Table 4. Comparison of passenger volumes: FlyAway Bus terminal versus Los Angeles International Airport.

	FlyAway Passengers			Los Angeles International Airport Passengers	
Year	Number	Annual Growth Rate (%)	Market Share (%)	Number	Annual Growth Rate (%)
1976	275 104		10.1	25 983 079	
1977	310 751	12.9	10.4	28 361 836	9.2
1978	415 759	33.8	12	32 901 361	16
1979	677 554	63	18.5	34 923 205	6.1

time to get to the bus terminal (42 percent drove 6-15 min, 37 percent drove 16-30 min, and 10 percent drove 31-45 min). FlyAway's travel time to Los Angeles International Airport from the valley terminal ranges from 30 min under free-flow conditions, to more than an hour during peak periods.

GROWTH RATES OF PASSENGER VOLUMES

When viewed in terms of Los Angeles International Airport passenger volumes, FlyAway has managed to capture a considerable portion of market share. This is illustrated in Table 4.

The market share is calculated by subtracting the 25 percent of Los Angeles International Airport passenger volume that is connecting traffic and then assuming that, of the remainder, 14 percent is currently based in the San Fernando Valley. [The valley's market share has declined from 15 percent in 1975 due to rapid growth in the passenger market located in Orange County (6).]

PLANNED IMPROVEMENTS AT LOS ANGELES INTERNATIONAL AIRPORT

The department of airports currently has a goal of building two major new terminals, three parking structures, and at least one phase of a double deck for the central terminal roadway before the 1984 Olympics. These improvements promise to create serious access problems during the several years of construction. Systems such as FlyAway offer the only hope for serving growing passenger volumes while roadway capacity is curtailed. In addition, when the second-level roadway is completed, special lanes will be provided for buses on the lower level, thereby more specialized service will be offered for bus passengers. In conjunction with this plan, the regional transportation plan specifies that special lanes for high-occupancy vehicles be provided whenever feasible (7). Such lanes are currently being planned for the freeways that access Los Angeles International Airport. If this system can be coordinated and implemented, remote terminals will clearly become increasingly attractive to passengers, employees, and airport operators.

If the FlyAway experience is at all typical of what a metropolitan remote terminal can do, the good news is that not only can such a system be useful and attract considerable patronage, it may also operate without subsidy.

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Publication of this paper sponsored by Committee on Airport Landside Operations.

Airport Geometric Compatibility of Future Aircraft

BARRY R. HOY

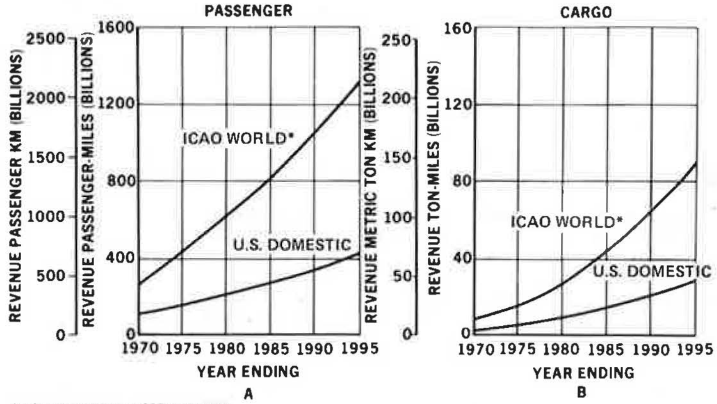
Capacity limitations at many of the major hub airports restrict the ability of carriers to add flights to accommodate increased demand. Increases in seating densities on existing aircraft will reach marginal comfort limits, and therefore, the demand can only be handled by the upgrading of existing airports, building of new airports, or the use of aircraft that have higher seating capacities. The last solution would impose greater operating and physical limitations on the airport system. The ability to physically expand airports and build new ones is subject to environmental and fiscal constraints and land availability and has proven to be almost impossible. Therefore, future growth will require the use of a greater percentage of aircraft that have large seating capacities. This paper analyzes the characteristics of wingspan and existing runway and taxiway separations at 31 hub airports. The effects of these characteristics are evaluated as a function of current airport runway and taxiway systems. The data and conclusions may be used to develop a technical rationale for accurate measurement of necessary separations and to help evaluate the adequacy of current airport standards as more large aircraft are accommodated in the future.

The possible construction of any new U.S. airports within this century is remote; however, air transportation is a rapidly growing industry (Figure 1) that seems to continually exceed planned capacities. The major aircraft manufacturers are receiving strong pressure from two sides:

1. The stressed operating environment, which requires more large aircraft to satisfy the continual increase in demand and relieve capacity problems, and
2. The difficulty in changing existing airports to meet the requirements of the large aircraft, as well as the lack of support by authorities for such changes.

The introduction of the wide-bodied aircraft

Figure 1. Future growth trends.



*NOT INCLUDING USSR AND PRC

REF CTOL TRANSPORT AIRCRAFT CHARACTERISTICS, TRENDS, AND GROWTH PROJECTIONS, JANUARY 1979

(e.g., DC-10, L-1011, and B747) brought initial compatibility problems to many airports because these aircraft were revolutionary in size and higher off the ground than their predecessors. Fortunately for the aviation industry, land was available for expansion of both airside and ramp areas. The cost of these airfield modifications and development of needed ground support equipment was the price paid for the increased productivity and preferred environmental factors of the wide-bodied aircraft. At present, however, the capability for unlimited airport expansion no longer exists and, because choices of alternative airport sites are very limited, increased dimensions for aircraft become exceptionally critical. Promotion of a larger wingspan is a prime example.

This paper assumes that the goal is to have unrestricted, maximum runway capacity during routine daily operations. Therefore, the airside system, runways, taxiways, and maneuvering procedures should reflect a design to accommodate this capacity. Visual meteorological conditions (VMC) and instrument meteorological conditions (IMC), the two weather operational criteria, play an important role in airport capacity and, consequently, aircraft sizing. IMC operations require relatively large landing sequences, but maximum airfield capacity is always achieved during VMC operations; therefore, IMC operations are not thought of as being significant relative to aircraft sizing as are VMC operations. Thus, IMC separation minimums are not discussed.

FUTURE AIRCRAFT TRENDS

Prediction of future trends in aircraft design is a required function of airport planning. Without trend forecasts, planners would be forced to design future airports around existing aircraft dimensions. Usually, the process from initial planning to end of construction before an airport becomes operational takes 10-20 years, and a master plan for the airport's future is designed for staged construction during the first 20 years of airport operation. Therefore, a good forecast, capable of meeting the needs for airport planning, should project a period of 30 years. At present, such a forecast has not been developed; however, the Aerospace Industries Association of America (1) published the following forecast of maximum aircraft dimensions for the period through 1995 (note: 1 m = 3.28 ft; 1 kg = 2.20 lb):

Item	Dimension
Wingspan (m)	Up to 84
Outer main gear wheel span (m)	Up to 20
Overall length (m)	Up to 84
Tail height (m)	Up to 23
Maximum gross weight (kg)	Up to 567 000

Douglas is currently projecting a more modest wingspan increase of 10-17 percent over present lengths. This percentage growth is based on general opinions expressed by the airlines to manufacturers as to their liability responsibilities (e.g., insurance premiums) and on apparent public lack of enthusiasm for giant aircraft that have seating capacities significantly higher than those of the B747. Thus, an increase in the present 60-m (196-ft) wingspan maximum could progress to a future possibility of 70 m (230 ft). The 70-m projection is used as the basis for this paper and, although a serious problem at several main hub airports, is speculated as compatible in most present airport systems.

Standards

Newly configured aircraft will operate in today's airports with minimum change in the location of airport components and, it is hoped, without further reduction of airport capacity. However, aircraft dimensions that are much larger than the Boeing B747 will challenge these airports in their present configurations. Therefore, the question remains, Just how large an aircraft will be compatible with a majority of present airport systems?

The general consensus is that the airside geometry of an airport is the most-critical, least-changeable part of the airfield's system, regardless of cost. This is due mainly to environmental considerations. Therefore, this paper is concerned with the runway and taxiway system (an apparent limited part of the airside geometry) and its relationship with wingspan dimensions.

The compatibility of an aircraft with its ground environment depends on interrelated aircraft and airport features, all of which must be considered by the design engineer. Each major airside component represents an interface with one or more aircraft features. Since airports are built to accommodate aircraft and ground vehicle modes to accomplish their interchange, it would be logical to have a system of airports designed scientifically in terms of related aircraft parameters. However, this is not the case in many airport standards. These standards are frequently based on experience and are revised, as necessary, to meet changing aircraft requirements. Figure 2 illustrates Federal Aviation

Figure 2. FAA airport components.

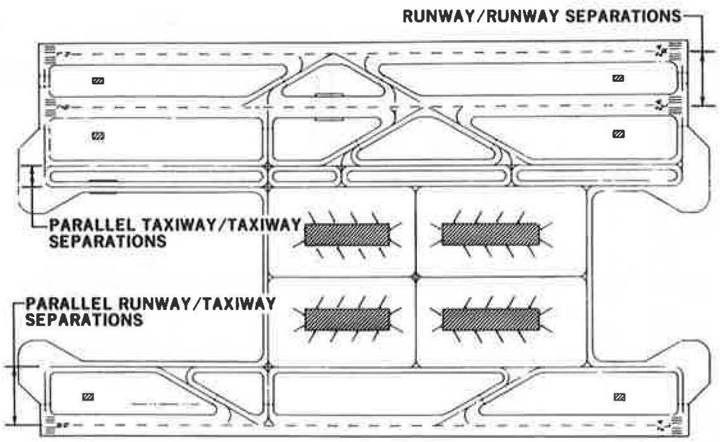


Table 1. Summary of recommended airport standards.

Item	Recommended FAA Standards (m) Design Group 2	Design Group 3	Design Group 4	Recommended ICAO Standards (m) Runway Code Letter A
Runway width	45.7	61		45.7
Taxiway width	23	23	30.5	23
Taxiway-taxiway separation[a]	91.5	91.5	110	85.4
Runway-runway separation[a]	305	366[b], 427[c], 854[d]		213.4
Runway-taxiway separation[a]	122	122	183	186.5

Note: 1 m = 3.28 ft.
[a]Visual flight rules.
[b]Maximum capacity.
[c]Opposite direction, day.
[d]Opposite direction, night.

Administration (FAA) airport components of a runway and taxiway system that are interrelated with aircraft parameters. These parallel components, runways, and taxiways are of immediate concern to this paper.

Since the United States is a member of International Civil Aviation Organization (ICAO), both the international specifications and domestic FAA standards must be considered. Table 1 summarizes the FAA and ICAO airport component sizes that are represented by standards of recommendations.

Aircraft and Airport Parameters

Airport component sizes advocated by the FAA and ICAO, although different, are based on traditionally accepted values and long-standing practices of safe operations. Past studies have revealed no clear evidence that these component sizes are too large or minimally safe or that their potential impact on the future system could be pervasive.

The most critical issues to wingspan and overall fuselage length are runway and taxiway system centerline separation criteria because of the inability to physically relocate either element in order to gain additional clearance distance (i.e., parallel runway, parallel runway and taxiway, and parallel taxiway separation distances). The recommended separation minimums in Table 1 address these issues.

Note that design group 4, as shown in Table 1 for requirements for aircraft larger than a B747, has several undefined areas as a result of unknown aircraft dimensions. This paper should encourage definition of these undetermined areas.

History provides us with a number of lessons. For example, FAA, in its original airfield geometrical and structural pavement-width standards for the three- and four-engined wide-body aircraft included these aircraft exclusively in a design group 3 category. Concurrently, FAA established and promoted dimensions of 30 m (100 ft) and 61 m (200 ft) for structural taxiway pavement width and optimum structural runway pavement width, respectively, for design group 3. However, subsequent actions of the FAA

1. Dropped the DC-10 and L-1011 into design group 2 (2, change 1),
2. Reduced the taxiway pavement width to 23 m (75 ft) (2, change 2) and set the minimum runway pavement width at 46 m (150 ft) with appropriate shoulders for design group 3, and
3. Made compensating adjustments to other taxiway dimensional criteria.

These changes were prompted by actual operational experience that indicated that these wide-body aircraft operators had already constructed facilities to the original standards or had engineering plans ready for implementation. The construction may have long-term payoffs but the added capital and interest might have been put to better use elsewhere.

In order to present an accurate picture of existing separations at major hub airports, 31 worldwide airports were selected for their large traffic volumes and varying airside layouts (see Table 2). A present separation analysis of each data-base airport is shown in Figures 3-5; all make reference to FAA-recommended minimums. As shown in Figures 3-5, several major hub airports are already experiencing pressure because of the separation minimums recommended for the 60-m (196-ft) wingspan of the B747 and, therefore, offer very limited capability to accommodate wingspans of greater dimensions comfortably.

EVALUATING AIRPORT RUNWAY AND TAXIWAY SYSTEMS

Conclusive evidence of possible reductions in recommended airside separation minimums to accommodate larger aircraft is difficult to obtain. This is mainly caused by a lack of technical rationale. In the evaluation of airport runway and taxiway systems it is important to not attempt to set a goal of reaching a total solution for airport limitations but rather to develop a basic method that permits more existing airports to become compatible.

Conservatism in separation minimums is herein

Table 2. Data-base airports.

Airport	Location	Airport	Location
Schiphol	Amsterdam, Netherlands	Los Angeles International	Los Angeles, CA
Athinai International	Athens, Greece	Barajas	Madrid, Spain
Hartsville International	Atlanta, GA	Dorval International	Montreal, Canada
Bangkok International	Bangkok, Thailand	Miami International	Miami, FL
Bombay International	Bombay, India	John F. Kennedy International	New York, NY
Ezeiza	Buenos Aires, Argentina	Charles DeGaulle	Paris, France
Maiguetia-Simon Bolivar	Caracas, Venezuela	Galeao	Rio de Janeiro, Brazil
O'Hare International	Chicago, IL	Fiumicino	Rome, Italy
Koeln-Bohn	Cologne, Germany	San Francisco International	San Francisco, CA
Kastrup	Copenhagen, Denmark	Singapore International	Singapore
Dallas/Ft. Worth	Dallas/Ft. Worth, TX	Kingsford Smith International	Sydney, Australia
Frankfurt	Frankfurt, Germany	Mehrabad International	Tehran, Iran
Hong Kong International	Hong Kong	Ben Gurion International	Tel Aviv, Israel
Honolulu	Honolulu, HI	Maribel	Montreal, Canada
Jan Smuts	Johannesburg, S. Africa	Tokyo International	Tokyo, Japan
Heathrow	London, England		

Figure 3. Parallel runway separations.

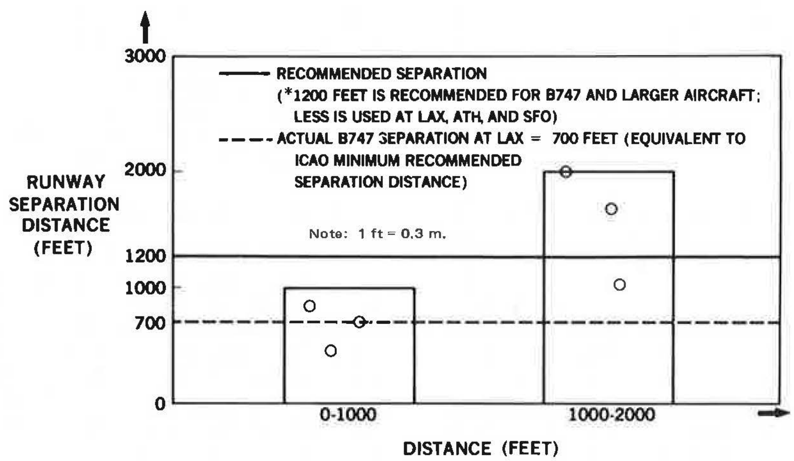


Figure 4. Parallel taxiway separations.

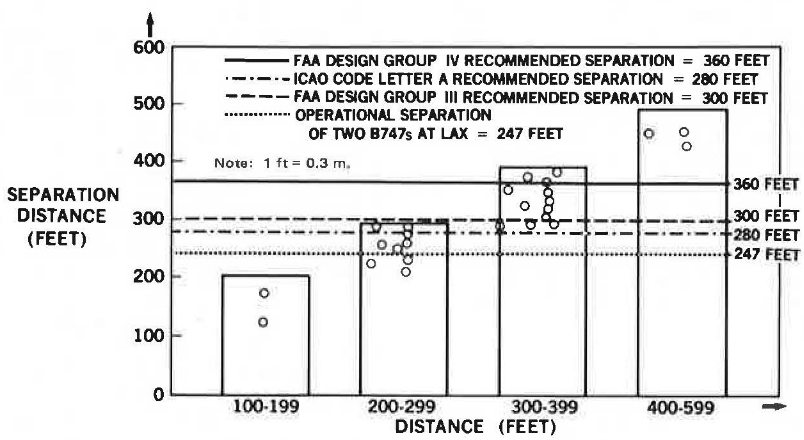
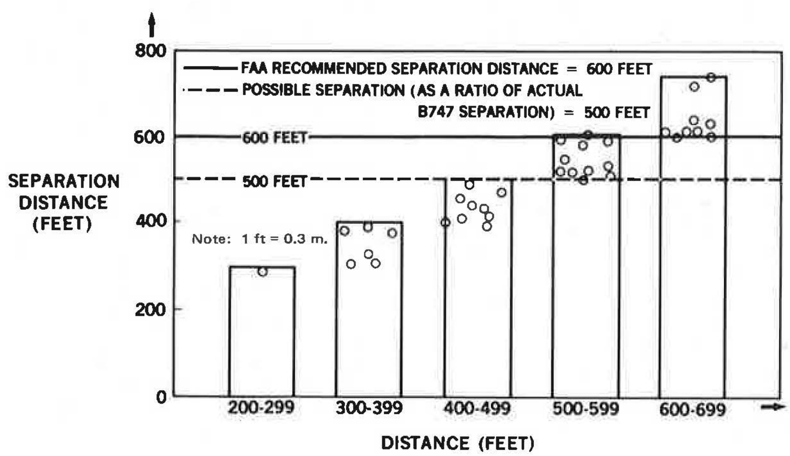


Figure 5. Parallel runway and taxiway separations.



discussed for parallel runway, parallel runway and taxiway, and parallel taxiway situations at the 31 airports. The approach taken, in the absence of a technical rationale for each parallel situation, is developed through (a) analysis of present FAA- and ICAO-recommended minimums listed in Table 1, (b) examination of various deviations from these recommendations, and (c) logical outlining of possible wingspan versus separation relationships. Separation criteria outlined by design group 2 have been examined extensively and tested over the years by various agencies and are considered to be optimum for comparison purposes when analyzing design groups 3 and 4.

Parallel Runways

Aircraft that have a wingspan greater than outlined by design group 3 (B747) and ICAO code letter A are currently defined within FAA design group 4 recommendations. Wingspan and fuselage dimensions categorized within these airport design groups affect parallel runway separation by influencing the position of taxiway hold lines, which define the necessary area for aircraft holding and safety spacing. Larger wingspan and fuselage lengths would, logically, demand greater hold-line distances for (a) additional safety separation distance for runoff clearance, (b) landing deviations, and (c) wake turbulence. Figure 3 depicts existing parallel runway separations and ranks the 31 airports. For the airports that are within the 213 m (700 ft) FAA and ICAO minimum [Los Angeles (LAX), San Francisco (SFO), and Athens (ATH)], no significant compatibility increase can be realized. For the remaining data-base airports (87 percent), parallel runway separations are not viewed as a restrictive factor on wingspan expansion. When compared with the daily use of the 213-m parallel runway separation at Los Angeles for unlimited operation of B747-sized aircraft, the design group 3 recommended separation of 366 m (1200 ft) outlined in Table 1 is considered quite conservative. However, caution is necessary in judging this comparison, because the criteria for determining separation distance are uncertain. Also, many parallel runway situations that consist of two sets of dual runways are individually designated for totally separate functions. Their relationship to each other, therefore, is only that of being parallel and is not considered an influencing factor in this paper (e.g., the dual parallel runways at Chicago O'Hare).

Parallel Taxiways

Present parallel taxiway separations for the 31 airports are shown in Figure 4. FAA- and ICAO-recommended separations are plotted along with operational separations of two B747s at Los Angeles International Airport. As can be seen, approximately 63 percent of the airports fail to meet the 110-m (360-ft) recommendation for design group 4.

Distance requirements for parallel taxiway separation are primarily a function of wingspan, main-gear tread, lateral deviation during movement, and required wingtip clearance. But, when the capability of making a 180-degree change of direction is required from one parallel taxiway onto a second parallel taxiway, wheelbase, steering capability, and taxiway width are also important. The recommended FAA separation distance for design group 3 (B747-sized aircraft) is 91.5 m (300 ft) centerline to centerline (Table 1) and 110 m for design group 4. In attempting to demonstrate the possiblity of lowering these recommended separation minimums, a search was made for airports that currently operate with less separation. One example found is the 75-m (247-ft) parallel separation between taxiway U and ramp taxiway T on the north set of parallel runways at Los Angeles International Airport, where two B747s operate (in passing) simultaneously without limitation as a routine procedure and with no instance of incident or accident. If safe operation of B747s can be performed with a 75-m separation instead of the recommended 91.5 m (a 16.5 m difference), then a wingspan as large as 72.5 m (238 ft) may prove safe and be proportionately compatible within the recommended separations. Initially, the Douglas-projected 70-m (230-ft) wingspan appears compatible for the 91.5-m recommendation, but caution is necessary in recommending any wingspan of a greater dimension, because the proportioning is only valid if (a) wingspan is the only aircraft variable, (b) wingtip clearance is not a function of wingspan, and (c) provision for 180-degree turn capability at design taxi speeds is not required. Therefore, before an accurate appraisal of reduction in parallel taxiway separations can be given, a technical evaluation of various projected aircraft characteristics and operating capabilities, including future design trends, should be undertaken.

Parallel Runway and Taxiway

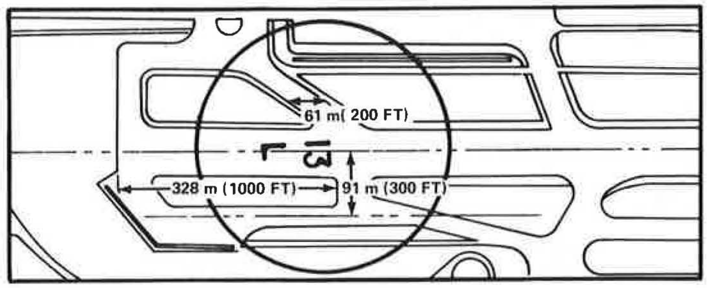
Design group 4 aircraft have a recommended runway and taxiway separation centerline-to-centerline distance of 183 m (600 ft) for simultaneous operation. This was recently changed from a long-standing 305-m (1000-ft) separation. Design group 3 aircraft have a recommended 122- to 152.2-m (400- to 500-ft) separation, depending on field elevation requirements for simultaneous operation. Comparison of the wingspan dimensions defined by these design groups and the recommended separation minimums imposed shows that the design group 4 separation of 183 m appears compatible for the 70-m wingspan of the projected design limit. However, contact was made with control tower personnel of Kennedy International Airport, who verified their endorsement, without reservation, of operating two B747s on parallel runway 13L and taxiway W, which have a 91.5-m separation. This particular example is depicted in Figure 6. With 91.5 m used daily as an operational procedure, an estimated 152.5-m (500-ft) separation is believed possible for the 70-m wingspan of the projected design limit. The thought is again of a proportionate nature, derived from the difference in recommended criteria and real-world practices, including safety requirements consideration.

The present 183-m separation minimum exceeds the specifications at many of the data-base airports; the possible 152.5-m separation would help to put more airports into a compatible category. Therefore, not all of the airports can become compatible with the theorized reduction of separation minimums but, as with parallel runway and parallel taxiway situations, more airfields are classified as compatible with an acknowledgment of possible nonessential separation. This is shown in Figure 5.

Analysis of a Maximum Wingspan

Critical airside areas have been examined in order to determine the capability of existing airports to serve an aircraft that has dimensions greater than the B747-sized aircraft of design group 3. As Figures 3-5 demonstrate, operations at several of the data-base airports are subjected to stress by the dimensions of the B747, with no foreseeable future capability for unrestricted handling of a larger aircraft. A maximum wingspan of 61 m (200 ft) seems necessary to ensure adequate separation

Figure 6. Example of operational separation at Kennedy International Airport.



for simultaneous, unrestricted operations at the domestic and international airports analyzed. This 61-m figure is dictated mainly by the narrow parallel runway separation at Los Angeles, San Francisco and Athens airports, and some additional airports are limited in required parallel runway and taxiway and parallel taxiway separations. By summarizing the presented material, and considering alternative or new airports in lieu of Los Angeles, San Francisco, Athens, Kennedy, and Copenhagen, which have the major limitations, the hypothesized wingspan of 70 m could be considered compatible. This 70-m wingspan is rational because of the small percentage change necessary and the desire for both economical and physical change in the next 20 years at most of the data-base airports. If this speculation is valid, in the past airports have paid a near-term large economic penalty by using too much separation; however, their capability to expand, if required, is enhanced.

Geometric layouts of runways and taxiways at airports to be used in this century and beyond will limit the unrestricted use of a wingspan less than 70 m in a few cases and more than 70 m in most cases. This relationship of maximum aircraft size to airport limits can only be changed by major construction efforts or aircraft design innovations, such as wingtip fold or winglets. To exceed this span recommendation would contradict necessary safety measures.

CONCLUSION

FAA advisory circulars, various handbooks and manuals, and ICAO's construction standards provide recommended separation criteria. Any new aircraft that have greater dimensions than their predecessors create changes in these criteria, which affect compatibility. Although a 70-m (230-ft) wingspan is compatible with many of the existing airports, a number of important international airports cannot accommodate an aircraft wingspan of more than 61 m (200 ft) without sacrificing their capacity to some degree. In this case, the manufacturers must analyze and weigh the impact of these restrictive airports on larger aircraft designs and either design within these restrictions or find alternative airports designed to accept larger aircraft. This is especially true at the larger metropolitan hub airports built prior to the introduction of heavy jet aircraft. These older airports have already reached or exceeded their planned traffic capabilities. Larger aircraft could help to alleviate this traffic problem, but not if it would interfere with the operation of other traffic or cost the airport such an exorbitant amount of money for rebuilding that it would be impractical. A major factor to consider is that some airports are unable to rebuild or change because of lack of space. The availability of alternative airports is limited, and usually they are far removed from the major city hub. If ground transportation for this added distance is not justifiable, then major reconstruction efforts would undoubtedly be needed to make these airports compatible for large operations. This would mean large acquisitions of land and an enormous financial investment.

An aircraft's compatibility with a particular runway and taxiway system is defined as where wingspan or fuselage overall length become critical. Each airport studied may serve aircraft that have a greater than 61-m wingspan, but not without delays, inconveniences, numerous changes in procedures, and encroachment of safety requirements.

It is concluded that a wingspan in excess of 70 m oversteps any capability of change to airside systems and precludes provision of an unrestricted, safe system. Consequently, it is presumed that airport authorities and regulatory agencies will be unwilling to accept a greater wingspan.

A maximum, totally compatible wingspan dictated specifically by runway and taxiway separations at all 31 data-base airports is 61 m. However, a 70-m wingspan is speculated to be compatible with all data-base airports (except Los Angeles, San Francisco, Athens, Kennedy, and Copenhagen) if minor changes are made to some of them.

RECOMMENDATION

A scientific rationale should be developed to technically define necessary separations dictated by aircraft physical and performance characteristics. This would facilitate determination of the airport components for future, large aircraft.

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Publication of this paper sponsored by Committee on Airport Landside Operations.