential flight paths
Medium haul:									
New York La Guardia, [illegible]	22	[illegible]	Converging approaches, separate short runways, reduced separation, aircraft reclassification, MLS, TMS, ASR-9, ASDE-3, TAGS, WVAS	F	Terminal configuration	E,F†	Roadways, mass transportation, helicopter shuttle	E,F	Departure thrust mangement, preferential flight paths
Santa Ana, CA	8	[illegible]	Separate short runway, reduced separation, MLS, TMS	[illegible]	Curbfront Improvements, terminal configuration	[illegible]	Roadways	[illegible]	Departure thrust management, preferential flight paths
Washington National, [illegible]	24	[illegible]	Reduced separation, MLS, TMS, ASR-9, ASDE-3, TAGS	[illegible]	Self-ticketing, baggage handling systems, terminal configuration, curbfront improvements	[illegible]	Roadways	[illegible]	Departure thrust management, preferential flight paths
Short haul:									
Chicago Midway, IL	[illegible]	[illegible]	Reduced separation, MLS, TMS	[illegible]	Curbfront improvements, terminal configuration	E	Roadways, mass transportation, helicopter shuttle	[illegible]	Departure thrust management, preferential flight paths
Detroit City, MI	196	[illegible]	Reduced separation, TMS, ASR-9	[illegible]	Terminal configuration		—		—
Houston Hobby, [illegible]	14	[illegible]	Reduced separation, MLS, TMS, ASR-9, airport surface operation procedures	[illegible]	Curbfront improvements, terminal configuration	E,F†	Roadways, mass transportation, helicopter shuttle	[illegible]	Departure thrust management, preferential flight paths
Long Beach, CA	4	[illegible]	Reduced separation, TMS, ASR-9		—		—	E,F	Departure thrust management, preferential flight paths
Medium hub:									
Long haul:									
Baltimore-Washington International, MD	[illegible]	[illegible]	Reduced separation, aircraft reclassification, MLS, TMS, WVAS	[illegible]	Parking		—		—
Memphis, TN	[illegible]	[illegible]	Converging approaches, independent parallel approaches, MLS, WVAS, reduced separation, aircraft reclassification		—		—		—
Milwaukee Mitchell, WI	[illegible]		—	[illegible]			—		—
Orlando, FL	[illegible]		—	[illegible]	—	E	Mass transportation		—
Reno, NV	[illegible]	[illegible]	Separate short runway, reduced separation, aircraft reclassification, WVAS	[illegible]		E	Roadways		—

[a]Federal Aviation Administration, *FAA Air Traffic Activity, FY 1982*.
†—Most severe problem.

SOURCE: Office of Technology Assessment.

Table 16.—Airport Technology Summary (continued)

Airport	Rank order by operations[a]		Airside		Airport terminal		Surface access		Environmental/noise
Salt Lake City, [illegible]	44	[illegible]	Converging approaches, independent parallel approaches, reduced separation, aircraft classification, MLS, WVAS	E	Baggage handling systems, terminal configuration	[illegible]			—
San Diego, CA	155	[illegible]	Reduced separation, aircraft reclassification, WVAS	[illegible]		[illegible]	Mass transportation	[illegible]	Departure thrust management, preferential flight paths
San Jose, CA	26	E		E†	Terminal expansion		—	[illegible]	Departure thrust management, preferential flight paths
West Palm Beach [illegible]	52	E,F	Airport surface operational procedures, taxiway design, WVAS, MLS	[illegible]	Curbfront improvements, terminal configuration	E	Roadways	[illegible]	Departure thrust management, preferential flight paths
Medium haul:									
Buffalo, NY	[illegible]			E,F†	Parking, terminal expansion	[illegible]			—
Charlotte, NC	[illegible]	[illegible]	Airport surface operational taxiway design	E	Terminal configuration			[illegible]	Departure thrust management, preferential flight paths
San Antonio, TX	[illegible]	[illegible]	Converging approaches, MLS						—
Tucson, AZ	[illegible]		—	[illegible]	Terminal expansion	[illegible]			—
Small hub:									
Ontario, CA	195	E	—	E†	Terminal configuration		—	[illegible]	Departure thrust management, preferential flight paths
Daytona Beach, [illegible]	63	[illegible]	Converging approaches, separate short runways, reduced separation, MLS		—		—		—
Commuter service:									
Anchorage Merrill, AK	27	[illegible]	Reduced separation		—	E	Roadways		—
Chicago Meigs, IL	299	[illegible]			—		—		
Farmingdale Republic, NY	76	[illegible]	Reduced separation	[illegible]			—	E,F	Preferential flight paths
Fort Worth Meecham, TX	11	[illegible]			—		—		
Fullerton, CA	112	[illegible]	Reduced separation		—		—		—
Houma, LA	—	[illegible]	Taxiway design, LLWSAS		—		—		—
Relievers:									
Arapohoe County, CO	16	[illegible]	Converging approaches, MLS	[illegible]		[illegible]			—
Baltimore Glenn L. Martin, MD	—	[illegible]	Taxiway design		—		—		—
Crystal, MN	171	[illegible]			—		—		—
Dallas Addison, TX	140	[illegible]	Reduced separation		—		—		—
El Monte, CA	164	[illegible]	MLS		—		—		—
Fort Lauderdale Executive, FL	101	[illegible]			—		—	E,F	Preferential flight paths
Hartford Brainard, CT	180	[illegible]			—		—	E,F†	Preferential flight paths
Kansas City Downtown, MO	160		—		—		—		—
Mesa Falcon, AZ	—	[illegible]		[illegible]			—		—
Novato, CA	—	[illegible]			—	[illegible]	Roadways		—
Van Nuys, CA	3				—		—	[illegible]	Preferential flight
General aviation:									
Aurora, OR	—		—		—		—		—
Carlsbad, CA	88	[illegible]			—		—	E,F	Preferential flight paths
Cincinnati Lunken, OH	115	[illegible]	Taxiway design, MLS	E,F			—		—
Greeley-Weld County, CO	—	[illegible]		E,F			—		—
Vero Beach, FL	119	[illegible]	Taxiway design	E,F		[illegible]	Roadways	E,[illegible]	Preferential flight paths

[a]Federal Aviation Administration, *FAA Air Traffic Activity, FY 1982*.
†—Most severe problem.

SOURCE: Office of Technology Assessment.