followed. The tutorial papers are followed by the reports of the workshop groups. Each group report contains the names of the participants in that group. The report concludes with a list of the names of the workshop participants and of the members of the sponsoring committee.

PLENARY SESSION - TUTORIAL PRESENTATIONS

THE VARIED ASPECTS OF AIRCRAFT/AIRPORT COMPATIBILITY AND ITS ACHIEVEMENT

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Abstract

Airplanes built by the major manufacturers operate at international and domestic airports throughout the world. The purpose of this paper is to identify the various elements that must be considered in compatibility studies of future aircraft that will be operating into this large airport system. Compatibility requirements for both the runway/taxiway system and the airplane at the apron terminal area are introduced. The paper emphasizes the requirement to reduce the operational ground time of the aircraft and to decrease airline total direct operating cost associated with any particular aircraft. Several trade studies are presented to demonstrate how aircraft design can affect both indirect operating cost and direct operating cost. Also discussed is the need for additional airport data and the fact that airport design standards cannot be used to determine the suitability of operating any aircraft into any existing airport. The paper highlights a number of problem areas that, if left unresolved, may lead to unsafe aircraft operations, incompatible future aircraft, and inadequate design standards for new airports.

Introduction

Thousands of commercial airlines operate at several thousand airports throughout the world with many types and sizes of aircraft. Aircraft sizes range from the smaller 6- to 10-passenger general aviation aircraft to the largest commercial aircraft carrying nearly 500 passengers. Each aircraft and each airport is designed to meet certain requirements in order to satisfy the needs of the airlines that use them. The challenge is to achieve a state where the airport and the fleet of aircraft using it are completely compatible. This challenge becomes the responsibility of the three major partners in the air transport industry - the aircraft manufacturers, the airlines, and the airport operators (Figure 1).

On the surface achieving compatibility between airports and aircraft seems a relatively simple task. It remains only to select the most critical aircraft that will use a particular airport and build or modify the airport accordingly. However, the task becomes increasingly difficult as the details of the design are established. First, the amount of documented information available to assist the designer is limited to a small number of FAA and ICAO documents. Second, it soon becomes apparent that the airport, which has a long life, should be designed to accommodate aircraft and operation levels expected twenty years in the future. Finally, the airframe manufacturers, in order to meet ever-changing airline requirements, are continually designing new aircraft, which may require different airport characteristics. As the time period for a new aircraft design is relatively short (less than five years), it is a difficult but necessary task to predict these future new designs.

Another aspect of the compatibility question is related to the airframe manufacturer's effort to design an aircraft that will provide the lowest overall cost of operation for the airline. In the past, this effort was primarily associated with trying to achieve the lowest direct operating cost (DOC). However, simply designing the aircraft for the lowest DOC does not ensure the lowest overall cost to the airline [total operating cost (TOC)] because such a new design may require substantial modifications/changes to ground service equipment and terminal gate installations, thereby increasing indirect operating cost (IOC). The manufacturer can not simply make a completely compatible aircraft in every case to minimize IOC, as he would then have to make compromises or otherwise be restricted in his effort to minimize DOC. The best solution lies in a compromise that yields the lowest TOC for the airline. This compromise solution must be determined by trade studies that consider the aircraft parameters and their effect on a predetermined group of airports and airlines.

Other compatibility aspects that must be considered are those associated with the community (noise and air pollution) and with operational safety. The community factors are important in determining overall aircraft and airport compatibility, but these factors are not discussed in this paper. Safety is a constant consideration in all compatibility work and integral to all the following discussions.

In the following sections, aircraft and airport compatibility aspects are discussed in detail. Most

Figure 1. Partners in the air transport industry.

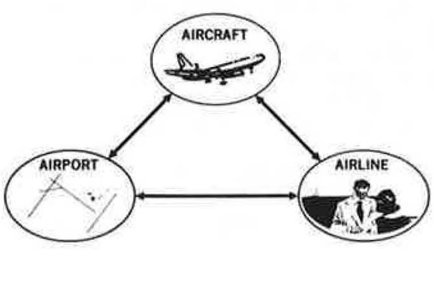


Figure 2. Boundary of airport/aircraft compatibility considerations.

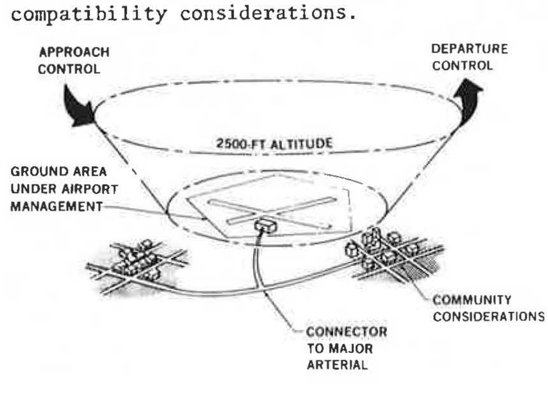


Figure 3. Aircraft design integration with airports.

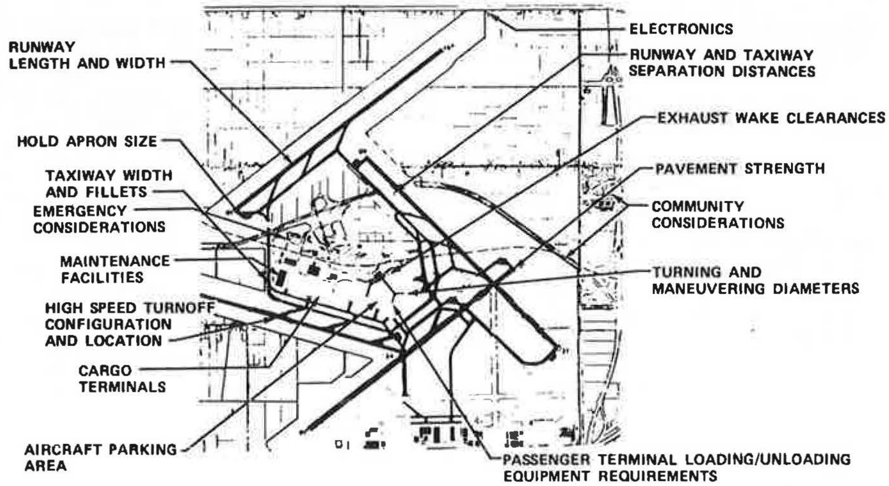


Figure 4. Elements of airport/aircraft compatibility.

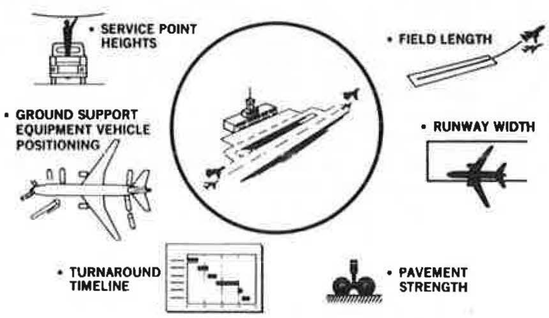


Figure 6. IOC/DOC versus time (domestic trunks).

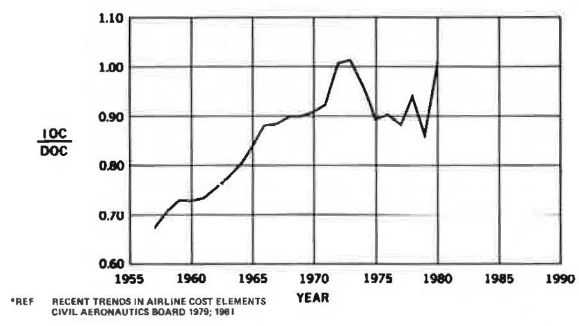
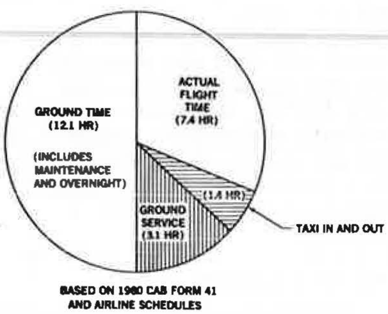


Figure 5. Average aircraft utilization (five domestic trunk carriers).



of the discussions describe areas of compatibility where the procedures and design parameters are fairly well understood. There are, however, areas of compatibility that still have not yielded to organized compatibility efforts and that are not well-defined. A number of these difficult aspects of compatibility are also highlighted.

Basic Airport/Aircraft Considerations

Airport and aircraft compatibility encompasses all the aspects in Figure 2. Our concerns begin when the aircraft enters approach control. From this point, we are interested in all aspects of aircraft ground operations under airport management. Our concern ends when the aircraft leaves departure control. In addition, we consider ground access into airports and environmental concerns associated with nearby communities. In summary, compatibility efforts deal with all aspects of the air transport activity with the exception of the enroute segment. A more detailed list of areas of compatibility concern relating directly to the airport airside is depicted in Figure 3.

Some of the significant areas of compatibility that must be considered are illustrated in Figure 4. At Douglas, new aircraft studies are initiated by evaluating the aircraft compatibility with the airside portion of the system of airports into which the aircraft is expected to operate. We are concerned with such things as runway length, runway width, taxiway width, pavement fillets, and pavement strength. Once it has been determined that the aircraft is compatible with the airside portion of the airport, we turn our attention to studying the aircraft and its requirements for maneuvering into, and parking at, the apron terminal gate. In this area, we are also concerned with the location of the various servicing points on the aircraft. Our objective is to minimize and/or eliminate sequencing of servicing operations. We also want the service points to be located in positions easily reached by ground personnel.

Our goal in developing a new airplane is to define the configuration in such a way that minimum manpower and minimum ground support equipment will be required. It is also our goal to do this in such a way that aircraft ground time is minimized, thereby increasing available flight time. The average aircraft utilization in a 24-hour period is depicted in Figure 5. As indicated, approximately 50 percent of the time the aircraft is either in maintenance or

Figure 7. Indirect operating costs for selected trunk airlines (1971).

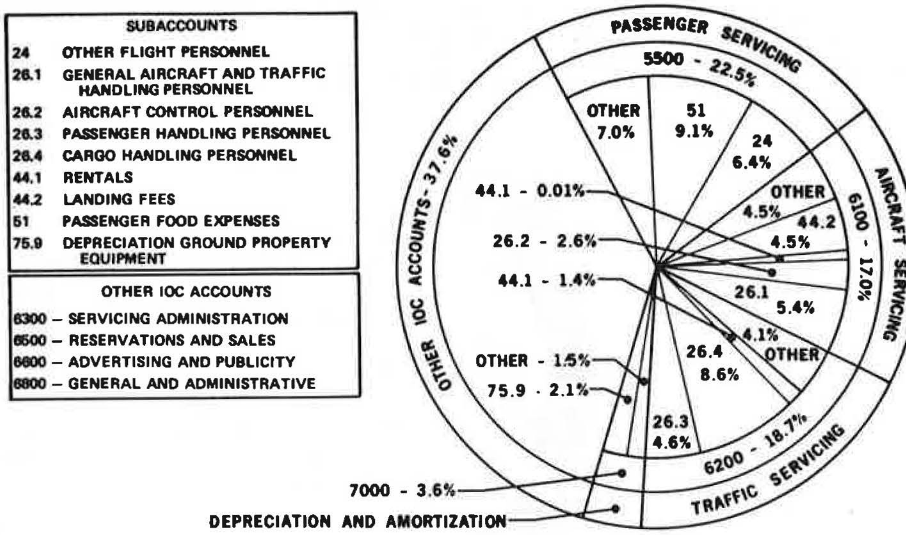


Figure 8. Aircraft cost versus airport cost.

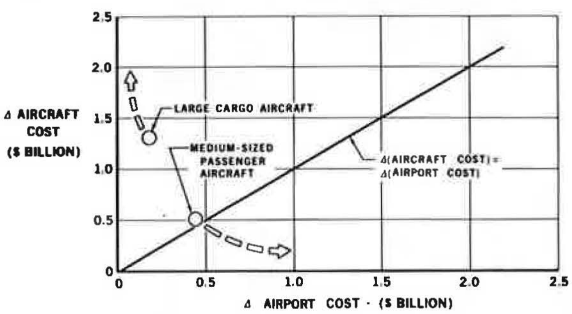
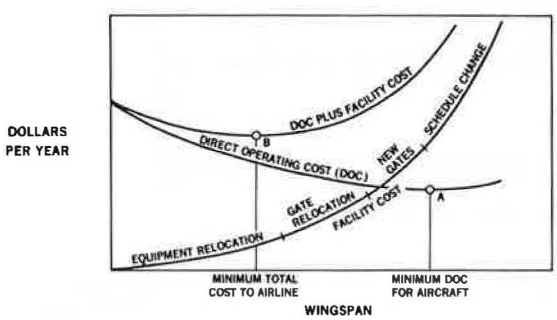


Figure 9. Systems approach to wingspan selection (apron/gate area).



overnighting. For the remaining twelve hours that the aircraft is in the operational mode, 38 percent of the time is spent on the ground at the airport. The primary thrust of airport/aircraft compatibility efforts is therefore to evaluate possible solutions to reduce this ground time, thereby allowing the airlines to increase their utilization of the aircraft.

In addition to reducing ground time, we must carry out our work in a manner such that the airlines' total operating cost can be reduced. Total operating cost is defined as DOC (fuel, aircraft depreciation, maintenance, flight crew, insurance) plus IOC (all other airline expenses). IOC includes all of the cost of handling and operating the aircraft at the airport. The ratio of IOC to DOC is plotted against

Figure 10. Airport/aircraft compatibility questions.

WHAT AIRPORTS MUST AIRCRAFT BE COMPATIBLE WITH?

WHAT MUST THE AIRCRAFT BE COMPATIBLE WITH AT THESE AIRPORTS?

WHAT ARE THE METHODS OF DEFINING COMPATIBILITY?

WHAT DATA ARE REQUIRED TO SUPPORT THESE METHODS?

HOW ARE DESIGN REQUIREMENTS SPECIFIED TO OBTAIN COMPATIBILITY?

HOW IS COMPATIBILITY INFORMATION DOCUMENTED AND PRESENTED TO EITHER AIRLINE OR AIRPORT OPERATORS?

time in Figure 6. Had a fuel cost situation not significantly increased DOC in the mid-1970's, the IOC would have continued its upward trend relative to DOC. In our compatibility work, we attempted to influence the development of both the airplane and the airport so that both IOC and DOC will decrease.

Figure 7 illustrates that there may be technical interfaces in over 60 percent of the airlines' IOC in the areas of passenger servicing, aircraft services, traffic services, depreciation, and amortization. It is in these areas that we should be attempting to improve the total airplane/airport system, thereby allowing the airlines to provide these services at a reduced cost.

Two examples of TOC considerations are shown in Figure 8 and 9. Figure 8 illustrates the results of a study comparing the cost of improving a number of airfield pavements versus various landing gear designs. For small aircraft it is more cost-effective to design the landing gear to be compatible with airfield pavement than to improve all of the pavements. Alternatively, for very large aircraft it is more cost-effective to improve the airfield pavements than to design the aircraft to be compatible with existing pavement strengths. Another tradeoff study in which both IOC and DOC were considered is illustrated conceptually in Figure 9. In this study, increasing aircraft wingspan versus airline terminal modification was compared. If minimum DOC is the determining criterion, the wingspan associated with Point A would be selected. However, if ground costs are also considered, a wingspan defined by Point B would be selected to provide the minimum total operating cost. Similar tradeoff studies need to be conducted for aspects such as airborne stairs versus passenger bridge/ground stairs, and airborne auxiliary power units versus ground power, among others. Finally, a list of key questions (Figure 10) is offered to assist the airport compatibility engineer in defining his effort with each aircraft of interest. It is necessary to identify the airport elements with which an aircraft must be compatible. The method of defining compatibility also must be identified, the data required to support these methods must be acquired, and the information has to be documented for use by various interest groups.

Figure 11. DC-10 United States airport data base (70 airports).

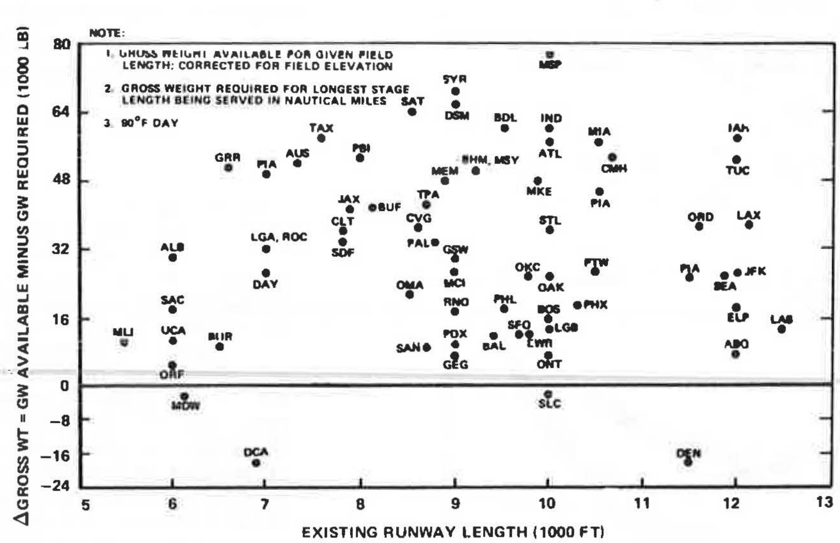
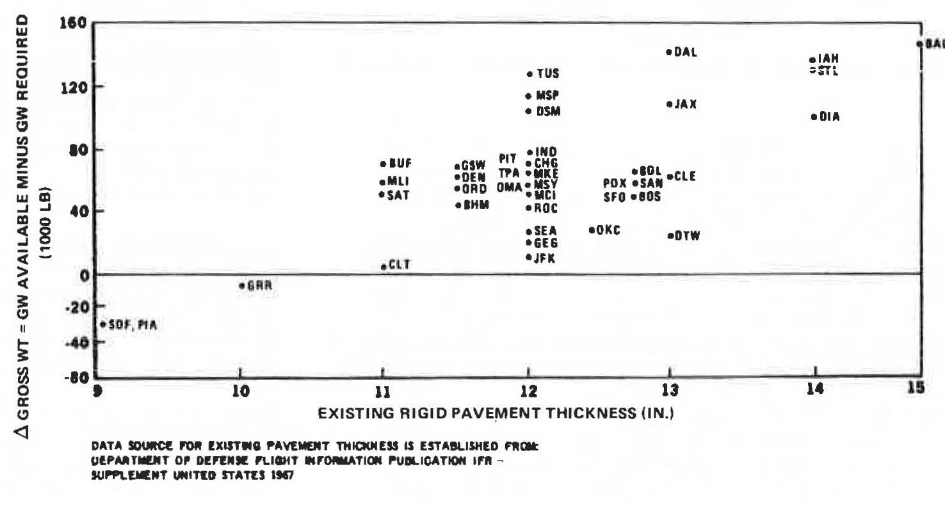


Figure 12. Runway length analysis for DC-10.



DATA SOURCE FOR EXISTING PAVEMENT THICKNESS IS ESTABLISHED FROM: DEPARTMENT OF DEFENSE FLIGHT INFORMATION PUBLICATION IFR – SUPPLEMENT UNITED STATES 1967

Figure 13. Rigid pavement analysis for DC-10.

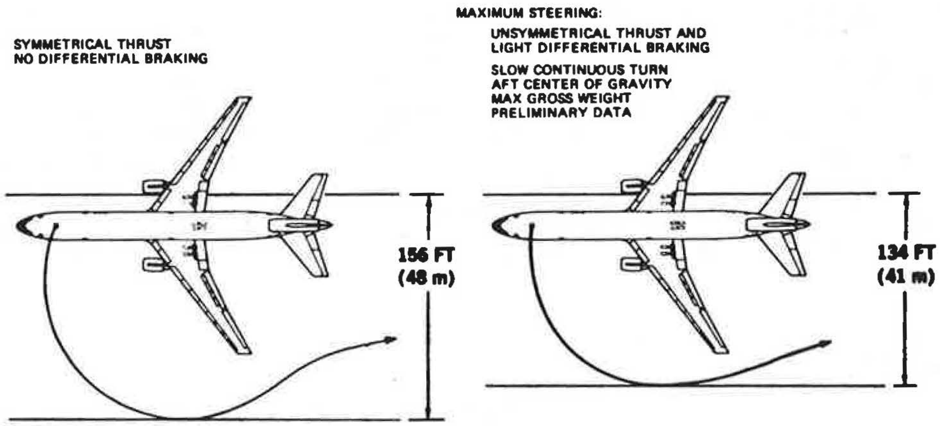


Figure 14. Pavement width requirement for 180-degree turn (DC-10 18.3-ft stretch).

Figure 15. Taxiway-to-taxiway geometry (cockpit-over-centerline steering).

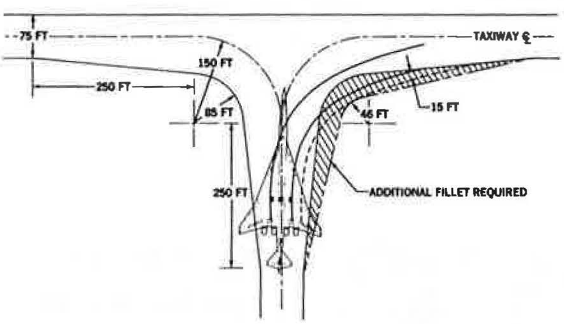
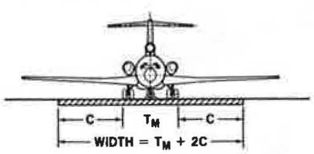
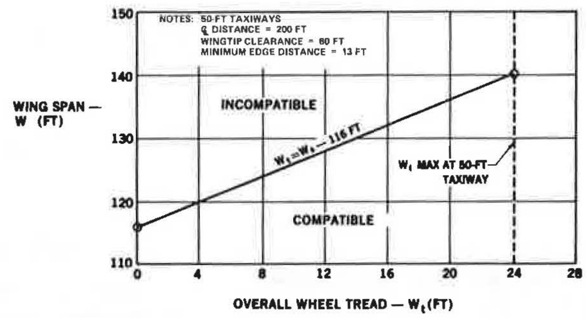


Figure 16. Taxiway width criteria.



TAXIWAY WIDTH*			
MODEL	T_M	C	W
727-100	23	13	50
727-200	23	17	75
747	41	17	75

Figure 17. Parallel taxiway separation criteria (group 1 aircraft).



Evaluation Techniques

This section deals with the techniques of establishing and documenting the compatibility of a new or derivative aircraft with the system of airports in which it is intended to serve. A majority of these techniques are quite well established. Others have been developed to resolve particular compatibility aspects of aircraft that have features unique to previous models. Some of the examples of these evaluation techniques are discussed in the following paragraphs.

There is a tendency in airport compatibility work to conduct compatibility studies for specific airlines that are considered to be kickoff customers for new aircraft. At Douglas, we believe that a broad domestic and international data base should be evaluated first, followed by specific airline studies. As an example, the U.S. airport data base that we selected for our compatibility studies of the DC-10 is shown in Figure 11. We chose the top 150 city-pairs based on the number of originating passengers. These 150 city-pairs contained the 70 airports shown.

As the DC-10 was a new, large aircraft, it was expected that difficulty might be experienced with takeoff performance. Figure 12 is the result of a runway length compatibility analysis involving the selected 70 airports. The effect of anticipated stage length was taken into account. In the illustration, the delta gross weight (ordinate) is the gross weight of the aircraft that can operate from the available field length (abscissa) minus the gross weight required to operate on the longest stage length from each of the 70 airports. The aircraft is compatible with those airports that are above the zero line, and airports with inadequate runway length are below the zero line. What had to be decided was whether to improve the aircraft performance, negotiate with airport authorities to lengthen the runway, or operate the aircraft with reduced payload.

Figure 13 shows the analysis of DC-10 compatibility with the 70 airports previously mentioned relative to rigid pavement strength. As in the field length evaluation, those airports above the zero line have adequate strength to accommodate the airplane at the gross weight required to serve the longest state length from each of the airports. Similar studies were conducted for flexible pavements.

In addition to pavement strength analyses such as those just discussed, the aircraft compatibility engineer is faced with evaluating the compatibility of the airplane with special structures such as the pile-mounted runway extensions at LaGuardia Airport. This involves a very sophisticated dynamic structural analysis of the loads upon various elements of the pier structure. Fortunately for the industry, few airports have this type of construction.

An important aspect to consider for each new model aircraft is its ability to negotiate a

180-degree turn on the airport runway. As an example, Figure 14 illustrates that a new stretch version of the DC-10 cannot routinely achieve a 180-degree turn on a 150-foot-wide runway. As a result, parallel taxiways or turnarounds at the end of the runways would be required for normal operations. With the use of differential thrust and light braking, the aircraft can make 180-degree turns within 150 feet, but only for limited operations as the fatigue life of the landing gears must be considered.

Another feature of airport geometry that must be considered is the design of the turns from taxiway to taxiway, taxiway to apron, and taxiway to runway. There are two methods of aircraft maneuver to be considered: judgmental oversteering (used primarily in the United States) and cockpit-over-centerline steering (the ICAO international standard). In Figure 15, a proposed version of the Douglas Advanced Supersonic Transport is shown negotiating a turn using the ICAO cockpit-over-centerline approach. As illustrated, the fillet design must be altered from the standard 85-foot radius to a 46-foot radius

Figure 18. DC-10 ground service connections.

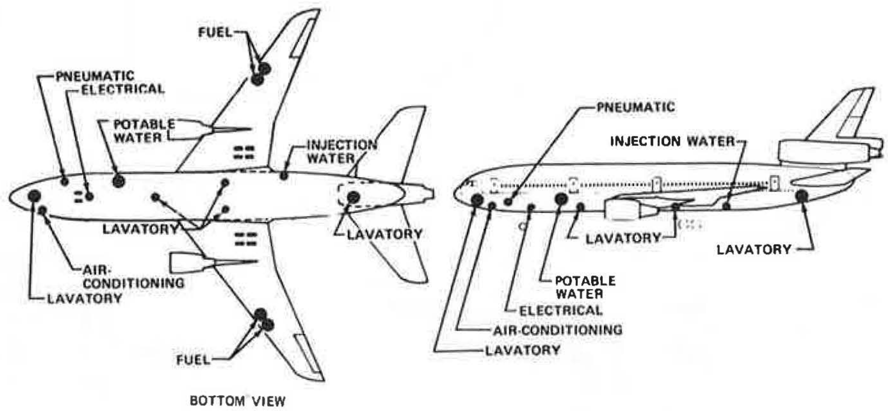


Figure 19. Proposed DC-10 ground servicing equipment arrangement (upper galley).

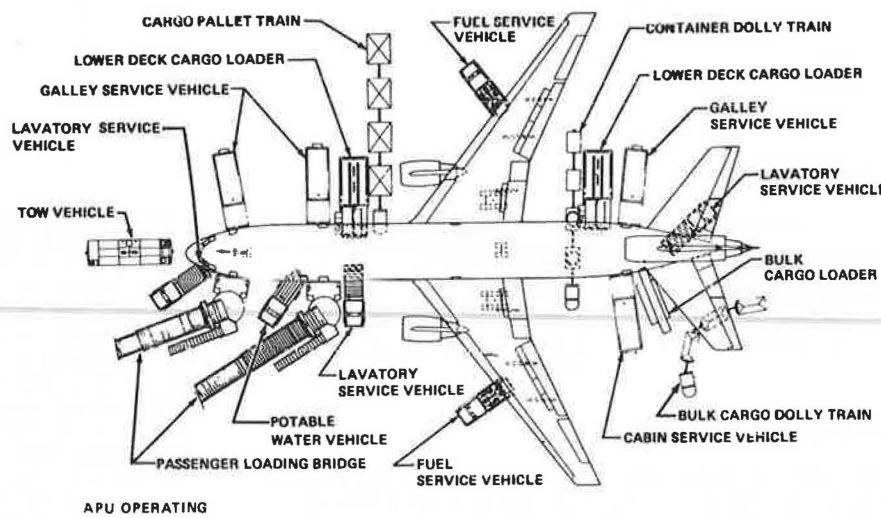
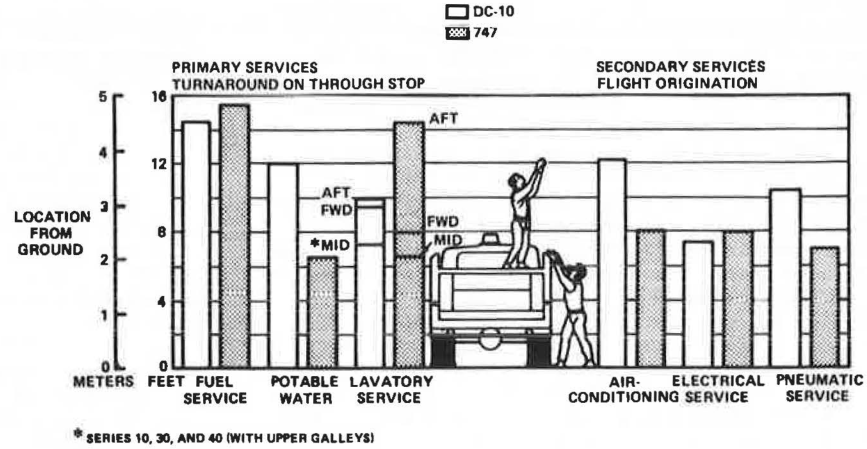


Figure 20. Service point height comparison.

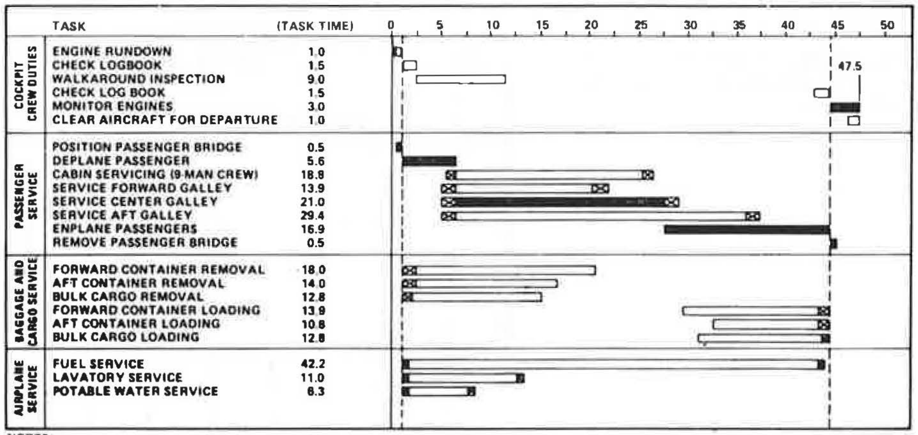


to accommodate this aircraft. The new fillet design satisfies the FAA's requirement of 15 feet between the outside of the tires and the edge of the fillet, but does not satisfy the ICAO requirement of 22 feet for the same dimension.

Caution is suggested when using FAA airport design standards for operational evaluations. Figure 16 is an illustration of difficulties that can be encountered. As shown, a taxiway width of 50 feet is recommended for the 727-100 aircraft, which has a gear tread width of 23 feet. Note that the recommended taxiway width for the 727-100, which also has a gear tread width of 23 feet, is 75 feet. A gear tread width of 24 feet is acceptable on a 50-foot-wide taxiway using the recommended taxiway edge clearance for Group 1 aircraft.

Another aspect of compatibility that must be considered is the relationship of the aircraft to

Figure 21. Turnaround timeline for a proposed DC-10 (18.4-ft stretch).



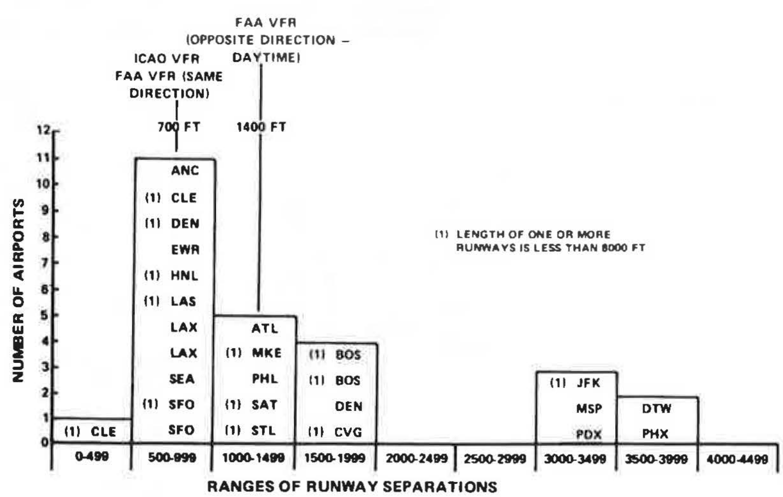
NOTES:

- ⊠ POSITION AND REMOVE GROUND SERVICE EQUIPMENT (NOT INCLUDED IN TASK TIME)
- ESTIMATES BASED ON 24 FIRST CLASS AND 302 COACH, 5300-N MI STAGE LENGTH
- SIMULTANEOUS DEPLANEMENT OF PASSENGERS THROUGH NO. 1 AND NO. 2 DOOR, 302 ENPLANEMENTS THROUGH NO. 2 DOOR
- 962-GPM REFUELING RATE USING TWO TRUCKS. TIMELINE INCREASES 9.1 MINUTES WITH ONE TRUCK AT 750 GPM
- UPPER GALLEY CONFIGURATION. TIMELINE INCREASES 10.1 MINUTES WITH TWO-TRUCK SERVICE
- AFT GALLEY CLOSED OFF DURING PASSENGER ENPLANEMENT

Figure 22. Airport information.

CURRENT SOURCES	SHORTAGE AREAS
• FAA/CAB INFORMATION	• RELIABLE, UNIFORM PAVEMENT DATA
• USAF DATA	• APRON AND GATE INFORMATION
• ICAO DATA BASE	• SINGLE SOURCE FOR AIRPORT LAYOUTS PLANS (ALPS)
• INTERNAL DOUGLAS INFORMATION	• ACTUAL AIRLINE TAKEOFF WEIGHTS
• AIRPORTS/AIRLINES/INDUSTRY GROUPS	• AIRPORTS DEVIATING FROM DESIGN STANDARDS
	• COMPUTERIZED, UNIFIED DATA SOURCE

Figure 23. Distribution of domestic parallel runway separations (centerline-to-centerline).



parallel taxiway separation. Using data from the taxiway advisory circular, the graph in Figure 17 can be constructed. The graph summarizes all of the critical parameters that affect the compatibility of a Group 1 aircraft with Group 1 taxiway geometry. Compatible wingspan-to-wheel tread relationships are noted.

There is great concern with aircraft wingspan and the ability to park the aircraft at the gate. We must consider the relationship of wingspan and fuselage as it affects the ability to maneuver the aircraft between the various fingers of the terminal. Engine blast on personnel, ground installations, and ground equipment is also a factor to consider.

When it has been determined the aircraft is capable of landing, taxiing, and parking, we are then interested in determining the location of ground servicing connections on new aircraft (Figure 18). Since our work is accomplished during the advance design phase of an aircraft that will not be in

Figure 24. Parallel runway-taxiway separations for non-U.S. airports.

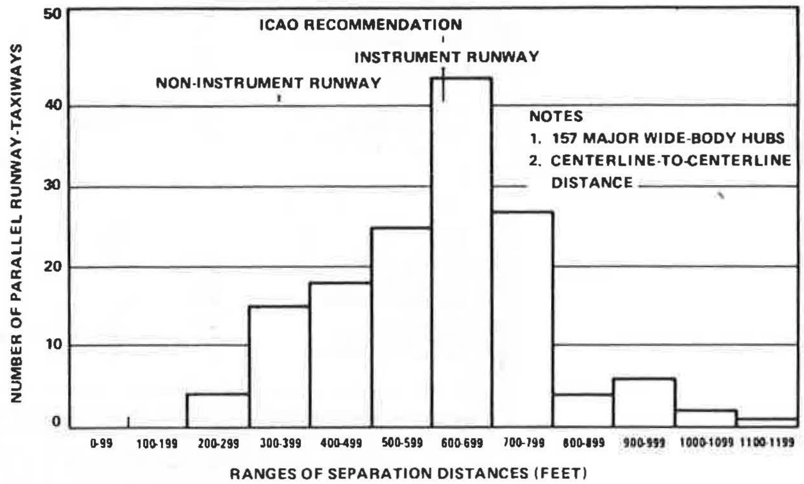


Figure 25. Clearance distances from taxiways.

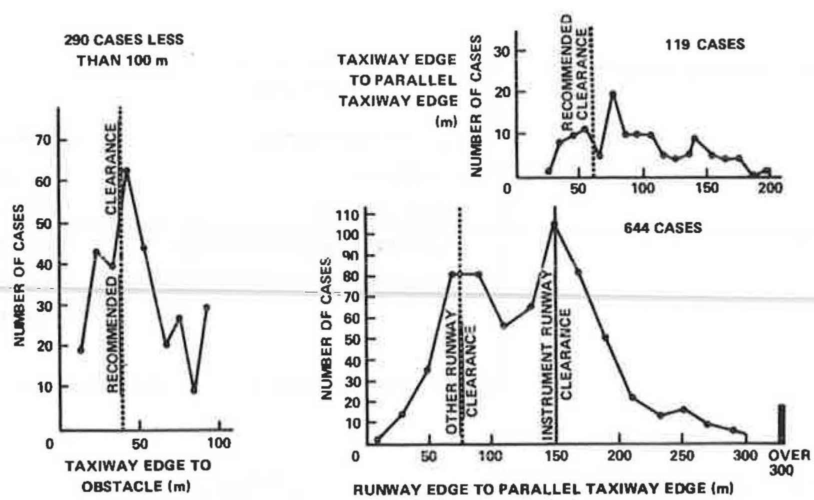
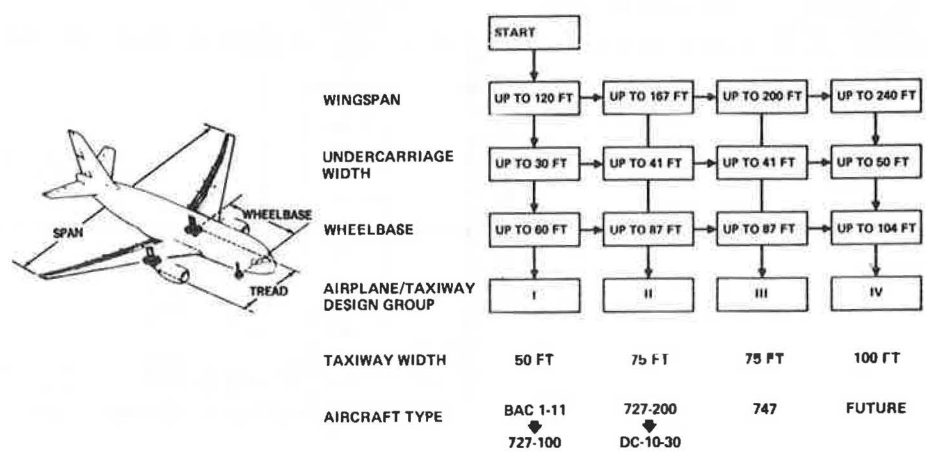


Figure 26. FAA taxiway width standard.



service for 4-6 years and will have a service life of 20-30 years, we must be aware of future trends in airline servicing procedures. Figure 19 illustrates a ground servicing equipment arrangement that does not have to be sequenced to service the aircraft. Ground service points are selected so that they can be serviced by men on the ground or men standing on conventional ground service vehicles. It is common to show these heights relative to existing aircraft to facilitate comparison (Figure 20).

As mentioned earlier in the paper, one of our main challenges in airport compatibility work is to reduce the ground time for the aircraft, thereby increasing the available flight time for the airlines. Figure 21 illustrates a typical turnaround timeline for the DC-10-30. Our job is to identify the critical timepath (crosshatched) and propose aircraft or airport changes that can reduce this time.

Future Considerations

There still remains a significant effort to establish and compile the techniques and data to determine all of the interrelationships between aircraft and airports. Great accomplishments have been achieved in the past decade, but there are areas of compatibility that have not been adequately addressed, primarily because of the difficulty in dealing with them. We need to improve our understanding of the relationship between aircraft operating requirements and airport geometrics and we need to develop techniques to provide an economic balance of compatibility so that the lowest overall system cost is achieved.

The U.S. Industry Working Group has developed several documents to distribute aircraft data to airport planners. These documents describe the characteristics of each airplane for airport planning purposes. They were developed in accordance with National Aerospace Standard 3601. This format has been adopted by all of the major airframe manufacturers throughout the world and provides a consistent and standardized format for each element of technical information. These documents have been of notable assistance to airport planners and airlines.

There are other basic sources of airport information that are available to assist in airport/aircraft compatibility analysis. Several are listed in Figure 22. Areas in which there is a deficiency of information are also listed in the same figure. They include such critical shortages as reliable, uniform pavement data and apron gate information, among others. Airport operators could provide valuable information to the air transport industry if a document paralleling the airplane characteristics document were developed, maintained, and distributed by each airport authority.

The commercial aircraft supplied by the major manufacturers operate at domestic and international airports throughout the world. Smaller aircraft operate not only at small airports but also at medium and large airports. Large aircraft, on the other hand, operate primarily at medium and large airports. It follows that, in the design of smaller aircraft, a larger number of airports must be considered in compatibility analysis than would be considered for large aircraft.

When an aircraft manufacturer is involved in the design of new large aircraft, the characteristics of existing airports must be considered. All airports do not share the same airside geometry, but exhibit a distribution like that shown in Figure 23. This figure depicts the distribution of parallel runway separations as a function of the number of U.S. airports. Figure 24 presents the distribution of parallel runway/taxiway separations for non-U.S. airports. Information supplied by ICAO (Figure 25) depicts the distribution of several airside parameters. Of special interest is the distribution of taxiway edge to parallel taxiway edge distances shown in the upper right corner. When the aircraft manufacturer is considering the design of a new large aircraft, the distribution of airside geometrics for existing airports must be considered. Additionally, it is necessary to decide whether the aircraft must be designed to be compatible with these existing airports or whether the aircraft will not operate into them. As critical as this consideration is, this is the area in which we have the least technical knowledge of compatibility requirements.

The FAA 150 series Advisory Circulars and ICAO Annex 14 define airport standards for the U.S. and international airports throughout the world. Unfor-

Figure 27. Runway width geometry.

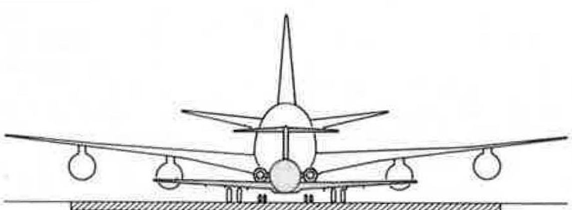


Figure 28. Takeoff weight-field length requirements.

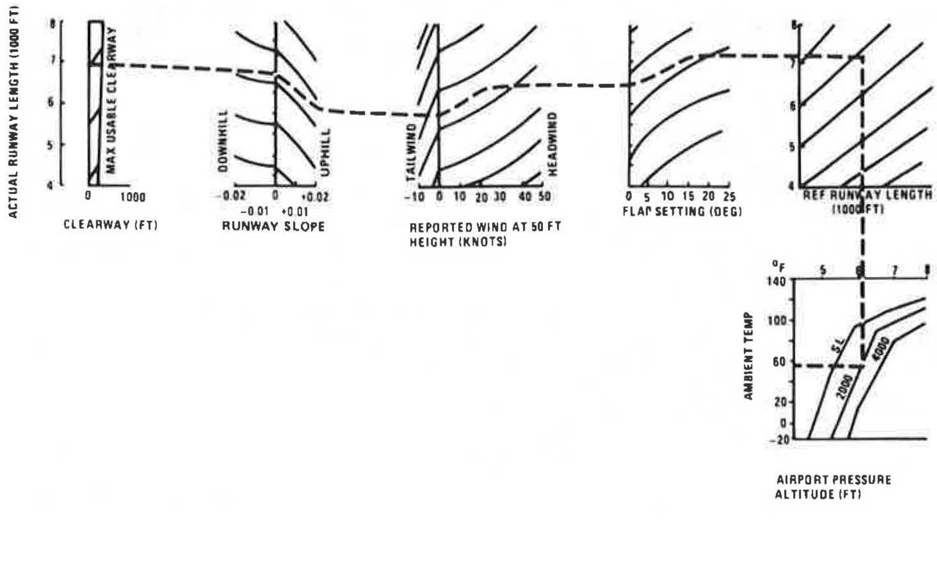
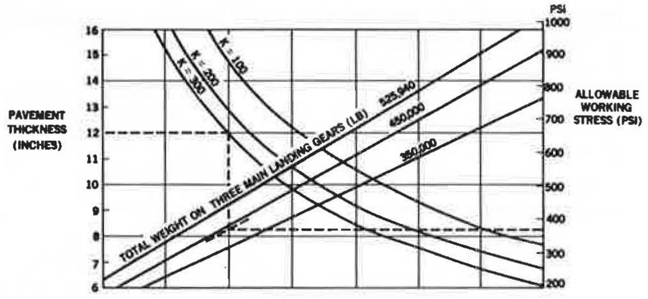


Figure 29. DC-10 rigid pavement requirements.



*REFERENCE: "DESIGN OF CONCRETE AIRPORT PAVEMENT," 1968 PORTLAND CEMENT ASSOCIATION COMPUTER PROGRAM

Figure 30. Conditions that may influence parallel runway separation.

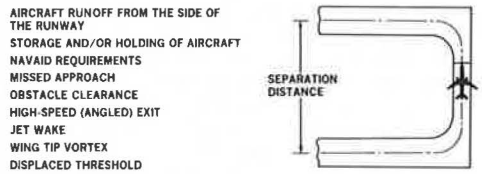


Figure 32. Holding clearance between closely spaced parallel runways.

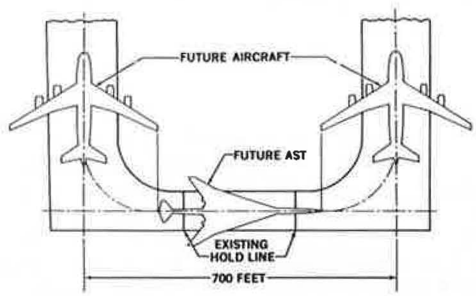


Figure 31. Conditions that may influence parallel runway/taxiway separation.

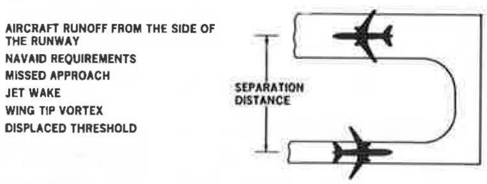
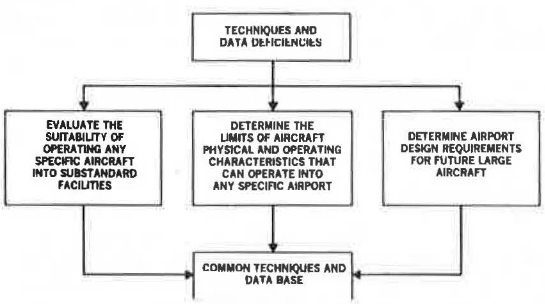


Figure 33. Techniques and data base requirements.



tunately, many people believe that airport design standards define facility requirements for operating a specific airplane. Airport design standards should not be used in this manner. As an example, Figure 26 portrays the FAA taxiway width standards. It shows that for Design Group 2 aircraft, a taxiway width of 75 feet is required for all aircraft from the 727-200, with a 23-foot undercarriage width, to a DC-10-30, with a 41-foot undercarriage width. Obviously, the 727-200 can operate on taxiways significantly narrower than those required by the DC-10-30. Another example deals with runway width (Figure 27). FAA runway width standards recommend 150-foot-wide runways for airports that receive either the DC-9 or the 747. Again, if the 747 can operate on a 150-foot-wide runway, the DC-9 can operate on a runway significantly narrower. Unfortunately, we do not yet have the techniques and data available to determine the minimum runway width required for the operation of any specific aircraft.

In some areas of compatibility study, all of the techniques are established but all the data required may not be available. As illustrated in Figure 28, we are able to determine the required field length taking into consideration such parameters as clearway, runway slopes, surface winds, flap settings, temperature, and altitude. While runway length is well-documented in various data banks and publications, clearways and stopways are not.

Figure 29 illustrates another area where we have the technique to evaluate landing gear design versus pavement requirements for rigid pavements. Given a working stress, the weight on the main landing gear, and the subgrade motulus K, one can determine the rigid pavement thickness requirements. In evaluating rigid pavements for operational consideration, thickness is relatively easy to determine and is presented in some reporting systems. However, these reporting systems uniformly fail to report the subgrade modulus. It can be seen in Figure 29 that the required pavement thickness increases as the subgrade modulus decreases.

There is also a great void of knowledge relative to airport airside compatibility requirements. As was previously mentioned, we do not have criteria to determine the minimum runway width required for the operation of any specific aircraft. As shown in Figure 30, we do not have operational criteria for runway/taxiway separation. Some of the consideration that may determine the operational criteria are listed. A similar problem exists on parallel runway separation. Figure 31 lists possible considerations that may determine operational criteria.

Figure 32 illustrates the parallel runway problem considering future large aircraft. Obviously, the aircraft shown cannot work in this geometry. We therefore have to determine the largest combination of wingspan, fuselage length, and possibly tail height that is suitable for operations on closely spaced parallel runways without reducing the capacity of the airport. Some people advocate that we improve our aircraft capacity problem by installing additional closely spaced parallel runways. Before we proceed along this path, we should be fully aware of the limitations that this will impose on future aircraft size.

As shown in Figure 33, the technique and data required to determine operational runway width, runway/taxiway separation, and parallel runway separation are common for (1) evaluating the suitability of operating any specific aircraft in substandard facilities, (2) determining the physical and operating characteristics of aircraft that can operate into any specific airport, and (3) determining airport design requirements for future large aircraft.

The Air Transport Association of America has stated that, even though more and more consideration is being given to airport requirements, there is still no means for the airlines to convey possible aircraft limits or airport constraints to the manufacturers based on the current airport system. The same statement also applies to the airport industry. Solving this problem is the largest challenge facing the airport/airline industry today.

Summary

This paper has described the current airport/aircraft compatibility activity at Douglas Aircraft Company. Our primary goals are to influence aircraft and airport design to minimize aircraft ground time and airline total operating costs. This provides the opportunity to increase the flight utilization of the aircraft and make our aircraft more economically attractive to both the airline and airport operator. The real challenge is economic compatibility, which ranges from designing the aircraft to be compatible with airports to designing the airports to be compatible with aircraft, thus achieving the lowest system cost. The importance of the worldwide distribution of airside geometrics on the development of new large aircraft was emphasized. Data deficiencies were described and technical deficiencies were identified in the airside operating area of the airport. It was pointed out that if we do not enhance our understanding of the relationship between aircraft operating requirements and airport geometrics, we may have unsafe aircraft operations, incompatible future aircraft, and inadequate design standards for new airports.