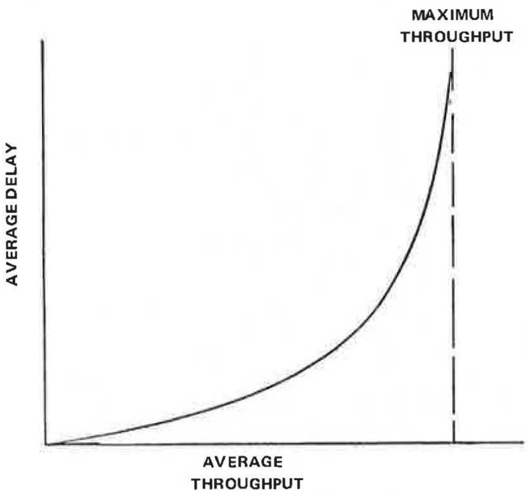
Figure 2. Delay as a function of throughput.



adding another lane to a freeway to reduce congestion: the typical experience is that almost immediately more people start using the freeway until it is as congestion-prone as before. While drastic approaches to demand management to reduce delay are likely to have a deleterious effect on network efficiency (and possibly service), relatively modest shifts in peak usage levels at individual airports should have a favorable impact on delay, and be a net gain for the scheduled air system.

The Management of Demand

The point has been made that there are sound economic reasons for the peaking of operations during the day at a few top airports. Thus any policies or actions aimed at modifying demand patterns to reduce delay should also be evaluated in terms of their impact on network economic efficiency and service characteristics.

It appears that delay levels in themselves are an important equilibrating force on the maximum usage peaks at individual airports. The shape of the curve of delay versus demand in Figure 2 suggests that a relatively small decrease in demand (actual usage level) from its current equilibrium point could substantially reduce average delay. To accomplish this requires that other forms of usage constraints would have to substitute for the role now played by delay.

While this appears simple in principle, identifying and implementing alternative allocation measures that are perceived to be both fair and efficient is extremely difficult. But if the perspective presented here is valid such demand management is the only way to reduce average delay.

The reliever airport program to provide alternative operating points for general aviation in large hub areas has been effective; this is reflected in Figure 1. There are problems, but it is almost inevitable that most general aviation traffic be diverted from saturated commercial hubs. It is hard to identify an alternative for this class of traffic.

The use of reliever or satellite airports for scheduled passenger flights is another matter. Network efficiency is achieved by interlining, and using two airports instead of one largely defeats this purpose unless extremely good ground transportation connects the two points. While there are some situations where the advantages of an uncrowded secondary airport outweigh the disadvantage of foregoing transferring traffic, it is not a large proportion of passenger movements.

Thus there are sound reasons why airlines want to fly into the same airports, and to do so at roughly the same time of the day. It is the necessary condition for an integrated air network. It should therefore be borne in mind that schemes to counter these tendencies carry a price in overall system cost or service. But if capacity is not available and capacity also has a cost -- there may be no alternative to some form of reallocation.

The two schemes most often suggested to redistribute operations are quotas or variable pricing approaches. The controllers' strike and its aftermath has given ample evidence of the difficulty in allocating quotas in a way perceived to be fair to all.

Quota schemes are also criticized because there are no price signals to flag economically inefficient allocation, which theoretically marginal cost pricing would do. The latter, though, has both practical implementation difficulties as well as a perception of unfairness: the cost in terms of delay caused by a small aircraft operation may be nearly the same as for a large aircraft, making the cost per passenger vastly different. Thus straightforward marginal cost pricing distinctly favors the large aircraft.

There is no easy solution, and it will require experimentation to find workable and acceptable schemes. It is also unlikely that there will be a universal approach; each area will evolve its own. The important thing is to remember that what happens at one large airport affects the whole system, and should be evaluated in that light.

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OPERATIONAL MEANS FOR INCREASING RUNWAY CAPACITY

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Hourly runway capacity can be defined as the maximum number of aircraft operations (e.g., arrivals and departures) that can use the runways in an hour under specific operating conditions. As the operating conditions change, so does the hourly runway capacity.

Increasing runway capacity by increasing the number and operational use of the runways depends on the ability to understand and manipulate these operating conditions.

The primary factors that influence runway capacity are listed in Table 1. Increases in runway capacity can be obtained by (1) recognizing which factors are fixed or variable in a specific situation, (2) understanding the effects of the fixed factors, and (3) manipulating the variable factors.

At most airports, many of the factors can be regarded as fixed (or at least susceptible to minor changes). Some changes can be considered for individual airports while other changes would require systemwide or regional implementation. Many changes are currently being considered by the aviation community. Seven examples of these changes are described below:

Table 1. Primary factors that influence runway capacity.

1. Runway Characteristics
   (Length, width, gradient, strength, marking, lighting)

2. Airfield Layout
   (Number, location, orientation and separation of runways, taxiways, parking positions)

3. Runways in Use
   (Active, direction of operation, arrivals and departures)

4. Weather
   (Visibility, ceiling, wind, precipitation, runway surface condition, temperature, pressure)

5. Aircraft Demand
   (Types, proportions, origins and destinations, arrivals and departures)

6. Navigation and Control
   (Landing and navigational aids, radars, communications, avionics)

7. Rules and Procedures
   (Separation standards, speeds, routes, climb and descent profiles, turns, acceleration and deceleration)

8. Human Skills and Motivation
   (Training and experience, incentives and penalties, examinations and licensing, stress and fatigue, working conditions)

9. External Constraints
   (Terrain and obstructions, restricted airspace, adjacent airports, noise sensitivity and abatement).

- Converging approaches
- Curved approaches
- Multiple glide paths
- Short runways
- Parallel runway separation
- Runway occupancy time
- Reduced aircraft separation.

Converging approaches - In Instrument Flight Rules (IFR) weather conditions, aircraft approaching two different runways must have protection for their missed approach courses. Currently, there is no standard set of procedures that would permit aircraft to make independent converging approaches to two runways at the same airport. Existing requirements described in TERPS require the runways to be several miles apart. The Federal Aviation Administration (FAA) is currently investigating ways of reducing the protected airspace requirements in order to permit converging approaches in IFR weather conditions. Figure 1 illustrates the concept of missed approach protection with converging approaches.

Both FAA and the U.S. Air Force have made progress in implementing converging approach procedures. Some examples are given in the following paragraphs.

In December 1982, FAA initiated dual approaches to two converging runways (8R, 17L) at Denver Stapleton International Airport, for use when weather conditions are 700 foot ceiling and 2 miles visibility or better. FAA has also published a notice of proposed rulemaking to implement simultaneous converging approaches to Runways 35L and 35R at Stapleton, useing a 10° offset Localizer Directional Aid/Distance Measuring Equipment (LDA/DME) approach to Runway 35R which is separated by 900 feet from Runway 35L. The thresholds of the two runways are staggered by approximately 5,800 feet, which provides some vertical separation between approach courses. The current proposal limits use to weather conditions that are 1000 foot ceiling and 3 miles visibility.

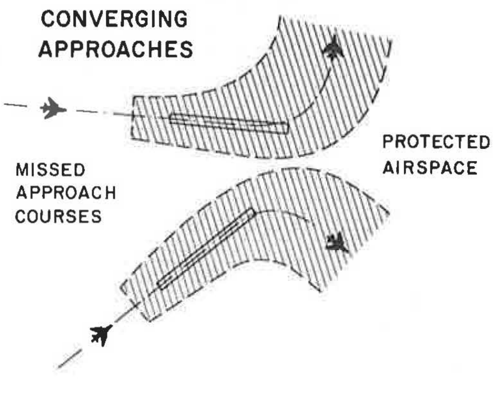
FAA also introduced an LDA/DME approach procedure in 1982 for Runway 12L at Lambert-St. Louis International Airport. This approach uses a parallel approach to a point in space, followed by a side-step to align with the extended runway centerline. During the one year evaluation period, simultaneous operations with Runway 12R are not permitted.

During 1983, USAF has initiated implementation of new launch and recovery procedures that utilize converging approaches when the weather conditions are 500 foot ceiling and one mile visibility or better. In these procedures, longitudinal separation is provided between aircraft on the two approach courses.

Curved approaches - The current instrument landing system requires aircraft to follow a straight-in approach for the last five or six miles to the runway threshold. In visual meteorological conditions, aircraft at many airports make curved approaches for efficiency, noise abatement, and other reasons. These curved approaches, however, cannot currently be conducted in instrument weather conditions. One of the planned capabilities of the microwave landing system is to permit curved approaches under such conditions.

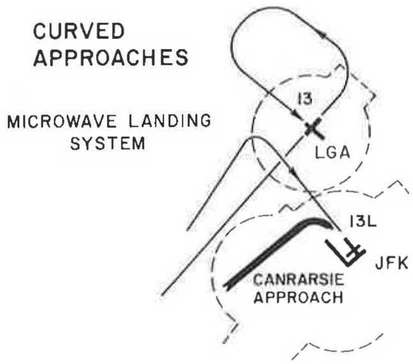
This capability would be particularly effective in New York (see Figure 2). In some wind conditions, the Canarsie visual approach to runway 13 at John F. Kennedy International Airport is used to overcome airspace conflicts with La Guardia Airport. A microwave landing system could permit a modified Canarsie approach to be conducted in instrument weather conditions, thereby separating the airspace of Kennedy and La Guardia.

Figure 1. Converging approaches.



The requirements for curved approaches include an MLS system, sophisticated avionics, and an approved procedure. FAA is currently examining avionics requirements, including the potential use

Figure 2. Curved approaches.



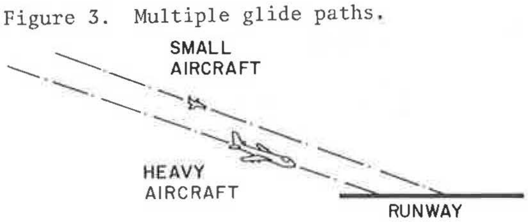
of a Cockpit Display of Traffic Information (CDTI) or other avionics to assist pilot orientation.

The first step towards curved approaches involves use of a segmented approach consisting of straight elements at angles to each other. Cooperation between FAA, deHavilland, and Ransome Airlines has lead to the use of this type of approach for some aircraft at Washington National Airport. Area Navigation (RNAV) equipment and other avionics allows the aircraft to follow pre-cleared standardized routings.

FAA is currently developing protected airspace and other requirements that would permit MLS approaches in IFR conditions.

Multiple glide paths - Wake turbulence can cause significant control problems for small aircraft following large and heavy aircraft. At present, all aircraft follow the same glide slope (2-1/2 to 3 degrees) when conducting a precision instrument approach. The addition of a second transmitter with its associated glide slope, such as that shown in Figure 3, could permit smaller aircraft to land further down the runway. The small aircraft would conduct their approaches above the regular glide path, and thereby overcome the wake turbulence

Figure 3. Multiple glide paths.



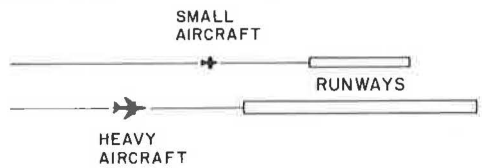
problem, permitting separations to be reduced considerably, and thus increasing capacity. If the vertical separations were sufficient, overtaking might be permitted, thereby resolving speed differential problems.

The proposed LDA/DME approach procedure at Denver utilizes vertical separations in the order of 300 feet to assure that heavy aircraft approaching Runway 35L remain below aircraft approaching Runway 35R.

The potential application of multiple glide paths seems to be most likely in situations where it can be combined with other changes such as curved approaches, short runways, etc.

Short runways - Use of parallel taxiways as general aviation runways, or construction of new short runways at some of the nation's larger carrier airports, could permit significant increases in capacity. The thresholds of the parallel runways could be located to achieve the benefits of multiple glide paths mentioned above (see Figure 4). Navigational aids, radar monitoring, and parallel runway separations would have to be established for aircraft to maintain independent flight tracks in the terminal area airspace on approach to the runways.

Figure 4. Short runways.



The Industry Task Force on Airport Capacity Improvement and Delay Reduction made several recommendations to FAA concerning operational means of increasing capacity, including the concept of separate short runways. The report noted that current benefits occur primarily in visual flight rule (VFR) conditions. Extending these benefits to IFR conditions requires the development of new approach procedures. The capacity improvement concepts investigated by the Industry Task Force are listed in Table 2.

Parallel runway separation - The FAA air traffic control rules specify that parallel runways must be separated by 4,300 feet or more so that independent simultaneous instrument approaches can be conducted to the two runways. This separation may be reduced in the future as new procedures and equipment are introduced. Dependent or staggered instrument operations are currently permitted to parallel runways separated by less than 4,300 feet, but by 3,000 feet or more. This parallel runway separation requirement could also be reduced, as could the separation between aircraft approaching the two runways. Figure 5 illustrates current and future separations.

Separations of 2,500 feet are being actively considered for implementation with simultaneous approaches. Improved radar monitoring may be needed to achieve this separation.

Runway Occupancy Time - A recent study performed by researchers (including the author) at the Institute of Transportation Studies (ITS), University of California, Berkeley, for the National Aeronautics and Space Administration (NASA) and the FAA, has

Figure 5. Parallel runway separation.

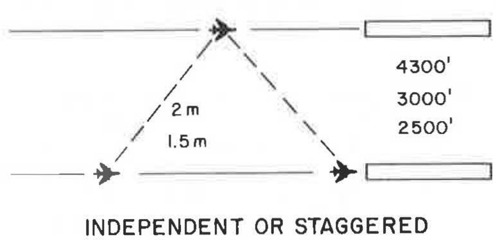


Table 2. Recommendations of the Industry Task Force on Airport Capacity Improvement and Delay Reductions.

Capacity Improvement Concept	Year to be Implemented	Potential Payoff	Likelihood of Success	FAA Resources Required	Comments/Recommendations to FAA	Relative Merits
Independent IFR parallel approaches with runway separations below 4,300 feet to as low as 3,000 feet	1984-1985	Large	Very good	Minimal	• Collect deviation data and conduct blunder simulations to determine if required NOZ reduction can be supported • Investigate and acquire new surveillance system • Change ATC rules	A
Dependent IFR parallel approaches with two-mile diagonal spacing between aircraft to runways separated by 2,500 feet	1982	Small	Excellent	Minimal	• Only need to change ATC rules • Implement immediately	A
Coverging IFR approaches	1985-1990	Large	Good	Moderate	• Develop criteria and guidelines • Gradual reductions in minimums likely	A
(1) Certificated IFR converging approaches (Ransome Airlines)	1983	Locally large	Very good	Minimal	• Demonstration completed • Expedite review of plan submitted	A
Triple simultaneous independent IFR approaches						
(1) Parallel instrument approaches to triple parallel runways	1983-1985	Locally large	Good	Moderate	• Develop guidelines and criteria for determining site-specific feasibility	A
(2) Dual parallel approaches plus a converging IFR approach	1985-1990	Locally large	Good	Moderate	• Recommendations for "Converging IFR approaches" (Item c) generally apply, but missed approach interactions are more complex	B
Separate short runway for Category A and B aircraft	1982	Locally large	Excellent	Minimal	• Evaluate on-site specific basis • Implementation of IFR approaches to parallel runways with reduced spacing or to converging runways increases potential applications	C
Wake vortex operational solutions	1985	Minimal to moderate	Good	Moderate	• Develop equipment to measure wind speed and direction on final approach at altitude • Evaluate use of higher glide slopes for lighter aircraft • Continue wake vortex research	C
Longitudinal spacing reduction (when wake vortex not a factor)	1985	Moderate to large	Very good	Moderate	• Runway occupancy time can be a major constraint • Confirm surveillance adequacy • May be site-specific and conditional	A
Simultaneous IFR approaches with a visual segment	1982-1985	Moderate	Excellent	Minimal	• Consider NAVAIDS and aircraft maneuvering requirements • Expedite review at airports such as Chicago O'Hare and Denver Stapleton	A

* A. Excellent
  B. Very Good
  C. Good

demonstrated that runway occupancy time can have a significant influence on runway capacity. Runway occupancy time can be reduced or better managed in a number of ways. Under some conditions, significant gains in runway capacity can be achieved (Figure 6). Further information is available in ITS Research Report 81-7.

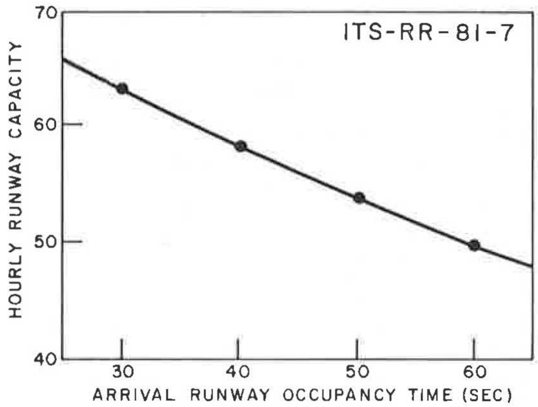
Reduced Aircraft Separation - For several years, the FAA has been investigating the possibility of reducing the basic radar separation between aircraft from three miles to two or two and one-half miles. Today's terminal radar systems seem to be sufficiently accurate to permit this reduction, but there are some concerns about wake turbulence. The FAA has been pursuing ways of predicting and detecting wake turbulence for several years.

Reduced situations of 1-1/2 miles are now being implemented by the U.S. Air Force for some specialized separations. In addition, on-board radar displays are being utilized by some U.S. Air Force aircraft to maintain separation without monitoring by ATC.

Conclusions

Each of the potential improvements discussed above (and several others under active consideration) offer great potential for capacity increases. Combinations of these improvements might double

Figure 6. Runway occupancy time.



capacity in some situations, resulting in considerable savings in delays and operating costs.

Implementation of changes to the ATC system is both lengthy and arduous, whether or not new equipment is involved. The process includes identifying problems, developing new ideas or innovations, and conducting research to develop and test these ideas. Any required equipment must also be developed, tested, and procured. New rules and procedures for the innovation must be developed as well. There is a significant period for review and testing, which can include review by experts, mathematical modeling, radar and flight simulator tests, and live field tests. Coordination, too, is necessary before the parties affected can approve of the change for implementation. It is not unusual for this implementation cycle to take ten or more years.

Significant effort is required to achieve some of these gains, and the gains must be matched by improvements in the en route and terminal airspace.

FLOW CONTROL, SPACING AND MANAGEMENT

Joseph D. Blatt, Aviation Consultant

Major opportunities for increasing airport and airway capacity exist through improvements of the efficiency of the air traffic flow control mechanisms An effective flow control mechanism would smooth out the flow of air traffic by monitoring the status of the system components - that is the weather, traffic and other physical and operational subsystems - and then with computer assistance derive scenarios that would maximize the traffic flow.

The original mission of the air traffic control services was to provide for the safe and expenditious flow of air traffic. Since the early 1970s, since the escalation of oil prices, the cost of aviation fuel has become a most significant element of aircraft direct operating costs. Air traffic control's mission had to be enlarged to provide for the fuel efficient flow of air traffic. Similarly, effective flow management must not only strive to maximize flow but to assure that the flow is organized in a fuel efficient manner.

The effectiveness and efficiency of an air traffic flow control mechanism is dependent upon the operation of the components and subsystems of the air traffic control system and on how well their parts work together and support one another. The available airport geometry; the runway surface texture and condition; the operating strategies employed; weather observation, collection, forecast and distribution systems available; the air traffic control techniques and hardware employed; the levels of skill of the system operators and system users and the air navigation and avionics available - all are part of the air traffic control system and all affect system capacity. It must therefore be assumed that if the air traffic control system is to maximize the flow of air traffic and provide for fuel efficient operations, then a management system must be developed which will be able to monitor all system parts and integrate the intelligence gathered.

At the present time inefficiencies in the management of the airspace are due, mainly, to the lack of accurate and timely information concerning the weather; the anticipated traffic demand (both IFR and VFR) on the system, and changes in airport configuration and airport capacities. The uncertainties thus created by this lack of information results in excessive spacing of aircraft, waste of airspace, reduced system capacity, traffic delays and waste of aviation fuel. Although it is estimated that 85 percent of the air traffic control system delays occur in the terminal area, many of these delays may have been caused by actions taken (or not taken) in the enroute area. The solution to the capacity problem cannot be sought exclusively in the terminal areas. Prior attempts to develop terminal area metering and spacing systems have conclusively proven that, due to the speed of modern aircraft and the number and complexity of the converging routes that bring traffic to the terminal area, it may be necessary to control the flow of aircraft from their point of origin to the destination airport. An effective flow management system will have to monitor all system parameters and accurately analyze the magnitude and interaction of air traffic flows from departure gate to arrival gate.

The Federal Aviation Administration (FAA) has established the Integrated Flow Management (IFM) program to develop an integrated network of flow management functions, supported to the degree practicable by automated capabilities to enhance the inherent operational and fuel efficiency of the ATC system. The integrated flow management function forms one element of FAA's advanced automation program. The need for this function is obvious and urgent. FAA should be encouraged to proceed as rapidly as possible with the development of this function. The capacity benefits anticipated by the development of sophisticated air navigation and traffic control aids, techniques and devices cannot be fully realized until an integrated flow management function is implemented. The research, development, test and evaluation and implementation of an optimum air traffic flow management system must be considered an evolutionary, long term (maybe never ending) program. Fortunately, benefits do not have to await the completion of the program. Benefits may be derived as soon as system segments are developed and implemented. FAA should give high priority to the installation of system segments as soon as they are implementable.

The present IFR capacity of the major airports is only 60 to 80 percent of the capacity available under VMC. Air carrier schedules are constrained (in addition to the constraints of an FAA imposed quota) by the IFR capacity, which is well below the VFR potentials of the airport. The result is overutilization of the facility in IFR and underutilization in VFR. It would seem that one of the initial objectives of an integrated flow management system would be to make IFR capacity more nearly equal to VFR capacity. To do this it will be necessary to reduce the longitudinal separation employed in IFR while improving the accuracy of the