TRANSPORTATION RESEARCH
CIRCULAR

Number 247, August 1982
ISSN 0097-8515

Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, DC 20418

1981 WORKSHOP ON AIRCRAFT AND AIRPORT COMPATIBILITY

mode
4 air transportation

subject areas
13 forecasting
21 facilities design
53 vehicle characteristics
55 traffic flow, capacity, and measurements

Report of a Workshop sponsored by the Transportation Research Board Committee A3A16 on Aircraft and Airport Compatibility, and held at the Westpark Hotel, Williamsburg, Virginia, October 26-28, 1981.

Workshop Chairman:
D. William Conner, Consultant

Report edited and prepared by:
A. Robert Kuhlthau, Department of Civil Engineering, University of Virginia

CONTENTS

SUMMARY

A two and one-half day workshop was carried out both to promote better communication between the several interest groups involved in aircraft and airport compatibility, particularly those emphasizing ground operations and to identify likely problems anticipated in compatibility as well as various tradeoff solutions involving the aircraft and/or the airport. There were 60 attendees at the workshop including a number from Canada and Europe.

A series of invited papers provided a relatively comprehensive coverage of the various facets of compatibility. A lead-off overview paper on compatibility and its achievement as seen by an airframe manufacturer was followed by four papers which addressed impacts on compatibility from anticipated changes in: the air transportation system; transport aircraft; airports; and operating procedures. A separate paper was devoted to aircraft noise as to its quantitative measure and effect on peoples' response, expected future impact from aircraft operations, and the potential for reducing this impact. A final paper described a method developed to identify and define potential compatibility problems and candidate solutions as influenced by quantitative changes in a great variety of characteristics of either the aircraft or the airport.

Attendees, divided into five groups, examined the following specific areas in detail: compatibility problems for each of the next three decades; methodology for stimulating compatibility; and institutional issues impacting the achievement of compatibility. A number of significant compatibility problems of varied nature were identified, with problems well downstream depending in considerable measure on the developmental scenario of conditions (e.g., demand, airports, energy) then existing. Present compatibility methodology was judged to be deficient in many respects with identified needs including the establishment and maintenance of a comprehensive bibliography and data bank, generation of additional data to fill significant voids, and improvements in certain analytical and physical procedures. Institutional issues identified as seriously impacting the achievement of compatibility were in the general areas of economics (underfunded research and development for airports, airport improvements), airport noise, and deficient long term planning (e.g., the air transportation system at the federal level, land use practices around airports at the local level). As part of their examination in the various areas, the five working groups recommended a number of specific activities as suitable for Transportation Research Board committee action.

INTRODUCTION

A. Robert Kuhlthau, University of Virginia

This workshop was organized and conducted by the Transportation Research Board, Committee A3A16 on Aircraft and Airport Compatibility, with the support of the Federal Aviation Administration and the National Aeronautics and Space Administration.

Committee A3A16, organized in early 1979, is concerned with the development and application of techniques for analyzing the interface, particularly on the ground, of civil aircraft with the airport and its environs, and for providing a basis for decisions concerning design and operations of aircraft and airports that are compatible, integrated, and cost effective. This committee's activities are considered to complement those carried out by the Transportation Research Board Committee A3A06 on Airport Landside Operations and Committee A3A14 on Airfield and Airspace Capacity and Delay.

Invitations to participate in the workshop were sent to leaders in all areas associated with the problems of aircraft/airport compatibility. This includes airframe manufacturers, airlines, airports, consultants, universities, and government regulators and researchers. Approximately 60 persons were in attendance and the list of names of attendees and their affiliations appears at the end of this document.

The workshop had three specific objectives.

1. Promote better communication between the several groups interested in compatibility by identifying what an aircraft (or airport) must be compatible with, methods for defining compatibility, the kind of data required to support these methods, and how best to document the compatibility information for use by the interested groups.

2. Provide the interest groups with an awareness and general understanding of the diverse physical and operating characteristics of the air transportation system, the aircraft, and the airports, as well as public demands, all of which can lead to incompatibility both now and over the next several decades.

3. Encourage more consideration regarding compatibility in the design of all-new (or modifications to existing) aircraft and airports by: identifying the most likely problems anticipated in compatibility; ranking the problems in importance; and identifying and evaluating from technical, economic, and institutional considerations, various tradeoff solutions involving the aircraft and/or the airports.

An additional benefit derived from the workshop is the expression of the collective opinions of workshop attendees regarding various compatibility problem areas. These opinions are expected to influence the direction of thrust and planning of future efforts of TRB Committee A3A16.

In format, the first day was devoted to a series of seven invited tutorial presentations aimed at providing a good background coverage in the various facets of the compatibility problem. Mr. William Shea, Associate Administrator for Airports of the Federal Aviation Administration, provided an authoritative insight to the role of the Federal government toward airport related research and other developments affecting compatibility.

Each attendee, on the second day, participated in one of the five discussion groups listed below.

- Group 1. Methodology for Stimulating Aircraft and Airport Compatibility.
- Group 2. Aircraft and Airport Compatibility Problems and Solutions: 1981-1990.
- Group 3. Aircraft and Airport Compatibility Problems and Solutions: 1991-2000.
- Group 4. Aircraft and Airport Compatibility Problems and Solutions: 2001-2010.
- Group 5. Institutional Issues Impacting Achievement of Aircraft and Airport Compatibility.

On the morning of the third day, the findings of each workshop group were presented to the entire assembly with attendent discussion and final comment.

In preparing this report of the workshop activities, the same chronological approach has been 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

William E. Parsons and Martin E. Wilfert,
Douglas Aircraft Company, McDonnell Douglas Corporation, Long Beach, California

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.

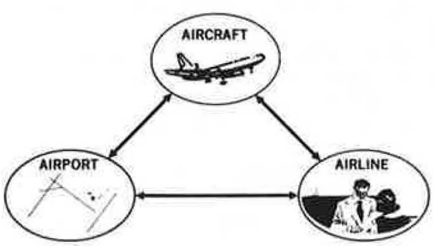


Figure 2. Boundary of airport/aircraft compatibility considerations.

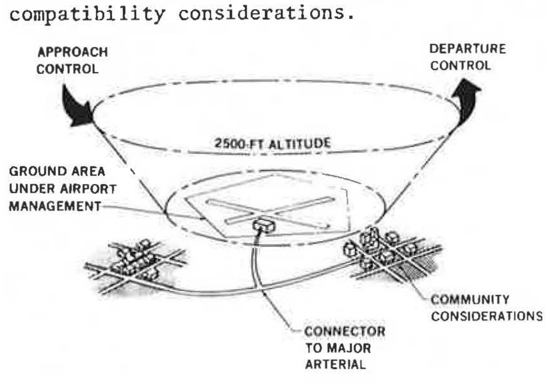


Figure 3. Aircraft design integration with airports.

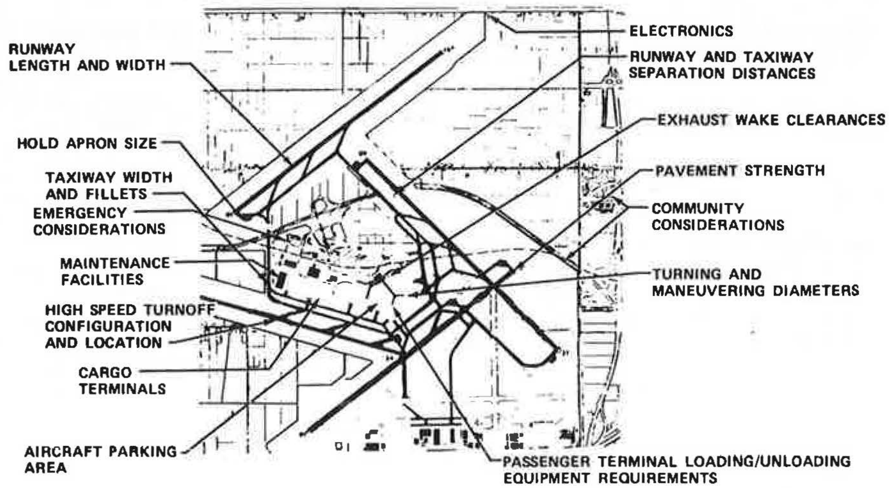


Figure 4. Elements of airport/aircraft compatibility.

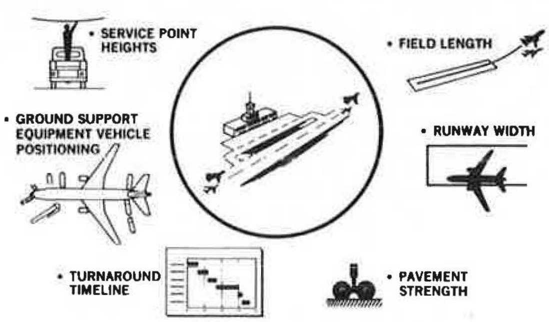
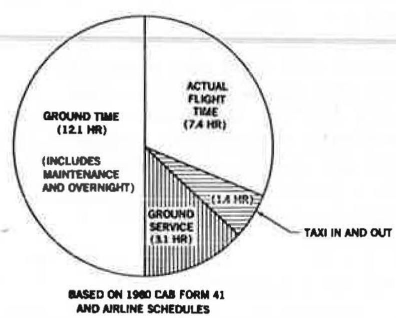


Figure 5. Average aircraft utilization (five domestic trunk carriers).

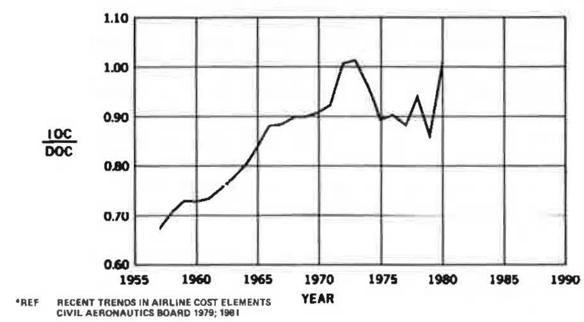


of the discussions describe areas of compatibility where the procedures and design parameters are fairly well understood. There are, however, areas of compatibility that still have not yielded to organized compatibility efforts and that are not well-defined. A number of these difficult aspects of compatibility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

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



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).

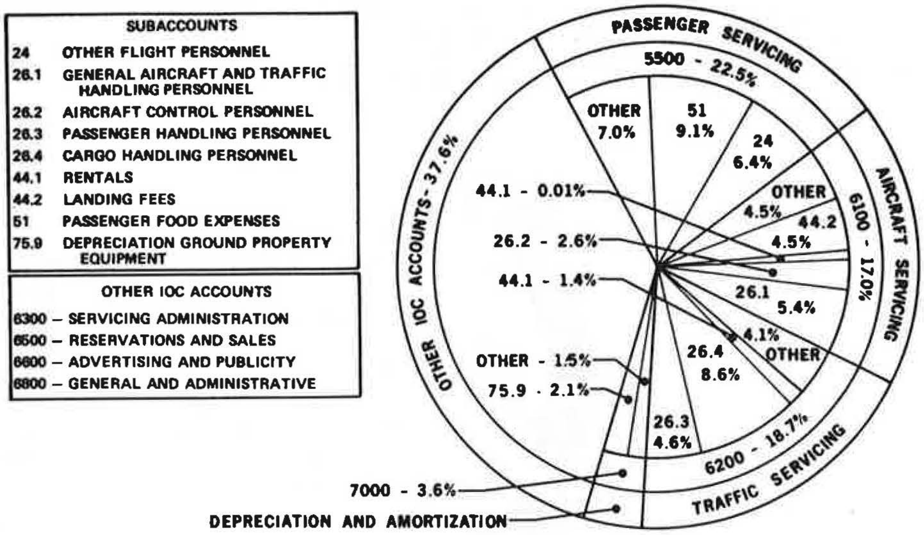


Figure 8. Aircraft cost versus airport cost.

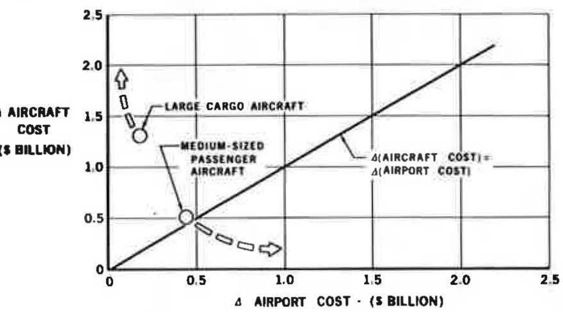
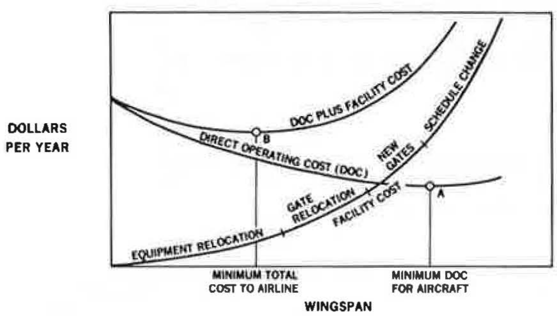


Figure 9. Systems approach to wingspan selection (apron/gate area).



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).

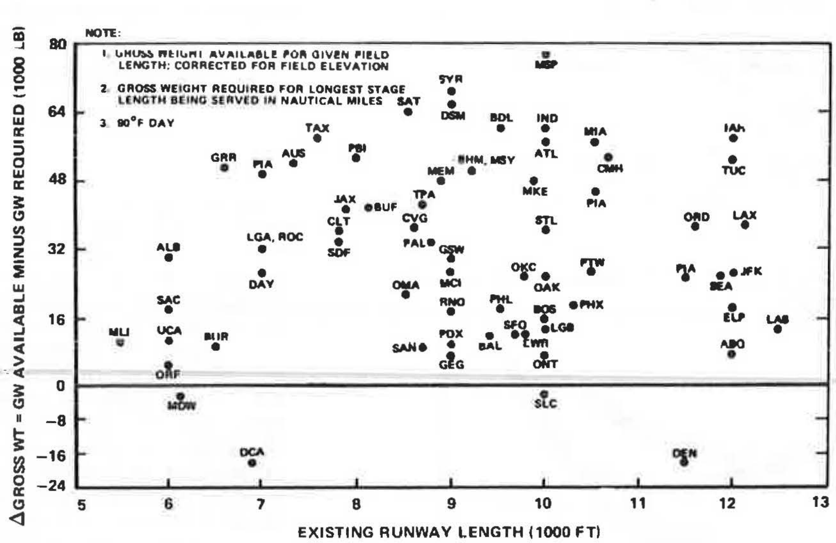
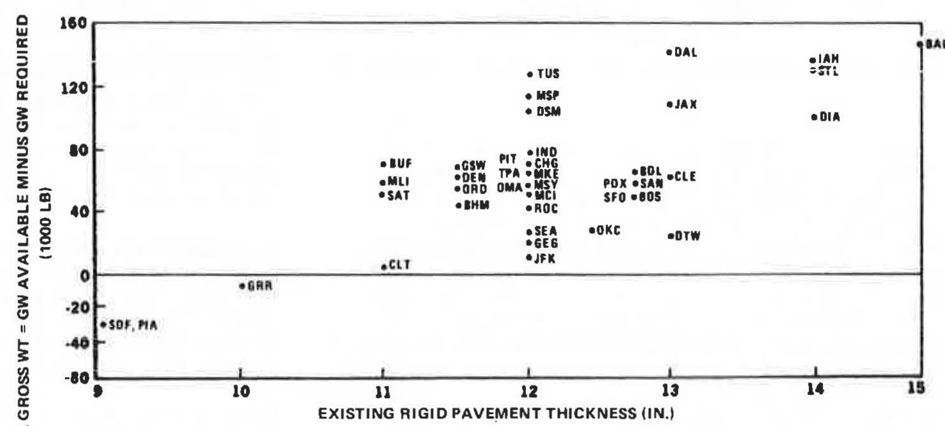


Figure 12. Runway length analysis for DC-10.



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.

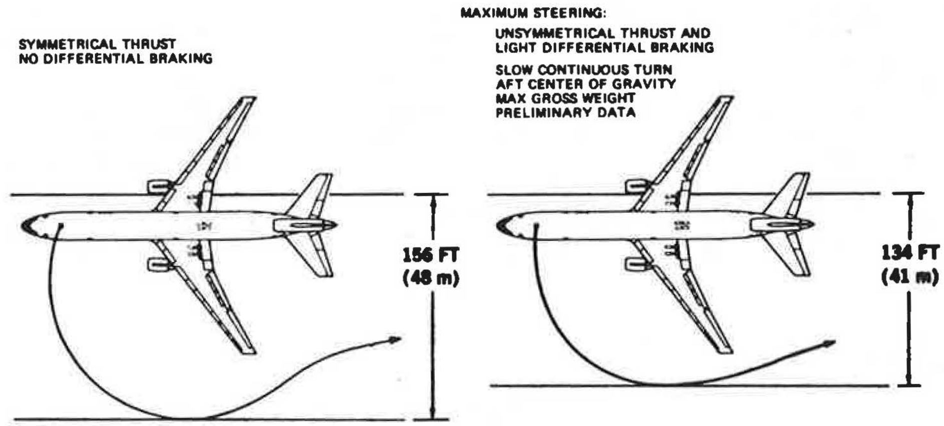


Figure 14. Pavement width requirement for 180-degree turn (DC-10 18.3-ft stretch).

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

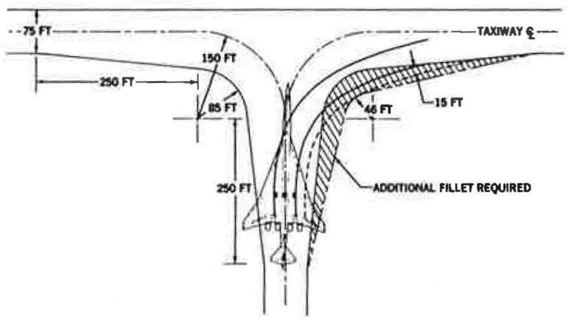
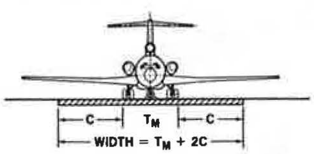
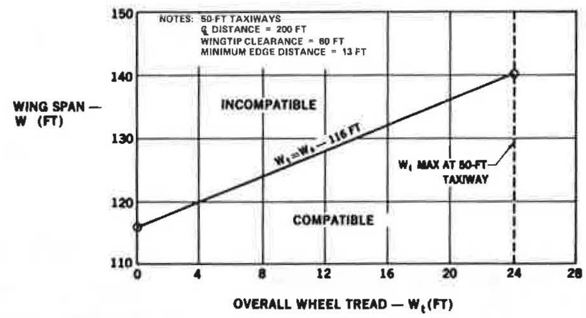


Figure 16. Taxiway width criteria.



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.

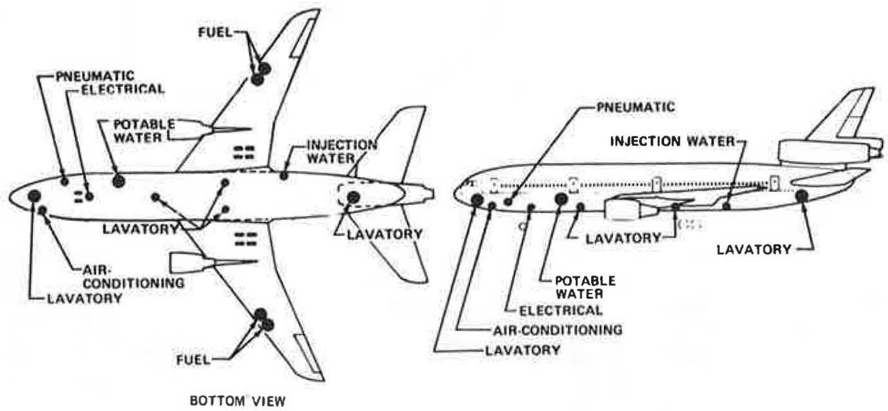


Figure 19. Proposed DC-10 ground servicing equipment arrangement (upper galley).

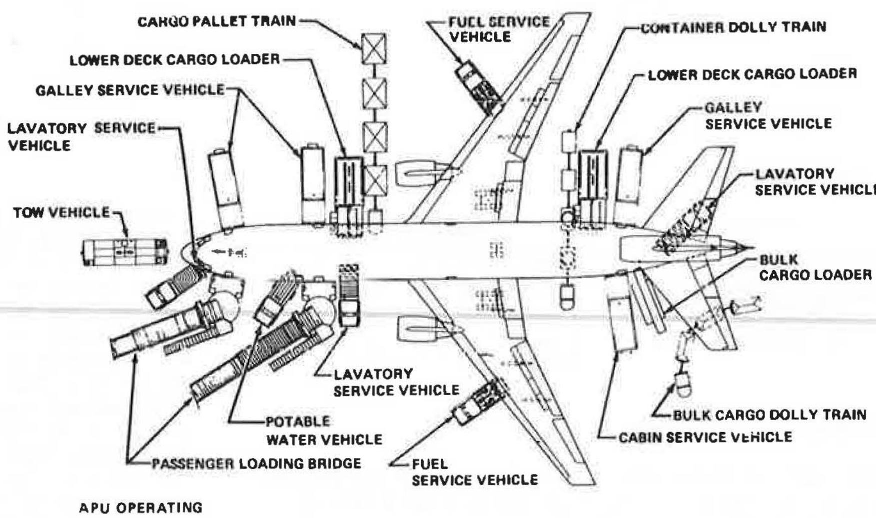
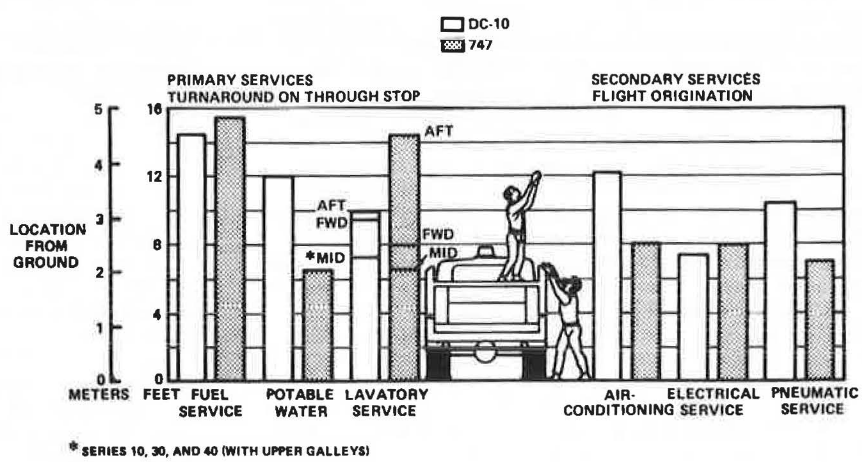


Figure 20. Service point height comparison.

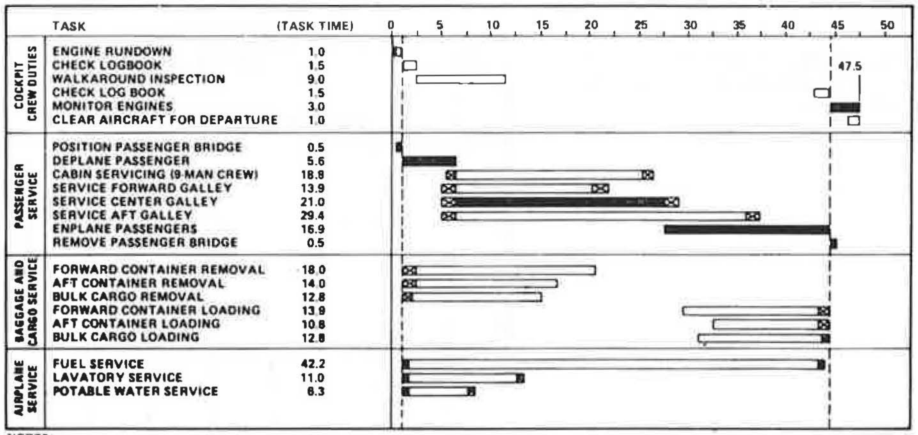


to accommodate this aircraft. The new fillet design satisfies the FAA's requirement of 15 feet between the outside of the tires and the edge of the fillet, but does not satisfy the ICAO requirement of 22 feet for the same dimension.

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).



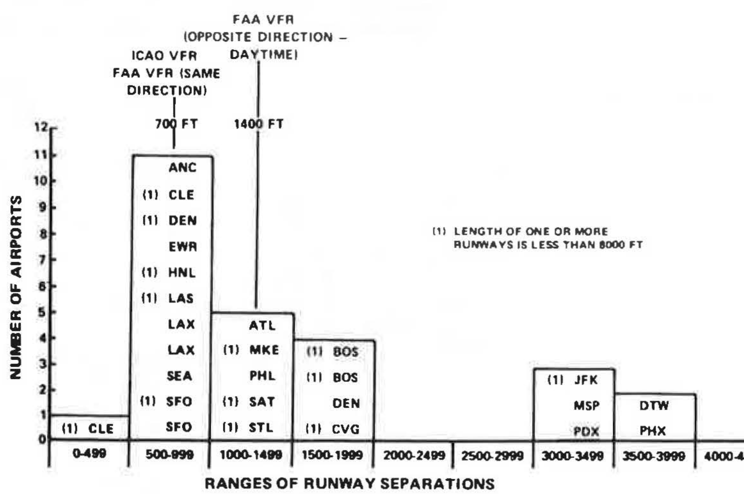
NOTES:

- ⊠ 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.

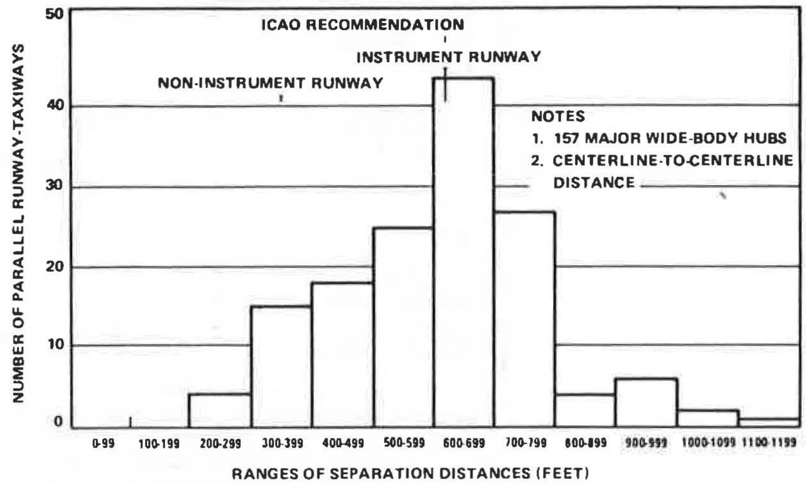


Figure 25. Clearance distances from taxiways.

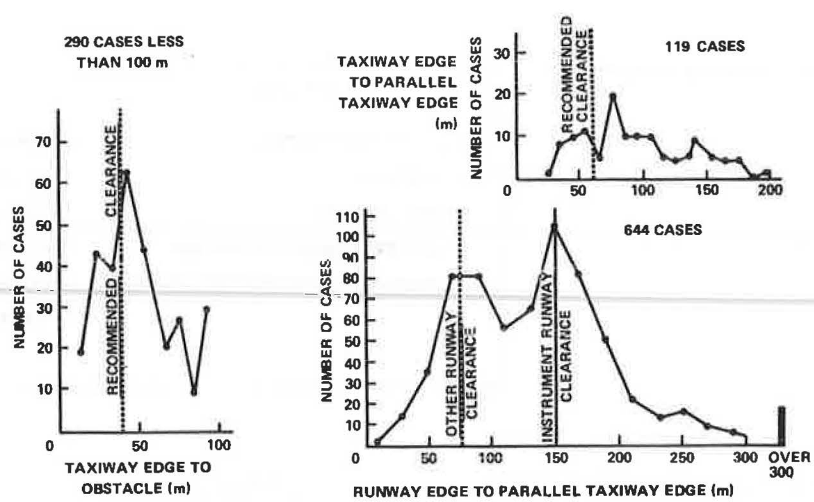
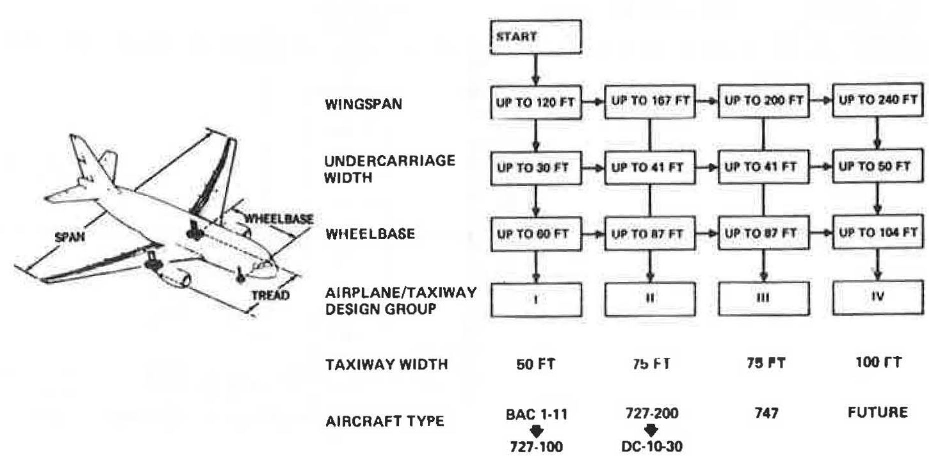


Figure 26. FAA taxiway width standard.



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).

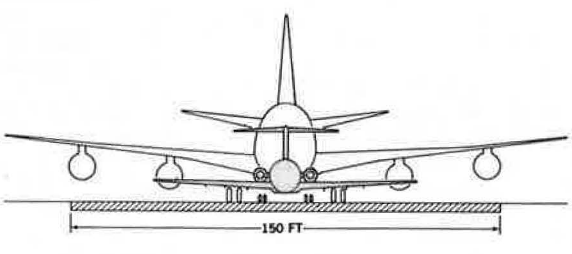
As mentioned earlier in the paper, one of our main challenges in airport compatibility work is to reduce the ground time for the aircraft, thereby increasing the available flight time for the airlines. Figure 21 illustrates a typical turnaround timeline for the DC-10-30. Our job is to identify the critical 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

Figure 27. Runway width geometry.



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 28. Takeoff weight-field length requirements.

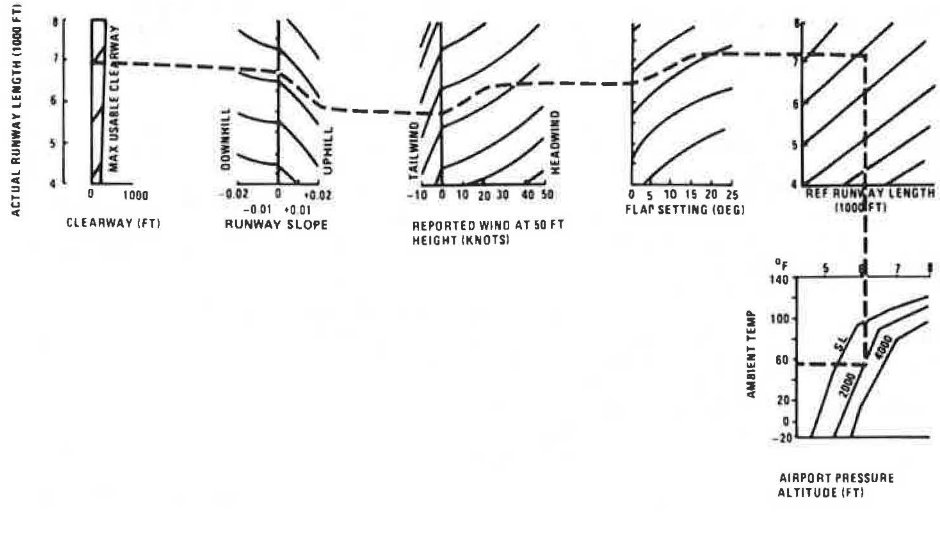
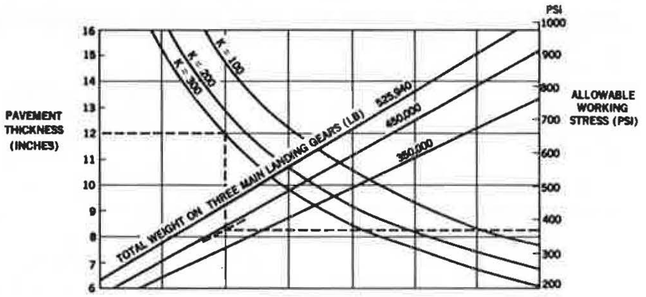


Figure 29. DC-10 rigid pavement requirements.



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

Figure 30. Conditions that may influence parallel runway separation.

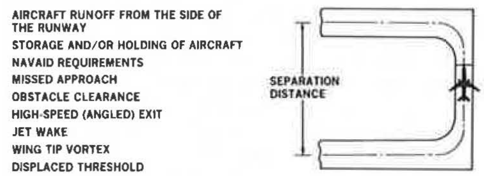


Figure 31. Conditions that may influence parallel runway/taxiway separation.

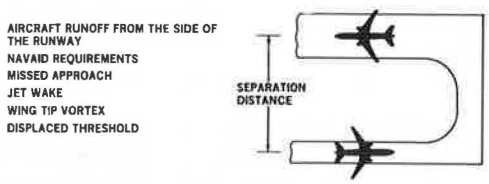


Figure 32. Holding clearance between closely spaced parallel runways.

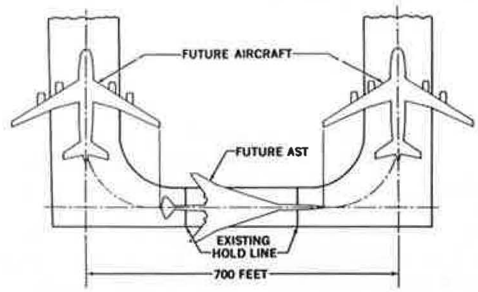
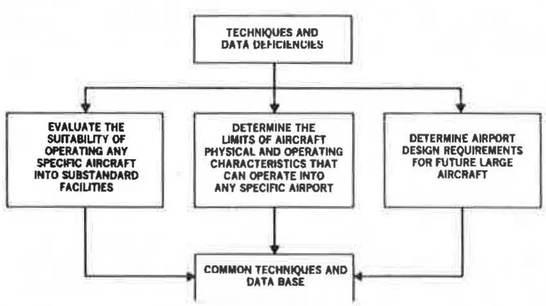


Figure 33. Techniques and data base requirements.



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.

AIR TRANSPORTATION SYSTEM CHANGES WHICH WILL IMPACT AIRCRAFT AND AIRPORT COMPATIBILITY

Philip H. Agee, Air Transport Association of America

Abstract

Forecasts of future air travel and rate-of-growth of the market are examined. The results of work by the FAA, ATA, and a private research group are compared and analyzed. It is suggested that the data indicate that the markets exhibit characteristics of maturity. The nature of the service industry as it will influence aircraft/airport compatibility is discussed, and although difficulties in predicting detailed changes in structure are apparent at this time, the implications are that deregulation will impose a dynamic future on the industry. An analysis of aircraft utilization indicates that since fixed costs, brought about by replacement of equipment, will dominate the future, emphasis will be on high utilization. Factors involved in predicting the impacts on airports of specific system, aircraft, and fleet changes are reviewed, and it is concluded that generalizations are very risky; rather, each case must be considered on an individual basis.

Before the future changes in and impacts of the air transportation system can be assessed, the forecasts of future travel and its growth rate must be examined, and the impact and rate of impact on the growth of passengers, and what impact this will have on the system changes must be determined. Forecasting is a difficult task, but it must be done. The Air Transport Association (ATA) has a responsibility to engage in the art of forecasting, as does the FAA.

Future Traffic Growth

At its annual Forecasting and Planning Review Conference in early October, 1981, FAA indicated that domestic passenger enplanements were estimated to grow at a rate of 4 percent per year over the period of 1980-1993. This translates to enplanements growing from about 280 million in 1980 to 470 million in 1993. The ATA "Domestic Industry Passenger Demand Forecast", developed in 1975, and most recently updated in 1980, is very close to that of the FAA. It projects a 4.5 percent growth per year through the year 2000. Since the ATA forecast is on a lower base and includes a smaller number of carriers, when scaled up to the FAA base, the market is forecast to reach about 620 million annual domestic passenger enplanements by the year 2000. Domestic revenue passenger miles (RPM's) are expected to grow at about 5 - 5.5 percent per year.

For United States international air passenger traffic (to and from the U.S.), ATA is currently projecting an average growth of 5.7 percent per year in the period 1980 to the year 2000. This is down slightly from the annual 6.0 percent which was forecase in 1976. In RPM's an annual growth of 6.5 - 7 percent appears reasonable internationally.

With regard to cargo, the ATA forecast includes the combined domestic and U.S. connected international enplaned cargo tons. It shows the average annual growth rate of 6.4 percent between 1980 and 2000, which is down from the figure of 7.2 percent per year which was forecast in 1978. In actual numbers this represents an increase from 4.6 billion tons at present to 16 billion tons in 2000.

To summarize these forecasts, it appears that deregulation may have had a short term stimulating effect, perhaps coupled with good economic years in 1978 and 1979, resulting in double digit growth rates. However, in 1980 and 1981 the national economic climate has brought the growth rate back down, making the projection of a steady average increase at the levels cited above appear to be quite realistic. The market gives every indication of being mature, and so it might be expected to plot a relatively steady course driven by those factors which went into the original projections.

Additional data to support this projection come from a survey done by Gallup for ATA. This type of survey has been conducted periodically for the past 19 years. The latest survey, conducted in 1981, indicates that 2/3 of the population of the United States have traveled on an airplane once in their lifetime, compared with 1/3 in 1962. Thus there has been a significant penetration of the potential passenger pool. Also, market growth rates of travelers will be tempered on the negative side by such things as reduction in population growth rates, inflation, economic downturn, interest rates, impact of fuel costs on fares, and the potential effect of telecommunications on travel - although this last topic is by no means clear at the moment. On the positive side there is an increase in disposable per capita income, which should stimulate additional travel. Taken together, all of these factors would seem to substantiate the slow but steady growth rate as projected by the ATA long range forecasts.

Returning to the Gallup survey and examining the population pyramids and how they track with time, i.e. how the frequency of travel varies with age group, some interesting observations arise. Consider the post-war "baby boom" group, which received encouragement to fly in the 1960's with all types of family, youth and student discounts. Apparently these tactics were successful in motivating these individuals to fly, since the percentage of the age 35 and under group which responded affirmatively to the question, "Have you flown within the past year?", increased from 14 percent in 1962 to 22 percent in 1970. But since 1970 this percentage has remained stable, and is now actually beginning to decline. The figure was 24 percent in 1980. Looking at other population age groups responding to the same question: the 35-55 group increased from 11 percent in 1962 to 27 percent which represents a plateau which has remained essentially constant for the past 7-8 years; similarly for the age group greater than 55, where the corresponding figures are 12 percent in 1962 and a 26 percent plateau.

All of these factors tend to support the concept of a mature market, and, in fact, the notion of double digit growth rates reappearing and persisting for any extended periods of time is not compatible with the slowing trend in population growth. Starting with the large base of air travelers which already exists, a sustained double digit growth rate would imply that in 30-40 years most of the people in the country would spend most of their time just flying around in aircraft.

Nature of Industry

Within the bounds set by these forecasts as to the size of the future market, one of the major questions affecting the issue of aircraft/airport compatibility is the nature of the service industry. Will it develop along the lines of a few carriers operating a limited number of aircraft of large size at low frequencies, or, at the other extreme, a large number of carriers operating a large number of smaller aircraft at high frequency? This is a real crystal ball type of issue, but based upon evaluating the considered opinions of a large number of sources, it is not surprising that the most probable answer lies somewhere in between. Just where is difficult to say, but it seems reasonably safe to predict that the system which evolves over the years will be quite dynamic in nature.

It appears that the trend among established carriers is to continue the hub and spoke, feeder and connecting format. These carriers see this mode as their major strength, and so those airports which are currently connecting hubs for major carriers are going to continue in that role. The new carriers which have recently appeared primarily as point-to-point operators, offering low fare service in high density markets with no interline agreements and very streamlined operations, will continue to come and go and will probably grow in number with time. The commuter carriers are picking up on the routes abandoned by the major carriers, as the latter make every effort to match their routes to their equipment so that it can be operated profitably. Both the commuters and the new point-to-point carriers are being selective in their new markets to assure that they do match well with their equipment.

Aircraft Utilization

Aircraft utilization has undergone a reversal in the past decade, and will most likely reverse again in the next decade. In the late 1950's and the 1960's the airlines had acquired new fleets of jet aircraft, and were saddled with tremendous fixed costs in having to pay for them. Thus, the objective was to use the aircraft as much as possible to generate revenue, since marginal operating costs for an additional segment or two, which might be added to a daily aircraft schedule, were relatively small. However, when the price of fuel jumped from 11.7¢ per gallon in 1972 to well over $1.00 per gallon today, the economics were completely changed. Whereas in the first case the extra segments could usually generate profit with a load factor of 20-30 percent, now over 50 percent load factors are required, and the airlines cannot afford to operate the aircraft over any but the very best segments. Thus, where the system was once driven by the desire to spread fixed costs over the largest possible route system, it is now driven by fuel costs, implying conservation and reduction of marginal stages.

However, the pendulum is about to swing again. Although the cost of fuel, now stable, will probably resume its rise in the future, it is not expected to be catastrophic, but rather tied very closely to the general rate of inflation. On the other hand, in order to obtain quieter and more fuel efficient aircraft, the airlines are about to embark into an era where they will have committed tremendous fixed costs to fleet replacement. This has already started with the DC 9-80. The B-767 will start operating in 1982, the B-757 in 1983, the B-737-300 in 1984, and some new 150 seat aircraft will undoubtedly become available in the later 1980's. Thus, fixed costs will again dominate the system, and more emphasis on utilization can be expected once again.

Some perspective on the extent of the fixed cost problem is provided by the ATA study published a few years ago. It was called "90 by 90", because it predicted that the capital needs of the air transportation industry would be $90 billion by 1990. Re-examining this position in terms of present developments, it still appears to be a valid estimate. Although the numbers, costs, and mixes of the aircraft have changed somewhat, it still adds up to about $90 billion by 1990.

Expected System Changes

This discussion will now focus on the system changes and the types of aircraft and fleet which will impact the airports in the future, and what the compatibility issues will be. Unfortunately, but in agreement with the previous presentation, the answer is that it is impossible to generalize. Each situation must be considered on a case-by-case, airport-by-airport, and airline-by-airline basis. It is impossible to make generalized statements about aircraft and their impacts. Thus it is necessary to develop specific forecasts for each airport under consideration. These forecasts involve such items as past passenger enplanements, future growth potential of the airport, trends in the share of traffic for the individual airport relative to the total U.S., the various social and economic variables for the local area (e.g. population, per capita income, employment, etc.). Using these factors, the percent share of the total market is forecast, and when multiplied by the total U.S. industry enplanements forecast, the projections of future enplanements at the airport are obtained.

This number is not related to the number of carriers serving that airport. To illustrate, the number of carriers at Phoenix recently increased from 7 to 16 in 1-1/2 years. Yet, in spite of the fact that Phoenix looks good from the point of view of many of the factors mentioned above, the number of enplanements declined 6.4 percent during 1980. This is relative to an 8.2 percent national decline. Thus, based on its good indicators, and as might be expected, Phoenix did better than the national average, but it is clear that the number of enplanements were not influenced by the number of airlines operating there. What did occur was a sharing of the market, with the incumbent carriers losing 16 percent of their previous business to the 9 newcomers. The number of enplanements has continued to decrease, dropping another 2.8 percent during the first six months of 1981, which is in line with the nation as a whole.

The real issue arising from these statistics is to identify the proper impact of the large increase in the number of carriers. It was not an increase in passengers, but rather a focus on the ability to accommodate the carriers properly. This emphasizes the fact that it is absolutely essential that terminal facilities be designed with flexibility and adaptability; with designs being functional and efficient for both the terminal and apron facilities, with both being able to accommodate the dynamic changes which will surely occur with time.

Returning to the general case, after forecasting the specific growth at each airport, the next question is to translate this into aircraft movements. This again involves specificity with regard to existing aircraft equipment, load factors, and fleet mix, and the impact this will have on the airport. Looking at the "design day", i.e. the average day in the peak month, and the "design hour" (the peak hour of the design day), terms generally used in the analysis of facilities, one can determine current utilization of existing facilities and develop the scope and sizing of future facility requirements.

The "design day" forecasted enplanements are divided by the projected load factor to obtain available seats. From this, the mix and number of aircraft movements can be determined to accommodate the available seats. This is accomplished by taking into account the historical mix of aircraft which provides the average number of seats per aircraft movement for each aircraft size category and the total "design day". Then, looking into the future, the retirement schedules for the various types of the existing older aircraft, the plans for replacing this equipment with larger, quieter aircraft, along with higher seating densities are all taken into account in determining the increase in the average seats per aircraft movement and total number of movements for each forecast period for both the "design day" and "design hour".

Studies have shown that the trend over the past few years, which incidently has been unaffected by deregulation, has been for a steady increase in average seats per aircraft movement of 2 - 4 per year. This appears to be a reliable figure to use as a reasonability check when forecasting the future fleet mix by equipment type and size categories for an airport. This future equipment mix is the primary indicator of any future compatibility problems that may be encountered for both the airfield and apron/terminal area.

There are impacts in a wide variety of areas. On the airfield side, overall aspects such as peak hour operations and capacity are of concern, as are the physical layout and lengths of runways, taxiway widths, separation distances, fillets, etc. Impact of extended wings and stretched fuselages on the existing runways, taxiways and hold areas, and their impact on the apron and gate areas must be determined. In the terminal, the impact of increased passengers on various functional areas such as ticket counters, bag claim, departure lounge, etc. are the important considerations to analyze.

Future Aircraft

Present indications are that in the 1980's, the aircraft mix will shift primarily toward a replacement of current aircraft with equipment of larger capacities. For example, the DC-8's, B-707's, B-737's, B-727-100's, smaller DC-9's, older B-727-200's, etc. will be replaced with new vehicles such as the B-767 and A-310 in the 200 seat range; the B-757 in the 175 seat range; and the B-737-300, A-320, proposed MDF-100, and perhaps a new Boeing plane for the 150 seat market. Although the DC-10, L-1011 and the B-747 will continue slowly to come on-line, the larger aircraft will not be the dominating factor in considering impacts on the airports. The predominance of the various new smaller aircraft in the 150-200 seat size category will be the major factor, along with the entry of the newer carriers who will be purchasing and flying some of the older equipment sold by the more established carriers.

The situation will be different at the major international gateway airports. Here the concern is primarily with the larger aircraft, including the B-747, DC-10, and L-1011. McDonnell Douglas is considering a stretched DC-10 for those markets which will not support the B-747. In addition, Boeing has also indicated some possible changes to its 747. For example, Swissair has already ordered a 200 inch upper deck stretch which will add an additional 32 passengers. This involves no other basic dimentional changes. However, a stretched body version, adding 31 feet to give an overall length of 263 feet, is also under consideration, as is a full double deck model of the existing B-747 aircraft. The stretched body version would increase passengers in a two-class operation to 565-600 passengers. The full double deck may run as high as 700 passengers. This latter aircraft will require a new wing which will increase span from 190 feet to 240-250 feet. This may well have an impact on airport compatibility, particularly with regard to various separation standards, fillets, etc. In addition, since the outboard engine will be out a little farther, runway and taxiway shoulder stabilization requirements may have to change. There will probably be an impact on gates; and it may be necessary to handle these aircraft with remote parking and transporters. The additional "slug" load of passengers at the various service areas (i.e. ticket counters, departure lounges, bag claim, etc.) in the terminal may necessitate some changes in accomodating these passengers.

Also on the stretched B-747, the struts of the main gear and nose gear will have to be lengthened three feet because of the rotation requirements during take-off. This will raise the sill height from 16 feet to 19 feet, which may cause difficulties with existing passenger loading bridges. If the double decked version is used, it will require access from a third level in the terminal, or the use of interior stairs to feed the upper level. Trade-off studies have been underway on this question, and it appears that the use of interior stairs will be selected. Emergency evacuation from the upper level may also cause some problems.

While it appears likely that one or both of these versions will arrive on the scene within the time frame covered by this conference, the key questions are how many aircraft, and how many airports will be affected? The list would seem to be limited to about nine in the United States: J. F.Kennedy, Honolulu, Miami, O'Hare, San Francisco, Dallas-Ft. Worth, Atlanta, Seattle, Los Angeles, and maybe Anchorage as a fuel stop.

Returning to the smaller aircraft, the B-767 will have a wing span of about 156 feet. While this is some ten feet longer than that on the B-707 and DC-8 aircraft it will replace, it is basically the same diminsions of the standard DC-10 or L-1011. It appears as though some trade-off has already been made in the B-767 design to accommodate airport compatibility. Initial studies indicated that the best wing span from the point of view of fuel economy would have been 176 feet, but as noted above this has already been reduced at the request of the airlines in their desire to fit this aircraft into the existing airport gate areas without too much disruption.

The current DC-9 has a wing span of 94 feet, and the B-727 of 108 feet, while the new B-757 will have a 125 feet span, and the MDF-100 will have a 113 feet span. Thus there will be increases of some 15 to 30 feet in wing span for this class of aircraft. Again, the situation will have to be examined on a case-by-case basis, emphasizing the previous theme of flexibility, incremental expandability, adaptability, functionality and efficiency of terminals to accommodate a changing fleet mix of aircraft.

It is helpful when airport operators are willing to be flexible and change basic terminal concepts developed before deregulation, in order to more efficiently accommodate today's requirements. For example, when American Airlines significantly increased its service at Dallas/Ft. Worth and made this station a major connecting complex, the airport was willing and able to switch its curvilinear "walk-to-gate" concept to a modified pier-finger complex to accommodate American's needs in a new terminal unit - and it had the flexibility to do so.

Another example of recent planning regarding the layout of the apron-gate area is the new midfield terminal at Atlanta. Considerable effort went into the determination of the separation between the individual terminals A, B, C, and D. It was finally decided that there would be nose-in parking with dual-line bypass taxiway capability, and the design aircraft would be the standard DC-10 or L-1011, and not stretched versions or the B-747. However, about 40 feet extra leeway was included, which will allow for some small variation in wing size, perhaps for the accommodation of winglets or a small stretch.

Important in making this basic decision were the trade-offs between the extra cost required to further increase the separation distance between the terminals. This includes such items as apron size, apron maintenance, taxiing distance, size of the people mover system, and the fact that the B-747 size aircraft was designed to be handled at the international terminal complex, and also could be accommodated at the ends of the other four terminals, if required at some future time. Thus, good economy was achieved while still preserving the concept of flexibility for possible future developments.

There are two areas of current concern to the airline industry regarding the airfield and apron area. Recently, heavy emphasis has been placed by both FAA and ICAO on providing for runway safety areas at all existing, as well as new runways. In planning for new runways at existing and new airports this makes lots of sense and is strongly encouraged. However, in retrofitting at existing airports the situation must be analyzed on a case-by-case basis. It certainly does not seem prudent to shorten runways just to improve the safety areas. It is hoped that the runway safety area standards can be interpreted with a sense of judgment on an airport-by-airport basis as they apply to existing runways.

Another area of concern involves a recent move by ICAO to establish a standard relating to providing an emergency evacuation capability from an aircraft on the ramp if it is being fueled with people on board. This requires that a large amount of space on the ramp be kept clear in the vicinity of all the aircraft emergency exit doors. Since the ramp already is a busy and congested place during periods of aircraft servicing, this new requirement is bound to seriously impede servicing, increase turnaround times, and be expensive to the airlines. The reasoning behind this decision is not clear. there has been fueling of aircraft with people on board all over the world for decades and, there has never been a serious accident resulting in loss of life. Therefore, why is it now necessary to alter the process? One of the dangers of such regulations is that they tend to be expanded and liberally interpreted by zealous individuals at the sites involved, and before long it may be dictated that crash-fire-rescue trucks must stand by at each such refueling. This example is cited as an illustration of the fact that all aspects of a problem need to be examined carefully before forging ahead with hastily contrived regulations.

Conclusions

This paper has pointed out several issues relative to the air transportation system changes which may occur in the future, and their impact on aircraft/airport compatibility has been identified. By and large they are matters of common sense. The conclusions reached are the following:

(1) System changes affecting aircraft/airport compatibility will be slow and evolutionary over time and not the quantum evolutionary type of change experienced with the advent of commercial jet aircraft in the late 1950's, and the introduction of the large B-747 in the late 1960's.

(2) The compatibility issues cannot be generalized. They must be considered on a case-by-case, airport-by-airport and airline-by-airline basis.

(3) Forecasts show that the growth of future U.S. industry passenger enplanements will exhibit the characteristics of a mature market.

(4) Future air transportation system changes will require airports to be flexible, functional, efficient, and incrementally expandable. These features must be applicable in all directions and involve all activities; e.g., one of the most critical problems today is the lack of outbound baggage makeup space at a large number of airports.

(5) Future aircraft will be quieter, which will be environmentally helpful to airports.

(6) On a case-by-case basis, the whole area of airport capacity must be examined. It is important that quotas or other forms of limitations be avoided, particularly in the key hub and connect-complex airports. Every effort must be made to allow the marketplace to take care of itself.

(7) Large aircraft (i.e. stretched B-747's) in the future will only be used in the gateway airports in international service. These aircraft will not be used in domestic service in this century.

CHARACTERISTICS OF PRESENT AND FUTURE AIRCRAFT IMPACTING AIRCRAFT AND AIRPORT COMPATIBILITY

D. W. Conner, Consultant, Yorktown, Virginia

Abstract

Results are reported of an opinion survey of selected individuals at the decision-making level within the five major manufacturers of transport aircraft in the United States and Europe. Opinions were obtained concerning both possible and probable existence of over fifty compatibility-related characteristics of transport aircraft in use in the years 1990, 2000 and 2010. Author's comments are also included on certain candidate new features as to technology status and developmental effort underway. The maximum size of aircraft is expected to increase, at a roughly uniform rate, to the year 2010 by 85 percent in passengers, 55 percent in airfreighter payload, and 35 percent in gross weight. Companion to the expected growth in payloads and gross weight was the identification of probable increases in aircraft geometrical dimensions and component capability, and use of double-deck passenger compartments. Wing span will increase considerably more than normally expected in order to provide wings of higher aspect ratio. New aircraft features coming into probable use include large turboprops, synthetic Jet-A fuel, winglets, wake-vortex-reducing devices and laminar flow control. New operationsl concepts considered probable include steep approaches, high-speed turnoffs, and taxiway towing for the aircraft, plus passenger bypass of the terminal building, expedited handling of belly cargo and an intermodal cargo container system for the payloads. Supplementing conventional transports by the year 2000 will be possible use of advanced supersonic transports and probable use of sizeable aircraft operable on short auxiliary runways.

Introduction

The selection of features and components to be incorporated into new transport aircraft involves striking a careful balance between the primary factors of customer demands, governmental regulations, technical state of the art, and economics. Compatibility of aircraft with the airport is also a concern, but on occasion, must suffer because of overriding considerations (e.g. introduction of the more economical jumbo transports). Compatibility with aircraft is a necessary design consideration in the modification of existing, or construction of all-new airports, both of which involve major efforts stretching over many years. It is therefore important to identify early-on any likely changes in the characteristics of future aircraft which would impact compatibility with the airport, particularly on the ground. Towards this end, the aerospace industry has a continuing effort underway to identify and periodically report on some of these characteristics, trends and growth projections for fifteen to twenty years in the future (1).

Compatibility-impacting characteristics can range from increase in size of various parts of the aircraft, through use of new types of subsystem components, to unique operational procedures involving the aircraft or its payloads. Identification is not needed of overall configurations of new aircraft, but rather of only those features likely to be incorporated into the aircraft which will change their compatibility characteristics either positively or negatively. New innovations in aircraft oftentimes require technology advancements before the concept can be put into service. As outlined and discussed in some detail by Hanks (2), the developmental status of most technology advancements falls into one of three sequential phases: concept assessments; proof-of-credibility; and product definition. As illustrated in Figure 1, all phases must be completed before commitment to product development is made. Also shown in the figure are the objectives of each phase, the number of years of effort normally involved, and the prerequisites of initiation of effort in each phase. The entire process can stretch over several decades, with a number of major decisions required along the way as to whether or not to continue to the next phase. While technical viability is a consideration in all of these decisions, the importance of a particular problem can change significantly with time (e.g. energy conservation).

In the initial or early steps of the cycle, decisions are often made by researchers or their organizations, but the ultimate decision on product commitment to a production vehicle is made by the aircraft manufacturer. This decision requires consideration and evaluation of a host of factors, many of which are nontechnical in nature. Thus, the opinions of industry decision makers must be given considerable credence regarding the likelihood of future characteristics of transport aircraft, both for change in vehicle size and for use of new concepts where the technology status has reached the product definition phase. However, for features that are in the concept-assessment or proof-of-credibility phase, where information available to industry is less complete, the opinions of the research community are also important.

This paper identifies and examines, principally from the viewpoints of aircraft manufacturers, likely changes in future transport aircraft that will impact compatibility with the airport over the next several decades. To obtain such viewpoints, an opinion survey was carried out by mail of selected individuals within the organizations of the five major manufacturers of transport aircraft in the United States and Europe. These findings, treated collectively, on compatibility-related characteristics of future aircraft are supplemented with comments by the author, as an informed researcher, on candidate new features regarding their technology status and the level of research, development and demonstration effort presently underway. The time frame of the examination extends from 1981 until the year 2010.

Opinion Survey

The intent of the survey was to obtain informed opinions regarding the likelihood of existence at future times of certain features, characteristics, and operations (collectively referred to hereinafter as characteristics) of civil transport aircraft which could impact, either positively or negatively the airports in the following respects:

1. Airport overall configuration and operation
2. Runway properties (e.g. geometry, strength, operations)
3. Taxiway characteristics (e.g. geometry, operations)
4. Apron features (e.g. geometrical clearances, services, facilities)

Figure 1. Technology development cycle for new concepts.

INCREASING TECHNOLOGY STATUS → PRODUCT COMMITMENT → IN SERVICE

PHASE:	CONCEPT ASSESSMENT	PROOF OF CREDIBILITY	PRODUCT DEFINITION	PRODUCT DEVELOPMENT
YEARS: (MEAN)	2-8 (4)	2-5 (5)	2-10 (6)	4-5
OBJECTIVE:	o ASSESS POTENTIAL	o ESTABLISH CREDIBILITY OF POTENTIAL	o INTEGRATED APPLICATION	o HARDWARE DELIVERY
PREREQUISITE:	o REAL OR PERCEIVED NEED	o POSITIVE INDICATED BENEFITS	o PROVEN TECHNICAL & BUSINESS BENEFITS	o ACCEPTABLE RISK o MARKET

5. Terminal building (e.g., geometry, payload handling provisions)
6. Maintenance of both the aircraft and the airport
7. Safety in the operation of both aircraft and the airport.

Impacts on the airport by an aircraft generally relate to the aircraft size and geometry, to certain aircraft systems, or to operations involving the aircraft and/or its payload. To keep the survey within manageable bounds, information was obtained only within areas judged to have the greatest impact, namely: (a) vehicle capacity and weight, (b) fuselage geometry, (c) landing gear system, (d) propulsion system, (e) aerodynamic system, and (f) operations.

The survey was conducted by mail of selected individuals at the decisionmaking level within the airframe industry. Request was made for opinions relating to the probability of existence in the years 1990, 2000 and 2010 of certain characteristics of transport aircraft then in use at some of the world's principal airports. Because of considerable uncertainty in such speculation, two levels of opinion were sought. The first level was of considerable optimism about possible use, where the probability of existence in a given year could be as low as ten percent. Demonstration use only of a characteristic, however, would not qualify it for inclusion. The second level was of more conservatism or probable likelihood, where the probability of existence in a given year was judged to be 50 percent or better. Participants were informed that personal (not corporate) considered opinions were needed, that opinions should address products expected of the industry as a whole, that replies would be treated collectively and that no identification would be made of the respondees of their affiliations.

Information was obtained concerning over fifty different characteristics. About one-half of these pertained only to the probability of existence of a given feature or operation (e.g. double-deck fuselage.) The remaining one-half pertaining to the probability of existence of a quantitative measure (generally for the limiting case situation) relative to a feature or operation (e.g. maximum landing speed). Bars with linear scales (e.g. knots, number of passengers) were provided for marking by the respondees at the appropriate scale locations. Two bars were provided for probabilities of existence greater than ten percent and fifty percent, respectively. The marking system used for all questions consisted of the use of a "g" for the year 1990, a "O" for the year 2000, and a "1" for the year 2010.

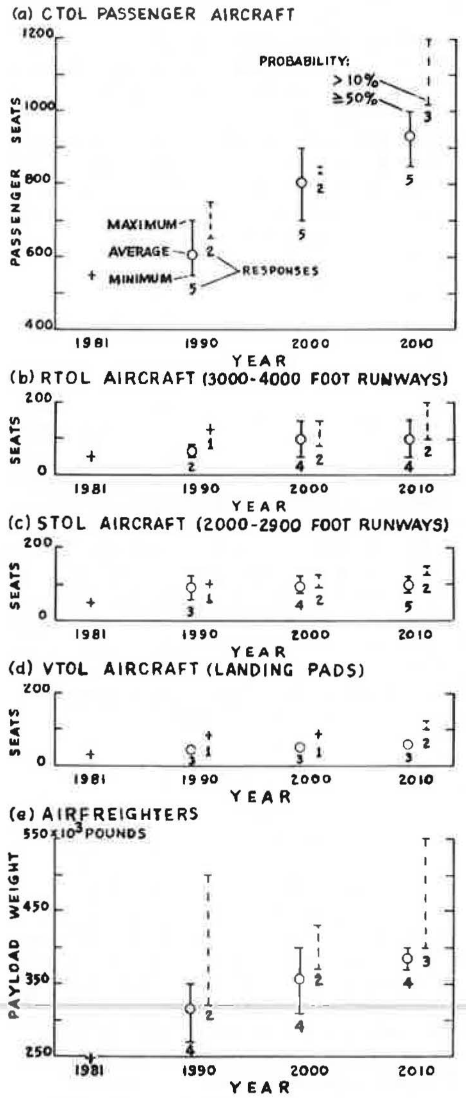
Survey responses were received from either the selected individuals or small teams organized by the selected individuals within the five (three domestic, two foreign) major manufacturing organizations of civil transport aircraft. In some cases, information was obtained from more than one division of a manufacturer. A total of nine responses from the five manufacturers were received with six being individual opinions and three being collective opinions of small teams. In only one instance was there a response from only one person within a manufacturing organization. Where there were several responses from within an organization, the responses on each question were melded to provided a single representative response. For quantitative-measure characteristics, this melding consisted of averaging the several values. For probability-of-existence characteristics, it consisted of using either the earliest indicated data where two responses were being melded, or the date favored by the majority where more than two responses were melded.

The response information considered representative of the five major manufacturers of transport aircraft is presented in Figures 2 through 18 for the years 1990, 2000 and 2010. Information pertaining to a quantitative measure (e.g. Figure 2) is shown in bargraph form with each bar extending from the minimum to the maximum value and with the average (arithmetic mean) value indicated by a symbol. A symbol is also used to denote the value existing in 1981 for the measure. The optimistic and conservative levels of opinion are represented by dashed-line and solid-line bars respectively. Varying degrees of conservatism were evident in the replies by the respondees, with several choosing to offer little or no optimistic speculation. Information pertaining to the probability of use of a given feature or operation (e.g., Figure 5) is presented as the sum of the responses pertaining to a given-year, given-probability combination. Since some respondees chose not to address all items of the survey, a notation is made at the bottom of each bar or column as to the number of responses represented (from one to five). As considered differences of opinion were sometimes evident regarding a given characteristic, interpretation of specific items in the survey results should include consideration of both the range in values of the responses as well as the number of responses represented. The discussion which follows generally will be directed toward the conservative (probability = 50 percent) opinion results.

Aircraft Size and Weight

The physical size of an aircraft, which is a prime factor in its compatibility with the airport, fundamentally depends on its payload. Accordingly, information was obtained on the upper limits of payloads expected over future decades in terms of maximum number of passengers for passenger aircraft and maximum gross payload weight for airfreighters. Opinions were obtained for aircraft using conventional runways, auxiliary runways of 3000-4000 feet for RTOL transport, and 2000-2900 feet runways for STOL transports, and landing pads for VTOL transports. Results indicate a continuing growth in maximum capacity of conventional transports (Figure 2a) with an 85 percent increase by the year 2010 to an average value of 930 passengers. Industry-wide opinions were reasonably consistent with little spread between replies. A similar trend in growth was not evidenced regarding the capacity of transports capable of operating onto auxiliary runways (Figures 2b and 2c).

Figure 2. Maximum payloads of transport aircraft: (a) CTOL passenger aircraft, (b) RTOL aircraft, (c) STOL aircraft, (d) VTOL aircraft and (e) airfreighters.



Maximum size is expected to increase to about 100 passengers by 1990 and then remain essentially constant thereafter. Apparently the use of large auxiliary-runway transports for shuttle or feeder service is not generally viewed by the airframers as a particularly attractive approach for relieving congestion in the system. Certainly there is no lack of technology for designing such aircraft, either with a conventional high-lift system and decreased wing loading (3) or with a powered-lift system and moderately high wing loading (4). A considerable difference of opinion was evidenced in the survey, however, with one response indicating probable use of a 150 passenger transport by the year 2000. The Japanese have plans to develop such a 150-passenger transport and are presently assembling a prototype of reduced size at Kawasaki. Only three respondees addressed vertical-takeoff-and-landing transports. They were in agreement that maximum capacity would increase to about 50 passengers by 2000 with little increase thereafter (Figure 2d).

Airfreighter maximum gross payload is expected to increase about 55 percent, to about 385,000 pounds by 2010, with one-half of the increase occurring by 1990 (Figure 2e). The need for larger airfreighters is consistant with the results of major systems studies carried out several years ago (5) which predicted significant growth in demand stemming primarily from international airfreighter services but with limited growth for U.S. domestic services. Also indicated by the study was the probable use of derivative widebody transports through the 1990's with all-new dedicated airfreighters not being used until sometime beyond the year 2000. The timing and size of such new airfreighters could well depend on factors such as a government's sharing of the RD and E costs by virtue of its need for a slightly modified version of a civil airfreighter (e.g., military airlifter). The study indicated such a civil airfreighter could fall anywhere within a wide range of sizes (up to one million pound payload) and still be economically attractive. Such thinking leads to the high peak values in optimistic opinions shown in Figure 2e.

Opinions regarding aircraft maximum gross weight at takeoff indicate an average-value increase of 35 percent to about 1,135,000 pounds by 2010 for both passenger transports and airfreighters (Figure 3). The near-term increase (to 1990) in maximum weight, however, indicates a much greater increase occurring for airfreighters than for passenger transports, which is consistent with the trend indicated earlier for payloads. Similarly, the optimistic-opinion values ranged much higher for airfreighters than for passenger transports. For both type transports, the percentage increase over the three decade period is much less for gross weight than for payloads, which reflects the great savings expected in both airframe weight and fuel consumption by application of advanced technology.

Fuselage Characteristics

An increase in the size of the fuselage generally accompanies any significant increase in the payload. Accordingly, opinions were obtained regarding the maximum fuselage length which is the fuselage dimension that most impacts compatibility. Incidentl adding three percent to fuselage length provides a close estimate of the overall length, including empennage overhang, which enters into the calculation of ramp area requirements. The survey results indicate an average value increase in probable maximum fuselage length of 16 percent to about 260 feet by 2010 (Figure 4). Opinions of the respondees were in close agreement with the most optimistic estimated peak-value being 280 feet.

If fuselage shapes are similar, the 16 percent increase in fuselage length will provide a 55 percent increase in volume, which matches the percentage increase expected in airfreighter payload. The floor area of single-deck passenger aircraft will increase only 35 percent, however, which is insufficient to accommodate the 85 percent increase expected in maximum passenger capacity. At least one-fourth of the passengers will have to be carried on a second deck. Probable use of fully double-decked passenger aircraft by the year 2000 was foreseen by all respondees (Figure 5).

Increasing demand and congestion may lead to various innovations in the air transportation system (6) which will require use of new fuselage concepts. The survey addressed some of these concepts which could impact compatibility. Other than use of double-deck arrangements, there was no general consensus regarding use of any of the other candidate configurations as indicated by Figure 5. However, two of the four respondees who answered questions pertaining to cargo aircraft, indicated probable use by 2000 of high-wing configurations for large civil airfreighters. A single vote for probable use by 2010

Figure 3. Maximum take-off gross weight: part (a) - passenger aircraft; part (b) air freighters.

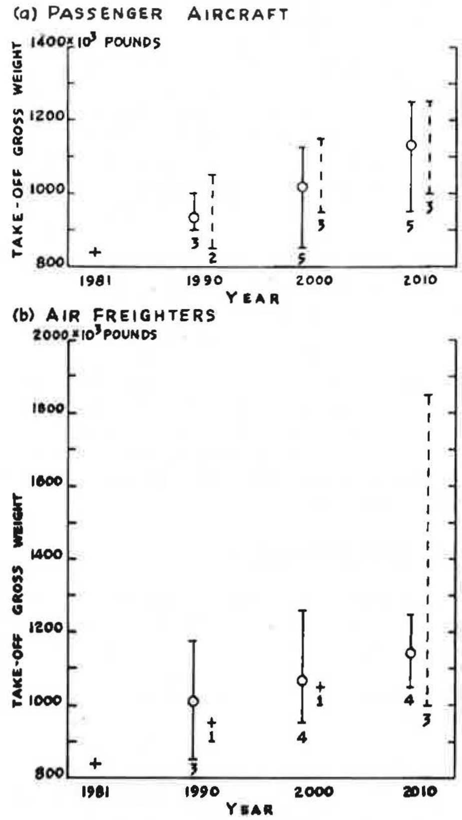
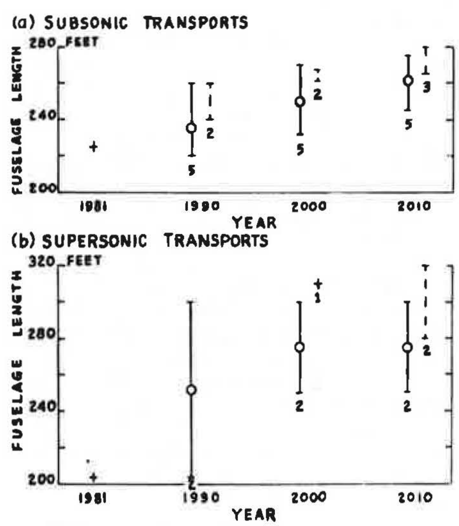


Figure 4. Maximum length of fuselages.



was received for each of three concepts: the flatbed airfreighter, the multibody airfreighter, and integrated wing body configurations (identified by two respondees to a request for other candidate concepts).

Landing Gear Characteristics

The maximum outer-wheel tread of the landing gear is expected to have an average value increase to about 47 feet for the years 2000 and 2010 (Figure 6a).

Figure 5. Use of new fuselage concepts.

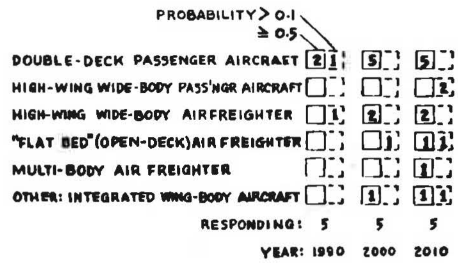
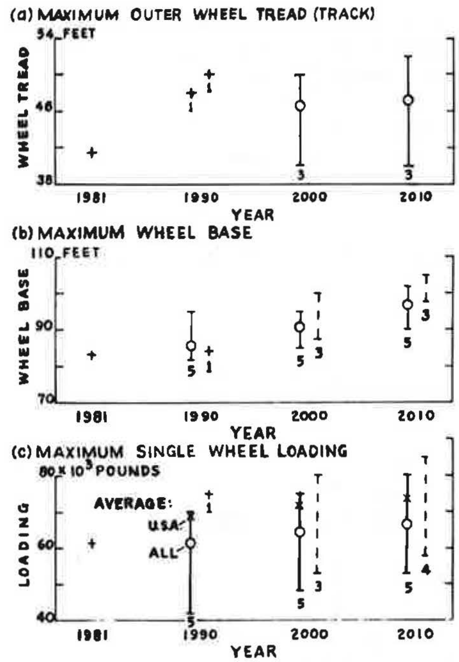


Figure 6. Landing gear characteristics.



This value amounts to 18-20 percent of the expected maximum wing span (Figure 13a) which lies well within the 15 to 27 percent region for existing aircraft landing gear (Figure 10 of 1).

The maximum wheel base is expected to have an average value increase of about 15 percent to 97 feet by 2010, with essentially all of the increase occurring after 1990 (Figure 6b). As a percentage of expected maximum fuselage length, this value is in the middle of the 35-40 percent region in which lies the wheel base of existing widebody aircraft (Figure 11 of 1).

The single-wheel maximum loading is expected to have an average value increase to about 67,000 pounds by 2010 (Figure 6c). To illustrate a dichotomy apparent in the opinions expressed, the average value for just the responses from the U.S.A. is also shown by a separate symbol on the bars of Figure 6c. Maximum loading values cited by American respondees averaged about 7000 pounds higher than the overall average throughout the entire time period. A difference of opinion may exist toward utilizing the maximum capability of tires (one presently rated at 62,000 pounds) because of concern about tire dependability and economics (Paper 30 of 7). In addition, increased loading of a given tire requires an increase in tire pressure, which adversely affects braking and skid control capability.

Figure 7. Maximum cockpit-to-maingear length.

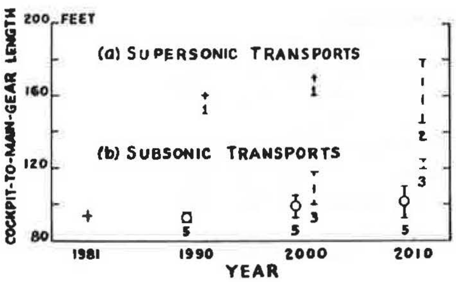


Figure 8. Use of new landing gear concepts.

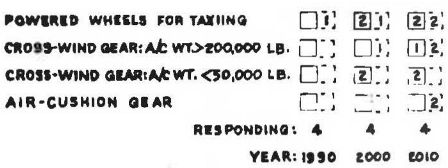
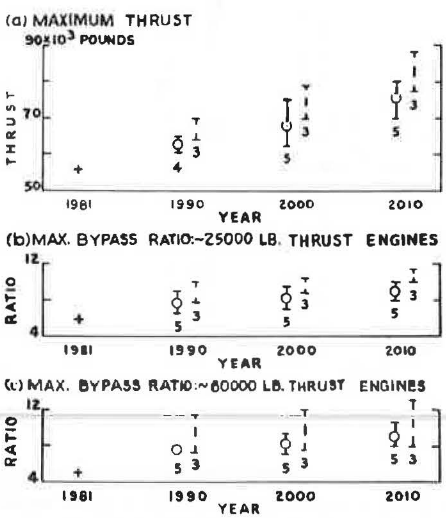


Figure 9. Characteristics of turbofan engines.



Increase in the maximum horizontal distance from the cockpit (pilot's eye) to the main landing gear can impact design standards for turn fillets on the airport. The survey results for supersonic transports (Figure 7a), while insufficient to provide any statistically significant quantitative values, were in general agreement with the values of 150 to 170 feet previously postulated (Figure 12 of 1). For subsonic transports, this distance will have an average value increase of about ten percent after 1990 and before 2010 (Figure 7b).

Several candidate innovations in aircraft landing gear were included in the survey and evaluated by four respondees. The four respondees considered powered wheels (for maneuvering in the taxiway-apron areas) to have possible use by 2010, with two respondees indicating probable use as early as 2000 (Figure 8). The technology status for powered wheels is still in the proof-of-credibility stage with only limited effort presently underway on a prototype system driven by a hydraulic motor. Cross-wind landing gear, in which the wheels align with the aircraft direction of motion, could ease aircraft operations into airports with single-direction runways. In response to a query about use of cross-wind gear on large and small transports, a majority of the respondees indicate possible use by 2010 on aircraft heavier than 200,000 pounds while two of the four respondees indicated probable use by 2000 on aircraft lighter than 50,000 pounds (Figure 8). The technology status for cross-wind gear is considered to be through the proof-of-credibility phase. The third innovation considered was the air cushion landing gear which would permit operation of any size transport on surfaces additional to paved runways including uneven ground, swamp, water, snow or ice. Two of the four respondees considered use of air cushion gear on civil transport aircraft to be possible but not probable by 2010. Its status of technology is still in the proof-of-credibility phase with successful flight experiments to date limited to light aircraft. The military, which has indicated need for such gear on larger aircraft, has been reluctant to fund the considerable technology development effort still required.

Propulsion System Characteristics

Opinions were in remarkably close agreeement regarding the outlook for turbofan propulsion. Single-engine probable maximum thrust level is expected to increase at a linear rate with time to an average value of 75,000 pounds by 2010 (Figure 9a). The percentage increase almost exactly matches the 35 percent increase expected in probable maximum air craft weight (Figure 6). Maximum bypass ratio for large engines is expected to increase significantly during the 1980's to a probable average value of 7.5 by 1990, and then at a slower rate to a value of about 9.0 by 2010 (Figure 9b), which is considered to allow a cruise Mach number of about 0.8. Compatibility problems in clearance between the ground and the larger diameter nacelles (inherent with larger bypass ratios) may arise but effort is underway to develop aerodynamic integration technology to allow locating engines closer to the wing chord plane. The benefits in decreasing both the specific fuel consumption and the terminal area noise as a result of increasing bypass ratio might be even greater with bypass ratios of 10 to 12 but such application would likely be limited to engines for airfreighters and short-haul passenger transports cruising at Mach 0.7 - 0.75. From compatibility considerations, a medium size engine in this category would seem attractive for short-haul transport use. A trend toward use of a higher bypass ratio for smaller engines is not foreseen, however, in the results of Figure 9b and 9c where essentially identical values are shown for both 25,000 pound and 60,000 pound thrust engines. The technology status for bypass ratio 10-12 engines essentially completed the proof-of-credibility stage in the NASA-QCSEE program (8) several years ago.

Opinions were quite diverse on use of large advance turbopropellers which have been advocated for saving fuel at cruise Mach numbers to 0.8. While most opinions were quite optimistic, one respondee considered use of turboprops by the year 2010 as being probable (in moderate size) for airfreighters but only as possible for passenger aircraft. Not only does a wide spread exist between the upper and lower probable values shown in Figure 10, but also (for a different mix of respondees) the range of the possible values is displaced downward, rather than upward, from the range of the probable values. Nevertheless, the majority of respondees consider as probable a large increase in the maximum power of

Figure 10. Maximum power for turbopropellers.

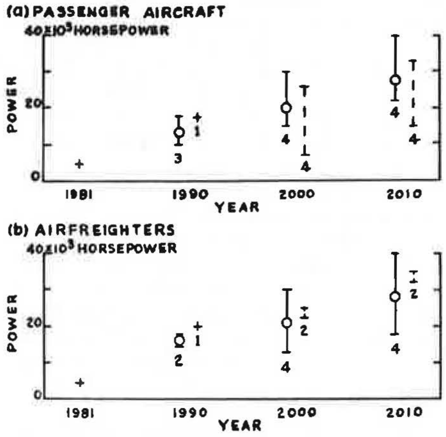
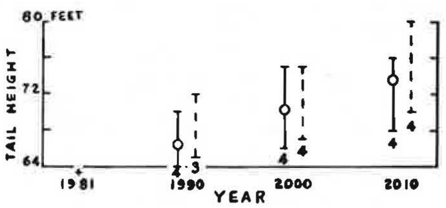


Figure 11. Use of alternate fuels.

Figure 12. Maximum height of vertical tail.



turbopropeller units used on both passenger aircraft and airfreighters. The average value estimate of 28,000 horsepower by the year 2010, which is more than five times that of turbopropellers presently available, is a size appropriate for widebody transports. Perhaps the diversity in opinion on turbopropellers stems from the technology status which is still in the proof-of-credibility phase. A great amount of technology must be developed for: propulsion-unit integration in an aerodynamically efficient manner; achieving a satisfactory acoustic environment, particularly in passenger compartments; providing a suitable structure for the very thin swept blades; and providing the required large gas turbines plus speed reducers which are long-lived and have low maintenance. A high level of effort sustained over a considerable time period will be required to supply the technology necessary for the industry to provide aircraft with propulsion units of a size approaching those shown as probable in 1990, 2000 and 2010. Research and development efforts underway and planned are considered by the writer as inadequate in meeting such a schedule.

Recent problems in the availability and cost of petroleum have led to consideration of alternative aviation fuels. Only three candidates have been identified as viable for aircraft: synthetic Jet-A (synjet); liquid methane and liquid hydrogen. Use of synjet was considered probable as early as 1990 (Figure 11) while neither liquid methane nor liquid hydrogen received much endorsement. This is not surprising as synjet is cheaper to manufacture from coal or oil shale and requires no change in either the aircraft or the airport. Liquid methane and liquid hydrogen (both cryofuels) require specially configured aircraft and major facilities at each airport for fuel storage and handling (9).

Aerodynamic System

Opinions concerning vertical tail height (Figure 12) indicate the maximum height is expected to increase after 1990 to an average value approaching 74 feet by the year 2010. A wide-band correlation curve (Figure 15 of 1) exists between tail height versus transport aircraft gross weight and includes an extrapolation to higher gross weights plus an offset band postulated for multi-deck configurations. The coordinate point of maximum tail height and maximum gross weight expected in 2010 is located at about the center of the band (whose width equals 11 feet of incremental tail height) for conventional transports but at the bottom edge of the offset band for multideck configurations.

Opinions varied radically (by as much as 80 feet) regarding the probable increase in maximum wing span (Figure 13a). The average values indicate a span of 250 feet can be expected by the year 2010 if not sooner. Only sixty percent of this increase is required to accommodate the expected increase in gross weight, provided there is no change in either wing loading or geometrical shape. A change in shape to increase wing aspect ratio to a value of 8.5, however, would account for the additional percentage in span. Increase in aspect ratio to 8.5 or even higher is a design trend already underway to decrease induced drag. Recent improvements in wing structural efficiency through application of thicker supercritical airfoils and advanced materials place the technology status of higher aspect ratio wings as past the product definition phase.

Significant increase in maximum wing span, indicated above, can have an adverse impact on compatibility with the airport, as was experienced in 1970 with the introduction of the Boeing 747. To minimize or avoid major disruptive world-wide modifications of existing airports, a need exists for cost-effective alternative wing configurations (e.g., wing folding) which are viable. The recently developed winglet is such a new concept which can reduce wing span appreciably. Most of the survey respondees agreed that winglets probably would be in use by 1990 (Figure 13b). Opinions as to the expected maximum span of wing-winglet combinations indicate average values throughout the entire time period will be about 10 feet less than for plain wings. This incremental decrease is less than one-half the potential available according to the results of an indepth analysis of optimized wing-winglet configurations, wherein it was found possible to decrease span by ten percent without adverse effects (10). Perhaps some respondees view the winglet application primarily for improving aerodynamic efficiency rather than for optimally minimizing wing span while maximizing efficiency. The technology status for winglets is considered to be nearly through the proof-of-credibility phase, with flight experiments underway utilizing widebody aircraft.

The survey addressed two other concepts for improving aerodynamic efficiency. One is the use of laminar flow control (LFC) on the wing to greatly reduce skin friction drag. The majority of respondees consider use of LFC as possible by the year 2000 and probable by 2010 (Figure 14). The technology status is in the proof-of-credibility

Figure 13. Maximum span of wing systems.

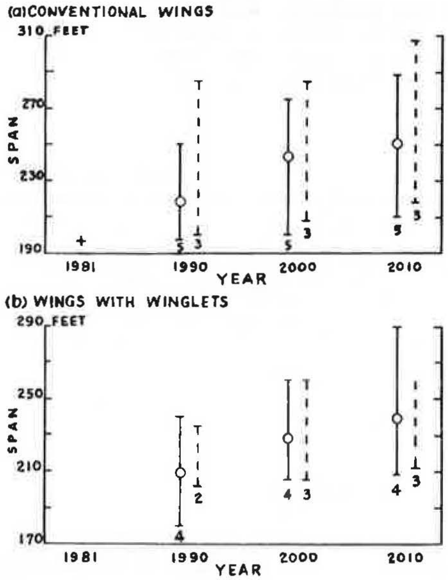
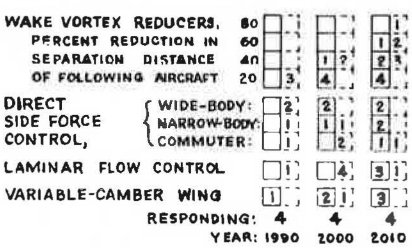


Figure 14. Use of new aerodynamic concepts.



phase with rather formidible requirements for practical LFC use still to be met, but substantial and su - sustained R and D efforts have been underway by NASA. As LFC surface contour shape, smoothness and porosity are critical factors, in situ surface cleaning may be required between flights when insect strikes occur on the wing leading edge. Extra precautions in airport ground maintenance and surface movement of other aircraft also will be required to avoid LFC surface contamination and damage. The second concept is variable camber, wherein the wing cross-sectional shape can be continuously and smoothly cambered to optimize the lift-drag ratio throughout the flight regime. Benefits include potential fuel savings of as much as four percent (11) plus a decrease in noise level during takeoff because of slightly lower power requirements and absence of noise-generating slots and gaps in the wing. Survey responses were mixed, ranging from no foreseeable use to probable use as early as 1990. A majority considered variable camber use as probable by the year 2010 (Figure 14). The technology status is still in the concept assessment stage with considerable technology requirements yet to be addressed. No significant effort is presently underway.

The survey also addressed two aerodynamic concepts which impact aircraft behavior in terminal area operations. One concept is direct side-force control to provide and maintain more precise positioning in cross-wind approaches which may be required to achieve the precision in positioning needed when aircraft spacing is compressed. As need for such control was considered as possibly differing for various size aircraft, opinions addressed use of direct side-force control on commuters, narrow-body transports and widebody transports (Figure 14). Only a minority of respondees considered such use as probable by the year 2010. Technology readiness for direct side force control is beyond the proof-of-credibility phase with many years of experience accumulated on research aircraft. The second concept is the use of wake vortex reducers to minimize wake intensity downstream of an aircraft, a limiting factor in the spacing of aircraft. Opinions were obtained concerning use of wake vortex reducers as providing a reduction by twenty percent increments in the separation distance of following aircraft. Four respondees considered the use of wake vortex reducers by the year 2010 as probable in providing a twenty percent reduction (Figure 14). Two of the four respondees considered a forty percent reduction in separation distance as probable by the year 2010. At present, the technology status is only in the concept assessment phase. Following several years of exploratory studies with no preferred concept identified, NASA recently initiated an indepth long-range program to provide a more fundamental understanding of the phenomena to better identify viable approaches for wake vortex reduction.

Aircraft Operations

Runway requirements depend not only upon the size and weight of aircraft but also upon their takeoff and landing characteristics. For example, as an aircraft's speed on the runway increases, its dynamic response to runway roughness or waviness increases significantly. The Concorde aircraft, with its limber fuselage and high takeoff speed, exhibited severe dynamic responses for some runways during early trial use, which required corrective action before regular use was initiated. Opinions were obtained in the present survey regarding maximum runway speeds. As shown in Figure 15, responses were in reasonable agreement that little change is expected to occur in maximum speeds to the year 2010 with the average value being about 185 knots for subsonic transports and 200 knots for supersonic transports.

Use of advanced supersonic transports is indicated as possible by the year 2000 and probable by 2010 as evidenced by opinions expressed by three respondees who replied to queries concerning characteristics unique to future supersonic transports (Figures 4, 7, 15 and 16). Results for Concorde operations indicate a demand exists for supersonic service, provided only modest fare surcharges are involved. Low surcharges are believed achievable in the future because of great advances in technology made in recent years. An advanced supersonic transport, with acceptable noise performance, should be able to achieve three times the productivity of a similar-size subsonic aircraft with the same payload while burning slightly less than two times the fuel (12). The first embodiment of such a design may well be a supersonic business jet as a significant worldwide market for this size aircraft is believed to exist. The start-up costs for this size transport aircraft should be significantly less than for a large supersonic transport.

The runway length required for takeoff increased with increase in aircraft gross weight until about the year 1965 but remained constant thereafter even though heavier aircraft were introduced (Figure 16 of 1). The trend toward no further increase in field length is expected to continue to the year

Figure 15. Maximum runway speeds.

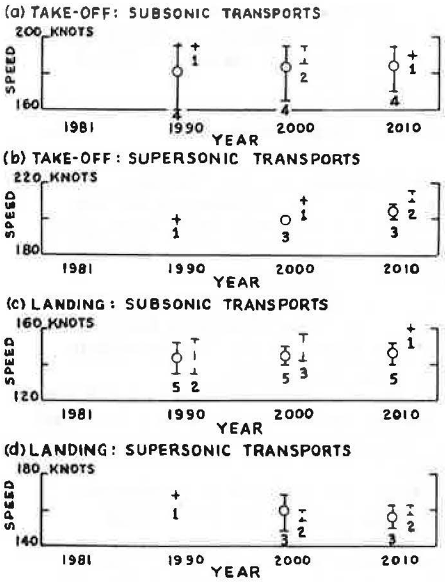
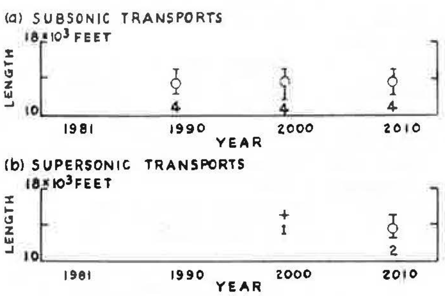


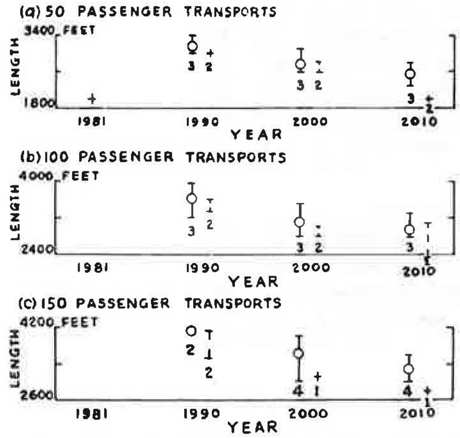
Figure 16. Maximum runway length.



2010 as evidenced by the survey data of Figure 16. Respondees were in agreement that the expected maximum runway length will remain essentially constant at an average value of about 14,000 feet for both subsonic and supersonic transports. Of course, variations in maximum length will exist between airports because of local factors including temperature, altitude, runway slope and obstructions.

The maximum length appropriate for short auxiliary runways at hub airports is also important because of the increasing need for such runways to off-load the main runways of commuter and feeder transport traffic. As discussed earlier, the survey indicated the average expected maximum payload for such transports to reach about 100 passengers by 1990. Advanced turbopropellers will likely be used if units of sufficient horsepower are available; otherwise turbofans will be used either with conventional mechnical flaps (and decreased wing loading) or with powered lift flaps (and conventional wing loadings). To sound out industry thinking about powered-lift applications, survey opinions were obtained concerning the minimum field length capability of powered-lift transports sized for 50, 100 and 150 passengers (Figure 17). Opinions were in close agreement that the minimum field length will increase as the payload becomes larger and that the accommodation capability of a given field length will increase with the passage of time. For example, a runway 3600 feet in length is expected to accommodate powered-lift aircraft whose capacities are 100 passengers by 1990, and 150 passengers by 2000. The status of powered lift technology is beyond the proof-of-credibility phase. For high thrust-to-weight configurations, product definition was accomplished in recent industry proposals submitted for the CX military transport competition. For moderate thrust-to-weight ratio configurations more suitable for civil transports, proof of credibility was accomplished in the flight test program of the NASA Quiet Short-Haul Research Aircraft (QSRA). Results indicate that transports having a wing loading of 90 pounds per square foot and a thrust-to-weight ratio of 0.30 can safely operate from runways 3000 feet in length (4).

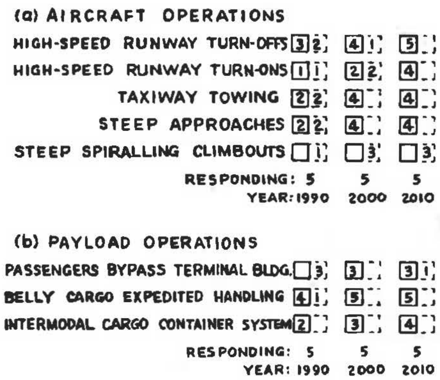
Figure 17. Maximum field length of power-lift aircraft.



Respondees were in general agreement concerning the probable use by aircraft of several advanced operational concepts at the airport (Figure 18). One such concept is directed primarily toward minimizing airport noise and fuel saving by the towing of transport aircraft on the taxiways. Use of taxiway towing is considered probable by 2000. Several other operational concepts can be considered as elements entering into improved terminal area operations to improve capacity and efficiency, enhance approach and landing capability in adverse weather and reduce the impact of aircraft noise perceived on the ground. One such concept is the use of steep approaches, which the respondees consider as probable by 1990. Use of the companion takeoff procedure of steep spiralling climbouts, however, is not considered probable even by 2010. Related concepts are the use of high speed runway turn-offs, considered as probable by 1990, and high speed turn-ons, considered as probable by the year 2010. The technology status of the several concepts entering into improved terminal area landing operations is nearing the product definition phase with major effort underway by the government which has produced considerable technology (7). Of particular interest to airports is the development of a system to extend automatic aircraft operations through runway rollout and turnoff. The system requires placement of a magnetic leader cable in the pavement to guide the aircraft (Paper 4 of 7). As effort to date has concentrated primarily on landing operations, the technology status of concepts entering into improved terminal area takeoff operations is less advanced and should be considered as still in the concept assessment phase.

Three advanced operational concepts for payloads were also examined in the survey (Figure 18). Passenger bypass of the airport terminal building was

Figure 18. Use of new operational concepts.



considered by a majority of respondees as probable by the year 2000. Use of concepts for expediting the handling of belly cargo from passenger transports is considered as probable by 1990. Such expediting, to more closely match the time required for handling passengers, certainly seems warranted by the increase in emphasis being given by the air carriers to the carrying of such cargo. Finally, the use of a truly intermodal cargo container system is considered as probable by the year 2000.

Acknowledgment

I would like to acknowledge the cooperation and effort of the considerable number of individuals within the community of transport manufacturers who generously provided opinions regarding selected characteristics of future aircraft. These perceptive and informed opinions, taken in toto, were the key ingredients not only in developing an interesting outlook regarding compatibility efforts but also in lending a degree of credibility to this outlook.

References

1. Anon. CTOL Transport Aircraft Characteristics, Trends and Growth Projections. Aerospace Industries Association of America, Third Edition, January 1979.
2. Hanks, Glen W.: Technology Advancements for Energy Efficient Transports. AIAA 80-0906, May 1980.
3. Morris, R. L.; Hanke, C. R.; Pasley, L. H.; and Rohling, W. J.: The Influence of Wing Loading on Turbofan Powered STOL Transports With and Without Externally Blown Flaps. NASA CR 2320, November 1973.
4. Cochrane, J. A.; Riddle, D. W.; and Stevens, V. C.: Quiet Short-Haul Research Aircraft - The First Three Years of Flight Research. AIAA 81-2615, December 1981.
5. Winston, Matthew M. and Conner, D. William: Air Cargo Market Outlook and Impact Via the NASA CLASS Project. SAE Paper 801058, October 1980.
6. Conner, D. William: Outlook for Advanced Concepts in Transport Aircraft. NASA TM 81810, April 1980.
7. Many Authors: 1980 Aircraft Safety and Operating Problems. A Compilation of Papers Presented at a NASA Conference November 5-7, 1980. NASA CP-2170 (2 Volumes) 1981.
8. Many Authors: Quiet Powered-Lift Propulsion. Compilation of Papers Presented at a NASA Conference held November 14-15, 1978. NASA CP-2077, 1979.
9. Witcofski, Robert D.: Comparison of Alternate Fuels for Aircraft. NASA TM 80155, 1979.
10. Schollenberger, C. A.: Application of an Optimized Wing-Winglet Configuration to an Advanced Commercial Transport. NASA CR 159156, November 1979.
11. Anon: Assessment of Variable Camber for Application to Transport Aircraft. NASA CR 158930, November 1980.
12. Maglieri, Domenic J.; and Dollyhigh, Samuel M.: Aircraft. Astronautics and Aeronautics, February 1982, pp. 26-38.

CHARACTERISTICS OF PRESENT AND FUTURE AIRPORTS IMPACTING AIRCRAFT AND AIRPORT COMPATIBILITY

Robert Aaronson, Port Authority of New York and New Jersey

Abstract

The airport characteristics affecting compatibility are reviewed in detail as applied to the airside and landside activities for both passenger and cargo traffic - domestic and international. The various concerns resulting from the impact of new aircraft or operating procedures on these characteristics are identified. Several of the major problem areas are discussed in some detail, and possible solutions, most of which involve trade-offs with existing designs or practices, are examined. The major problem areas are shown to be dominated by the constraints imposed by the lack of available land for expansions, and by other interactions with the surrounding community.

Introduction

Did the airlines realize, when they made their initial decisions to buy wide bodied jumbos that they would eventually have to pay hidden costs of several billion dollars for airport changes? Yes, the jumbo jet's introduction in the 1970's forced this scale of massive investments in new and existing airport facilities. At Kennedy Airport, several hundred million dollars were involved. A quick review of the Port Authority's investment just in runways and taxiways at this airport shows that this amounted to over $50 million in the late 1960's and early 1970's, and of course, this figure can be multiplied several times over when considering changes which were required in terminal buildings, cargo areas, on-airport and access roads, parking lots, utilities, new equipment, and other associated fallout. Considering the worldwide use of these aircraft, a similar story was repeated at more than ten score airports and the full effects have not yet rippled through the system.

While costly, these changes were made, and the growth in passengers and cargo has been handled, even with prevailing peak hour problems.

Today, however, many airport operators considering additional development are asking the question "Is it possible?" before "Can we afford it?"

Most airports existing today had their origins in the 1930's and 1940's at the beginnings of commercial aviation. These airports were originally located outside or at the edge of town and their size was a function of the large aircraft then on the drawing boards. Medium size busy airports such as Cleveland, Philadelphia, Boston, and Newark come to mind, and small airports such as Washington National and New York's LaGuardia are foremost in importance.

A typical large commercial aircraft being considered in those days was a DC-6 with a wing span of 117 ft., a length of 100 ft., and a 58 passenger capacity. Today's wide-bodied aircraft, of course, have wing spans of 160 to 200 ft., lengths up to 230 ft., and passenger shock loads of 300 to 500 people. There is even talk of aircraft with wing spans reaching 300 ft., overall length of 400 ft., and passenger capacities of 800 people - all before the end of the century.

This leads to a current preoccupation with squeezing these aircraft into existing airports - a little like putting the toothpaste back in the tube. For while aircraft were getting larger, city development since the 1940's came right up to the airport boundaries and these facilities wound up in an extremely sensitive urban environment.

Many legal, environmental, financial and community constraints on new airport construction as well as on the expansion of existing airports are manifested. In fact, in many critical geographical areas, the maximum achievable airport size and configuration within which to accommodate commercial aircraft are being approached.

Airport Characteristics Affecting Compatibility

Which are the airport characteristics bearing on the aircraft/airport compatibility question? Airport physical characteristics are the most obvious but equally important are environmental effects on physical and procedural changes. Also of concern are the technological advances which will be required to accommodate future aircraft operations.

Runway strength, length, width, safety areas, and end safety areas are primary considerations. New aircraft must in virtually all cases be able to operate from existing runway lengths. Ways may be found to strengthen pavement in spite of temporary operational problems, but there will only be rare cases where runways can be extended significantly. Fortunately, an examination of the top 30 air carrier airports in this country shows that most can offer runway lengths at or above 10,000 feet for most wind conditions. Isolated cases such as Washington National and LaGuardia with runway lengths around 7,000 feet need to be confined to certain stage length missions and this is already happening.

Close behind the runway questions are those concerning taxiway strength, width, radii, shoulders, and clearances to other taxiways and obstacles. Again - except possibly in the case of taxiway bridges - upgrading of taxiway strength, width, radii, and shoulders is primarily a question of money and finding ways to do the work without shutting down the airport. The clearance item is not as easy. For example, FAA standards call for a separation of 400 feet between runways and taxiways, and 300 feet between taxiway and taxiway - for any airport accommodating B-727-200 aircraft or larger. For future aircraft beyond the B-747 and up to a wing span of 240 feet, these separations become 600 feet and 360 feet respectively. At many air carrier airports these lower separations do not exist and even at those airports where they do exist, there is no room for future increases. Miles of taxiway systems are "boxed-in" between runways and apron areas - at Kennedy Airport virtually all of the peripheral taxiway system serving the passenger terminals falls into this category.

Aircraft structural bridges or decks deserve special attention because of the difficulty in strengthening these or bringing them up to future width standards. The runway decks at LaGuardia Airport will require a major investment to strengthen even to the limited additional extent feasible. Complete rebuilding for substantial increases in aircraft weight would cause very serious operational dislocations.

Obstacle clearance becomes more important as wing spans, wheel base and gear spacing increase. This applies particularly to ground movements on taxiways and ramps as well as to flight operating clearances. Current FAA standards call for taxiway obstacle free widths of 340 ft. for B-727-200 aircraft up to B-747, and 400 ft. for future 240 ft. wingspan aircraft. Again, many airports have no hope of ever achieving complete 200 ft. separation between taxiway centerlines and obstacles.

Physical clearance to or interference with critically located electronic facilities, such as ILS glide slopes and visibility measuring transmissometers, would also be concerns. New large wingspan aircraft with massive metallic reflecting surfaces might jeopardize low visibility operations because of physical and electronic clearance considerations. Technological advances are required here, along the lines of the less sensitive Microwave Landing Systems.

Ramp area limitations may be paramount since such items as ramp strength, gate position clearances, and taxilane clear areas must be reconsidered. This is especially critical since in many cases one new aircraft will displace two existing smaller aircraft positions because of overall area constraints. This has already happened in attempting to fit the current crop of aircraft into apron areas. This applies not only to accommodating the wide-bodied aircraft but in many cases to the DC-9-80 and the 727-200. Subsidiary to these concerns but important are existing investments in second level loading devices and aircraft parking and docking guidance systems.

Fueling systems and procedures could be affected by substantial increases in aircraft size and configuration. Large sums spent for existing underground fuel systems may need to be written off before their time, unless procedural or technological advances can accommodate the greater demand within the distribution system in place. Projecting the analysis to the end of the century, alternative future fuels and their associated ground systems must be considered. A number of studies have shown that hydrogen or methane will be the next step in aircraft fuels. If this is the case, or even if the move is simply to synthetic fuels, substantial ground storage and distribution facilities will almost certainly be required, and the safety questions associated with certain of these fuels - not only within the airport but with regard to adjacent communities - must be solved.

Of course, increases in aircraft size mean increases in passenger capacity and loads, further straining increasingly inadequate terminal building facilities. With the moves over the last two years to higher density seating, these effects are already appearing, but shock loads of 300 to 500 passengers will become the norm at most terminals rather than the exception. Hold room size, counter space, processing space are among the concerns.

- Baggage handling problems, which today put this item among the top reasons for real passenger delay, may change from a problem to a nightmare, unless the technical and procedural developmental work underway today emerge into the realm of feasibility.
- Curb frontage and auto parking lot processing capacity relate to these higher peak loads, while internal and external roadway capacity, and parking lot size relate to total annual increases in passenger loads as well.
- Security clearance points, hold areas, and procedures will need to be reexamined, expanded, or modified in order to process large aircraft loads on a "normal" rather than exception basis.
- All of this expansion must take place while also permitting the needed ramp expansion on one side and roadway/parking lot work on the other side. The exceptional airport with undeveloped land may need to follow the path of Newark and Atlanta and provide completely new terminal areas.

For the international passenger, the current unique American approach to entry facilitation must be thrown out and replaced with a more effective and humane way. In fact, the need to do this exists now at many major entry airports, where fully loaded wide-body aircraft arrivals must often be kept waiting for extended periods before finding a gate. This is due to a combination of the peak loads as well as the pace and method of federal entry processing. Little hope for additional federal manpower is possible in today's climate, so procedural changes are imperative. These may be perhaps as radical as the use of advanced technology detection equipment, and the preclearing or on-board screening of passengers - possibly using surrogate inspectors.

A whole host of additional concerns about larger aircraft have yet to be touched upon.

The current fleet of monster size crash-fire-rescue trucks, with their incredible quantities of fire fighting agents, frequently roar down runways and taxiways at high speeds in order to meet minimum response time requirements. Have we not reached the upper limits of vehicle capability and is the next step the very expensive alternative of several levels of duplication in fire stations and equipment around the airport?

Virtually each new aircraft type, or derivative, over the last twenty years, have used larger, more powerful, engines. Assuming that this historical trend continues, there is a need to redo or extend runway blast pads, runway and taxiway erosion pavement, and those large areas of erosion pavement needed adjacent to most taxiway turns. Blast fence anchoring, baffle design, and height all will require analysis and possible change. Terminal building facades, ramp structures and service vehicles will be subjected to higher blast levels. One alternative may be to adopt new methods - such as the long-distance, "highspeed" towing of aircraft to remote areas for start-up. There are, of course, serious complications associated with this option ranging from slowing down aircraft ground movements to constructing a whole array of start-up areas and tug return roads - if room can be found.

What will be the impact of the larger wingspan aircraft equipped with larger more powerful engines on the myriad visual aids around the airport? Signs may need to be relocated further from aircraft pavement and therefore made larger and stronger. Elevated lighting fixtures are more susceptible to damage. A typical example was the initial effects of the B-747 takeoffs in France on edge lights and the subsequent development by the French of a low profile runway edge light. In this country strengthening redesigns were required. In-pavement lighting fixtures may also require strengthening for higher roll-over or impact wheel-loading.

Will these new aircraft put pilots higher or at radically new viewing angles so that vision cut-off or distortion of current ground visual aids, such as lighting, reflectors or marking, results? This was the case with wide-bodied aircraft where up to 70 feet forward of the aircraft was out of sight. New patterns might be required with increases in quantities of aids.

Will major improvements in the quality and quantity of runway visual aids be required because these new aircraft, following historical trends, land or depart at higher speeds?

Will systems such as fog dispersal equipment become a requirement if advancements in avionics combined with improved and highly reliable ground electronic aids speed the coming of extremely low visibility operations. Fog dispersal equipment is installed at several European locations on essentially a prototype basis and may require substantial additional development work.

Will these heavier aircraft hurtling down runways at presumably higher speeds exacerbate the current disturbed situation surrounding the subject of runway surface traction? During a contentious ICAO meeting earlier this year pilot, and to an extent airline, organizations sought to require the airport operator to measure surface friction on a real time basis and eventually provide this information to pilots. This premature action was thwarted by focusing attention on the fact that these measurements, even when properly taken, do not correlate with aircraft stopping performance and those assembled agreed to a major conceptual change. That is, measurements were determined to relate to "friction characteristics" and not "braking action". This is not to say that the desire to improve the margin of safety during inclement weather is not present, but it is imperative that further developmental work take place before considering the real time use of measurements and the potentially disasterous effects of providing possibly erroneous information to pilots. After all, it is the airport operator who would be charged with making the system work, in spite of the real life problems he would face in obtaining "legally" reliable measurements. For sure, improvements in the reliability and availability of the equipment-operator combination would be required and a way must be found to speedily take these measurements without long runway shutdowns.

Airports with substantial cargo movement will have problems in somewhat different forms. For example, heavier loads will certainly be involved, and the presumably larger volume capacity of the new aircraft will require larger storage and freight transfer facilities. Also, much of the cargo movements these days is in the belly of passenger aircraft and upper deck of combi aircraft. Current problems with the volume of vehicle movements between the airport freight handling areas and passenger terminal, and the loading operation at these terminals, will worsen.

Last on the list but not the last in importance is sensitivity in communities surrounding airports to aircraft noise. This subject will be discussed by another speaker in more detail but it must be understood that this sensitivity will dictate continual reductions in noise most likely even beyond current Federal regulations. In fact, it is conceivable that in heavily impacted communities or in states charged with regulating noise, local regulations will require action on non-conforming aircraft prior to Federal deadlines.

Identifying Critical Factors

The previous list was long and not all completely connected with new aircraft. It is true that part of the list is also associated with the growth in the industry and, to an extent, with the evolution towards continued operations in extremely poor weather conditions. However, it is important to cite all of these, since an airport operator's ability to accommodate larger or different aircraft may often reduce his already marginal ability to react to other changes. Only in the abstract can one experience a single isolated stimulus.

The next step is to examine some of these existing and future concerns and attempt to isolate those which will cause major problems. Certainly, the first problem is with space or real estate, whether speaking about existing or new airports. For a variety of reasons, airports and the aviation industry are not always regarded as friends. In spite of the jobs that they provide, the economic development they stimulate, or the convenience they provide for easy access to the rest of the country and the world. Rather, in most of the areas where the effects listed are expected, severe community pressures exist against airport expansion. Or, environmental or legal constraints preclude expansion. At LaGuardia Airport, there has been an effort for over ten years to advance a project to provide a partial runway end safety area in Flushing Bay. However, New York City and State property and environmental considerations form a "gridlock" that may be impossible to break out of.

With very limited exceptions, new airports or major expansions of existing airports in areas of strong aviation growth will be extremely difficult if not impossible. Therefore, all aspects of new aircraft that impact space considerations at an airport are critical. New runway length requirements, greater clearance requirements between runways and taxiways, taxiways and taxiways, apron gate positions, and between runway, taxiways, taxilanes and obstacles will be physically impossible in many airports. However, some resolution to this situaiton may be found by reducing clearance margins through rigorous empirically based analysis similar to the effort at FAA's Oklahoma City office in developing the "Collision Risk Model" for runway clearance criteria.

As an example of revised clearances, consider the situation at LaGuardia Airport. While this airport does not handle four engine jets, the DC-10, L-1011 and A-300 have been safely introduced. Prior to that introduction, the taxiway to taxiway separation standard for these aircraft - 300 feet - was analyzed, and it was concluded that 235 feet could be used. The case was made to the FAA and a reconstruction of our taxiway system to this standard proceeded. This reconstruction is virtually complete and the last gap will be closed within the next few years. The rest is history - these aircraft were introduced in the early 1970's and their numbers have increased ever since, albeit on a scale reduced from forecasts.

To a lesser extent, it has been possible to accommodate these wide-bodied aircraft and stretched DC-9's and 727's within existing apron areas by tighter apron control. Outboard finger gates for the larger of these aircraft have been used and these aircraft are moved in and out of position with little impact on the adjacent peripheral taxiway system. However, this process has gone about as far as it can go in the Central Terminal Area and any further airline changes will almost require metal passing over metal, or major adverse impact on the adjacent taxiway system - and this will not be acceptable.

Perhaps farther in the future cost-effective technological advances in taxiing aircraft sensing and guidance systems will be achieved, enabling margins to be cut further. Of course, at some point the overall airport size envelope will of necessity constrain aircraft size.

Another problem could be the operational impact of new development. All construction, even within existing property rights, must be capable of being done without severe operational penalties or the "medicine may kill rather than cure". The first airports that come to mind when thinking about operational complexities associated with construction are smaller ones such as Washington-National. However, even at airports with multiple sets of parallel runways, operational considerations have a heavy impact. A major decision on the type of reconstruction design for the Bay Runway at Kennedy was essentially dictated by the need to minimize the loss of this heavily used departure runway. As to terminal areas, for every airport that can accommodate new terminal locations such as Atlanta and Newark, there are one or two that cannot and must build essentially on top of or alongside the existing one.

Another very inflexible area is community reaction to environmental and safety matters. Aircraft noise is a paramount consideration and colors every other aspect. This will be discussed in another paper.

Other environmental concerns must be addressed and satisfactorily handled or local political approval of airport changes will not be forthcoming. These include: direct water and air pollution; adverse local effects of increased vehicular movements and concentrations; and impacts on river or tidal movements. Any future proposals for environmentally sensitive facilities, such as hydrogen fuel storage systems, would likewise need to be satisfactorily handled.

The pace of technological progress could be a problem. Increases in runway or runway system capacity require substantial technical work in the areas of wake vortex detection and dissipation, terminal airspace efficiency, and poor weather guidance in the air and on the ground. High speed airport access at a reasonable cost is also high on the list of technological needs. The list is long, ranging from the detection of drugs to the rapid recovery of baggage.

Summary

The commercial aviation industry arrived at today's highly reliable system while overcoming constant obstacles along the way. The industry is confident that it can continue to handle market growth. However, airport operator concerns must be factored into the total equation as early as possible before making decisions on new equipment. Following the airport problems encountered in the 1970's with the introduction of the "jumbos", it was thought that things had been turned around - the attention of airlines and manufacturers had finally been focused on the problems. Lately, with the increases in the price of fuel and with the intense effects of deregulation, disturbing talk is heard again. That is why these meetings are particularly appreciated. They present the opportunity to raise caution flags and to work with others in the industry to plan intelligently for the future.

GOVERNMENT's ROLE TOWARD AIRPORT-RELATED RESEARCH AND COMPATIBILITY (Luncheon Remarks)

William F. Shea, Federal Aviation Administration

As background for my comments on airport research, let me briefly overview the scope of FAA's airports program.

The airports mission of the FAA is to foster and promote the development and maintance of a safe and efficient national system of airports. In addition to dealing with issues and constraints like noise and capacity, our mission encompasses responsibility for several programs and functions. These include developing standards for airport planning, design, construction, safety, and operations; developing and publishing the national airport system plan; administering the airport development and planning grant programs; processing airport environmental actions; administering the airport safety and certification programs; ensuring airport compliance; collecting and maintaining airport facilities data; conveying or leasing of Federal land and surplus property for airport purposes; and, representing FAA interests in international aviation. In addition, we are responsible for the operation, maintenance, and development of Washington National and Dulles International Airports.

Research is required to support our standards for airport design and construction at the airports which provide the terminals in our national air transportation system. That research is of primary interest to you. I will, therefore, concentrate my remarks on that facet of the FAA's airports program.

As we pursue the construction of a national system of airports, we have found few, if any, airport sponsors able to undertake their own research. Some state aviation organizations have limited capability to undertake or participate in airport research. State departments of transportation and universities are slightly better off in terms of resources and capability to conduct airport research. This, however, still leaves the primary responsibility for airport research to private industry with input from the Federal government.

Aircraft manufacturers have large and fruitful research and development programs. Most industry elements, and aircraft manufacturers in particular, are normally restricted, however, in terms of research and development to a single product or a few related products. These organizations rarely consider questions relating to optimization of combinations of alternative products or airport construction practices. That means the questions regarding standards and practices to improve transportation safety, reduce construction costs, and/or increase operational efficiency remain unanswered. The research needed to answer these questions is therefore normally left to the level and agencies of government with resources to support these substantial research requirements.

I am concerned that in our R&D efforts, we remain ever more aware of the requirement for team effort between the private operators, industry and government. The various levels of government, the aircraft manufacturers, the military, and the pavement industry have a great challenge ahead to work toward accomplishment of our overall research needs. Academia, the private sector, and foreign airport research organizations must interface with our research programs to provide, as a minimum, advice but more probably answers to some of our pressing compatibility questions. I know the Transportation Research Board will help us to maintain awareness and coordination on all research conducted by the various organizations which are part of the U.S. and foreign government airport research team, as well as foreign R&D. It will take us all to assure that the most pressing needs are emphasized and there is no duplication of research effort.

FAA has a long-term commitment for improvement in the capacity of the nation's airports. Our own R&D organization has published some 200 reports relating to airport problems. This achievement has been buttressed by the support of the Transportation Research Board and the industry working group. Your help in obtaining required resources was significant. You are well aware of the competition to obtain airport R&D funds.

Today, funds are very constrained for research. We are continuously examining our airport research needs or initiatives to identify and prioritize our requirements. I am pleased to inform you that an FAA medium- and long-range airport research needs and initiatives document was released recently. A number of you reviewed the draft. We appreciate all the constructive comments you sent us. This plan provides the philosophy behind our needs for airport R&D, i.e., to assure airport-aircraft compatibility. It also prioritizes our requirements. That is the good news. The availability of resources to fulfill our needs is limited. The entire FAA research budget has been trimmed. The airport share has been no exception. For this reason, more and more dependence must be placed on research efforts by our partners in airport research.

Even as resources become more and more scarce, we recognize we must continue to look for new ideas or improved techniques to assure our continuing world leadership in aviation and airport design. A few of the newer areas being considered for research, or for which research has been started in the U.S., include:

- Simulating, with computer models, possible changes in an airport's configuration which, when coupled with aircraft operational characteristics, such as vortex generation, and requirements, such as the need for triple or closer parallels, will improve capacity.
- Keeping aprons and bridge structures free of ice and snow by utilization of waste heat from the terminal building.
- Providing either a substitute for, or an extender of, asphalt.
- Improving on landing aids for identification of airports without a paved runway.
- Adopting a new noncorrosive chemical for ice control.
- Reducing the cost for maintaining good frictional characteristics on pavements.
- Finding more effective fire extinguishing agents or procedures.
- Electronically monitoring runway surface conditions inclusive of water depth.

As long as FAA has its role in the design and construction of airports, we must continue to pursue airport research. This is absolutely essential to assure all users that our standards are safe, efficient, and provide for technologically advanced airport development.

Our largest single research effort for airports is the airport pavement program. It reflects the fact that paving is the largest single construction cost item. Improved paving techniques, therefore, provide the greatest potential for savings. More than one-half of the airside construction aid money is spent on pavements. One high intensity edge light will cost roughly the same as one yard of pavement concrete. For that reason, we received widely varying answers from different people on R&D priorities.

To assure aircraft-airport compatibility, airport operators and airport design engineers are going to have to continue to keep up with aircraft development and airspace utilization progress. They must at the same time keep abreast of the latest technology in construction practices. The challenge of keeping up, however, applies even more to the managers and implementers of research. The FAA and the international aviation community look to the products of U.S. research for the basis of standards, and the planning for each airport. To solve the mixed problems of compatibility between aircraft, airports and communities must be a number one transportation priority. Obviously this will require substantial research efforts.

Airport-aircraft compatibility must be approached from both directions. Let me illustrate the "must" in terms of the required bilateral participation required to reduce or resolve airport capacity, approach clearance, and pavement strength compatibility problems.

As we look at trends in aviation, it is obvious that new aircraft are larger. Existing aircraft are being stretched, sometimes with appreciable increases in wingspan. Oftentimes the gross weight increases; and if it is not technically and economically feasible to avoid it, the gear, tire weight and tire pressure will increase. The FAA looked at the current and future economic impact of aircraft growth versus airport growth in 1973. This was published as our R&D report "Aircraft Pavement Compatibility." Not only has considerable time passed since that study but the trends of today's economy suggest the work being undertaken here is the appropriate beginning for a revision of our 1973 conclusions. A pavement is only a foundation for the aircraft wheel. It transmits the applied energy to the subgrade as evidenced by deflection, and, unfortunately, deformation and cracking. Heavier loads accelerate deformation and cracking. They reduce pavement life unless a balance in pavement bearing capacity versus strength is reestablished by increasing the strength of the pavement. Increases in tire pressure and, to a limited extent, increases in individual aircraft loads can be provided for by overlays. Substantive increases in gross weight and gear loads involve the deeper layers of the pavement, the drainage requirements, and foundation characteristics. An overlay is often only a temporary solution and in many cases is a questionable approach to solving the increased weight. On the other hand, a reworking of the foundation by the airport sponsors may not be possible. The alternate, which is a redesign of the landing gears, is probably even less feasible. My answer to this dilemma is at best only a partial answer. We must depend on improved two-way communication and cooperation between aircraft manufacturers and airport operators and their designers.

Advanced planning for research to resolve these compatibility problems, as we are exploring here, is absolutely essential; the final element of the solution or solutions will then come from carrying out the research to resolve those pressing problems.

A similar situation applies in terms of the configurations of our nation's airports. The standards for layout of an airport, the runway lengths and the obstruction clearing of the approach surfaces have been modified to reflect aircraft requirements. Trade-offs are again involved. Longer wings mean less fuel but may require increased taxiway clearance. Increased landing gear spacing means improvement in pavement flotation but requires larger fillets. Wide bodies mean more efficient transportation but may require changes to our lighting and marking to maintain visibility from the flight deck. I believe that in the past R&D has been an extremely productive tool and will continue to have a constructive role in the analysis of these conflicts. If we have a good analysis, I know we will find the optimum solution.

Finally, we have been using an airport delay simulation model to study air traffic delay causes and potential solutions at a number of major hub airports. These have been team efforts with the airport owner, the using airlines, and the FAA, that will allow the user to evaluate alternative airport designs, proposed improvements, and possible changes in operational demand, aircraft mix, and ATC procedures for their incremental effect on the capacity of the airport.

In working with the model, the FAA has recently developed a number of refinements and would like to undertake a project to consolidate these refinements. It will result in a user document which would allow the model to be released and used by the public. Assembling the input data and running the model to produce meaningful results is just one example of the requirement for team cooperation and meaningful dialogue between the airport operator, the users, and the FAA. If we achieve an increase in the airport's capacity, it is through joint participation by several parties and an open and candid approach to both the problems and alternative solutions.

Airport-aircraft compatibility problems have been with us and will remain with us. FAA feels it has a major responsibility for work, including research, to help in resolving these problems. The Transportation Research Board also recognizes both the need and a share in the responsibility. I know we all represent areas where there is intense competition today for limited resources. But, I am convinced, that compatibility is an area where we are working together and can minimize the resources required for research. To that end, I am confident the problem identification and research proposed as a result of this meeting will achieve a high payoff and contribution to a great aviation system.

OPERATING PROCEDURES OF AIRCRAFT AND AIRPORTS LIKELY TO IMPACT THEIR COMPATIBILITY

Anees A. Adil, Federal Aviation Administration

Abstract

Some innovative airport capacity improvement concepts that could be safely implemented over the next ten to twenty years are described. Many of these concepts could be quite compatible with today's aircraft and airports in providing air traffic services that satisfy safety and efficiency requirements. To implement many of these near term evolutionary concepts, which have been discussed for many years, very minimal changes are required from existing Air Traffic Control (ATC) operating procedures, as well as improved hardware/software that is either state-of-the-art or nearing the completion of development by the Federal Aviation Administration.

Problem Areas

What are some of the specific areas where aircraft and airport compatibility will be more aggravated unless the FAA engineering and development (E&D) initiatives in airport capacity/delay are exploited to their maximum potential?

First, many air carrier aircraft have flight management computer systems with 4D RNAV capability that can consistently deliver an aircraft over the threshold with an error of 2-3 seconds. However, because of variations in runway occupancy time, aircraft aerodynamic and avionics capabilities, and numerous airport dynamic variables associated with airspace management and airport airfield operational configurations, the present ATC system is capable of providing an 18-21 seconds (1σ) accuracy. This incompatibility, which results in excessive delays and fuel losses will increase as the introduction of new air carrier aircraft (e.g., B-757, 767) are added in significant numbers to the fleet.

Second, the Airline Deregulation Act of 1978 has brought extremely important changes to the U.S. air transportation system. While the full impact of deregulation is yet to be measured, there has been a considerable change in the character of the industry. Patterns of service, route structures, and equipment usage are changing dramatically. At many of the major airports delays have been increasing rapidly, even though only a modest growth in air traffic has been taking place in the past few years.

Third, as more aircraft enter the fleet and become equipped with MLS avionics, operational procedures must be developed to fully exploit the MLS applications that offer potential for improving airport capacity and aircraft delay at congested airports, as well as noise relief to residential communities around the airports.

Fourth, operational solutions to minimize aircraft wake turbulence and the potential for real-time wake vortex prediction and tracking could provide the means to gain back the airport capacity losses that resulted in the early 1970's, when longitudinal separations between leading and trailing aircraft during airport terminal operations were increased up to 6 nmi. and 120 seconds for aircraft arrivals and departures respectively. Unless something is done, this problem will become much worse as more commuter/GA aircraft are mixed in streams containing the larger air carrier fleet.

Finally, airspace and airport demand are expected to increase significantly over the next decade. In order to accommodate that demand it will be necessary to increase capital investment in the system - new and improved airport facilities, navigation and landing aids, and air traffic control facilities. Unless these capital improvements are made there is the potential that in some areas of the country the system will become saturated, and in order to maintain the current high levels of safety, it may be necessary to impose constraints on demand. We all believe that FAA's mission is to develop and maintain a safe and expanding system of airports and airways.

Some proposals are presented later that should allow more compatibility between aircraft and airport issues described previously. First, a discussion of the background of airport capacity, lessons learned from FAA/industry airport capacity/delay studies and analyses, methods to increase airport capacity, major FAA efforts in capacity/delay, and products developed by the FAA should be discussed.

Background

The background of the airport capacity/delay problem is as follows. In the late 1960's the air carriers identified increasing levels of delays in terminal area operations at major air carrier airports. In 1974 the FAA reported to Congress on the eight airports analyzed for airport capacity solutions. This led to the organization of FAA/industry task forces to study the thirty busiest airports in the U.S. Reports have been made public for Chicago O'Hare, Denver, Atlanta, St. Louis, Los Angeles and San Francisco, and the others are expected soon. Using the recommendations from the airport capacity/delay task forces and other promising concepts developed during the most recent E&D initiatives conference, a report was issued in January, 1980 defining those airport capacity initiatives.

IFR delays in the terminal area have been estimated by the task forces to cost users between $500 million and $750 million annually and should approach $5 billion annually in 1999, as shown in Figure 1.

The results of the airport capacity/delay task force studies are summarized in Figure 2. Using the airport airfield capacity and delay simulation models, the FAA applied these tools to estimate both the present average delay estimates (eight minutes per average aircraft operation) and the 1987 delay (25 minutes per operation). It was found that both near term and far term airfield and E&D improvements were needed to cope with future demand at major airports.

As shown in Figure 3, based on the use of these models, peak hour IFR demand exceeds IFR capacity today at large hub airports by about 143 percent. The airport analyses indicate delays now reach one hour and more per aircraft operation during IFR peaks, and that delays averaged eight minutes per aircraft operation at those hubs in 1978 and have increased steadily through 1980.

To summarize the situation regarding delays, three main conclusions can be drawn.

(1) Even if only a modest two percent annual growth in aircraft operations is considered, the task forces believe that delays may average 25 minutes per aircraft by the year 1987. This means that even with moderate growth the problem is becoming increasingly more severe.

Figure 1. Cost delays (IFR) in terminal area.

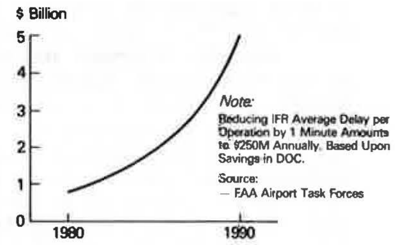


Figure 2. Task force results.

- Developed and Applied an FAA Airport Airfield Capacity Model and Delay Simulation Model, Which Received Broad Acceptance by Aviation Community.
- Average Delay per Operation at Five Airports (ATL, DEN, JFK, LGA, SFO) Runs 8 Minutes (1978) and Increasing to 25 Minutes in 1987.
- Demonstrated to the Aviation Community, Based on Believable Delay Cost Basis, that Both Near Term (1982-1985) & Far Term (1987-1990) Airfield and E&D Improvements' Are Needed to Cope with Demand at Major Airports.

Figure 3. Task force results using airfield capacity delay models.

IFR Demand - Capacity

Airport	Peak Hour IFR Operations Demand	Peak Hour IFR Operations Capacity	Demand/Capacity
ATL	137	107	(128%)
DEN	99	63	(157%)
JFK	88	53	(166%)
LGA	77	60	(128%)
SFO	72	53	(136%)
Average			(143%)

Source: Task Forces (ATL, DEN, NY, SFO)

(2) Considering the airport facility improvements contemplated by the task forces at the airports mentioned, they found that new runways which allow independent IFR operations would afford the biggest benefits by reducing average delays approximately 50 percent.

(3) Near term improvements such as ATC procedures and more navigation aids can provide modest gains, except at JFK where average delay reductions of about 30 percent may be possible. However, even if all the non-technology (operational) improvements were implemented - and many are controversial at the airports and even within the task forces - delays can be expected to be 50 percent greater by the mid-80's than they are today.

The causes of airspace and airport system delay are illustrated in Figure 4 and can be summarized as follows:

- the proximity of other airports,
- ATC rules, regulations and procedures such as separation standards, runway occupancy rules, and the impact of wake vortex on spacing requirements,
- physical limitations on airspace/airfield,
- meteorological conditions,
- available minimums,
- runway configuration management, and
- airport demand.

The question that must be addressed next is what are the fundamental ways to increase airport

Figure 4. Causes of airspace/airport system delays.

Although 84% of NASCOM Delays Are "Weather Related", the Following Factors Are Also of Importance to System Delays:

- The Proximity of Other Airports
  - (e.g., JFK, LGA, EWR)
- Air Traffic Control Rules, Regulations, and Procedures
  - Arrival Separations (3, 4, 5, 4, 6 rule)
  - Runway Occupancy (Only one aircraft allowed on runway)
  - Departure/Arrival Spacing (Currently limits departure if following arrival less than 2 nm from threshold)
  - Departure Separation
    Wake Vortex Effects IFR & VFR Alike
    HH: 90 Sec.; HL, HS: 120 Sec.; All Others: 60 Sec.
- Physical Properties of the Airspace/Airfield
  - E.g., Obstructions, Displaced Thresholds, Exit Locations and Intersections, Gate Locations Relative to Exits; Weight Restrictions on Runways
- Meteorological Conditions
  - For a Constant Demand Average Delay at ORD Can Vary Between 3 and 37 Min./Operation Because of Prevailing Wind Conditions, Capacity Changes Dramatically with Changes in Ceiling/Visibility; Braking Action Increases ROT
- Available Minimums
  - Unavailability of Precision Approach Guidance Increases Delays During Reduced Weather Minimal Conditions
- Runway Configuration Management
  (Selection of maximum capacity configurations based upon weather, equipment, demand, etc.)
- Aircraft Demand
  (En route & terminal area; arrival/departure, queues; gate availability)

Because of the factors cited above, the efficiency of the system requires an optimal balance between all of the above. What are some of the fundamental ways to increase airport capacity and hence reduce aircraft delays?

capacity and reduce airport delays. Basically, airport capacity can be increased by:

- improvements to airports,
- reducing the IFR separation standards,
- creating additional IFR arrival streams, and
- managing the demand for aircraft services during peak hour operations.

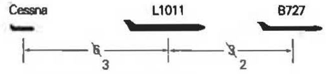
First, increasing the efficiency at airports by the addition of new runways, taxiways, NAVAIDS, and ATC procedures could reduce the delays as much as 50 percent. However, it is unlikely that full implementation can take place at the congested airports.

Second, as shown in Figure 5, reducing aircraft IFR separation standards to 2-3 miles could save between 50-75 percent in aircraft delay costs. It is unlikely that full implementation would occur throughout the system without lengthy and extensive operational testing. The major hurdle in the reduction of IFR longitudinal separation standards is the alleviation and avoidance of wake turbulence hazards to following aircraft.

One of the most promising ways to increase airport capacity is to provide more arrival streams to conduct instrument approaches. This is illustrated in Figure 6. Such approaches, either independent or dependent, would be made to existing runways that are presently available at many of the congested hub airports. These concepts include converging (non-parallel) approaches and the combination of parallel and converging approaches that are used today during VMC conditions. We have identified a total of 89 airports which could provide for 134 potential applications of one or more airport capacity improvement concepts. Benefits in improved arrival capacity when compared with a single runway range from 40-50 percent for dependent approaches, 100 percent for independent approaches, and a 140-155 percent capacity improvement for triple approaches.

Finally, demand management can help. Today there are quotas at O'Hare, Kennedy, LaGuardia, and Washington National, and if demand management and

Figure 5. Reduced IFR separations.



- Could Save 50-75% of Delays
- Full Implementation Unlikely
- Wake Turbulence Problems

Figure 6. More IFR separations.

- Non Parallel, Reduced Parallels, Small Aircraft Streams, Triples
- Could Save Up to 50% of Delays
- Requires New Research
  - Present Separation Standards Limit Application to VMC Only
  - New Operational Procedures Need to be Developed to Exploit Full Potential

Figure 7. MLS **applications.**

- Provides Independent Streams of Commuter/GA Aircraft to Separate Short Runways
- Provides Simultaneous Approaches to Triple Parallel Runways
- Provides IFR Capability of Non-Parallel Approaches
- Reduction in the 4300 Foot Independent Parallel IFR Centerline Separation Requirement
- Accomodate Dependent IFR Approaches to Closely Spaced Dual Lane Runways Under Wake Vortex Constraints
- Simplified Siting Criteria for Small Airports

redistribution were applied throughout the national air system, a 50 percent reduction in delays could be achieved. Techniques such as holding aircraft on the ground and flow control are additional methods to manage the demand, and today these procedures are mandatory during the emergency period presently in force. The issue is still debatable as to whether demand and delay management will be voluntary or mandatory after the ATC system is rebuilt.

The benefits of microwave landing systems (MLS) are of major concern today, and they show great promise for increasing airport capacity as shown in Figure 7. MLS can provide the means to safely guide instrument approaching aircraft and accommodate missed approaches to separate short runways, triple parallel runways, converging runways, and during instrument operations, to independent parallels with less than 4300 feet centerline spacing. Higher glide slope requirements for ILS operations to closely spaced runways could assist wake vortex operational solutions by keeping lighter aircraft above and away from the hazardous wake vorticies. Finally, small airports can be accommodated more readily with MLS.

Use of separate, short runways for general aviation and commuters provide an operational solution to vortex separation problems and help cope with the growth of general aviation/commuter operations. But such runways must be located in positions where they can be operated completely independently. Full use of such runways at specific airports may require the definition of triple parallel operations, as at O'Hare, Dallas/Ft. Worth or Atlanta. Resolution of airspace conflicts may be required as for example at Kennedy where the small runway exists but is not routinely used because of potential conflicts with other operations. The precision paths available from MLS should help. MLS may provide solutions to potential obstacle clearance, terrain or siting problems at Denver, where a study was recently completed on the feasibility of a short general aviation runway.

MLS may help reduce the 4300 foot parallel separation requirement for general aviation and commuter traffic on parallel short runways by providing additional navigation precision, high glide path angles for extra spacing, and as above, by providing precision missed approach capability, MLS would also provide the ability to restructure approach paths at selected airports to permit segregated approaches to short runways by general aviation, helicopters, and commuter operators. The use of the variable glide paths available with the MLS will permit small aircraft to follow "heavies" at a higher glide path angle as a means to ensure protection from wake turbulence.

Next, the current major Engineering and Development programs of the FAA are reviewed.

Wake Vortex

When the wake vortex problem was recognized nearly ten years ago, two efforts were undertaken. One, by NASA, concentrated on the mechanics and causes of wake vorticies, and methods to alleviate them at the source. These efforts have not reached the stage where either the airframe manufacturers or the users feel implementable wake vortex alleviation systems are achievable.

FAA undertook the development of wake vortex detection and avoidance systems, and has been moderately successful in characterizing wakes and developing meteorological ways to predict the probable location of wake vorticies. A system under test at O'Hare has proven technically workable, but has not been found operationally acceptable by some of the users.

It is clear that the current promise of full wake vortex detection and alleviation system is less than NASA or FAA had hoped. While the research and development work will continue, and there is some hope for active wake vortex sensors, we must concentrate also on other approaches, because the wake vortex problem continues to be a major constraint to IFR capacity. This year we are planning to test the performance of NOAA's FM-CW Doppler weather radar to detect wake related echoes from large aircraft landing at Denver.

Automated Metering and Spacing

Automated metering and spacing has long been discussed as a potential source of at least evening out capacity at a given airport, and some have felt that capacity might be increased. Yet, the achievement of automated metering and spacing in implementable form has proven elusive. We have come to appreciate the truly remarkable capability of human controllers to manage terminal air traffic and to achieve efficient airport operations -- capacities which may be extremely difficult to duplicate with automation. There are, of course, things that have been done and there are more things that will be done, especially as the problem of fuel conservation becomes more critical.

Operational Techniques for Capacity/Delay Improvement

Washington has been working with the Great Lakes Region to design a configuration management system for O'Hare to aid the assistant chief (AC) of the facility in the selection of best runway configuration to minimize delays. A basic system was tested

Figure 8. Longer term E&D programs.

- Continuation of Wake Vortex R&D
  - Vortex Alleviation
  - Prediction and Tracking of Vortices
  - Knowledge of Vortices Beyond Outer Marker
- Automated En Route ATC (AERA) System
  - Major Automation Process
  - Will Feed Integrated Flow Management Program
- IFM-Optimize Fuel Efficiency of ATC System While Maximizing Airport Thruput
- Cockpit Display of Traffic Information (CDTI)
  - Possible Aid to Pilot Acceptance of Automation and Reduced Spacing

Figure 9. FAA flow programs in operating services.

- Central Flow Control Facility
  - Fuel Advisory Departure Procedures (FAD)
    - Voluntary Cooperation with the NAS
  - Quota Flow
    - Management of High Altitude Air Traffic
- En Route (ARTCC's)
  - En Route Metering Implementation in Progress at 20 NAS Stage A Centers that Service 18 Terminals (ERM-1)
- "Operation Free Flight"
  - Study Reviewed the System of Today and Found that a Limited Capability Exists to Handle Direct Flights.
- National Airspace Review
  - A Systematic Review of the Current Airspace Operations & Efficiency:
    - (1) Evaluation of Airspace Structure at FL 180 and Above
    - (2) Evaluation of Airspace Structure Below FL 180, and
    - (3) Integration of E&D Programs, Systems & Procedures into NAS.

Figure 10. Bottom lines.

- Reduced Longitudinal Spacing from 3.0 to 2.5 nm (IFR) Possible Today Under "No-Wake-Vortex-Hazards" Conditions

  Requires:
  - Removal of Wake Vortex Restrictions when Wakes Are Not a Factor
  - Development of Operational Procedures
  - Acceptance by Pilots/Controllers
- Further Reduction to 2.0 nm Minimum

  Requires:
  - Solution to the Vortex Problem
  - Improved Runway Occupancy Times
  - Better Over-the-Threshold Delivery Accuracy
  - Resolution of Operational Problems
  - Development of Operational Procedures
  - Acceptance by Pilots/Controllers
- Solution to Improved Traffic Flow Not Based Solely on Maximizing the Landing Rate of a Runway; a Balance of Aircraft Demand, Terminal Area Operations, and Airport Capacity is Required to Achieve Optimal Airport Thruput.
- Upgraded O'Hare Runway Configuration Management System Being Developed for Test and Evaluation at ORD (9/81).
- Integrated Flow Management
  - Critical Element in Optimal Tradeoffs Among:
    - ☐ Delays
    - ☐ Capacity
    - ☐ Fuel Consumption
  - Must Integrate the Functions of:
    - ☐ National Flow Management
    - ☐ En Route Flow
    - ☐ Terminal Flow
    - ☐ Airport Operations
    - ☐ New Aircraft Capabilities — 3D/4D RNAV, Performance Computers

off-line at O'Hare. It incorporates equipment/runway outages, wind and ceiling visibility, demand and Midway Airport interactions. We are developing an enhanced runway configuration management system that will be capable of operating in a "stand alone" computer system for the AC in keeping airport capacity at peak levels.

Also, the phase of evaluating the technical feasibility of instrument approaches to separate short runways for commuters/general aviation, to converging runways, to close spaced parallels for independent and dependent operations, to triple runways and operational solutions to wake vorticies for closely spaced parallels has been completed.

Integrated Flow Management

A "strawman" concept and operational description has been developed for a program called integrated flow management. This program should help achieve optimal trade-offs between delay, capacity and fuel efficiency at major terminal complexes in the longer term. The integrated flow management concept must integrate the functions of national flow management, en route metering, terminal flow and airport operations. This concept will use automation tools to permit the best possible integration of a variety of services and capabilities, including optimal fuel-efficient flight paths, the capabilities of 3D and 4D area navigation, adequate wake vortex protection, an optimum metering, sequencing and spacing system to ensure minimum time deviation over the threshold, the capability to provide conflict-free paths which recognize limitations of weather and shear, and runway occupancy time monitoring and control. A method for best integrating these capabilities into the system and establishing the impact of ATC automation planning will be examined.

Figure 8 summarizes several programs under way for the longer term. FAA and NASA both are continuing to work on improvements in wake vortex alleviation and avoidance, and another search for a long-range, real-time vortex sensor which can reach out beyond the outer marker will be made. The work being done in the automated en route air traffic control system, the AERA program, will evolve into terminal automation as well, and will become an element of the integrated flow management (IFM) system. The IFM program will achieve optimum fuel efficiency while maximizing aircraft flow through the airport. The FAA program to examine the capabilities and limitations of cockpit displays of traffic may show that they can be a part of the future terminal system.

The operating services of the FAA have accomplished several things related to improvements in aircraft flow as illustrated in Figure 9. For example:

- Central flow control has been operating successfully for a number of years and is improving. It has provided an important operational element which can be fed into an integrated flow management system. Fuel advisory procedures have been implemented to absorb severe delays on the ground with significant fuel savings.

- Terminal area delays are minimized by providing to the centers realistic acceptance rates at an airport for the runway configuration in operation, and a more efficient flow of aircraft results in the system.

- Implementation of the first phase of en route metering is nearing completion for 18 of the busiest airports. Today's system can accommodate some direct flights

Figure 11. A rough estimate of potential savings from improvements at specific airports.

Applications of	At These Airports	Potential Total Annual Savings of
■ Triple Parallels	ORD	$10 M[1]
■ Reduction of Parallel Runway Spacing Reqts.	DEN	$10 M[1]
■ IFR Approaches to Converging Runways	DEN, DFW, IAH, MIA, ORD, STL, New York	$70 M[1]
■ Separate, Short GA Runway	ORD, ATL, PHL, DFW, JFK, DEN, STL	$60-150 M[2]
■ Configuration Management	ORD	$15 M[1]

Note: These benefits are an estimate of potential savings only and are not cumulative; require E&D products (e.g., MLS, etc.)

Sources: [1]Task Forces; [2]FAA-EM-79-19

Figure 12. Airport capacity/delay E&D products.

	Development Completed
■ Reduced Final Approach Spacing Feasibility Analysis to Achieve 3.0, 2.5 & 2.0 nmi Minimum Longitudinal Spacing	8/79
■ Potential Benefits of Using Short Runways at 30 Major Aiports	9/79
■ Feasibility Study of a Separate Short Runway for Commuter and GA Aircraft at Denver	9/80
■ Development of a Terminal Area Airspace Model for Application on Integrated Flow Management Program	9/80
■ Completed Validation of Airfield Delay Simulation Model for FAA/Industry Airport Task Forces	9/80
■ Methodology for Analyzing Feasibility of Dependent Parallel Instrument Approaches for	
– Analysis of Airborne Separation	9/80
– Control of Mixed Arrival & Departure Runway Operations	9/80
■ Completed Development of Upgraded FAA Airfield Capacity Model	3/81
■ Safety Analysis & Equipment Requirements for Independent & Dependent Parallel Instrument Approaches at Reduced Runway Centerline Spacing	5/81
	Due Date
■ Safety Analysis, Equipment & Controller Staffing Requirements & Preliminary Procedures for	
– Instrument Approaches to Triple Parallel Runways	9/81
– Instrument Approaches to Converging Runways	9/81
■ Safety Analysis, Equipment & Procedures Required for Reducing Aircraft Longitudinal Spacing to 3 nmi on Instrument Approaches to Dependent Parallel Runways	9/81
■ Real-time Planning Aid for O'Hare Assistant Chiefs to Consistently Select Maximum Aircraft Thruput for ORD	
– Initiate Test & Evaluation of Runway Configuration Management System	9/81
– Complete Test & Evaluation, Document Software	9/82

for air carriers with flight management computer systems. A more comprehensive review of the national airspace has been initiated by the FAA and this activity is expected to continue actively into 1984.

Benefits

What are the results, benefits, or "bottom lines" as they are commonly called, from these developmental activities? They are summarized in Figure 10. Briefly,

- Minimum longitudinal separation standards for IFR can be reduced from 3.0 to 2.5 nmi, when wakes are judged not to be a factor. Operational testing and evaluation of procedures are required before implementation can be initiated.

- To achieve a 2 nmi. minimum spacing requires a solution to the wake turbulence problem, as well as compatibility between runway occupancy times and over-the-threshold delivery accuracy. However, testing and evaluation of operational changes is still required.

- A balance between demand, terminal area operations and airport capacity is the key to optimal airport thruput.

- A configuration management system for assistant chiefs at O'Hare has been developed and is ready for test and evaluation.

- The IFM program is a critical element in trade-offs between aircraft delays, airport capacity and fuel consumption. All of the functions of national, en route and terminal flow as well as airport and aircraft capabilities must be integrated in a systematic manner.

Several potential improvements which promise high payoff as seen by the task forces and the FAA are discussed next. These improvements have the potential to reduce the cost of delays by millions of dollars as shown in Figure 11, but fall short of completely eliminating them, particularly if increased aircraft operations and changes in mix impose greater demand on airports in the future. Federal expenditures for R&D to accomplish them appear worthwhile, but they may be viewed only as ameliorations of the problem. Complete solutions are likely to be achieved only through major capacity increases that involve the construction of new runways. In some cases, new airports, and more intensive management of demand, including the redistribution of traffic between airports may be required to make the most efficient use of available capacity.

Figure 12 presents a list of FAA engineering and development products showing the studies, analyses, models, methodology, safety analysis and equipment/controller staffing requirements developed for the highly promising airport capacity improvement concepts. The major product that is ready for testing and evaluation is a real-time planning aid for the O'Hare assistant chiefs to consistently select the maximum capacity configuration for that airport.

Finally, Figure 13 summarizes the aircraft flow improvement programs. Perhaps the most interesting and the most valuable airport capacity/delay improvements in the long run are direct and indirect

Figure 13. Summary of aircraft flow improvement programs.

- ■ Wake Vortex Relief and Reduced Longitudinal Spacing
- ■ O'Hare Runway Configuration Management
- ■ Use of Separate Short Runways by GA and Commuter
- ■ IFR Approaches
  - – Triple Parallels
  - – Closely-spaced Parallels
  - – Converging IFR Approaches
- ■ Reduction of Parallel Runway Spacing Requirements
- ■ Airport Surface Traffic Control
- ■ Microwave Landing System Applications
- ■ Integrated Flow Management (Including metering and spacing)
- ■ Automated En Route ATC System Development and Extension
- ■ Cockpit Display of Traffic Information
- ■ Demand Management Impact Assessment

techniques to overcome the wake vortex problems, better innovative use of runways and runway configuration, the use of separate short runways at major airports by general aviation and commuters, independent and dependent IFR approaches including reduction in IFR centerline spacing requirements for independent approaches, applications of the microwave landing systems, and an integrated flow management concept. The prospective payoff from technology changes and improvements seems high, and seems to us to be very much worthwhile. The technology can offer important benefits, but probably not enough to solve the anticipated problems of capacity, demand, and delay, even under modest growth assumptions. However, in the near term, significant terminal area capacity improvements would result in the system if the operating procedures that have been developed for all the innovative concepts are tested and accepted by the users and operators of the ATC system.

AN ASSESSMENT OF THE NOISE IMPACT ASPECTS OF AIRCRAFT AND AIRPORT COMPATIBILITY

Kenneth McK. Eldred, Ken Eldred
Engineering, Concord, Massachusetts

Abstract

This paper briefly describes the quantitative measures of noise appropriate to airports, the response of people to noise outside their homes, and land use criteria. It then presents a summary of the estimated current and future noise impact from airport operations, and an assessment of the potential for reducing their impact through airport noise control programs.

Introduction

In the late 1960's the Civil Aviation Research and Development (CARD) study (1) found aircraft noise in the vicinity of airports to be a major impediment to the development of airports and the growth of the civil aviation system. Subsequent events have proved this finding to be correct. Law suits, environmental impact statements, and state and local attempts to regulate airports, brought the development of existing airports to a crawl - and the development of new major airports practically to a complete halt.

Today, over a decade later, noise is still a major impediment to airport development, and it may continue to be an impediment for the next twenty years. Yet there is now some light at the end of the tunnel. The retirement of older noisier aircraft with their replacement by new quieter aircraft is underway. This accomplishment is the result of government and industry research and development since the late 1950's; Federal Aviation Administration (FAA) certification for noise beginning in 1969; and the design and production of new, quieter aircraft beginning in the early 1970's. We must not be lulled into believing that these achievements are sufficient to solve completely the nation's airport/aircraft noise problem in the very near future. They will not. But, they will bring sufficient improvement to offer the hope that the civil aviation system will gain some credibility with airport neighbors. And, hopefully, the system will have the wisdom to build on its new credibility to establish better working relationships among airports, their users and their neighbors.

Noise Descriptions and Their Application to Aircraft/Airport Noise

Magnitude and Frequency Weighting

A person's ability to perceive a specific sound depends upon its magnitude and character, as differentiated from the magnitudes and characters of other competing sounds in the environment. The magnitude of sound is generally described as its level, which is proportional to the logarithm of the mean square of the sound pressure fluctuations at a measuring microphone. The unit of magnitude is the decibel (dB).

There are many subjective attributes which can be used to describe the character of a sound. The most important have to do with its frequency content and its temporal pattern. Frequency spectrum content may be described in terms such as high pitched hiss, low rumble, tonal, broadband, etc. People hear sound at frequencies between 500 and 5000 hertz better than they hear sounds at lower or higher frequencies. Therefore, to measure the magnitude of sound in a way that is proportional to its perceived magnitude, it is necessary to weight the low and high frequency sounds so that they contribute less to the measured magnitude than do sounds at the middle frequencies that are heard more readily. The frequency weighting most commonly used for this purpose is the A-weighting which rolls off the low and high frequency sounds in much the same manner as can base and treble controls on a hi fi set.

The zero decibel value on the A-weighted sound level scale (sound level for short) is the reference pressure of 20 micro pascals (micro-newtons per square meter). This value was selected because it approximated the smallest sound pressure that could be detected by a human. The average sound level of a whisper at a one meter distance from the person who is whispering is 40 dB; the sound level of a normal voice at a one meter distance is 57 dB; a shout one meter away is 85 dB.

A more complex and more accurate frequency weighting to account for human perception is the perceived noise level. This scale was developed during a decade of research into aircraft sounds. It, together with a correction penalty for pure tones, is the magnitude scale used in measuring aircraft noise for certification. For a typical aircraft sound the value of the tone-corrected perceived noise level is typically 12-16 dB greater than that of the A-weighted sound level.

Time Variation of Sound Level

The temporal patterns of the A-weighted sound level are most easily observed on a continuous graphic level recording, such as the two eight-minute samples illustrated in Figure 1. One of the most striking features of these temporal patterns is that the sound level varies with time over a range of 33 dB, which is a ratio of 2000 to 1 in sound energy.

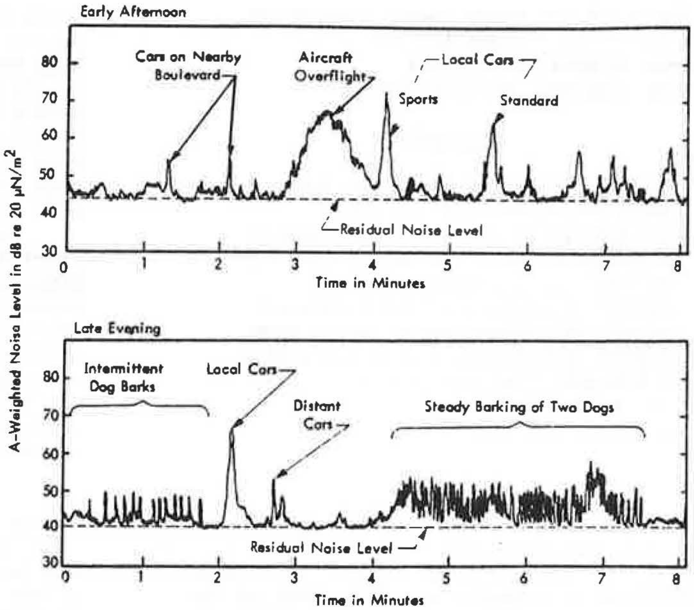
In these examples the sound seems to be characterized by a fairly steady state lower level, called the residual level, upon which is superimposed short term increases in sound level associated with various discrete (individual) single events. These single event sounds may be partially defined by their magnitudes or maximum sound levels. But they may also be characterized by their time patterns. The sound level of the aircraft in the example is greater than the residual sound level for approximately 80 seconds, whereas the sound levels from the cars are greater than the residual for much shorter durations ranging from about 5 to 20 seconds. Clearly, if the sound associated with one or more of these single events were of sufficient magnitude to intrude on a person's activities, the duration of the single event might be expected to effect the degree of intrusion, and of annoyance.

Experiments have demonstrated these effects and shown that the proper measure of the sound associated with a single event is to add all the sound energy together throughout the duration of the event. The quantity which expresses the total sound associated with a single event is sound exposure level (SEL) when the instantaneous magnitude of the sound is the A-weighted sound level. The analogous quantity, when tone-corrected perceived noise level is used as the measure of the instantaneous magnitude of the sound, is the effective perceived noise level (EPNL). EPNL is the primary quantity used for noise certification of aircraft under FAA regulations in FAR Part 36. (4) EPNL values are typically 2-6 dB greater than SEL values for aircraft sounds.

Duration and Number of Events

The large variation in sound level seen in the two samples of Figure 1 make it difficult to find any single number to characterize the amount of noise

Figure 1. Two samples of outdoor noise in front yard in Pacific Palisades (2), (3), with microphone 20 feet from the street curbing.



in either sample. One could identify the maximum and residual sound levels but this would leave out the important factor of the duration of the sound at levels between the maximum and residual levels. One could also describe the statistical properties of the sound in terms of the time above each of several levels selected to be at convenient intervals. But this would lead toward the use of many numbers to describe a noise rather than toward the use of a single number.

One solution to this problem is to determine the level of a steady-state sound which has the same A-weighted mean square sound pressure as does the actual time varying sound. This quantity is termed the Equivalent Sound Level (L_{eq}). Its principal virtue, besides providing a single number description of a complex time history of sound levels, is that its magnitude correlates well with the effects of sound on people. (5) This correlation extends over a wide variation in types of sound levels and time patterns, and effects, which range from speech interference to risk of hearing loss. L_{eq} is also the basis for the day-night sound level which is most often used to describe the outdoor noise environment.

The day-night sound level (L_{dn}) is defined as the A-weighted equivalent sound level for a 24 hour period with a +10 dB weighting (or penalty) applied to equivalent sound levels occurring in the nighttime hours between 10 P.M. and 7 A.M. The nighttime penalty acts to increase the apparent levels at nighttime by 10 dB. Hence, an environment that has a steady daytime L_{eq} of 60 dB and a nighttime L_{eq} of 50 dB, has a weighted nighttime level of 60 dB (50 + 10) dB and a day-night sound level of 60 dB. The day-night sound level was developed by the Environmental Protection Agency as the principal descriptor for outdoor noise in the community (5). It has subsequently been adopted by the Department of Defense, Department of Housing and Urban Development (6), and by the FAA for airports in its regulations in FAR Part 150.

The analogous quantity to L_{dn} in the perceived noise level system is the Noise Exposure Forecast (NEF). This quantity uses a 12 dB nighttime weighting rather than a ten dB weighting. The numerical value of NEF is generally approximately 35 dB less than that of L_{dn}.

Figure 2 gives an example of annual average day-night sound level contours around Logan International Airport The L_{dn} 65 and 75 dB contours are depicted with heavy lines. The relative size and shape of these contours is a function of the relative utilization of the six runway ends for takeoffs and landings. Also illustrated in the figure are typical values of sound exposure level (SEL). These values range between about 90 and 96 dB on the L_{dn} 65 dB contour. This variation in the value of SEL on a given L_{dn} contour reflects the variation in the relative number and type of operations on the various runways since:

$$L_{dn} = \overline{SEL} + \log N_e - 49.4 \text{ in dB}$$

where $\overline{SEL}$ is the mix average sound exposure level at a given location

and N_e is the effective number of operations (either takeoffs or landings) equaling the number of daytime operations plus ten times the number of nighttime operations

Response of People to Noise

Many of the effects of noise on individuals are highly dependent on specific situations and not readily generalized. However, three primary direct effects - activity interference, annoyance and hearing loss - have been studied extensively, and their statistical relationships to noise provide the primary quantitative basis for noise evaluation and control. These quantitative relationships are summarized by EPA in its Levels Documents (5), and have been extended in the area of environmental assessment by the National Research Council, in its guidelines for assessment of the environmental impact of noise (9). The two effects applicable to airport noise, activity interference and annoyance, are summarized in the following.

Activity Interference

Social surveys have developed information on activity disturbance from environmental noise. In the late

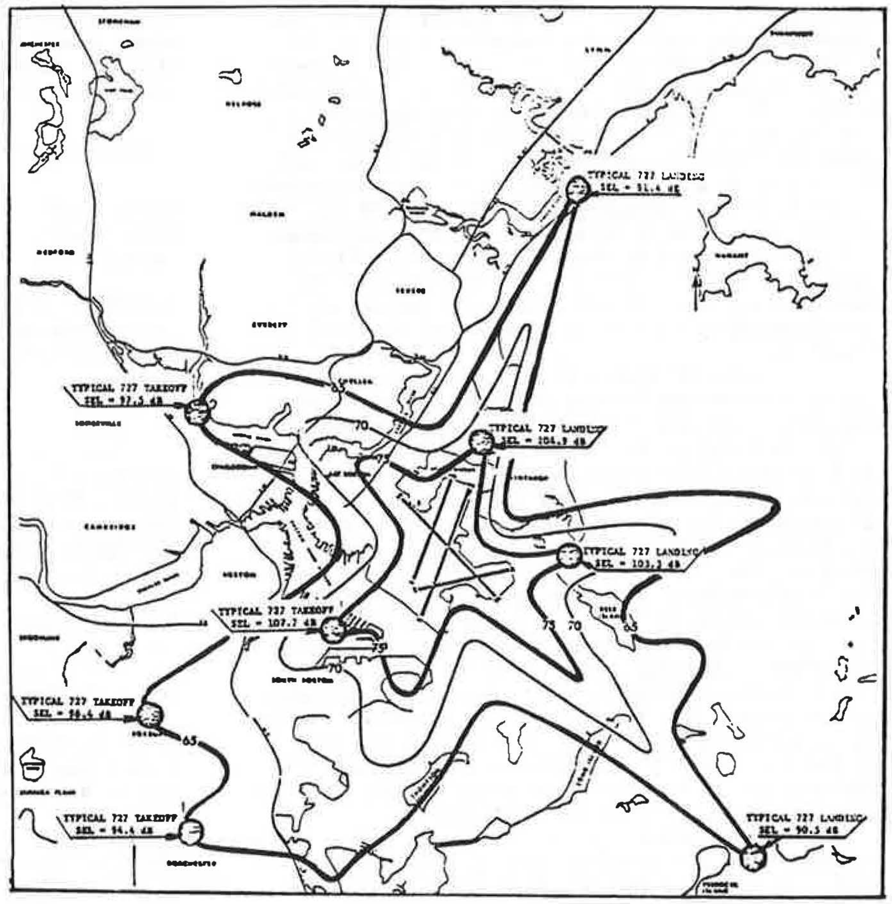


Figure 2. Example of cumulative noise contour from airport operations.

1960's, a survey (10) of over 4000 persons who were exposed to airport/aircraft noise revealed that the activity interference most often cited as extremely disturbing involved speech listening. (Table 1)

Table 1. Rank order of activities by percent extremely disturbed* by interference of aircraft noise (10).

	Percent
TV/Radio reception	20.6
Conversation	14.5
Telephone	13.8
Relaxing outside	12.5
Relaxing inside	10.7
Listening to records/tapes	9.1
Sleeping	7.7
Reading	6.3
Eating	3.5

*Percent scoring 4 or 5 on a 1-5 scale.

The first three of the activities in Table 1 involve speech communication. Here, the degree of interference is readily quantified in terms of sound level and listening situation. For the other six activities, the degree of interference often depends upon factors other than the magnitude and character of the noise, and these factors are not readily quantified. Note that criteria have not been established for noise levels which interfere with listening to music at home, although such criteria do exist for performing arts halls.

Interference with Speech Communications

Noise can interfere with speech communication in situations encountered at home, at work, in vehicles, and in other settings. Of chief concern to the majority of the exposed population is the effect of noise on face-to-face conversation indoors and outdoors, telephone use, and radio or television enjoyment. The extent to which noise affects speech communication depends on the location (whether indoors or outdoors), the magnitude of the noise, and the vocal effort of the talkers. It is possible to maintain communication over a wide range of intruding noise if the voice level is raised, but there is an upper limit above which no speech communication is possible. As the magnitude of noise is brought below this limit, the quality of communication steadily improves until a lower limit is reached where no interference can be detected.

The chief effect of intruding noise on speech is to mask the speech sounds and thus reduce intelligibility. The important contributions to intelligibility in speech sound cover a range in frequency from about 200 to 6000 Hz, and at each frequency speech has a dynamic range in level of about 30 dB. The intelligibility of speech will be nearly perfect if all these contributions are available to a listener for his understanding. But when noise masks, or covers up, some of these contributions, the intelligibility deteriorates. The amount of this deterioration depends on the noise level, the speech level and the degree to which the noise frequencies coincide with the important speech frequencies.

The results of speech research can be used to determine the levels of noise that will produce varying degrees of masking as a function of vocal effort and the distance between talkers and listeners. Other factors, such as the talker's language, the listener's motivation, and of course, the sharpness of the listener's hearing also influence intelligibility. The effects of noise in masking normal conversational speech in a home indoor situation are shown in Figure 3. If the level of the noise does not exceed 45 dB, 100 percent speech intelligibility is often assumed possible. If the level of the noise is then increased to 65 dB, the sentence intelligibility is expected to drop to 95 percent. If the words in the speech are not so familiar as those contained in ordinary conversational sentences, the intelligibility will be less than that depicted in Figure 3.

The level of speech sounds decreases as the distance increases between a talker and a listener. However, in an indoor situation, the distance over which the level decreases is limited by the enhancement of the speech sounds by reflection from the various surfaces and objects in the room. At greater distances in the room between talker and listener, the listener is in the reverberant field where the level of the speech sounds is essentially constant. The relationships shown in Figure 3 apply in the reverberant field of a room in a typical home when the distance to the reverberant field is approximately one meter (1.1 yard). If a room has significantly more acoustic absorption than assumed, the distance to the reverberant field increases somewhat, and the intelligibility is slightly less than that shown. If the room has significantly less absorption, the distance to the reverberation field and the intelligibility is somewhat better than shown.

Outdoors, where the talker and listener are not surrounded by the sound-reflecting surfaces of a room, the level of the speech sounds continues to decrease with increasing distance between talker and listener. Table 2 presents the maximum noise levels allowable for marginal communication conversation at the indicated distances and voice levels.

Figure 3. Sentence intelligibility for normal voice as a function of the steady background sound level in a typical indoor home situation (9).

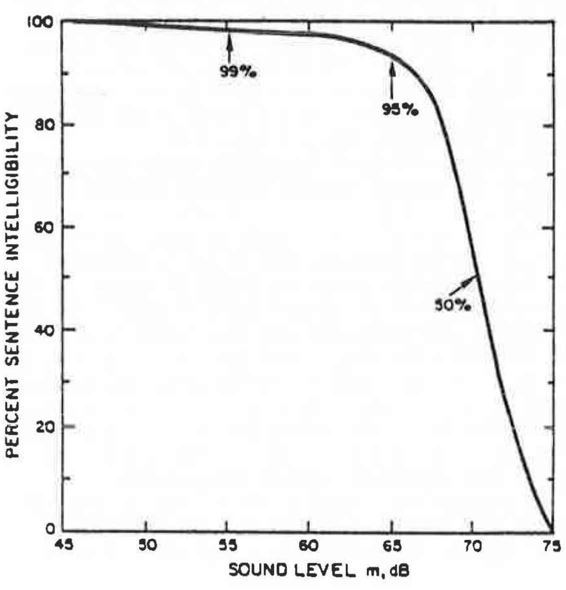


Table 2. Relationship between maximum A-weighted sound levels in dB which allow marginal communication (95 percent sentence intelligibility) over various distances outdoors* (11).

	Distance in Meters				
Voice level	0.5	1	2	3	5
Normal voice	72	66	60	56	52
Raised voice	78	72	66	62	58

*Subtract 20 dB to obtain levels for which no interference is expected (100 percent sentence intelligibility).

These maximum noise levels allowable for 95 percent sentence intelligibility are about 20 dB greater than the maximum noise levels allowable for 100 percent speech intelligibility, just as shown in Figure 3 for the indoor situation. However, outdoors, for a given noise level intelligibility may be improved by moving closer to decrease the distance between speakers, in addition to increasing the vocal effect.

For situations in which the magnitude of the noise fluctuates with time, the equivalent sound level may be substituted for the steady state sound level in either Figure 3 or Table 2. This substitution has been shown to be valid for real highway noises and other fluctuating noises. (12), (13)

Annoyance

The cumulative effect of activity interference by noise is often measured in terms of annoyance. Although other factors, such as attitude towards the noise source, may influence an individual's reaction to activity interferences, the percentage of people annoyed, or highly annoyed, in a given environmental situation provides a useful index of the severity of the situation. The relationships between noise and annoyance have been deduced from a series of social surveys and examination of community complaints and reactions to intruding noises.

The results of social surveys in several countries have been combined to give a general relationship between long-term average outdoor environmental noise in residential areas and the annoyance of the residence. (14) The surveys were associated with several types of noise situations, including noise resulting from urban traffic, highways, railroads, and airports. The results for 12 of the 19 surveys studied clustered closely around an average curve of all of the data, as shown in Figure 4. The results of the seven surveys that did not cluster as closely as those shown still had essentially the same average values.

The annoyance data are given in terms of the percentage of respondents who reported that they were highly annoyed by the noise. For this purpose, the people counted as "highly annoyed" are those whose response was in the top 27 to 29 percent of an annoyance scale ranging between "none" and "extreme," and for surveys where the scale steps were named, those who categorized themselves as "highly" or more than "highly" annoyed.

The results show that fewer than five percent of of the people are highly annoyed when the L_{dn} is less than 55 dB, and more than 37 percent of the people are highly annoyed when the L_{dn} is more than 75 dB. (14) These results are averages of many individuals, levels and situations. They appear to be useful in a statistical sense when applied to a large population over a range of situations. However, they may not give good predictions for an individual situation or for an individual person. For example, recent annoyance data at Burbank (15) shows much higher annoyance from aircraft noise than would be expected from the results in Figure 4.

For specific situations other factors must be considered, such as attitude toward the source of the noise, the relationship between the general background noise and that of the intruding noise, and the amount by which sound is attenuated from outside to inside (for example, windows typically open or closed). These factors have been partially evaluated in studies of community reaction. (2), (3) Their inclusion in the analysis may give significant improvement in specific situations.

Community Reactions

Analysis of the community reaction to a variety of types of intruding sounds demonstrates that the degree of reaction varying between "none" and "vigorous" is a function primarily of the relative level with and without the intruding noise. Corrections for other factors, such as prior experience, attitude, and the character of the noise, can improve the accuracy of this relationship. The principal corrections used for normalization were to add 5 dB to the level of the intruding noise if there was no prior experience with the noise, if it was of impulsive character, or if it contained prominent pure tones. A negative correction of 5 dB was applied to the level of the intruding noise if the noise occurred in winter only or the windows were always closed, or if the community had considerable prior exposure and a good relationship with the noise maker (see (3) for additional detail).

The results of applying these corrections to the intruding noises measured in 55 cases is shown in Figure 5. Approximately one-half of these cases involved steady state industrial and residential noises and the other one-half consisted of time varying transportation and industrial noises.

The non-reaction response in Figure 5 corresponds to normalized outdoor L_{dn} ranging between 50 and 61 dB with a mean of 55 dB. This mean value is 5 dB below the value of 60 dB that characterizes the noise in a residential urban community (5) and that is the baseline category of normalizing the data. Thus, these data indicate that on the average no community reaction to an intruding noise should be expected when the normalized L_{dn} of the intruding noise is 5 or more dB less than the value of the L_{dn} existing in the absence of the intruding noise.

The data in Figure 5 indicate that widespread complaints may be expected when the normalized value of the outdoor L_{dn} of the intruding noise exceeds by 5 dB that L_{dn} existing without the intruding noise. Vigorous community reaction may be expected when the excess approaches 20 dB. The standard deviation in these data is 3.3 dB about their means and a tolerance band of ±5 dB envelopes approximately 90 percent of the data. When the data are not normalized, the correlation becomes much less, with the standard deviation increasing from 3.3 to 7.9 dB.

Land Use Criteria with Respect to Human Response

The Environmental Protection Agency (EPA) in its levels document (5) identified for residential areas L_{dn} of 55 dB as the "level...requisite to protect the public health and welfare with adequate margin of safety," the words in quotations representing its congressional mandate. (16) This level was derived by selecting 45 dB within a home as compatible with 100 percent speech intelligibility, adding 15 dB to account for the average noise reduction of a home with partially open windows, and subtracting 5 dB as a margin of safety to account for other effects. It should be noted that this identified level of 55 dB is not a regulation.

EPA, in its strategy document, (17) first recommended immediate efforts to reduce noise exposure to a L_{dn} value of no more than 75 dB. This value is essentially consistent with the L_{dn}

Figure 4. Summary of annoyance data from 12 to 19 surveys in which data show close agreement. (14)

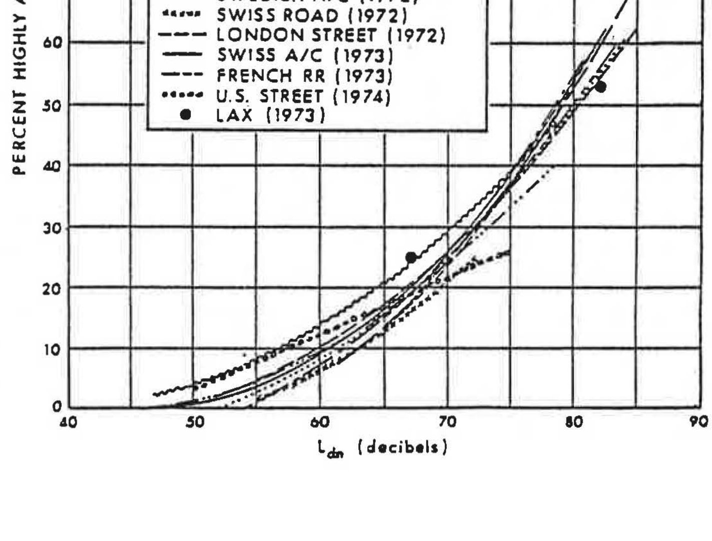
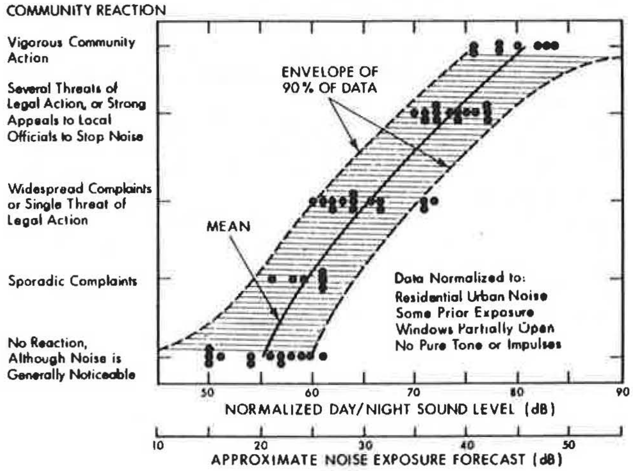


Figure 5. Community reaction to intrusive noise of many types as a function of the normalized day/night sound level. (3)



previously identified (5) as a maximum level with respect to protection of hearing. Second, EPA recommended reduction of environmental noise levels to L_{dn} 65 dB or lower through vigorous regulatory and planning actions. Third, EPA recommended adoption of L_{dn} 55 dB as a goal to be considered "to the extent possible" in the planning of future programs.

An L_{dn} of 65 dB is the maximum level acceptable to HUD (6) for residential housing sites without special approvals. HUD also considers that noise levels above an L_{dn} of 75 dB are unacceptable for residential use. Similarly, the FAA (7) considers L_{dn} values of less than 65 dB to be normally compatible with all land uses and values of more than 75 dB to be normally incompatible with residential land use, even with increased noise reduction. More detailed sets of recommendations are contained in both of these regulations.

Estimate of Current and Future Noise Impact

Several studies have been conducted since 1970 to estimate the impact of the noise from airport operations on neighboring residents. The maximum value of the population estimated to reside in areas where the L_{dn} exceeded 65 dB (NEF 30) was variously estimated between 5.0 and 7.5 million people. (18), (19), (20), (21), (22), (23)

An estimate of the national variation of this noise exposure for the years 1960-2000 is given in Figure 6. (24) It shows a rapid increase of the population exposed to L_{dn} values greater than 65 dB from zero to 95 percent of its maximum value in the ten years following the introduction of the B707 turbojet airliner in 1948. The estimate shows little change in the early 1970's, a maximum of 100 percent in 1975 then a decline to 50 percent in 1985. It should be emphasized that these estimates are for the national fleet, not for specific airports. The noise impact at many of the large international airports peaked in the early 1970's and then began to decrease as wide-body jets replaced narrow-body four engined jets. However, the noise impact at other smaller airports with only JT8-D aircraft was still increasing in the late 1970's because of increased numbers of operations, and without a significant change in fleet mix.

It should be noted that the most perceptible decrease in population impact to be seen in Figure 6 is due to be completed in 1985 when the majority of the older noisier aircraft will be either retrofitted or retired. After that date, the estimated decrease in noise impact continues, but at a much slower rate, with the noise dominated by Stage 2 JT8-D powered aircraft, the B727-100-200, B737-100-200 and the DC9-10-50. If these aircraft were to be retired by the year 2000, the percentage of the maximum population exposed to airport noise in excess of an L_{dn} of 65 dB would be reduced from 37 percent to approximately 13 percent. However, even this 13 percent of 5-7.5 million would be 650 thousand to 1.0 million people. Without retirement of earlier JT8-D aircraft or other airport noise control programs, the number of people exposed to levels exceeding an L_{dn} of 65 dB are estimated to be 1.85-2.75 million in the year 2000.

Potential Noise Reduction 1982-2000

The total noise around an airport is usually displayed in contours of equal cumulative noise, such as those on Figure 2. The magnitude of the total noise impact at an airport is usually stated as either the area or the population as a function of contour noise level. For a specific airport the contour noise levels, sizes, shapes and populations encompassed are principally dependent on the seven factors listed in Table 3.

It has been shown (24) that these seven factors can be subdivided into two almost independent subsets that may be called 1) the aircraft noise characteristic, and 2) the airport noise impact potential (see Table 3). The airport noise characteristic contains the three factors that are most strongly correlated with the total noise output at an airport, or that of the national fleet. The airport noise impact potential contains the four factors that are most strongly correlated with the shapes of the noise contours and their spatial distribution with respect to population.

The magnitude of the noise impact potential at an airport may be expressed directly in terms of population versus related noise level or the combination of population versus area and area versus relative noise level. The relative noise level must be suitably chosen so that the absolute value of the noise at an airport may then be estimated using the aircraft noise characteristic. The aircraft noise characteristic at an airport may be represented by the L_{dn} calcuated in the airport fleet operations at a fixed distance from the aircraft and for a specified engine thrust.

For national estimates, the aircraft noise characteristic level can be obtained by estimating the L_{dn} (or NEF) at a selected distance for the fleet average daily operations and relating it to area. The best correlations between the estimated aircraft noise characteristic level and area have been found in one study to occur when the characteristic level was calculated for maximum climb thrust at a slant distance of 1000 feet. (21) The results for the national data base derived in this manner (24) are summarized in Figures 7 and 8.

Figure 7 shows that the relative national population potentially impacted by aircraft noise is a smooth function of the noise contour area. Figure 8 shows that the estimate total area within L_{dn} 65 dB (NEF-30) is well correlated with the air carrier fleet total aircraft noise characteristic level (FTNCL). The FTNCL is calcualted by computing the takeoff sound exposure after cutback of thrust for

Figure 6. Estimated change in relative population residing within noise contours of NEF 30, 35 and 40 dB (equivalent to L_{dn} of 65, 70 and 75 dB respectively) for airport operations from 1955-2000 and constant 1970 population. (24)

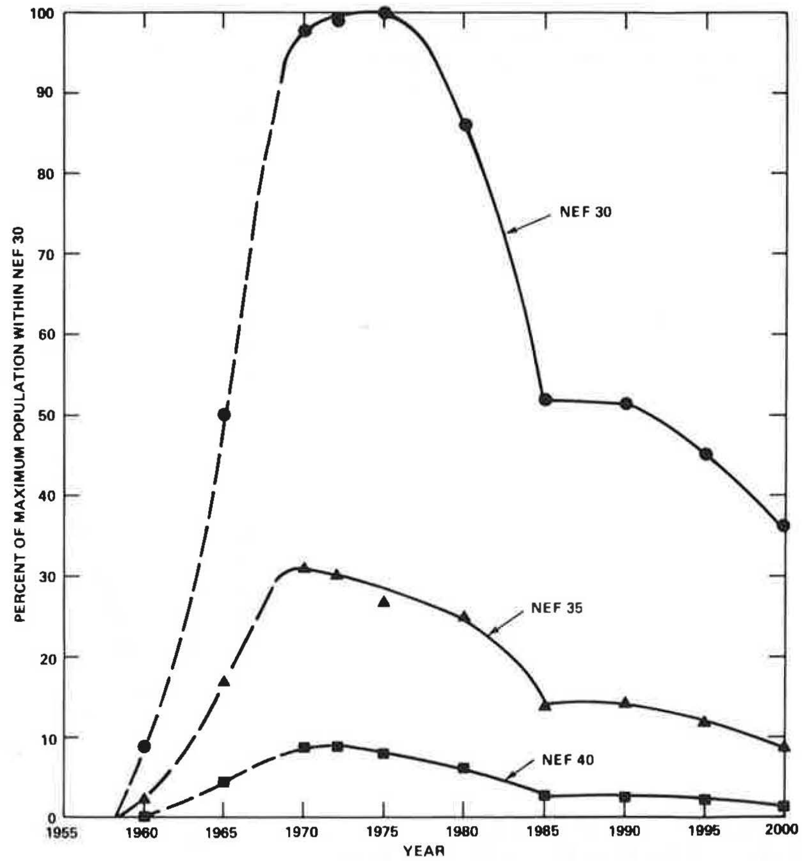


Table 3. Factors in airport noise impact.

a) NOISE VS DISTANCE BY AIRCRAFT TYPE	AIRCRAFT NOISE CHARACTERISTIC
b) NUMBER OF OPERATIONS BY AIRCRAFT TYPE	
c) RATIO OF THE NUMBER OF DAYTIME TO NIGHTTIME OPERATIONS BY AIRCRAFT TYPE	
d) FLIGHT PROCEDURES (THROTTLE AND FLAP MANAGEMENT) USED FOR LANDING AND TAKEOFF BY AIRCRAFT TYPE	AIRPORT NOISE IMPACT POTENTIAL
e) STAGE LENGTHS (TAKEOFF AND LANDING WEIGHTS BY AIRCRAFT TYPE)	
f) SPATIAL CONFIGURATION AND RELATIVE UTILIZATION OF THE FLIGHT TRACKS BY AIRCRAFT TYPE	
g) SPATIAL DISTRIBUTION OF POPULATION	

each type of aircraft at a slant distance of 1000 feet times its average daily operations and summing over all aircraft types.

Figure 9 shows the estimated change in FTNCL for commercial operations in the U.S. from 1960 through 1995. Its value reached a maximum in 1975 of about 9 dB greater than its value in 1960. Its value in 1985 is about 2 dB less than in 1975, and in 1995 one dB lower than in 1985. However, if the JT8-D aircraft were retired by 1995 the FTNCL in that year would be about 8 dB less than its 1975 value, almost reducing it to its value in the early 1960's.

It should be noted that the national fleet average noise characteristic level has been steadily going down since 1960 at a rate of about 3.3 dB per decade. This rate of decrease should continue approximately to the year 2000-2005 when the fleet will become almost entirely composed of aircraft certificated for noise to the levels of the FAR Part 36 - Stage 3.

Goals for Source Reduction

Analysis of the relationships in Figures 7 and 8 indicates that to reduce the population exposed to an L_{dn} in excess of 65 dB to 0.3 percent to 1.0 percent of its maximum value requires a reduction of 16-19 dB below the 1975 value in the fleet average noise characteristic level (FANCL). This reduction would result in levels that are 6 to 9 dB below the levels for an all high bypass fleet. Similar analysis of single event data (25) indicates that to attain negligible population within a L_{dn} 65 dB at an average busy runway for a hypothetical 220,000 maximum gross weight fleet average aircraft requires levels that are 14-16 dB below the 1975 values and 9-10 dB below the Stage 3 levels. Satisfying these requirements would mean that the EPNL limit for takeoff would be about 85 EPN dB for a 220,000 pound max-gross weight aircraft.

This analysis shows that considerable additional source reduction would be required if source reduction were to be the only method of controlling airport noise. And even if a Stage 4 regulation with levels 10 dB below Stage 3 were a possibility, which it is not, at least today, one would not expect to realize

Figure 7. Relative population as a function of contour area. One hundred percent has been variously estimated to be between 5 and 7.5 million people. (24)

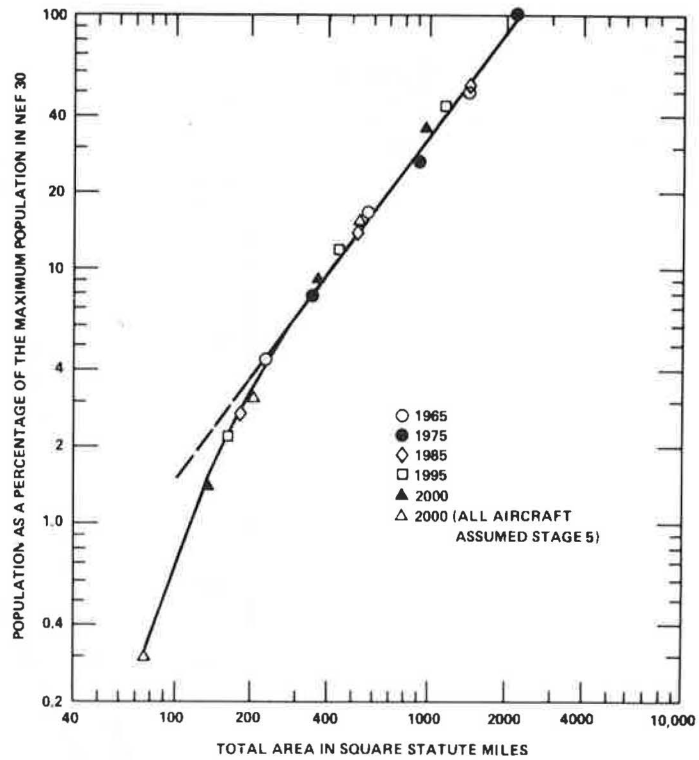
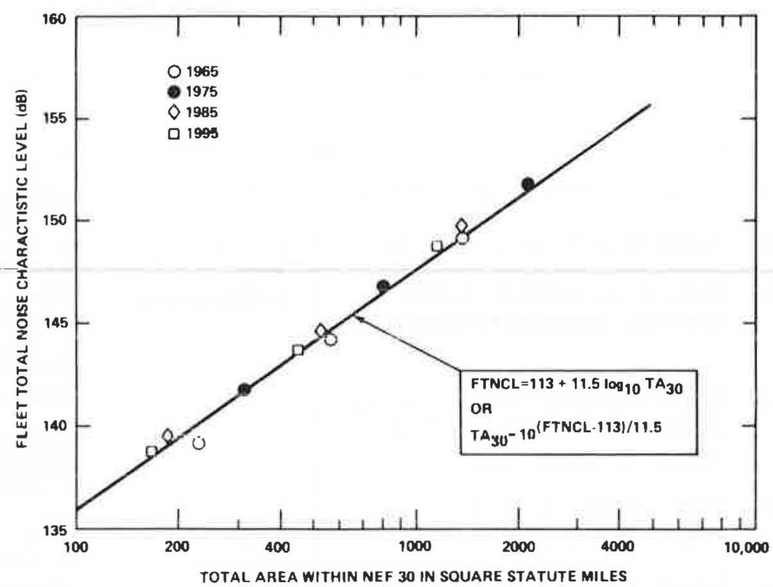


Figure 8. Estimated relationship between total contour area within NEF 30 (TA_{30}) (almost the same as L_{dn} 65 dB) and the air carrier fleet total characteristic noise level (FTNCL) for the national civil airport system. (24)



a Stage 4 fleet before the year 2015 to 2020. Thus, even under the most optimistic scenarios it is clear that additional source reduction beyond Stage 3 cannot be counted on for added potential airport noise reduction in the near term. Therefore, additional near term noise reduction must be found when possible at the airports where it is required. (26) (28) This airport specific approach, coupled with continued vigilance towards reducing certification levels by as much and as soon as technologically practical and economically feasible, should speed the long term solution to the airport noise problem.

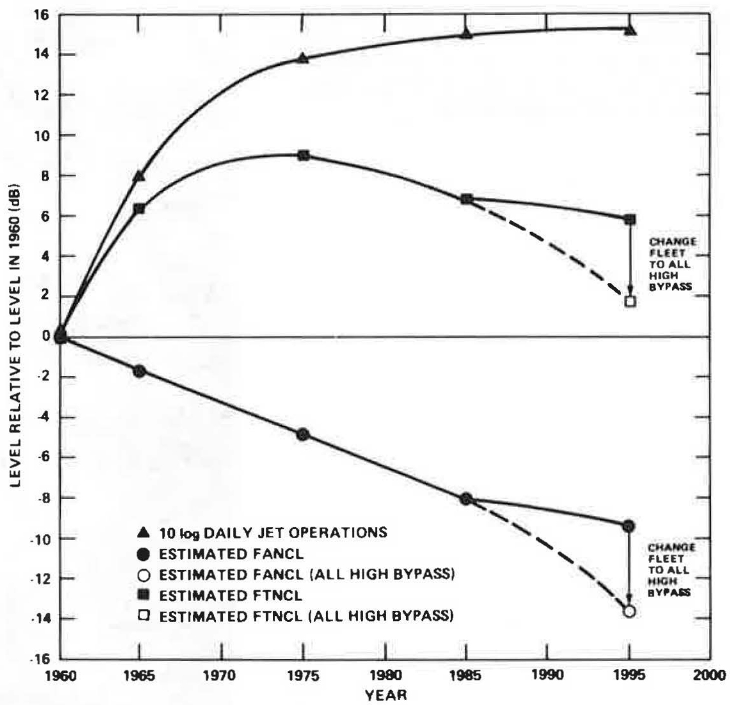
Noise Control Options at Specific Airports

The significant factors for the noise at any specific airport were summarized in Table 3. Each has potential use for noise control. However, as will be seen in the following brief analyses there may be significant economic and other conseuqences associated with achieving noise reduction by use of some of these factors.

a. Maximum Noise level Restrictions in the Community

The basic noise versus distance by aircraft type as used here is considered to be fundamental to the design - and thus controlled through the FAA certification process. However, an airport can

Figure 9. Relative change in fleet average noise characteristic level (FANCL), ten log average daily air carrier operations and fleet total noise characteristic level from 1960 to 1995. (24)



establish limits on the maximum levels of noise at stated positions or distances, which could be set to prohibit the use of the airport by noisier aircraft. These limits may be set by time of day, e.g., nighttime limits are often lower than are daytime limits.

There is considerable controversy over how these limits are to be applied: 1) to assure that they are non-discriminatory, and 2) over how much curtailment of operations through progressively more restrictive noise limits is permissible before it is considered to interfere with interstate commerce. Finally, direct economic costs and inditect costs resulting from a decrease in availability of transportation service, may become a significant factor depending upon the fleet mix at a specific airport, and the proportion (and function) of the fleet affected by the limit.

b. Restrictions of Number of Operations by Aircraft Type

Limiting the number of operations by aircraft type is very difficult under current legal constraints, except for curtailing operations of the noisiest or largest aircraft by an appropriate non-discriminatory regulation (see a. above). In some situations the airport fleet may contain only one type of aircraft, or its noise may be dominated by a significatn number of operations by one type of aircraft. If it is impracticable to consider eliminating service from that type of aircraft,then some noise reduction could be obtained by reducing the numbers of its operations. There usually are at least two problems with this approach. First, limiting operations is not very cost effective, i.e., a 1 dB improvement requires a 21 percent reduction in operations and a 3 dB improvement requires a 50 percent reduction in operations. Second, with deregulation, there are considerable legal hurdles to overcome in endeavoring to find a practicable and legal scheme for controlling the numbers of operations.

c. Restrictions of Nighttime Operations

The nighttime noise penalty of 10 dB in the day-night sound level descriptor means that the noise from one nighttime operation is counted the same as is the noise from ten daytime operations of similar character. Thus, for airports which have nighttime operations (10 P.M. to 7 A.M.), their reduction often appears to have considerable potential to reduce noise impact. Often, considerable progress may be achieved through working with the airport's user-operators to eliminate nighttime flights that have only marginal benefit, rescheduling other operations and providing quieter aircraft for nighttime. This latter result can be achieved for all nighttime operations by a nighttime noise limit (see a. above).

A total curfew on nighttime operations exists at several airports in this country and abroad. However, the ability of an airport proprietor to establish a curfew may be severely restricted by various legal challenges, and may result in a significant loss of transportation service. Also, once a curfew is established it may prove difficult to remove at some future date when aircraft are quieter. Finally, it should be recognized that once the nighttime operations become less than 2.6 percent of the total day operations their elimination would result in less than a one dB reduction in L_{dn}. And if nighttime operations are one one percent of the total day operations, their elimination would result in a reduction of only o.4 dB in L_{dn}.

d. Noise Abatement Flight Procedures for Takeoff and Landing

There exist potential noise reductions to be obtained from the use of improved throttle and aircraft configuration techniques for both landing (29) (30) and takeoff. (25) (31) If these procedures could be tailored to specific airport requirements, the gains could even be greater. However, there is considerable controversy over the notion of changing cockpit management procedures from airport to airport, particularly with respect to pilot workload and safety implications.

An analysis (25) of takeoff procedure for several types of aircraft generally supports the procedures suggested in FAA AC91-53 (31) for national uniform application. Additionally, it recommends that JT8-D powered aircraft B727, B737 and DC9 use the maximum cutback suggested in FAA AC91-53, rather

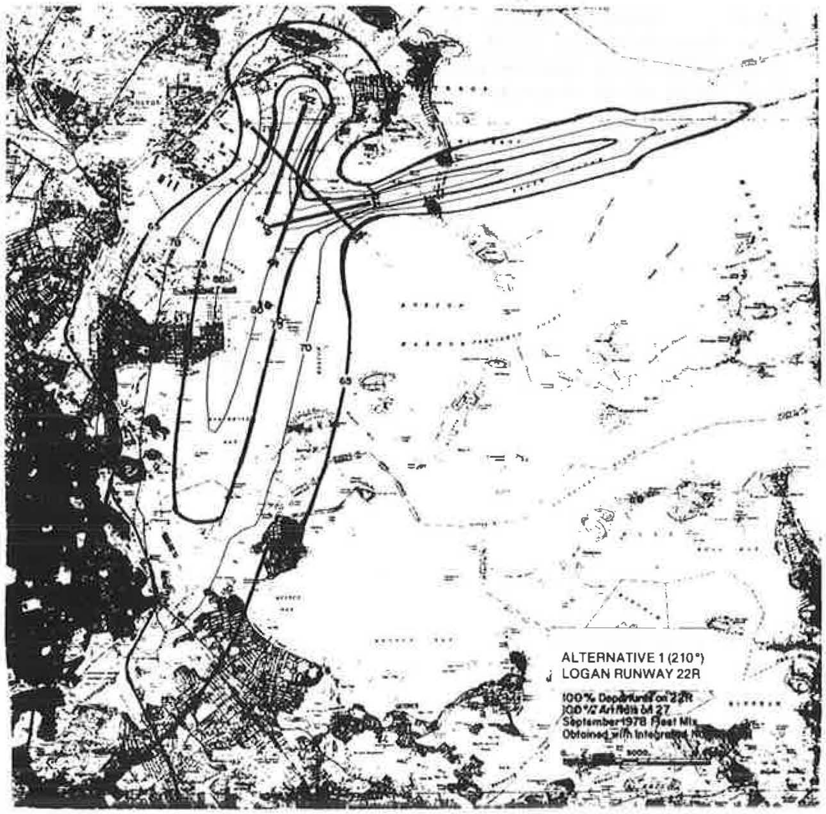


Figure 10. Example of contours of day-night sound level for 100 percent operations arriving on Runway 27 and departing on Runway 22R at Logan International Airport for 1978 operations (27).

than the minimum. For application to specific airports it concludes:

1. For all aircraft with high and intermediate values of noise reduction with thrust cutback; i.e., B727, B737, DC9, DC10 and L1011:
   a) If the populated area is close to the airport, attain the maximum altitude before reaching the populated area, then initiate maximum cutback, and subsequently resume climb thrust either after passing the populated area or when attaining an altitude where the noise on the ground is estimated to be less than a pre-selected value.
   b) If the populated area is far enough from the airport to allow completion of partial or complete cleanup before reaching the populated area, initiate acceleration and cleanup at the lowest safe altitude, then initiate maximum cutback at the beginning of the populated area, and subsequently resume climb thrust as above.
2. For aircraft with low climbout performance and with low values of noise reduction with thrust cutback, i.e., B707, DC8 and B747, attain the maximum altitude before reaching the populated area, then initiate minimum thrust cutback and proceed to cleanup and continue to climb.

c. Stage Length Restrictions

The weight of an aircraft has a significant effect on its potential noise impact during takeoff or landing operations. Thus, restricting the maximum distance (Stage length) to be served from a specific airport may have the collateral effect of minimizing some of the heaviest takeoff weights at the airport. Such restrictions exist at some airports and may be particularly appropriate and legally defensible at airports which are located in close proximity to a larger and less restricted airport. The effectiveness of such restrictions would depend upon their nature, the practices of the user-operators in terms of aircraft weight (e.g., ferrying fuel on certain routes), typical payloads, destination and fleet mix and other factors. The cost of such restrictions would be highly dependent on the specific situations.

f. Optimized Use of Airport Spatial Configuration and Aircraft Ground Tracks

In developing noise reduction alternatives for a specific airport one of the first factors to examine is the location of its flight tracks with respect to land use. It is desirable that these tracks be located to make maximum use of compatible land uses such as water, industrial, commercial and agricultural. Where opportunities exist for changing flight tracks to reduce their noise impact potential, they should be carefully studied with respect to noise benefits, local air space management, fuel cost, time cost and other factors.

The Logan Runway 22R departure study (27) is one of the more detailed studies of flight track alternatives. Figure 10 illustrates the L_{dn} contours for a day on which all aircraft were assumed to arrive on runway 27 and depart on runway 22R. The contours are for the 210° departure, one of six alternative tracks in the study. The population living in areas where the L_{dn} (maximum day) exceeded various values for each of the alternatives is summarized in Table 4. It is clear that there is a large variation in population impact amongst the alternatives and that the alternative 6, which ultimately was chosen, represented a significant reduction in population impact relative to alternative 1, the base case.

Table 4. Estimated number of people living in areas to the south of Logan Airport where the noise from departures exceeds certain day-night sound levels for alternative departure procedures from runway 22R and arrivals on runway 27. (All aircraft are assumed to use these two runways for an entire 24-hour day).

	ALTERNATIVES					
	1	2	3	4	5	6
DAY-NIGHT SOUND LEVEL (L_{dn}) EXCEEDED (dB)[1]	210°	180° Right	180° Left	160° Radial	195° to 220° Radial	100° Heading
65	91,300	36,600	9,700	4,800	66,500	2,800
70	22,400	600[2]	2,700[2]	700[3]	10,400	1,900[3]
75	7,900	0	0	0	600	0
80	3,300	0	0	0	0	0

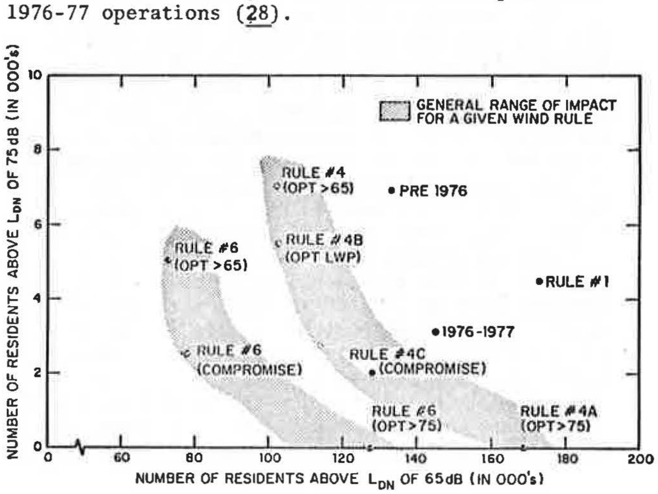
Notes

1 These levels should be reduced by approximately 5 dB to relate to yearly average exposure.

2 These population counts for 180° right and 180° left should be equal since the two procedures are identical until outside the L_{dn}70 contour. The difference arises from the fact that the radar traces from which flight tracks were modeled differed slightly on 2 days that the procedures were tested.

3 These figures should be equivalent. However, the contours for Alternative 6 include two population centroids that lie just outside the contours of Alternative 4.

Figure 11. Approximate number of residents in areas above L_{dn} 65 and 75 for various runway utilizations and wind rules at Logan International Airport with 1976-77 operations (28).



Once the flight tracks have been optimized at a specific airport, opportunities for reduction in population impact may exist by optimizing the relative utilization of these tracks. The potential for utilization of the tracks associated with each runway depend upon the wind and weather conditions, the capacity of each runway (or runway combinations) to meet demand, runway length, etc. In general, preferential runway assignments can only be made in weather conditions that meet the visibility, wind velocity and direction and runway conditions established by the FAA. (32)

Figure 11 illustrates the potential sound in a previous study (28) for varying population noise impact at Logan International Airport as a function of wind rule (safety criteria for preferential runway use). Rule 1 required that all operations utilize the runway most nearly aligned into the wind. Rule 4 was the then existing FAA order and Rule 6 was an FAA proposed revision. The current FAA order (32) is thought to be intermediate between Rules 4 and 6.

It is clear that, for Logan, there is a considerable ability to control runway utilization to minimize the number of people most heavily impacted (L_{dm} greater than 75 dB) at the expense of increasing the number of people where the L_{dn} is greater than 65 dB, or vice versa. The decision of which alternative utilization to chose for a given wind rule poses a difficult choice for the airport and the affected populace and their representatives. The reduction in noise impact for this example for Rule 4 was about equal to that which would result from a one dB reduction in aircraft source noise, and for Rule 6 a two dB reduction.

Obviously the potential for reduction in noise impact by optimizing flight tracks and runway utilization is highly variable amongst airports as it depends entirely on local geography and other local factors. It is not possible to generalize its potential to the national level with any degree of certainty.

g. Allowance for Spatial Distribution of Population

The spatial distribution of population is an independently variable factor although its importance stems from the relationships between the location of flight tracks and people. For airports located in the countryside where the population is very low, some form of control of land use development is essential to prevent future encroachment in noisy areas. For many years zoning has been advocated for this purpose, but it has been found in practice to be a fairly weak and unreliable tool. More success has been found through actual purchase of the land or of aviation easements to the land.

Where populations already exist in high noise areas, and where optimization studies show that meaningful noise reduction will not be possible for the foreseeable future, the remaining possibilities are land use conversion to more compatible useage or soundproofing.

Proposed Noise Reductions for the Next Twenty Years

The results of the various noise reduction techniques discussed above cannot be easily extrapolated to the nation because there are insufficient comparable studies to give good estimates of the national effect of measures at individual airports. However, it is useful to update the similar estimates made by this author in 1978, (26) recognizing that some of these estimates are more tenuous than others. The results are summarized in Table 5.

Table 5. Estimate of National Average Noise Reduction in Decibels of Various Air Carrier Aircraft/Airport Noise Reduction Options

Item	1975 fleet	1985 fleet after retrofit	2000-2005 fleet*
Basic aircraft noise	0	3	10
Improved landing procedures	0-1	0-1	0-1
Improved takeoff procedures	0-2	0-3	0-1
Airport optimization	0-5	0-5	0-5
Range of reduction	0-8	3-12	10-17
Average value of reduction	4	7.5	13.5
Effect of increased operations	0	-1	-2
Average net reduction	4	6.5	11.5
Percent of 1975 population** estimated within L_{dn} 65 dB			
Basic aircraft noise only	100%	50%	13%
Average net reduction	37%	16%	4%

*Assumed all high bypass
**No population growth is assumed, only that population that existed in 1975 is included.

Concluding Remarks

We are now in the first era of significantly perceptible airport noise reduction. The Stage 1 four-engined narrow-body aircraft are being phased out other Stage 1 aircraft are being retrofitted - and, new quieter Stage 3 aircraft are arriving in service.

The net result of these actions on a national basis is estimated by 1986 to be a 50 percent reduction in impact from its maximum reached in the mid-1970's. However, these benefits are expected to accrue primarily to those large airports that have had significant numbers of 707/DC8 aircraft. At other airports served by the smaller JT8-D powered aircraft - the increase in their operations is expected to negate part of the gains of retrofit.

Advantage should be taken of this transition to a new situation in which noise control is perceptible. The opportunity is available to convince noise impacted airport neighbors that the civil aviation system is trying to reduce noise, and is making progress. To the extent that this progress can be credibly demonstrated, there is now a unique opportunity to establish a more positive relationship between airports, their users, and their neighbors, bringing changes away from confrontation towards rational discussion, and to use this relationship to develop airport specific long range plans to attain minimum future noise impact consistent with community and industry economic and other constrants.

At airports with noise problems, continued consideration is needed on all aspects of noise control including:

- Optimized flight tracks to avoid population to the extent possible. This may mean new runways at some airports.
- Optimized runway preference to minimize total impact - include consideration of seasonal factors and time of day.
- Relevant noise abatement thrust and flight management procedures for landing and takeoff.
- Potential noise limits, noise charges and other methods to encourage use of quieter aircraft, particularly at night.
- Acquisition and redevelopment of some areas which have high noise impact (L_{dn} greater than 75 dB) both now and estimated to continue in the foreseeable future.
- Soundproofing of some residences in areas of significant noise impact (L_{dn} 65-75 dB) both now and estimated to continue in the future.

Full application of these techniques might be expected to reduce the population impacted to as little as one-third that impacted without their application, but there may be some airports where little reduction is practicable.

On a national level it must not be concluded that the national airport noise problem will be solved totally by the introduction of the Stage 3 airplane, although problems at many specific airports may be solved. Quieter aircraft are still needed to offset the adverse effects of increases in operations and to relax costly restrictions at specific airports that were required for noisy aircraft. There is a need to establish a national set of goals for future aircraft/noise certification that are compatible for existing airports. A rough estimate of that goal would be a future fleet average aircraft with an EPNL of 85 EPNdB for takeoff at 6500M from start of roll. This goal is about 12 dB below the current Stage 3 limits. The technical capability is available to make realistic studies that are required to develop the information that can be used to decide the tradeoffs amongst alternatives and arrive at a consensus goal. It should be used to reach a conclusion.

Second, technical studies should be undertaken to develop the R&D requirements to eventually attain the capability to design economically viable and productive aircraft to meet the consensus goal. These studies should look at both the aerodynamic and engine side of the problem - together. Special attention should be given to low speed lift/drag ratio, maximum lift, number of engines, thrust-weight ratio, higher noise reduction for thrust cutback, higher bypass ratio, optimum design of engine cycle for mission thrust requirements and improved acoustic treatment.

Finally it is important that the airport, airline and aircraft industries become comfortable with noise and bring it out on the table as just another factor to be considered, just as are items such as pavement thickness, gate clearance, and capacity. The aircraft industry and government made enormous progress in this area, as witness the noise reductions achieved in the new aircraft. They have progressed because they consider noise throughout the aircraft and engine design process, rather than attempting to deal with noise only after the design has been finalized. The rest of the civil aviation systems should be able to find a way to accomplish the same thing - to forget the concept of noise as "a nasty problem dreamed up by a group of zealots that is best hidden under a pile of sand," and begin to think of noise as just one more human engineering factor to be included in optimizing the initial design of airports and of the entire civil aviation system. A realistic and positive approach should lead to real progress.

References

1. Civil Aviation Research and Development Policy Study, Joint DOT-NASA Report DOT TST-10-5, NASA SP-266, March 1971.
2. K. M. Eldred, Community Noise, EPA Report No. NTID 300.3, December 1971.
3. K. M. Eldred, Assessment of Community Noise, Noise Control Engineering, Vol. 3, November 1974.
4. Noise Standards for Aircraft Type Certification, CFR Part 36, 1969-1981.
5. Information on the Levels of Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety, EPA 550/9-74-004, March 1974.
6. Noise Abatement and Control: Criteria and Standards Policy, 24 CFR Part 51, 1979.
7. Interim Airport Noise Compatibility Program, 14 CFR Part 150, 1981.
8. Preferential Runway Alternatives for Logan Airport, prepared for the Massachusetts Port Authority, BBN Report No. 3777, March 1978.
9. Guidelines for Preparing Environmental Impact Statements on Noise, Report of WG 69, CHABA NRC, 1977.
10. W. K. Conner and H. P. Patterson, Community Reaction to Aircraft and Noise Around Smaller City Airport, NASA CR-2104, August 1972.
11. J. D. Webster, Effects of Noise on Speech Intelligibility, American Speech and Hearing Association, No. 41, February 1969.
12. K. S. Pearson, et al., Time Varying Highway Noise Criteria, Bolt Beranek and Newman, Inc., Report 2739, November 1974.
13. K. S. Pearsons, et al., Speech Levels in Various Environments, Bolt Beranek and Newman, Inc., Report 3281, October 1976.
14. T. J. Schultz, Synthesis of Social Surveys on Annoyance Due to Noise, J. Acoust. Soc. Am., 64, 2 (August 1978).
15. S. Fidel, et al., Community Sensitivity to Changes in Aircraft Noise Exposure, BBN Report. Na. 4212 for NASA Langley, March 1980.
16. Noise Control Act of 1972, Public Law 92-574, October 27, 1972.
17. Toward a National Strategy for Noise Control, EPA ONAC, April 1977.
18. Report of the President to Congress on Noise, EPA, February 1972.
19. J. E. Wesler, Airport Noise Abatement - How Effective Can It Be?, Sound and Vibration, pp. 16-21, February 1975.
20. C. Bartel and L. C. Southerland, Noise Exposure of Civil Air Carrier Airplanes Through the Year 2000, EPA 550/9-79-313-1, February 1979.
21. K. M. Eldred, Estimate of the Impact of Noise from Jet Aircraft Air Carrier Operations, EPA, BBN Report 4237, September 1980.
22. FAR Part 36 Compliance Regulation, Final Environmental Impact Statement Pursuant to Section 102(2)(c), PL 91-190, FAA, US DOT.
23. Aviation Noise - The Next Twenty Years, EPA 550/9-80-310, February 1980.
24. K. M. Eldred, Model for Airport Noise Exposure on a National Basis - 1960 to 2000, Proceedings of Internoise 1980, Vol. 2, pp. 803-808.
25. K. M. Eldred, Aircraft Noise - Takeoff Flight Procedures and Future Goals, BBN Report 4662R for EPA, November 1980.
26. K. M. Eldred, Aircraft Noise Control, Proceedings of Internoise 1977, pp. 123-135.
27. Final Environmental Impact Statement Departure Procedures Runway 22 Right Logan International Airport, ANE-500-79-3, FAA, US DOT, March 1980.
28. R. L. Miller and K. M. Eldred, 1978 Preferential Runway Study for Logan International Airport, BBN Report 4603, February 1981.
29. Assessment of Technological Progress Made in Reduction of Noise from Subsonic and Supersonic Jet Aeroplanes, ICAO Circular 157-AN/101, 1981.
30. The Noise Benefits Associated with the Use of Continuous Descent Approach and Low Power/Low Drag Approach Procedures at Heathrow Airport, CAA Paper 78006.
31. Noise Abatement Departure Profile, Federal Aviation Administration Advisory Circular, AC 91-53, 17 October 1978.
32. National Safety and Operational Criteria for Runway Use Programs, Federal Aviation Administration Order 8400.9, November 1981.

A SYSTEMS APPROACH FOR IDENTIFYING POTENTIAL PROBLEMS IN AIRCRAFT AND AIRPORT COMPATIBILITY

A. Robert Kuhlthau and Ira D. Jacobson,
University of Virginia, and Curtiss Swanson,
Western Michigan University

Abstract

A methodology has been developed for determining the effects of changes in aircraft dimensions or characteristics on the ability of these aircraft to operate at airports. The intent of the methodology is to identify and define, quantitatively whenever possible, the potential problem areas. It does not offer solutions, but can be very valuable to a designer by providing assistance in evaluating design changes. It can be used in real time in the design process.

The methodology is based on three interaction matrices: (1) aircraft/aircraft, which indicates other aircraft quantities which might be affected by the initial changes contemplated; (2) aircraft/airport, which indicates airport characteristics which might be affected by the aircraft changes; (3) airport/airport, which indicates additional airport quantities which may have to be altered if others are changed. By using these interaction matrices in conjunction with a set of data banks involving airport and aircraft data, OAG schedules, and published literature or regulations, the user can be presented with all available information on each potential point of incompatibility between a new aircraft design and specific airport operations.

The methodology is structured about two user-interactive computer programs which start with a definition of a candidate aircraft. The procedures are reversible so that the methodology can be applied to analyze the effects of changes in airport design on the ability of the airport to accommodate aircraft.

An illustration is provided by considering some prospective changes to a standard commercial jet transport.

Introduction

The matter of aircraft/airport compatibility is of great importance when considering possible new aircraft designs which might result from research and development programs. Although these new designs might lead to improvements in aircraft operating performance, and hence lower seat mile costs, they may require major changes to existing airports in order to realize these performance gains. Thus, the airports, if not altered, may impose constraints on the aircraft which may nullify part or all of the performance improvement; or, the cost of removing these airport constraints may equal or exceed the economic gain from the new aircraft. Since all economic gains and losses are ultimately reflected in the pricing of the system product, viz. an aircraft seat (or ton) mile, it is important that new aircraft designs reflect a maximum of economic gain and productivity increase when viewed from the entire air transportation system.

The overall system is very complex. When a change is made to one or more design parameters of an aircraft there are numerous points of interaction where the possible effect of these changes may require changes in other parts of the system. These interactions can be with other parts of the aircraft (a self-interaction), or with components or parameters of the airport (joint-interactions). Furthermore, the problems exist in both directions, i.e., as new airports are built or old ones modified, changes in the numerous design criteria associated with an airport may generate both self- and joint-interactions requiring either additional changes in the airport design or restricting certain aircraft from using parts or all of the airport. When addressing problems of such complexity it is essential to have available a methodology which will assure that, when entering a system at any point (i.e., making one or more design changes in either the aircraft or airport), a rigorous and systematic analysis will be made of all potential interactions throughout the system. This methodology should identify the interaction points, describe the nature of each interaction, classify the types of impacts which result, and guide the user to all available material which can be used in evaluating the extent of the effect of the interaciton on the system. The methodology does not provide solutions. This is the responsibility of the user (engineer or analyst). What the methodology does is provide these users with tools for identifying all the potential problems, outlining the perspectives from which they must be viewed, and assisting in assembling the information required to approach the problem solution phase. This paper outlines such a methodology which is under development at the University of Virginia and is supported by the NASA/Langley Research Center under Contract NAS1-16286, Task 1.

General Approach

The procedure has been divided into two separate routines. The objectives of the first routine are to provide the analyst with a list of all the information which is required to evaluate the total effect of any given system change, and to identify how much of this information is readily available and where it can be found. Additional steps can be added, if desired, to catalog the information and make it available for immediate access.

The second routine is designed to assist the analyst in making the evaluation, once the information has been gathered. It should be emphasized that this second routine does not generate solutions. Its role is to indicate the magnitude of the problems to be encountered by making a system change. However, some guidance toward possible solutions can be obtained by repeated applications of the process with varying values of the design parameters involved in the key interactions, and then comparing results.

The first routine is referred to as a "search" and the second as an "evaluation." Each will be discussed separately.

The Search Routine

This routine is based on the formation of two types of data banks, and the appropriate steps for accessing them. The first type of data bank involves interactions between system components. There are three types of interactions which must be considered when making a change in any system component. To illustrate the process it will be assumed that a change in some component of an aircraft is contemplated, e.g. wing span.

Step 1. Identify all other aircraft components or characteristics that might change due to the change in wing span; e.g. wing area, aircraft weight, take-off and landing field lengths, etc. are some of the things that should be examined.

Implementation of Step 1 requires the formation of what is called an "Aircraft/Aircraft Interaction Matrix." The role of this matrix is simply to identify all of the potential interactions which do exist. However, additional qualitative information can be presented to the analyst within the matrix format by classifying the interactions as strong (S), Medium (M), or weak (W).

Step 2. For each aircraft component or property for which an interaction has been determined in Step 1, identify all airport components or characteristics which might be affected by the aircraft change; e.g. increased wing span might require changes in gate spacing, or taxiway separation, and an increase in aircraft weight due to the increased wing span might require additional runway pavement thickness, etc.

Implementation of Step 2 requires the formation of what is called an "Aircraft/Airport Interaction Matrix." The mission is similar to that of the first matrix except that now the emphasis is on the effect of aircraft on airport, and in this case it is desirable to be able to read the matrix in both directions, i.e. enter it either by means of an aircraft change or an airport change. As before, the interaction can be identified as to the level of severity.

Step 3. For each airport component identified in Step 2, determine other airport components or characteristics which might be affected by a change in the original items, e.g. the increased gate spacing, if required by the increase in wing span, could reduce the number of gates and affect airport capacity; or it could require additional gates encroaching on taxiways or on space for operation of ground service vehicles, etc.

Implementation of Step 3 required the formation of what is called an "Airport/Airport Interaction Matrix." It is similar in structure to the matrix in Step 1.

Step 4. Iterate. The new airport categories identified in Step 3 are now run through Step 2 to see if any additional aircraft categories are involved; if so, they go through Step 1, and the result through Steps 2 and 3, etc. until no new interactions are generated in Step 2.

Step 5. Provide specific information as requested for those aircraft/airport interactions selected from the list obtained in Step 4.

This step requires the formation of several types of informational data banks providing specific details concerning the nature of the interaction identified. These are true data banks rather than matrices, and so they can be constructed and arranged to be most useful to the initial process of problem identification. The number and type of data banks to be constructed is arbitrary, as is the size of each. Our experience to date has indicated that the following data might be particularly useful.

(1) Definitions: A definition of terms used in listing the interaction as identified in each interaction matrix, and a brief qualitative statement describing the nature of the interaction.
(2) Bibliography: This would contain citations of all literature pertaining to each particular interaction identified in the three interaction matrices. Abstracts could be included if so desired.
(3) Constraints: Short statements concerning current guidelines or restructions placed on any of the quantities involved in each interaction by regulatory bodies such as FAA or ICAO.
(4) Data and Formulas: Quantitative relationships which would provide a capability for estimating the magnitude of the interaction. Actually, several versions of this type of bank might be useful. Each could be oriented toward a specific evaluation measure, such as:
    - effect on the environment
    - productivity
    - user acceptance
    - technological requirements
    - capital costs
    - operating costs
    - etc.

At the present time the aircraft/airport mutual interaction matrix and the aircraft/aircraft self interaction matrix have been developed in detail. The general categories of components used in each of these are shown in Tables 1 and 2. (1)

To date, the interaction matrices have been developed only for the airside and terminal interface portions of the airport complex. The terminal itnerface is arbitrarily defined to stop at the areas within the terminal building to which the passengers are introduced as they enter the terminal building from the deplaning mechanism, or the area at which baggage or cargo is first deposited after unloading. These restrictions were imposed because they were the areas of prime interest to the sponsor, and seemed adequate to demonstrate the principles of the methodology. This is not intended to imply that there are no aircraft interactions with landside or curbside functions of the airport terminal.

With regard to the informational data banks, these are essentially openended, and their complete assembly was beyond the scope of the present work. Thus, they have been constructed only to the extent required to illustrate their applications in the methodology. It should be noted, however, that once they are developed they are universal in nature and can be used by all groups concerned with the general problem of aircraft/airport compatibility.

The Evaluation Routine

The objective of this routine is to guide the user through the process of determining the overall effect on airports or operations at airports resulting from a change in aircraft components or

Table 1. Major aircraft elements of aircraft/airport interaction matrix.

AC0100	Aerodynamic Design And Functions
AC0200	Aircraft Velocity
AC0300	Aircraft Control And Stability
AC0400	Aircraft Geometry
AC0500	Aircraft Structures
AC0600	Aircraft Weights
AC0700	Landing Gear System
AC0800	Propulsion System
AC0900	Fuel System
AC1000	Passenger System
AC1100	Baggage And/Or Cargo System
AC1200	Auxiliary Power Requirements
AC1300	Misc Gate Service Requirements
AC1400	Lighting System
AC1500	Radio/Navigation Systems
AC1600	Instrumentation Capability
AC1700	Operating Scenarios
AC1800	Aircraft Departure/Arrival Mix
AC1900	Aircraft Separation
AC2000	Flight Crew Operation Procedures
AC2100	Aircraft Service Procedures; Overall
AC2200	Aircraft Ground Servicing Points
AC2300	Aircraft Classification
AC2400	Human Factor Considerations

Table 2. Major airport elements of aircraft/airport interaction matrix.

AP 100	Air Traffic Control
AP 200	Airport Setting
AP 300	Airport Geom. Design-Airside
AP 400	Airport Config.-Airside
AP 500	Airport Capacity-Airside
AP 600	Apron Geom. Des.-Landside
AP 700	Apron-Gate Configuration
AP 800	Apron Vehicle Circulation
AP 900	Airport Capacity-Landside
AP 1000	Structural Design Of A/P Pavem
AP 1100	Airport Drainage/Snow Removal
AP 1200	A/P Lighting
AP 1300	Term. Area Des.-Pax Handling
AP 1400	Term Area Des.-Baggage/Cargo
AP 1500	Aircraft Fuel Servicing System
AP 1600	General A/C Servicing
AP 1700	Jet Blast And Noise Protection
AP 1800	Airport Emergency Service

characteristics. At the present time all the development work has used this approach, although no problems are anticipated in reversing the procedure to start with changes in airport design characteristics. This is simply a matter of making modifications to the computer program and involves no fundamental issues.

Thus, the process must start with an INPUT from the user which defines the objectives desired when using the methodology. This normally consists of two parts.

1. Conditions imposed by the user

The purpose here is to classify the problem in accordance with a variety of conditions which will then allow the most efficient utilization of the program. To accomplish this, the user is asked to describe the problem in terms of two global kinds of information.

a. Problem type - What are the system properties under consideration in formating the problem? At the present time the procedures are designed to accommodate the following user conditions (or specifications).

(1) Change in one or more aircraft dimensions.

(2) Set of design specifications for a new aircraft or an existing aircraft (or class of aircraft).

(3) A particular operational pattern.

(4) Statements similar to (1) and (2), but relating to airports.

b. Scope - In the interest of efficiency of time and cost, the bounds of the problem should be properly defined. This involves such matters as:

(1) The operational type of aircraft involved, e.g. range, gross weight, use (passenger, cargo, both).

(2) The types of terminals which should be considered, e.g. commercial, general aviation, both, major hubs only, etc.

(3) Special restrictions at terminals, e.g. used with transporter, tug for parking, etc.

2. Results desired by the user

What question or questions does the user wish to have answered? Currently, the procedures anticipate providing information relative to the following three general types of questions:

a. What effect will a given set of aircraft specifications have on one airport (or a set of airports)?

b. What aircraft could use an airport having a particualr set of design characteristics?

c. What is the largest aircraft dimension (or set of dimensions) which can be accommodated at a given airport (or set of airports)?

Once the inputs are defined, the logic of the procedure developed thus far is based on comparing the problem specifications with what is currently happening in the world's air transportation system (or the part of it specified by the user). If the aircraft specifications provided do not exceed bounds already established by the current system, then no problems should be anticipated with the new aircraft. Or, if the current system is operating with exceptions to generally accepted practices, then the position of the new aircraft relative to these exceptions needs to be analyzed. Finally, if the new aircraft specifications do exceed the bounds at one or more specific airports or groups of airports, then a complete table of the discrepancies can be obtained as computer output. The table would list for each aircraft parameter involved those interaction points at each airport where a violation of current guidelines, standards, or regulations does occur.

To make this initial comparison requires three new data banks.

a. Aircraft data - This is a catalog of all geometric and performance data for all current aircraft, aircraft engines, ground service equipment, etc. For the most part this information is available from the manufacturers, but needs to be stored and indexed properly in order to be accessible for the purposes for which it is needed.

b. Airport data - This is a catalog of all geometric and performance of operational data for the airports of the world which should be included in the system. Although some data are available from the FAA and ICAO records, it is not clear that all data which would be valuable for a compatibility analysis can be obtained without a considerable increase of effort in this regard. For example, gate assignments by airline and airline space distributions in the terminals are sometimes difficult to obtain, but would be required if it was desired to limit the analysis to one (or a subgroup) of airlines.

Table 3. Keyword list.

1. Acceleration	29. Engine	57. Narrow	85. Temperature
2. Aisles	30. Exhaust	58. Navigation	86. Terminal
3. Altimeter	31. Floor	59. Noise	87. Thickness
4. Approach	32. Food	60. Obstacle	88. Thrust
5. Area	33. Fuel	61. Operations	89. Time
6. Aspect	34. Fueling	62. Pavement	90. Tire
7. Baggage	35. Fuselage	63. Power	91. Tires
8. Brakes	36. Gear	64. Propeller	92. Touchdown
9. Cabin	37. Ground	65. Radar	93. Tower
10. Capacity	38. Heating	66. Radio	94. Traffic
11. Cargo	39. Height	67. Radius	95. Transceiver
12. Category	40. Horizontal	68. Rollout	96. Transponder
13. Cleaning	41. Hydraulics	69. Rotation	97. Turning
14. Clearance	42. Idle	70. Seats	98. Utilization
15. Cockpit	43. IFR	71. Seating	99. Velocity
16. Container	44. Impact	72. Separation	100. Vertical
17. Control	45. Instrument	73. Servicing	101. View
18. Cooling	46. Landing	74. Size	102. Visual
19. Crew	47. Lateral	75. Span	103. Volume
20. Deceleration	48. Lavatory	76. Speed	104. Wake
21. Deicing	49. Length	77. Stability	105. Water
22. Diameter	50. Light	78. Start	106. Weight
23. Differential	51. Lights	79. Stop	107. Wheel
24. Director	52. Loading	80. Structures	108. Wheels
25. Doors	53. Longitudinal	81. Sweep	109. Wide
26. Electrical	54. Maneuverability	82. Tail	110. Wing
27. Emergency	55. Medium	83. Takeoff	
28. Emissions	56. Mix	84. Taxi	

c. Airline operations data - This would be the equivalent of the Official Airline Guide tapes. These are readily available for a price and cover most areas of the world. Some manipulations of the data might be required to obtain gross activity records and their time distributions for individual airports. In some cases these later data might come from records of regulatory agencies such as the tower activity statistics maintained by FAA.

Illustration of the Methodology

To illustrate the use of the methodology an example has been constructed which has the general objective of examining potential compatibility problems of the Boeing 737-300. This was simply an arbitrary selection based on data available in publications such as Aviation Week and Space Technology, etc. Only selected dimensions and characteristics were used which would be sufficient to illustrate the procedures.

Search routine

Although major parts of this procedure are incorporated in the evaluation methodology as a subroutine, the search routine can be very valuable to the analyst, particularly when used in a very general sense. For the purposes of this illustration, let us select just two components from our B737-300 example and initiate a search based upon the possibility of changing the length and span dimensions of the aircraft.

Step 1 The routine is initiated by calling a "menu" of the various programs available to the user. The initial program selected from the menu is usually a keyword search. The computer presents the user with the keyword list shown in Table 3. The use of the keyword list is necessary in order to assure that all elements in the matrix involved with the item of concern are identified. In the current example the need for the keyword list is trivial, but in general, this is not so.

After being presented with a list, the user is instructed to enter the keyword(s) for which a search of the aircraft element file is desired. In this case two words are entered.

SPAN
LENGTH

Step 2 The aircraft element file is searched by the computer and all element numbers containing the two selected keywords are displayed. In this case they are

AC 0410 - WING SPAN
AC 0420 - OVERALL LENGTH

Step 3 The next program selected from the menu is the aircraft/airport interaction matrix. Each of the element numbers from Step 2 is entered independently and the interaction matrix is searched by the computer and all airport elements interacting with the specified aircraft elements are displayed. For this example the following are obtained.

Parameters Affected By AC0410 Are

AP0324	Runway Length
AP0511	Runway Capacity
AP0521	Acceptance Rate From Runway/TA
AP0522	Taxiway CAP/Crossing Active RN
AP0321	Runway Widths and Slopes
AP0342	Runway/Taxiway Separation
AP0341	Taxiway/Taxiway Separation
AP0630	Apron Overall Dimensions
AP0623	Taxilane To Parked A/C
AP0625	Parked A/C to A/C Separation
AP0730	Terminal Gate Size
AP0351	Holding Bay Dimensions
AP0740	Overall Apron Layout
AP0360	Overpass Structures
AP0830	Service Vehicle Row
AP0840	Transporter Row
AP0770	Terminal/Taxiway Conf.
AP0720	Terminal/Gate Parking Conf.
AP1340	Horizontal Terminal/AC Connect
AP1320	Loading Bridges and Ramps
AP1370	Concourse Design
AP0343	Runway To Runway Distance

Parameters Affected By AC0420 Are

AP0639	Apron Overall Dimensions
AP0623	Taxilane To Parked A/C
AP0625	Parked A/C to A/C Separation
AP0730	Terminal Gate Size
AP0351	Holding Bay Dimensions
AP0740	Overall Apron Layout
AP0830	Service Vehicle Row
AP0840	Transporter Row
AP0770	Terminal/Taxiway Conf.
AP0611	Apron Taxilane Width
AP0622	Taxilane to Building Separation
AP1380	Concourse Width
AP1330	Terminal/AC Connector Location

Step 4 Having obtained all the potential interaction points for each aircraft element, we next wish to determine what information is available concerning these interactions. Returning to the menu, acquisition can be made to any of the informational data banks discussed earlier. Either the entire list of interactions can be used or information on only a selected list can be requested. To illustrate, let us select the bibliography program and request information on the following interactions:

AC0410/AP0321
AC0410/AP0342
AC0420/AP0625.

The computer will search the bibliography files (which are by no means complete, but contain only a few references inserted for the purposes of illustration) and display what it finds. In the version shown below, the references are displayed by a file citation code, but full citations can be made available if desired.

References For AC0410/AP0321
ZPARS-75a
ICAO-14
150/5335-4

References For AC0410/AP0342
ZBOE-79a
BLOC-69
150/5335-1a
150/5335-4

References For AC0420/AP0625
BLOC-69
ZPARS-75a
150/5335-2

Evaluation Routine

This procedure begins with a problem definition phase which has two purposes. First, it provides the analyst with an opportunity to tailor a particular problem to specific and limited requirements on the one hand, or to run a very general problem if this is desired. Second, in the case of the limited problems, the computer time can be reduced significantly. In general the approach is to classify airports, aircraft, and airlines in appropriate ways so that the analysis can be made using all classes, single or multiple classes, or individual units as the case may be.

Four definition sections are currently used. The first, shown in Figure 1 defines the airport set of interest; the second, Figure 2, selects the airline activities of interest at the airport set; the third, shown in Figure 3, selects the general classes of aircraft to be used in comparison with the "subject" aircraft; while the fourth, also in Figure 3, establishes the scope of the interaction analysis desired.

In defining the airport set, the air carrier airports can be subdivided into classes as designated either by ICAO or FAA; general aviation airports are classified according to the four principal types defined by FAA in the National Airport System Plan.

Aircraft can be subdivided according to the following.

Range
- >2600 Nmi
- $1000 \leq R \leq 2600$ Nmi
- 1000 Nmi

Gross Weight
- >350,000 lbs
- $60,000 \leq W \leq 350,000$
- $12,500 \leq W \leq 60,000$
- < 12,500

Type of Terminal Involved at Airport
- Commercial General Aviation
- General Aviation

Basic Use of Aircraft
- Passenger
- Cargo
- Mixed

Is a Transporter Required for Loading and Unloading?
- Not Possible
- When Desirable
- Mandatory

Figure 1. Airport setup program.

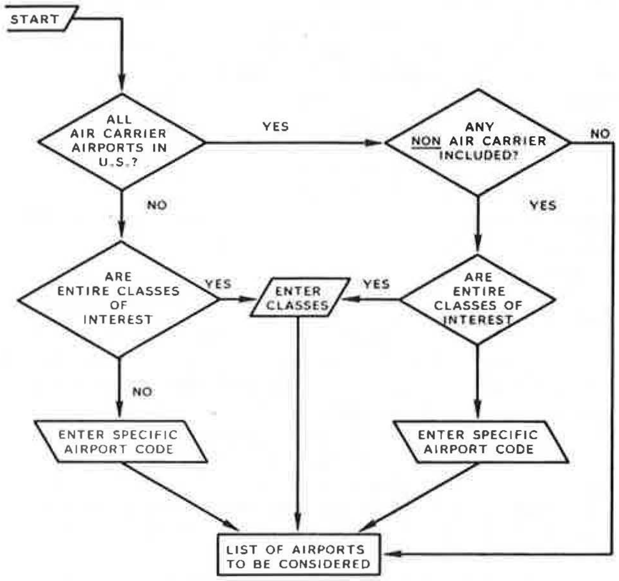
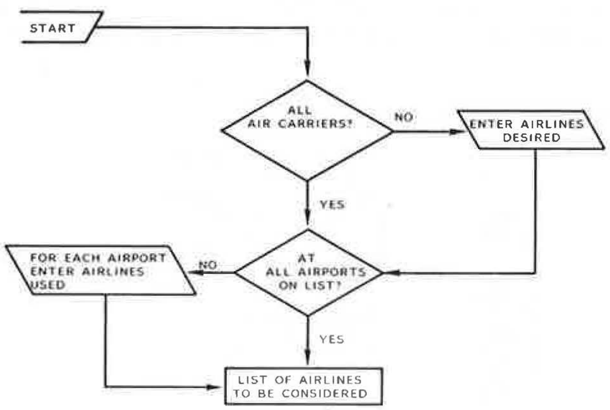


Figure 2. Airline setup program.

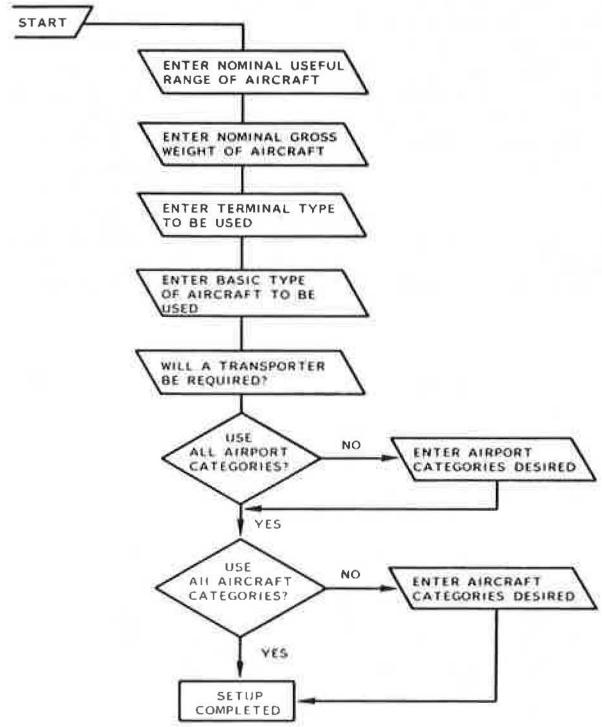


In the pages that follow, a hypothetical problem involving the potential of using a 737-300 at a selected set of airports in the Maryland-Virginia-North Carolina area will be carried through in some detail to illustrate the method. The data, which have been placed in the data banks in order to conduct this exercise, came from books and records which were immediately available to the authors. While it is believed that the aircraft data used represent current values, it was not possible to verify the figures found for the airports. Thus the conclusions reached in the exercise do not necessarily imply that this would be the actual result at the airports involved.

In presenting the problem analysis, the actual interactions between the computer and the analyst are shown. The various actions are identified as follows:

__, a question asked by the computer
[], a response made by the analyst (an input)
--, an output from the computer presenting the result of an operation which it performed.

Figure 3. Aircraft and scope setup.



In general throughout this analyses, the input information will be shown in Figures and the computer outputs will be listed in Tables. In either case, when only a few lines are required, they will be presented in the text.

Figure 4 shows the results of the definition phase for airports and airlines, while Figure 5 presents the same information for the aircraft and the general scope of the analyses. The problem has been defined as examining the potential of the candidate aircraft at six air carrier airports,

ORF - Norfolk, VA
CHO - Charlottesville, VA
RIC - Richmond, VA
ROA - Roanoke, VA
BWI - Baltimore, MD
RDU - Raleigh-Durham, NC

in comparison with the commercial passenger operations of all airlines at those airports using aircraft of range 1000-2600 Nmi, gross weight 60,000-350,000 pounds, and permitting the use of a transporter if needed. Furthermore, a complete interaction analysis is desired.

The main program begins by determining whether the current problem is to be an analysis of a candidate airport or a candidate aircraft. In this case it is an aircraft. It next requests that all the aircraft elements which are to be considered for the candidate aircraft to be entered by number. In this exercise the following list was entered:

0111, 0112, 0120, 0130, 0140, 0150, 0180
0210, 0213, 0216, 0250
0410, 0412, 0415, 0420
0520
0610, 0620, 0650
0720, 0780
0810, 0811, 0820, 0830, 0840, 0870, 0880, 0812, 0816, 0818
1010, 1110, 1170

After this entry is completed the computer then automatically goes to the aircraft/aircraft self interaction matrix and generates a printout of additional aircraft elements which should be included for a thorough analysis. This printout is shown in Table 4. Note that the interaction matrix tells us the highest level (strong, medium or weak) of the interaction with any of the original set of elements.

The next several stages of the program are designed to allow the analyst to edit the list of Table 4. Either additions or deletions can be made and this can be done by either entering element code numbers, classes of code numbers or by use of the keyword list. Since these are routine operations, they are not discussed here in any detail. In the current example the edited list is shown in Table 5.

Having determined the final set of characteristics of the candidate aircraft to be used in the analysis, the program is now ready to begin the main part of the evaluation. The output will consist of the formation of two lists of airports: those, if any, at which no problems can be anticipated for the candidate aircraft, and those, if any, where potential problems cannot be eliminated, together with information on the magnitude of the possible problem. The general routine for the program is shown in Figure 6. A search is made which compares the characteristics of the candidate aircraft with aircraft that are currently operating at the selected airport set, or have operated there in the past. The search involves use of the Official Airline Guide (OAG) schedules and the airport data bank. If the OAG schedules indicate that the candidate aircraft should be acceptable at a given airport because a more restrictive aircraft has already operated there, then the airport bank is examined to see if there were any waivers or constraints on this operation. If so these are noted in the entry for that airport.

The input data for the candidate aircraft is shown in Table 6, where the option for English units has been chosen, and the output data from this procedure as applied to the illustrative example is shown in Table 7. For each airport a list is presented in Table 7 of those elements of the candidate aircraft which have not been exceeded previously by

Figure 4. Airports and airlines definition (sample problem).

START

- Aircraft Airport Compatability Set Up Program
- Identify the Airports of Interest
    - All Air Carrier Airports in U.S. (Y or N)? [N]
    - In an Entire Class of Airports of Interest (Y or N)? [N]
    - Enter 3 Letter Code for Airport (0 to Stop Entry)? [ORF]
    - Enter 3 Letter Code for Airport (0 to Stop Entry)? [CHO]
    - Enter 3 Letter Code for Airport (0 to Stop Entry)? [RIC]
    - Enter 3 Letter Code for Airport (0 to Stop Entry)? [ROA]
    - Enter 3 Letter Code for Airport (0 to Stop Entry)? [BWI]
    - Enter 3 Letter Code for Airport (0 to Stop Entry)? [RDU]
    - Enter 3 Letter Code for Airport (0 to Stop Entry)? [O]
    - Are Any Non Air Carrier Airports to be Included in Analysis? [N]
    - Are Activities of All Air Carriers Desired? [Y]

Table 4. Sample problem: output of aircraft/aircraft interaction matrix.

S	AC0110	Coefficient of Lift	S	AC0770	Landing Gear Footprint
S	AC0113	Aerodyn Effect of Wing Span	S	AC0790	Braking System
S	AC0114	Aeordyn Effect/Horztl Tail Span	S	AC0813	Engine Servicing Rqmnts
M	AC0115	Wing Dihedral	S	AC0814	Engine Noise Production
S	AC0150	Aspect Ratio	S	AC0815	Engine Emissions Levels
S	AC0160	Wing Sweep Back	S	AC0817	Engine Thrust Reversing
S	AC0170	Wing Thickness Ratio	S	AC0818	Engine Overall Width
S	AC0190	Wake Turbulence	S	AC0819	Engine Location from Nose
S	AC0211	Vertical Velocity at Takeoff	S	AC0850	Propeller Diameter
S	AC0212	TCA Maneuvering Velocity	S	AC0860	Propeller Ground Clearance
S	AC0214	Balanced Fld Take/O Dist Requi	S	AC0190	Type of Fuel Req.
S	AC0215	Landing Roll Distance	S	AC0920	A/C Fuel Capacity
S	AC0217	A/C Velocity at Lift-Off	M	AC1011	Number of Galleys
S	AC0218	L/D Ratio at Best Angl Clb Vel	M	AC1012	Number of Lavatories
S	AC0220	Touchdown Velocity	S	AC1013	Special Servicing
M	AC0230	Rollout and Taxi Speed	S	AC1014	Pax Cabin Volume
S	AC0240	Deceleration Rate	S	AC1040	Cabin Floor Height To Ground
S	AC0260	Stall Velocity	M	AC1050	# of Aisles and Crossovers
S	AC0270	Minimum Control Velocity	S	AC1060	Food Servicing
S	AC0280	Acceleration and Stop Velocity	S	AC1070	Potable Water Servicing
S	AC0290	Velocity Over 50' Obstacle	S	AC1080	Lavatory Service
S	AC0310	Longitudinal Stability/Rotation	S	AC1090	Cabin Servicing
S	AC0320	Longitudinal Stability/Landing	M	AC1110	# & Location of Doors-Cargo
S	AC0330	Longitudinal Stability/Takeoff	S	AC1120	Baggage/Cargo Floor Heights
S	AC0340	Dynamic Longitudinal Stability	S	AC1130	Baggage/Cargo Moving System-AC
S	AC0350	Directnl & Lateral Stability	S	AC1140	Baggage/Cargo Container Size
S	AC0360	Min. Control Speed Stability	S	AC1150	Maximum Cargo Weight
S	AC0370	L. Speed/Close Maneuverability	M	AC1160	Interline/Intraline Baggage Fl
S	AC0413	Fuselage Width	M	AC1180	Loose Baggage Reqs.
S	AC0414	Fuselage Length	S	AC1210	A/C Electrical Power Needs
S	AC0430	Overall Height	S	AC1220	A/C Gt[d] Heating & Cooling Rqmts
M	AC0440	Fuselage Height	S	AC1230	A/C Ground Start Reqs.
M	AC0450	Fuselage Overwing	W	AC1320	Hydraulic System
M	AC0460	Fuselage Underwing	S	AC1330	Airframe Deicing Reqs.
S	AC0470	Wing Height Above Ground	S	AC1410	A/C Position Lights
S	AC0480	Horizontal Tailheight To Ground	S	AC1440	Cabin Courtesy Lights
S	AC0490	Wing Sweep Back	S	AC1710	Terminal Control Area
S	AC0510	Wing Structures	S	AC1720	Tower Control Zone
S	AC0660	A/C Empty Weight	S	AC1810	A/C Size Differential
M	AC0710	Wheel Tread Dimensions	S	AC1820	Flight Velocity Differential
M	AC0711	Tire Pressure	S	AC1940	Lateral Separation Dual Rnwy
S	AC0712	Tire Pavement Contact Area	S	AC2010	Landing Phase-Operations Proc.
S	AC0713	Equivalent Single Wheel Load	S	AC2020	Takeoff-Operations Procedure
W	AC0714	Wheel Spacing Per Wheel Group	S	AC2110	Gate Occupancy Time
S	AC0716	Nose Wheel Turn Angle	S	AC2220	Servicing from Vehicles/Loc.
S	AC0715	Min Pavemt Width 180 Turn	S	AC2230	Staging of Servicing
S	AC0730	# of Tires on Main Gear	S	AC2310	Wide Bodies/Heavy
S	AC0740	Tire Configuration	S	AC2320	Narrow Bodies/Medium
W	AC0750	Tire Tread Design	S	AC2330	Light Transport
S	AC0760	Landing Gear Impact Dynamic	S	AC2340	Medium Class

Table 5. Sample problem: edited list of aircraft characteristics to be used in the analysis.

AC0120	Wing Loadings at Takeoff
AC0130	Wing Loading Landing Weight
AC0140	Thrust Loading
AC0150	Aspect Ratio
AC0180	Wing Area
AC0111	Horizontal Tail Area
AC0112	Vertical Tail Area
AC0114	Aerodyn Effect/Horztl Tail Spa
AC0210	Approach Velocity
AC0220	Touchdown Velocity
AC0240	Deceleration Rate
AC0250	Acceleration Rate
AC0260	Stall Velocity
AC0213	Takeoff Run Dist Requiremt
AC0214	Balanced Fld Take/O Dist Requi
AC0215	Landing Roll Distance
AC0216	FAA Landing Distance
AC0410	Wing Span
AC0420	Overall Length
AC0412	Horizontal Tail Span
AC0414	Fuselage Length
AC0415	Aux Wing Tip Devices
AC0510	Wing Structures
AC0520	Fuselage Structures
AC0610	Aircraft Gross Weight
AC0620	Landing Weight
AC0650	Max Fuel Weight
AC0715	Min Pavemt Width 180 Turn
AC0720	Wheel Base Dimensions
AC0760	Landing Gear Impact Dynamic
AC0770	Landing Gear Footprint
AC0780	Minimum Turning Radius
AC0810	Engine Location/Dist to A/C CL
AC0820	Engine Location/Dist Othr A/C
AC0830	Engine Height Abv Ground
AC0840	Engine Air Inlet Location
AC0870	Engine Thrust/Exhaust Velocity
AC0880	Engine Thrust/Exhaust Velocity 10
AC0811	Idle Thrust/Exhaust Velocity
AC0812	Engine Brkawy Thrust Rqmnts
AC0814	Engine Noise Production
AC0817	Engine Thrust Reversing
AC0818	Engine Overall Width
AC0819	Engine Location From Nose
AC0920	A/C Fuel Capacity
AC1010	Seating Capacity/Single Level
AC1040	Cabin Floor Height to Ground
AC1014	Pax Cabin Volume
AC1110	# & Location of Doors-Cargo
AC1170	Maximum Baggage/Cargo Volume
AC1210	A/C Electrical Power Needs
AC1330	Airframe Deicing Reqs.
AC1810	A/C Size Differential
AC1940	Lateral Separation Duel Rnwy
AC2010	Landing Phase-Operations Proc.
AC2020	Takeoff-Operations Procedure
AC2110	Gate Occupancy Time

Figure 5. Sample problem: aircraft and scope definitions.

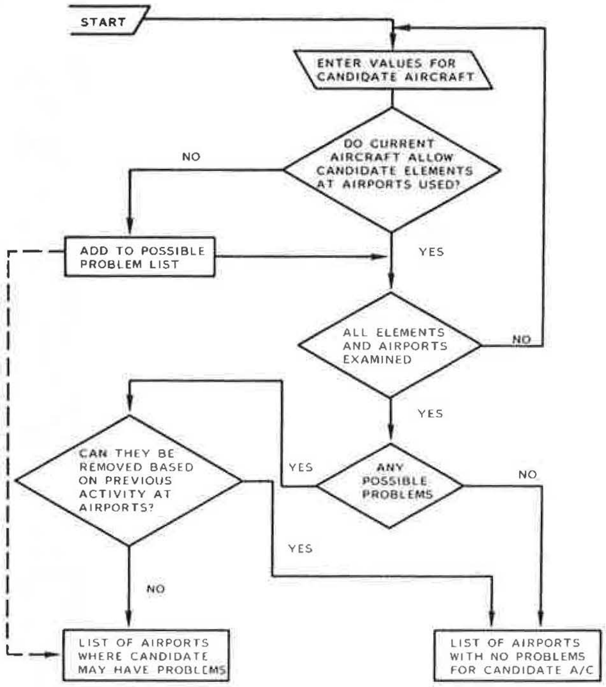
Classification of Aircraft for Analysis

- Enter the Nominal Useful Range of the Aircraft
  - L - (Range 2600 Nautical Miles)
  - M - (1000 Range 2600)
  - S - (Range 1000)
- Enter Range Category (L,M, or S)? [M]
- Enter the Nominal Gross Weight of the Airport
  - 1 - (Weight 350,000 lbs.)
  - 2 - (60,000 Weight 350,000)
  - 3 - (12,500 Weight 60,000)
  - 4 - (Weight 12,500)
- Enter the Weight Category (1,2,3, or 4)? [2]
- Enter the Terminal Type to be Used
  - C - (Commercial
  - G - (General Aviation)
- Enter Type (C or G)? [C]
- Enter the Basic Use Type of the Aircraft
  - P - (Passenger)
  - C - (Cargo)
  - M - (Mixed)
- Enter the Use Type (P,C, or M)? [P]
- Will the Aircraft Require Use of a Transporter for Loading and Unloading
  - 1 - (Not Possible)
  - 2 - (When Desired)
  - 3 - (Mandatory)
- Enter Category (1,2, or 3)? [2]

Extent of Interaction Analysis Required

- Is a Complete Interaction Analysis Involving All Airport Characteristics Desired (Y or N)? [Y]
- Is a Complete Interaction Analysis Involving All Aircraft Characteristics Desired (Y or)? [Y]

Figure 6. Airport evaluation program.



operations of any other aircraft. The value column provides the data on that element for the candidate aircraft, while the Δ column gives the differential (in the same units) by which the candidate aircraft exceeds the value of the same element for the most restrictive aircraft which has used that airport. For example, considering Charlottesville, the takeoff run distance requirement for the 737-300 is 7000 feet which is 200 feet more than the requirement for any other aircraft which has previously used Charlottesville.

The program now provides the analyst an opportunity to examine any or all of these potential problem points by comparing them with what actually exists at any or all of the airports in question. This process is illustrated by considering a few specific cases. The first step is to request the aircraft/airport interactions at each of the desired airports. The computer-analyst dialogue is as follows:

- Do You Want AC/AP Interactions For Any Airports Listed (Y or N)?
- Do You Want AC/AP Interactions For All Airports Listed (Y or N)?
- Enter Airport(s) By Three Letter Code (Enter 0 to Stop Entry)
  [CHO, BWI, 0]

The program then displays the results as shown in Table 8 for CHO and Table 9 for BWI. The indication of a Q by an entry means that quantitative data are available for those interactions.

The illustrative example then continues by examining in more detail a few of these interaction points which may be problematic. The first is prompted by the fact that the nominal landing field distance at CHO is 690 feet greater than for other aircraft using CHO. Again, the computer-analyst dialogue goes as follows:

Table 6. Numerical input of elements for candidate aircraft.

- Will the input data be in English units or metric (M - metric, E - English)? [E]

- Input the following data

AC0111	Horzontal Tail Area	Sq.Ft.?	292.5
AC0112	Vertical Tail Area	Sq.Ft.?	270
AC0120	Wing Loading at Takeoff	Lbs./Ft2?	119.9
AC0130	Wing Loading Landing Weight	Lbs./Ft2?	96.3
AC0140	Thrust Loading	Lbs./Lbs.S.Th.?	3.115
AC0150	Aspect Ratio	?	8.7
AC0210	Approach Velocity	MPH?	157
AC0220	Touchdown Velocity	MPH?	135
AC0250	Acceleration Rate	Ft/Sec2?	10.3
AC0213	Takeoff Run Dist Requiremt	Ft.?	7000
AC0216	FAA Landing Distance	Ft.?	5360
AC0410	Wing Span	Ft.?	94.8
AC0412	Horizontal Tail Span	Ft.?	42
AC0414	Fuselage Length	Ft.?	105.6
AC0415	Aux. Wing Tip Devices	Y or N?	Y
AC0420	Overall Length	Ft.?	109.6
AC0430	Overall Height	Ft.?	36.5
AC0520	Fuselage Structures	Ratio?	0.95
AC0610	Aircraft Gross Weight	Lbs.?	124500
AC0620	Landing Weight	Lbs.?	103000
AC0650	Max Fuel Weight	Lbs.?	36450
AC0715	Min Pavemt Width 180 Turn	Ft.?	65.1
AC0720	Wheel Base Dimensions	Ft.?	40.8
AC0780	Minimum Turning Radius	Ft.?	66.8
AC0810	Engine Location/Dist To A/C CL	Ft.?	16.5
AC0820	Engine Location/Dist Othr A/C	Ft.?	6
AC0830	Enginer Height Abv Ground	Ft.?	1.5
AC0840	Engine Air Inlet Location	Ft.?	2.35
AC0870	Engine Thrust/Exhaust Velocity	Ft./Sec?	85
AC0880	Engine Thrust/Exhaust Velocity 10	Ft./Sec?	86
AC0811	Idle Thrust/Exhaust Velocity	Ft./Sec?	45
AC0812	Engine Brkawy Thrust Rqmnts	Ft./Sec?	72
AC0816	Engine T.O. Thrust or H.P.	Lbs.?	40000
AC0818	Engine Overall Width	Ft.?	5.9
AC0819	Engine Location From Nose	Ft.?	34.8
AC0920	A/C Fuel Capacity	U.S. Gal.?	5360
AC1010	Seating Capacity/Single Level	Pax.?	132
AC1014	Pax. Cabin Volume	Ft.3?	5210
AC1170	Maximum Baggage/Cargo Volume	Ft.3?	1000

- Do You Want Specific Interaction Data For Any Airports Listed (Y or N)? [Y]

- Do You Want Specific Interaction Data For All Airports Listed (Y or N)? [N]

- Enter Airport(s) By Three Letter Code (Enter 0 to Stop Entry)
  [CHO
  0]

- Enter Interaction Code (AC0000/AP0000) - Enter 0 to Stop Entry
  [AC0216/AP0324]
  0

- Specific Interaction Information

AC0216	FAA Landing Field Length	5596
AP0324	Max Runway Length	6000
	Delta = - 404	

This indicates there is 404 feet of runway reserve at CHO and so the landing length will not be a problem there. Note that in this case the Landing Field length is corrected for conditions at CHO.

Next, the use of a potential problem area where only qualitative information is available is illustrated.

- Do You Want Specific Interaction Data For Another Airport or Airport Set (Y or N)? [Y]

- Enter Airport(s) By Three Letter Code (Enter 0 to Stop Entry)
  [CHO
  0]

- Enter Interaction Code (AC0000/AP0000) - Enter 0 to Stop Entry
  [AC0120/AP0324
  0]

- Specific Interaction Information
  AC0120 Wing Loadings At Takeoff
  AP0324 Max Runway Length

  AC0120/AP0324 Wing Loadings Will Affect Runway Distance In That As Wing Loadings Increase Holding Other Variables Constant, Runway Length Increases

This calls attention to the takeoff length problem and so this is examined in more detail.

- Do You Want Specific Interaction Data For Another Airport Or Airport Set (Y or N)? [Y]

- Enter Airport(s) By Three Letter Code (Enter 0 To Stop Entry)
  [CHO
  0]

- Enter Interaction Code (AC0000/AP0000) - Enter 0 To Stop Entry
  [AC0213/AP0327
  0]

- Specific Interaction Information

AC0213	Takeoff Dist Requirements	7100
AP0327	Takeoff Field Length	6900
	Delta = + 200	

Here we see that there will be a problem (the runway is short by 200 feet) and, from the data provided, the analyst could compute the reduction in weight required for operation at CHO, or apply some standard average cost allowance for increasing runways by 200 feet. Such standard computation programs could be included in the computer package if desired.

Conclusions

A methodology has been devised which will assure that all aspects of the problem of determining aircraft-airport compatibility are taken into account when considering the design of new aircraft or derivatives of existing vehicles. The methodology is programmed in an interactive mode using Wang Basic.

Dimensions and operating characteristics of the candidate aircraft must be entered and then the following information is automatically provided to the extent requested.

1. Other aircraft dimensions or characteristics which might be affected by changes in the original set.

2. All airport dimensions or characteristics which will be affected by this expanded aircraft set.

3. Other airport quantities which might have to be altered if there are any changes required in those quantities involved in Item 2.

Table 7. Potential incompatibilities of candidate aircraft at airport set.

ORF - Norfolk, VA		Value	Δ
AC0120	Wing Loadings at Takeoff	119.9	+ 4.7
AC0412	Horizontal Tail Span	42	+ 5.2
AC0415	Aux. Wing Tip Devices		
AC0820	Engine Location/Dist Othr A/C	6	- 1.7
AC0830	Engine Height Abv Ground	1.5	- .2
CHO - Charlottesville, VA			
AC0120	Wing Loadings at Takeoff	119.9	+ 4.7
AC0213	Takeoff Run Distance Requiremts	7000	+ 200
AC0216	FAA Landing Distance	5360	+ 690
AC0210	Approach Velocity	157	+ 5
AC0220	Touchdown Velocity	135	+ 3
AC0412	Horizontal Tail Span	42	+ 6
AC0415	Aux. Wing Tip Devices		
AC0820	Engine Location/Dist Othr A/C	6	- 1.7
AC0830	Engine Height Abv Grond	1.5	- .2
AC0840	Engine Air Inlet Location	2.35	- .25
AC1010	Seating Capacity/Single Level	132	+ 1
RIC - Richmond, VA			
AC0120	Wing Loadings At Takeoff	119.9	+ 4.7
AC0412	Horizontal Tail Span	42	+ 5.2
AC0415	Aux. Wing Tip Devices		
AC0820	Engine Location/Dist Othr A/C	6	- 1.7
AC0830	Engine Height Abv Ground	1.5	- .2
AC0840	Engine Air Inlet Location	2.35	- .25
ROA - Roanoke, VA			
AC0120	Wing Loadings at Takeoff	119.9	+ 4.7
AC0216	FAA Landing Distance	5360	+ 560
AC0210	Approach Velocity	157	+ 5
AC0220	Touchdown Velocity	135	+ 3
AC0412	Horizontal Tail Span	42	+ 6
AC0415	Aux. Wing Tip Devices		
AC0820	Engine Location/Dist Othr A/C	6	- 1.7
AC0830	Engine Height Abv Ground	1.5	- .2
AC0840	Engine Air Inlet Location	2.35	- .25
AC101	Seating Capacity/Single Level	132	+ 1
BWI - Baltimore, MD			
AC0126	Wing Loadings at Takeoff	119.9	+ 4.7
AC0415	Aux. Wing Tip Devices		
AC0820	Engine Location/Dist Othr A/C	6	- 1.7
AC0830	Engine Height Abv Ground	1.5	- .2
AC0840	Engine Air Inlet Location	2.35	- .25
RDU - Raleigh/Durham, NC			
AC0120	Wing Loadings at Takeoff	119.9	+ 4.7
AC0412	Horizontal Tail Span	42	+ 5.2
AC0216	FAA Landing Distance	5360	+ 310
AC0415	Aux. Wing Tip Devices		
AC0820	Engine Location/Dist Othr A/C	6	- 1.7
AC0830	Engine Height Abv Ground	1.5	- .2
AC0840	Engine Air Inlet Location	2.35	- .25

Table 8. AC/AP interactions at CHO which are potential problems.

AC0120		Wing Loadings at Takeoff	
	AP0324	Runway Length Requiremts	
	AP0327	Takeoff Field Length	Q
AC0216		FAA Landing Distance	
	AP0324	Runway Length Requiremts	Q
AC0210		Approach Velocity	
	AP0118	Aircraft Traffic Flow Control	
	AP0153	Glideslope Requirements - Electronic	
	AP0241	Part 77 - Approach Surface	
	AP0511	Runway Capacity	Q
	AP1213	Glideslope Requiremts, - Visual	
AC0220		Touchdown Velocity	
	AP0324	Runway Length Requiremts	Q
	AP0334	High Speed Exit Design	
	AP0335	Runway Exit Locations	Q
	AP0512	Runway Occupancy Time	Q
AC0412		Horizontal Tail Span	
	AP0342	Runway/Taxiway Separation	Q
	AP0341	Taxiway/Taxiway Separation	Q
	AP0511	Apron Taxilane Width	
	AP0521	Apron Taxilane/Taxilane Separation	Q
	AP0623	Taxilane to Parked A/C	
	AP0625	Parked A/C to A/C Separation	
	AP0720	Terminal/Gate Parking Configuration	Q
	AP0730	Terminal Gate Size	Q
	AP0830	Service Vehicle Rights of Way	
	AP0840	Transporter Rights of Way	
	AP1320	Loading Bridges and Ramps	
	AP1340	Horzontl Terminal/AC Connector Locatn	
	AP1370	Concourse Design	
AC0415		Aux. Wing Tip Devices	
	AP0720	Terminal/Gate Parking Configuration	
	AP0830	Service Vehicle Rights of Way	
	AP0840	Transporter Rights of Way	
	AP1320	Loading Bridges and Ramps	
	AP1340	Horizontl Terminal/AC Connector Locatn	
AC0820		Engine Location/Dist Othr A/C	
	AP0830	Service Vehicle Rights of Way	
AC0830		Engine Height Abv Ground	
	AP1223	Runway Lights and Signs	Q
	AP1231	Taxiway Lights and Signs	Q
	AP1350	A/C to Building Connectors	
	AP1610	A/C Service Equip Design	
	AP1710	Airport Blast Deflectors	Q
AC0840		Engine Air Inlet Location	
	AP0370	Surface Debris - Runway/Taxiway	
	AP0650	Surface Debris - Apron Area	
	AP1130	Snow Removal Requiremts	Q
AC1010		Seating Capacity/Single Level	
	AP0931	Pax Flow Rates and Acceptance	Q
	AP0932	Holdroom Capacity	Q
	AP0933	Pax/Visitor Capacity	Q
	AP0934	Concourse Flow Rates	Q
	AP0935	Transporter Capacity	Q
	AP1310	A/C Availability - Deplan/Enplan	Q
	AP1320	Pax Loading Bridges and Ramps	
	AP1330	Multiple Location of Connectors	
	AP1360	Transporter Design	
	AP1311	Transporter Fleet Size	Q
	AP1420	Baggage Flow Rates	Q

4. All available data, constraints, literature, analysis, etc. pertaining to any of the interactions referred to above.

5. A determination of whether or not aircraft having dimensions or characteristics greater than those of the candidate aircraft currently operate or have operated in the past at any particular airport of concern.

6. A list of those airports for which compatibility with the candidate aircraft cannot currently be established, and, for each airport on this list, a notation of the interaction points in question together with all data relating to these points.

Table 9. AC/AP interactions at BWI which are potential problems.

AC0120		Wing Loadings at Takeoff	
	AP0324	Runway Length Requiremts	Q
	AP0327	Takeoff Field Length	
AC0415		Aux. Wing Tip Devices	
	AP0720	Terminal/Gate Parking Configuration	
	AP0830	Service Vehicle Rights of Way	
	AP0840	Transporter Rights of Way	
	AP1320	Loading Bridges and Ramps	
	AP1340	Horizontl Terminal/AC Connector Locatn	
AC0820		Engine Location/Dist Othr A/C	
	AP0830	Service Vehicle Rights of Way	
AC0830		Engine Height Abv Ground	
	AP1223	Runway Lights and Signs	Q
	AP1231	Taxiway Lights and Signs	Q
	AP1350	A/C to Building Connectors	
	AP1610	A/C Service Equip Design	
	AP1710	Airport Blast Deflectors	Q
AC0840		Engine Air Inlet Location	
	AP0370	Surface Debris - Runway/Taxiway	
	AP0650	Surface Debris - Apron Area	
	AP1130	Snow Removal Requiremts	Q

Opportunity for editing is provided so that the user may establish the scope of the analysis desired. This can involve either restricting the process to a limited portion of the analyses (e.g. only selected interactions) or operations at a limited set of airports, etc.

The intent of the methodology is to identify and define (quantitatively whenever possible) the potential problem areas. It does not offer solutions, but can be very useful to a designer by providing assistance in arriving at solutions. For example, the designer can enter a range of numbers for each of the key aircraft dimensions under consideration, and by repeated application of the routine can follow the trends in compatibility and the changes in interaction points.

One of the key features of the methodology is that it can be used in real time in the design process. Thus it should make an important addition to automated aircraft design procedures such as IPAD. As the designer begins to determine relationships between configuration and performance from the normal IPAD process, the compatibility of the various configurations with the world's airport system can be ascertained immediately. It is recommended that an objective of making this methodology compatible with IPAD be given high priority in the near future.

The application of the methodology is dependent upon the availability of several rather large and detailed data banks:

1. Design and performance specifications for existing aircraft.

2. Dimensional and operating data for all airports of potential concern -- including any restrictions placed on operations of any specific aircraft at these airports.

3. Schedules of current and past aircraft operations at the various airports.

4. Literature, design equations, regulations, constraints, etc. relating to all aircraft/ airport interactions points.

Reference

1. A detailed presentation of the subcomponents of aircraft/airport mutual interaction matrix and the aircraft/aircraft self interaction matrix, and the actual aircraft/airport matrix can be found in A. R. Kuhlthau and Ira D. Jacobson, "Aircraft/Airport Compatibility Methodology," Final Report, Contract NAS1-14908, Task 10, University of Virginia Report UVA/528184/MAE-CE81/101, August 1981. The aircraft/aircraft matrix is currently available from the authors, and it will be published together with the airport/airport matrix as soon as the latter is completed.

REPORT OF THE FINDINGS OF THE WORKING GROUPS

This section presents the reports made by each of the working groups at the conclusion of the workshop. However before doing so, it may be advantageous to record the lists of tasks presented to each group prior to the meeting.

Group 1

1. Identify for use by the other groups all the categories of problems which can exist in compatibility between civil aircraft and the airport and its environs.
2. For each problem category, identify and assess as to adequacy, the methods and units of measure used to define compatibility.
3. Describe and assess existing and candidate techniques (including the kind and extent of data required as input) for identifying and analyzing potential problems in aircraft and airport compatibility.
4. Assess the need for a data bank for compatibility analysis, and if needed, outline recommendations regarding its scope, and how best to obtain, document and disseminate such data, plus identification of candidate organizations and sources of funds for data bank implementation and update.
5. Identify any critical technology needs associated with items 1-3 above, and where indicated, develop recommendations for specific research including a descriptive outline, estimated magnitude of resources involved, and time frame of activity.
6. Recommend future activities for the TRB Committee on Aircraft/Airport Compatibility in the area of methodology for identifying and addressing the problems of compatibility.

Groups 2, 3, and 4

1. Identify for Group 1 one or more compatibility problems foreseen in the decade being addressed by your group wherein present methods for defining compatibility are less than adequate.
2. Identify for Group 5 consideration, any particularly sticky institutional issue foreseen as hindering the implementation of candidate solutions to one or more of the significant compatibility problems of the decade being addressed by your group.
3. Describe and rank in importance the significant compatibility problems foreseen as likely to occur in the decade being addressed. For each problem, identify the fundamental issue or issues (e.g., land use, environment, economics) which makes it a problem.
4. For each of the significant problems, identify alternate candidate solutions and evaluate them from technical, economic and institutional considerations, insofar as possible in the time available.
5. Identify any new technology needed for the candidate solutions and assess the adequacy of R&D effort underway to provide the technology in a timely fashion. If there are glaring deficiencies, develop recommendations for specific new research including the descriptive outline and estimated magnitudes of resources required.
6. Recommend future activities for TRB Committee A3A16 in the area of compatibility problems and solutions.

Group 5

1. Identify, by analysis of several past histories, the major institutional issues that slowed or even halted the execution of various measures aimed at improving or fully achieving aircraft and airport compatibility in specific problem areas.
2. Identify, by case history analysis similar to (1), the various approaches or strategies used in the past that successfully coped with institutional issues which were present or arose during execution and successful completion of measures which enhanced compatibility.
3. Identify, including inputs for Groups 2, 3, and 4, institutional issues foreseen as possibly hindering implementation of various candidate solutions to present and future compatibility problems.
4. Develop strategies, based on the results of (1) and (2), deemed best for coping with the various institutional issues identified in (3), insofar as possible in the time available.
5. Identify any study or analysis efforts that appear warranted for improving the methodology for coping with institutional issues. Include descriptive outlines and estimates of the resources needed.
6. Recommend future activities for TRB Committee A3A16 in the area of coping with institutional issues.

Group 1 - METHODOLOGY FOR STIMULATING AIRPORT COMPATIBILITY

Participants

Walter P. Ericksen, Chairman
Group Engineer, Airport Compatibility, Lockheed-California Co.
Roy C. LeCroy
Manager, Operations Research Department, Lockheed-Georgia Co.
Agam Sinha
Group Leader, Mitre Corp.
Ira D. Jacobson
Professor of Mechanical and Aerospace Engineering, University of Virginia
James W. Bushee
Chief, Design and Operations Criteria Division, Office of Airport Standards, Federal Aviation Administration
Harvey Hubbard, Consultant

Introduction

In examining the question of a methodology for stimulating aircraft/airport compatibility, the Working Group felt that it was necessary to start with a scoping of the group assignment. In general, it was felt that the issues to be addressed included:

- Approaches to problem solving
- Description of problem
- Tools available
- Sources of data
- Subsequent follow-up action.

A portion of the time was spent discussing typical problems, and defining the characteristics of the aircraft/airport type of problem. This enabled the group members to agree upon a general scope for deliberation. It is clear that in the

:craft/airport arena there is a lengthy list of ɔblems or problem areas that one can study in pth. These range from a systematic approach to ɜtermining runway friction without interfering ith aircraft operations, to developing a method for ɜccurately accounting for the impact of a proposed change to an aircraft on the indirect operating costs (IOC) of a user airline. It became apparent that using a specific problem area to develop a methodology for attacking that problem and others would result in a solution plan which would be very difficult or impossible to follow in such a broad field containing such a plethora of problems. Thus, the group agreed that a more useful approach in the time available would be to look at the problems from a much broader perspective. The goal adopted was to develop a methodology outline which would allow solution to most of the problems currently existing, and also provide a framework for isolating and evaluating other issues of concern in the future.

Conclusions

Before discussing the group's findings and recommendations, it is useful to enumerate some of the conclusions reached.

- A useful methodology has been outlined.
- Resolution of most problems requires a major interdisciplinary effort.
- There is no cohesive library of relevant documents to support the methodology.
- There are voids in the available data.
- The complexity and extent of the information needed for analysis suggests automated data processing techniques.

In the following sections, each of these areas will be discussed, followed by the recommendations of the group.

Methodology and Its Implementation

In discussing a methodology, the group came quickly to a consensus that the approach to the problem was not unique. Thus, the skeleton of a workable method was arrived at without any appreciable discussion. Most of the deliberations centered on shaping the generally agreed upon method into a framework for the aircraft/airport compatibility problems. The problems were viewed as having four major subelements, each having numerous subdivisions:

Aircraft
Airports
Airspace
Community

Although not meant to be all inclusive, each of these areas can be thought of as being subdivided into major elements as follows:

Aircraft
- Geometry
- Operating Characteristics
- Weight
- Propulsion System
- Avionics
- Service Requirements
- Aerodynamic Systems
- Environmental Characteristics (e.g. noise, pollution, blast, etc.)

Airports
- Layout (e.g. runways, taxiways, etc.)
- Setting (e.g. site, surroundings, access, etc.)
- Terminal Facilities (e.g. apron, gates, etc.)
- Service Facilities
- Navigational Aids (i.e. visual and electric landing aids)
- Environmental Controls
- Crash-Fire-Rescue
- Management

Airspace
- Navigation Facilities (e.g. ILS, MLS, etc.)
- ATC Procedures (e.g. metering, spacing, patterns, noise abatement, etc.)
- Obstacles
- Restrictions

Community
- Geometry (e.g. street layout, rivers, etc.)
- Demographics
- Obstacles
- Political Environment (e.g. curfews, noise, etc.)
- Planning (e.g. land use, zoning, etc.)

In discussing each of these areas it is important to note first, that these lists are not all inclusive, nor are they mutually exclusive. It is apparent that drawing sharp dividing lines between all of the divisions and elements is not possible. The items listed are given for reference only and a complete list for each category will have to be developed with much more extensive study than is possible at this workshop. Another important note is that the elements given must be broken down into many subdivisions, reflecting the component levels for each element. For example, within the category aircraft, and element, geometry, the subdivision into wing, body, tail, etc. must first be made, and then these further subdivided into span, chord, length, etc. When completed, a thorough taxonomy of all elements which enter the aircraft/airport compatibility problem will be available for analysts.

To describe the methodology briefly, an aircraft/airport compatibility issue drives the system. The first step is to take the issue at hand (e.g. to determine the effect of an increase in span on the ability to use the new vehicle in the current operating system, to analyze the optimum number of wheels for a new landing gear design, to determine the cost trade-off of an aircraft versus an airport modification to accomplish the same end, etc.), and scope it -- vis-a-vis the objective, the constraints, the environment, the user of the result, etc. Next, all of the interactions between each element in each category must be determined. It is anticipated that rather large and extensive interaction matrices will have to be developed to indicate all of the possible interactions both within each category (self interaction) and across categories (mutual interaction). Much of this work has been done, through the efforts at each of the major airframe manufacturers, who have been studying this problem for many years, and through the research being done at the University of Virginia. When all the interactions have been determined, they must be filtered or edited to eliminate any of the interactions that are either of secondary importance or in which the analyst has no interest. Each of the interactions which survive this screening process can then be divided into two groups. The first group contains those interactions for which the influence is known and for which some determination of the compatibility issue can be made. The decision can be made in any of a number of ways, including:

- experience,
- data from data banks,
- cost information,
- standards and criteria,
- forecasts,
- analytical techniques, and
- other.

A second group of interactions is simultaneously formed which consists of two major elements: first, those interactions for which data may exist, but for which only the gathering of these data is needed to reach a conclusion; and second, those interactions for which there is not sufficient information available to draw any conclusions.

The method then proceeds as follows:

1. Evaluate all of the interactions for which the influence is known. If the issue can be satisfactorily handled, continue to step 2. If not, draw whatever conclusions that are estimated, make recommendations, and communicate the results to all interested parties.

2. Identify and collect any data needed for those interactions identified as important, and for which only a lack of known data prevents a decision from being drawn. If the issue can then be satisfactorily handled, continue to step 3. If not, draw any conclusions that are possible, make recommendations, and communicate the results to all interested parties.

3. Conduct any research that is needed to allow a resolution of the issue. After the research has been conducted, provide the channels necessary to transfer the results to the accepted body of knowledge so that the interaction can be added to those that are known. Execute step 1 for this interaction. Continue this process until all unknown interactions have been moved into the known area, or until all interactions of primary importance have been exhausted.

4. Make conclusions, recommendations, and communicate the results to all interested parties.

It should be noted that in any real problem the analyst must stop at some point, exhausting the resources of either time or money in the study of the issue at hand. It is thus vital at the start of this process to include an interdisciplinary team to reduce the number of interactions that must be examined to a manageable number. As the methodology is used over time, more and more of the unknown interactions will become quantified, and through the use of modern digital computer techniques, automation will speed the process enormously.

To accomplish this process requires the ability to reference many types of data. Obviously, data on aircraft characteristics and operating scenarios are needed. Data on airport characteristics, air traffic control procedures, and individual community characteristics are also needed. The amount of data desirable is very large and beyond the ability to handle without resorting to automation. Some of these data already exist, while some are not available in any convenient accessible form. It will require a long time to acquire all of the data banks needed, but that task must be begun. In fact, at the present time there is no centrally located facility through which one can get a comprehensive bibliography of all of the relevant information on any of the aircraft/airport compatibility issues. One of the findings of this Working Group is that the interdisciplinary nature of the problem makes the data far flung and not easily identifiable nor locatable. A centralized library source must be found.

Recommendations

The Working Group made several recommendations to provide guidance for the TRB Committee on Aircraft/Airport Compatibility. Each of these recommendations fills a need in terms of the methodology adopted by the Working Group as a model for solving current and future compatibility problems. Where possible, the Working Group has suggested who the sponsor should be, the time period involved, and a priority ranking.

1. Establish Bibliography
   - Identify existing data sources, and
   - Develop and maintain a comprehensive bibliography on:
     - Aircraft characteristics
     - Airport standards
     - Trends
     - Research results
     - Regulations
     - Papers
     - Etc.

   Sponsor: Organization similar to the Air Transportation Research Information Service or by contract
   Time period: One year minimum, probably longer
   Priority: High

2. Generate Interactions List (or Matrix)
   - Establish interdisciplinary team to generate interactions and determine severity level of each.

   Sponsor: TRB Committee A3A16 Members
   Time period: Establish Group - January 1982
   Complete Task - January 1983
   Priority: Moderate

3. Additional Data
   - Identify need for additional data
   - Generate data as needed

   Sponsor: TRB Committee A3A16
   Identification: by contract
   Data collection: Industry/Government
   Time period: Complete identification - must be coordinated with #1.
   Priority: Moderate.

Group 2 - AIRCRAFT/AIRPORT COMPATIBILITY PROBLEMS AND SOLUTIONS: 1981-1990

Participants

Vincent Bonaventura, Chairman
Assistant Chief, Aviation Planning Division, Port Authority of New York and New Jersey

M. B. Clancy
General Manager, Airports Development, Aer Rianta, Dublin

Armen Der Hohannesian
Director of Aviation Planning
Hoyle, Tanner & Associates, Inc.

Larry Donoghue, President, Ralph Burke Associates
avid Hanchet, Transport Canada
,tuart Holder, Landrum and Brown
Roy McQueen, NATC-Yang & Assoc.
George T. Paris, Airport Engineer, Hayes, Seay, Mattern & Mattern
William E. Parsons, Chief Program Engineer, Airport/Aircraft Compatibility, Douglas Aircraft Co.
Peter Reaveley, Miami International Airport
David Stephens, NASA Langley Research Center
Ralph W. Stone, Department of Civil Engineering, University of Virginia

Introduction

The goal of the Working Group was to identify problems relating to aircraft and airport compatibility during the period from 1981 to 1990. Further, the group was to identify relevant issues and research and development programs essential for solving the problems identified.

Procedure

The members of the group separately identified potential problems of aircraft/airport compatibility for the time frame of concern. These were then shared within the group. Eliminating duplicates and combining related problems lead to the formation of a definitive list of 19 problems. This list was then prioritized by having each member select the five problems which in his opinion were of the highest priority, assigning 5 points to the first, 4 points to the second, etc. The scores of the twelve members were then combined, and the 19 problems were then ranked in accordance with the total score assigned by the group. Table 1 lists the problems in priority order with the combined scores included.

Time did not permit an in-depth examination of all of the 19 problems, and accordingly, the first six problems, representing about 73 percent of the total score, were discussed in more detail. This is not to imply that the remaining thirteen problems are not significant; indeed, they could be of serious concern to airports and airlines.

Results

The following is the consensus of the group concerning the first six problems listed in Table 1.

1. Problems associated with the introduction of new and recent aircraft into the airline system.

The issue is that the compatibility of aircraft and airports is not yet accurately and scientifically defined. When land becomes scarce, relatively simple solutions tend to disappear, and it becomes more critical to establish scientific approaches relating such things as wing span, fuselage length, tail height, aircraft operational characteristics, etc. with runway/taxiway clearances, runway/runway clearances, taxiway/taxiway clearances, etc.

Support is recommended for a research and development program to obtain the techniques, criteria, and data bases needed to relate aircraft physical and operating characteristics with airport airside geometrics. This is a large undertaking which will probably require the combined support both of industry and government.

The general discussion indicated that very few new airports will be developed and that expanding most existing airports will be very difficult if not impossible. Thus, the problem is most significant and of high priority.

Table 1. Problems in Aircraft and Airport Compatibility - 1981 to 1990.

Rank	Problem	Score
1.	Impact of recent and new aircraft	34
2.	Noise impact reduction	31
3.	Pavement design and maintenance	24
4.	Air carrier/commuter/general aviation integration	19
5.	Integration of CTOL/STOL/VTOL	12
6.	Systems approach to increase reliability of airport lighting and navigational aids	11
7.	Define compatibility	7
8.	Legal and regulatory environmental constraints	7
9.	Forecasting aviation demand under changing conditions	7
10.	International facilitation	6
11.	Problems of joint use airports	4
12.	Continuation of surge loading problem	4
13.	Ground access	4
14.	Passenger service improvement and reliability	3
15.	Greater efforts in F & E programs	3
16.	More carry-on baggage space	2
17.	Inadequate funding of STOL research in U.S.	1
18.	Unloading of cargo at passenger terminals	1
19.	Impact of multiple fuels	0

2. Problems associated with noise impact reduction.

It is recognized that significant reductions of noise impact by improvements in the aircraft, by changes in operational procedures, and by land use changes will become increasingly difficult in the future. Thus, the issue that evolved from an extensive discussion was that the problem was becoming less technical in nature and was becoming more and more a problem of public relations or community relations, where human factors and psychology become more dominant in achieving proper solutions.

The group could not reach agreement that improved measurement of noise impact was required. Some felt that existing procedures were adequate. However, the group was of the opinion that the problem remains a very important one and that more time than was available during this workshop was required to establish a proper research and development program. It is therefore recommended that a sub-committee of the TRB Aircraft/Airport Compatibility Committee be established to pursue this issue.

3. Problems associated with pavement design and maintenance.

The group recognized a need for pavements design with full consideration for life cycle costs and the impact on operations of shutdowns caused by pavement failures and rebuilding. Increased priority should be given to the funding of research and development to study:

a. The history of airport pavements from design to the present with details of their environmental and operational exposure, and the history of their condition and repair over their lifetime.
b. The use of overall weight of the aircraft as well as its gear and wheel loads in pavement design criteria, as some are now doing in Europe. Part of the concern is with the pavement subgrade.
c. The interaction of the pavement and the aircraft as a result of pavement roughness.
d. Roll over load stresses in comparison to static load stresses where pavement discontinuities exist.
e. Load transfer between pavement slabs.

4. Problems associated with the integration of air carrier/commuter/general aviation into an airport and its local airspace.

The group recognized a concern for the effects of mixing various aircraft types and services upon safety, airport systems capacity, passenger convenience, interlining, cost, terminal space, etc. A number of possibilities were discussed as appropriate for further consideration of this problem; among them are:

a. The construction of special facilities on air carrier airports for commuters and general aviation.
b. The promotion of intersection take-offs for small aircraft.
c. The construction of runway turn-offs suitable for small aircraft.
d. Where possible, commuters should be permitted to operate to and from main terminals; where not possible, convenient ground transportation should be provided to the main terminals.
e. The promotion of the preservation and improvement of small airports (relievers), both private and public, and the encouragement of their use by general aviation.

The group proposes studies to determine the location of commuter and general aviation facilities on air carrier airports so as not to impact seriously on air carrier operations, but at the same time to enhance passenger convenience. Studies are also proposed concerning the advantages of introducing by-pass taxiways for departing aircraft which are delayed by enroute or destination problems, and additional pavements for arriving aircraft which are delayed by the lack of available gates.

5. Problems associated with the integration of CTOL/STOL/VTOL aircraft into an airport and its local airspace.

A major concern was expressed for safety and efficiency in mixing these types of aircraft, and the following problem areas were considered as appropriate for further study:

a. The use of separate airspace to increase system capacity in recognition of the different aircraft characteristics.
b. An apparent lack of familiarity in handling STOL and VTOL aircraft and the need to train controllers to recognize and handle the differences.
c. The difficulty of building and maintaining heliports in major urban areas because of land use and associated high value of the land.

The FAA Helicopter Research Program Plan was an important effort toward resolving these problem areas.

6. Problems associated with the reliability of airport lighting and navigational aids.

A concern was expressed for the effects of the failure of visual and navigational aids at airports. Primary concern is with safety. In addition, such failures can not only shut down runways, and thereby affect the capacity of discrete airports, but they can thereby affect capacity of major portions of the entire aviation system as well. A number of thoughts were expressed relating to the possibility of increasing the reliability of such systems. These were the redundancy of components and systems; interleaving of circuits; back-up regulators; solid state equipment; stand-by equipment; and the development of navigational aids which are easier to site, resulting in minimum restricted areas, unaffected by large aircraft, and having minimized reflections from structures, etc.

It is proposed that a research and development program be funded to address this problem and its potential solutions.

General Observations

This group recommends that the TRB Aircraft/Airport Compatibility Committee closely follow the FAA research and development efforts in order to be prepared to comment on the program design and draft reports if requested to do so.

The importance of allocating a fair share of the research and development budget to airport related improvements is emphasized.

Indirect operating costs in airline operations are now about equal to direct operating costs. Thus, it is suggested that a study is needed to examine means for reducing and controlling the indirect operating costs.

Problems in Methodology (referred to Group 1)

1. The development of a universal runway friction measuring system that does not interfere with flight operations.
2. The development of a usable standard for evaluating helicopter noise.

Institutional Issues (referred to Group 5)

1. Streamline project procedural steps from concept to completion.
2. Concern over any possibility of the transfer of regulations and standards from the federal level to the separate states.
3. The implications of deregulation on U.S. relations with ICAO and foreign nations and operators, especially concern over the possibility of 50 Departments of Transportation having separate sets of regulations and standards.
4. Concern for consistent interpretation of regulations by and within federal agencies.
5. The lack of a single international forum for the exchange and sharing of R & D results.
6. Problems of joint use of airports by military and civilian occupants.

Group 3 - AIRCRAFT/AIRPORT COMPATIBILITY PROGRAMS AND SOLUTIONS: 1991-2000

Participants

George P. Bates, Jr., Chairman
Consultant
William Bigler
Department of Mechanical and Aerospace Engineering, University of Virginia
Eric de Boer
Airside Planning and Development, Schipol Airport Authority
Thomas Galloway
NASA/Ames Research Center
George C. Greene
NASA/Langley Research Center
Lawrence P. Greene
Aeronautics Consultant
Roy Lange
Lockheed-Georgia Co.
Domenic J. Maglieri
NASA/Langley Research Center
Jan Roskam
Department of Aeronautical Engineering, University of Kansas
Harold Smetana
Airport Plans Division, Federal Aviation Administration
Chess Webb
Aeronautical Development Planning, Transport Canada

Procedure

The initial step was to receive a short briefing from the FAA representative on the content of the federal scenarios for the 1990's. Next the group proceeded to discuss a series of topics relating to aircraft/airport compatibility problems in order to reach a consensus on the probable status of the issues in the time frame of interest. These topics either were introduced by the chairman or arose spontaneously from the group's discussion. Finally, summary statements were prepared for each of the discussion areas, reflecting the developments, needs, appropriate actions, etc.

In general, this report will follow the above format. After a brief summary of the federal position, the significant comments of the group members on the various issues will be included in a section entitled "Discussion". Finally, a "Conclusion" section will summarize the consensus on each topic.

Federal Position in the 1990's

If the current pending legislation regarding the Airport Development Air Program (ADAP) is passed and the program of "defederalization" becomes a reality, then the Federal government will probably not be a critical factor in the future. This is because the largest 40 to 70 airports would become independent, and federal funds going to the smaller airports would be made through block grants to the states. The independent airports would remain eligible for money for navaids development, but would have to obtain funds for general development and maintenance from user fees or taxes that might be approved.

Under the original ADAP concept and the program, some 50-60 percent of funding for all runways, navaids, and some terminal improvements has come from the program. During the past ten years ADAP money has provided 6600 grants to 1800 airports. Last year the ADAP grants totaled $450 million. If the program continues under the same concept, the annual funding in constant dollars would probably see little or no increase over time.

The current National Airport System Plan (NASP) shows 3600 airports with a development cost over ten years of $12.7 billion to $13 billion. As much as 15 - 20 percent of the money is to go to reconstruction of runways during the 1990's, with a large amount also going to lighting and pavements. These improvements will cause service disruptions and delays due to the shutting down of runways and airports.

Flow Control

Flow control is currently operating well with fine cooperation from the airlines. All schedules are on tape and are matched against the destination airport's acceptance rate. The primary goal of the original flow program was fuel savings, but with the inherent changes made in the ATC system in the aftermath of the PATCO strike, the system immediately hit saturation at a large number of points. Thus the flow program was implemented to control the demand on the ATC facilities. It is quite probable that even with an increase in controller personnel, aviation will grow to the point where saturation will again be inevitable. Since the flow control system seems to work, it will be a likely candidate for future implementation.

One problem recognized in this regard was the need for serious consideration of the extent to which general aviation would be allowed to participate in the system when it is under complete flow management. The matter is particularly important relative to corporate and business jets, the number of which is expanding rapidly as a result of shrinkage in the breadth of the air carrier system which seems to be the result of deregulation.

ATC Regulations and Procedures

The general consensus was that ATC procedures are the limiting factor in airport capacity. It appears as though little improvement has resulted from ten years of ATC studies. The operational concepts may need to be updated, rather than just regulations and procedures. Perhaps total automation of ATC, with some flexibility when needed, will be the answer. The current system certainly would have trouble in handling a large number of commuter and general aviation operations at a reliever airport close to a major air carrier airport. With regard to procedures, it was felt that some operational rules are archaic, and need to be reconsidered, e.g. fuel reserves, climb rates, and separations.

Approach Control

The key to this area was felt to be the Microwave Landing System (MLS). Although some participants felt that a large number (200) of MLS systems would be in operation by 1990, the consensus was somewhat more reserved than this. Although both ICAO and FAA have decided to go with MLS, budgetary constraints may retard its implementation. The importance of stressing an early implementation of MLS was agreed upon.

Airport Operational Problems

The future potential growth of air cargo may have an important impact on airport design. Air now carries less than one percent of the intercity cargo movement, but with the deterioration of major highways, this will undoubtedly be on the increase, and the growth rate may be relatively strong.

Another possibility is the development of very large cargo aircraft to serve a combined military and civil airlift capability, with aircraft operated by both sectors. These large aircraft would undoubtedly have higher tire pressures to accommodate the larger gross weights, but they would only be used at a limited number of airports - perhaps about ten. They may be used primarily at military air bases (including the civil operations) which will be especially adapted to handle large amounts of cargo.

It does not appear very feasible to anticipate the expansion of existing airports to optimize operations with large aircraft, In most cases additional land is simply not available, and most runways and taxiways are already at maximum density with regard to width and spacing. Nevertheless, it was anticipated that if larger aircraft offering good operating economy and market adaptability were designed, the airlines would buy them and bring pressure on the airports to accommodate them. Some innovations, such as foldable wings, might help the situation, but additional work to update airport design standards to allow large aircraft operation with increased safety was recommended.

No new airports were included in the NASP, but innovation and redesign will increase capacity at one or two major airports during the 1990's. Military airports may see more civilian use, and STOL runways will probably be used to complement the regular air carrier runways.

Noise

Noise will continue to be a problem around airports. Land use planning has been tried as a means for controlling noise problems. It has been useful through the involvement and education of more citizens and the reduction of court action. However, it has not been as effective as it might have been, due to the fact that governing bodies have reacted to pressure and allowed non-compatible development.

Among the suggestions discussed for improving the noise situation were:

- increased funding for the soundproofing of buildings as opposed to land acquisition,
- better interaction between designers, operators, and land use planners - perhaps stimulated by TRB; a recent meeting along these lines at NASA/Ames was quite successful.
- determination of what constitutes reasonable lower standards for noise levels,
- effect of MLS on the noise problem, and
- marketing and education programs.

Pavements

Methods need to be found to avoid the use of salt on pavement during the winter. Evidence of the deteriorating effect of salt, and of hard freezes is strong. For example, taxiway pavement lasts 30 years without salt and in climates where the temperatures are not below -10°C; where colder tempreatures are common the equivalent time might be five years, but with the use of salt, only one year.

Research is needed to increase surface lifetime and durability, and improve roughness and waviness characteristics. New materials such as composites and composite matrices should be given thorough consideration, as they are developing rapidly.

Aircraft Ground Movement and Control

Several topics fitting into this category were discussed by the group.

Ground Steering of Aircraft - ICAO has accepted the idea of cockpit-over-guidance-line steering, but the current FAA design guidelines still insist on cockpit-over-the-centerline steering. This requires larger turning radii, and wider taxiways and fillets. However, the former method might have some disadvantages at night. It was felt that the technology was available to utilize the advantages of the guidance-line method, but it may not be economical at this time.

Holding of Aircraft Awaiting Take-off - Arrangements definitely need to be made to assure that an aircraft can bypass the hold line and take-off if it is the first to receive clearance to its destination. It was felt that 4-D flow management would be a big help in this problem, and that implementation of MLS would allow holding closer to the runways, thus increasing the area available for holding and maneuvering aircraft.

Loading and Unloading - As airplanes become larger, it may become necessary to use more remote parking with transfer of passengers to the gate by a transporter. Unless handled properly, this may introduce delays which will lengthen the overall trip time for the passenger. Of particular importance in this regard are the baggage handling delays, which tend to be prodominate at the present.

Gate Standardization - One future prospect may be the restriction of gates to a single type of aircraft (i.e. different gates for each type). Such standardization would facilitate the aircraft handling, reduce the number of servicing points and the number of people and pieces of equipment needed at each gate. The net results would probably be a reduction in turn-around time, and the ability to design more gates into a given length of concourse. However, benefit-cost and trade-offs would probably be needed in order to determine the proper extent of the standardization.

Ground Control Procedures - These are currently poor, and little progress is in sight. The efficiency of movement of aircraft on the ground needs to be improved, and further work on this topic should be undertaken very soon.

Aircraft Flight Controls

As indicated previously, ATC currently limits what can be done at the airport. As things begin to improve, it will be necessary to provide better equipment in the aircraft, such as enhanced flight controls and on-board control displays. Probably integrated flight and propulsion controls will be required. In this way both the pilots and the ATC controllers will be managers of the system rather than just operators.

Aircraft Certification Procedures

By the 1990 time frame, many innovations will be introduced into aircraft design, both in the nature of new component technology and new materials, especially composites. There will also be a large number of new aircraft introduced to meet the needs of the smaller commuter or regional airlines, and to respond to a foreseeable increase in the use of business jets or other corporate aircraft in the system. In order to have these needs met in a timely fashion which will be of benefit to the entire industry, it will be necessary to devise new certification techniques to allow rapid introduction of new concepts and methods in the design and operation of aircraft.

Wake Vortices

At the present the wake vortex problem poses a serious limitation on capacity at many airports. The group did not feel very optimistic about the results to be expected from the present research program in this area, e.g. there really is no data base available, and the current detection and prediction systems seem less than reliable or are very uneconomical. The feeling was that vortex solutions probably lie in aircraft design, but this will not result in operational vehicles until the late 1990's.

Recommendations

As a result of the discussions summarized in the preceeding section, the group agreed upon recommendations for research and development activity or other actions currently needed in most of the areas. These are listed below in no particular order of priority.

Aviation System Concept
Develop system concept model to examine aircraft mix, routes, ATC concepts, navigation systems, airport activity (both volume and type).

ATC Procedures
Conduct major review of NAS and TERPS procedures to improve capacity by rapid use of new technology.

Develop aircraft flow management criteria for implementation of an automated system using 4-D navigation.

Approach Guidance
Speed up implementation of MLS technology at airports to allow an increase in capacity with improved safety and reduced noise.

Airport Design Standards
Update design standards or guidelines to improve airport safety while allowing operation of aircraft with increased gross weight, wing span, and fuselage size/length.

Noise
Develop new aircraft/airport noise standards for 1990 and the technology to achieve these standards, giving attention to areas such as:

- source reduction
- operational procedures
- land use planning
- approach fan noise
- aerodynamic noise
- auxiliary power unit noise.

Pavement
Develop technology to increase pavement lifetime, surface durability, and provide better surface roughness characteristics.

Develop new de-icing technology which avoids the great problems inherent in the current method of using salt.

Aircraft Control
Provide operational and certification criteria to use integrated flight and propulsion controls to allow 4-D flight path control.

Aircraft Certification
Improved techniques are required to permit rapid introduction of new concepts and methods in the design and operation of new and retrofitted aircraft of all sizes and types.

Airport Ground Guidance
An improved system for the guidance and control of aircraft on airport surfaces is required.

Airport Capacity - Wake Vortices
Develop technology to prevent/reduce the formation of wake vorticies.

Develop an operationally feasible system to locate the wake vortex pattern near airports.

Develop operational techniques to reduce effects of wake vorticies on aircraft.

Group 4 - AIRCRAFT/AIRPORT COMPATIBILITY PROBLEMS AND SOLUTIONS: 2001-2010.

Participants

Louis Williams, Chairman
NASA/Langley Research Center
Anees Adil
Program Manager, Airport Capacity/Delay, Federal Aviation Administration
Richard Adams
Systems Control Inc.
William Cox
Executive Vice President, Talbert, Cox & Associates
Cornelius Driver
NASA/Langley Research Center
Andrew Harris
Harris, Miller, Miller, Inc.
Ernest Millen
NASA/Langley Research Center
Floyd Newton
Douglas Aircraft Company
Curtis Swanson
Department of Civil Engineering, Western Michigan University
Charles Tackaberry
Chief, Airport Systems and Services, Transport Canada

Scenario for the Time Frame 2001-2010

It became apparent early in the discussion that the group needed to concern itself first with a future scenario and associated fundamental assumptions. The feeling was that this was a necessary step to take before any part of the group assignment could be successfully addressed. As it turned out, much time was spent on scoping this task. There was concern among some that it was necessary to look beyond current compatibility problems. The consensus was that a realistic future view must include solutions to today's problems.

However, structuring and setting a futures scenario would have to be made in light of some basic assumptions. It was agreed by all that days could be spent developing a variety of scenarios which might include the necessary numbers needed to identify detailed problems and solutions. Therefore, it was agreed that a more broad, simplistic approach was necessary. This approach would include the following assumptions.

First, that Group 2 and 3 (1981-1990, 1991-2000 time frames) will insure that the air transportation system survives the major transitory changes brought about by:

- Deregulation
- Economic fluctuations
- Defederalization
- ATC rebuilding
- Energy short-falls

Second, the future view must reflect an evolutionary process versus a revolutionary process. To clarify this point it was suggested that a revolutionary process be defined as being similar to that which occurred when the piston-props were phased out and the jet transports were phased in during the 1960's. It was generally agreed that an evolutionary process is much more likely to occur to the year 2010 than a revolutionary one.

Figure 1. Preferred air transportation system - Years 2001-2010.

PREFERRED AIR TRANSPORTATION SYSTEM

Years 2001 - 2010

Scenario		
·Socio-Econ.	Slow, but steady standard of living growth	Essentially unconstrained traffic growth
·Demand	Accept a 4-fold increase by 2010	
·Aircraft	Accept aircraft from small GA to largest transports	
·Airport	Pretty much in place, plus new relievers	
·ATC	More automated, flexible, safer	
·Environment	Noise - still a problem but better Emissions - under control	
·Energy	Avialable without any significant quantum jumps	

From these discussions the structure of the future scenario was developed. Seven characteristics were chosen to describe the 2001-2010 scenario. These are given along with their respective descriptors in Figure 1. It is interesting to note that the final group scenario reflected a "preferred" air transportation system by 2010 which in turn reflected a modest but steady growth in the standard of living and energy availability without any significant quantitative jumps. It was hard to determine if this reflected the group's optimism or pessimism about the future.

Institutional Issues

Since Groups 1 and 5 needed an early input, consideration of methodology and institutional issues were addressed next. Actually, the sequence of activity here became beneficial to the group because in the scenario dialogue process, a number of concerns were expressed by the participants which led to an interesting discussion about institutional issues. An underlying feeling within the group was that in order for the preferred scenario to become more probable, there is a need to remove a number of institutional constraints. One central need is that long-range planning must be conducted in an environment that is free from the 2-4 year political change in direction. Considerable concern was expressed at this point that without long-range planning and funding, the current defederalization of major airports, for instance, may have a negative impact on both compatibility problems and their solutions by 2010. There was general agreement that there will likely be a need to have some organization, perhaps quasi-public or a free enterprise corporation, with the responsibility, authority and funding for long-range air transportation planning, coordination and implementation. This would include funding for airports as well as airways facilities development. In addition, concern was expressed over union acceptance of high technology automation. This automation is very likely to be both in ATC and cockpit by 2001. Thus, the overall concern is that a number of public and private institutional issues must be addressed in the near future because these issues will impact our ability to cope with and solve many third decade compatibility problems.

Methodology

Methodology issues developed along three lines. First, there is a need for better analysis methodology. In addition, there is a need for a standard accounting system to measure the impact of aircraft design on airport costs and airport design on aircraft costs. Second, a concern was expressed about the continuation of airline data collection for compenhensive system tradeoff analysis after CAB sunset. There is evidence that good methodology is forthcoming but without a continuation of consistant information; obtaining the required input data may be extremely difficult -- particularly for long-range analysis. Third, there was a concern that airport/aircraft methodology, usage and interpretation required experienced personnel and expertise across broad disciplines. What are these required levels of sophistication and knowledge and what disciplines?

Discussion

Using the previous material as background, the challenge was to expand on some of the necessary conditions required at the aircraft/airport interface to meet the agreed upon scenario. A number of key relationships and associated impacts were identified. With four-fold increase in air service demand likely by 2010 and with the airport system being pretty much in place, it became apparent to the group that many more major airports will become congested, even given that there will be capacity "fixes" during the first and second decades. In addition to the projected larger aircraft in the system by that time, the growth in commuter traffic, RTOL, VTOL and general aviation aircraft will require a significantly better airways and airport system by 2010. Thus, the group identified, after some lengthy but informative discussion, four necessary conditions for the 2001-2010 time frame. First, maximum utilization of the airspace is essential. If the traffic flow system between the airports cannot handle the expected volume then the congestion problem at the airports is not likely to happen. Neither will supply meet demand at a desired point. Second, maximum utilizaiton of existing airports is essential. Airport capacity must be balanced with the more automated, flexible airways system of the future. Third, there must be an increase in the development and utilization of additional airports, particularly reliever airports. And fourth, ground side passenger handling and access systems must be of significantly greater capacity: particularly surface transportation.

Since the group was primarily interested in the airport/aircraft interface, much discussion was centered around identifying some key elements necessary to achieve maximum utilization of existing airports. Through these discussions seven elements were identified:

- Minimum separation of arrivals
- Optimum runway and taxiway configuration

- Maximum gate utilization
- Coordinated servicing of aircraft
- Streamlined passenger/baggage handling
- Standardized and updated airport emergency procedure, standards and equipment
- Environmental compatibility solutions

These have been summarized in Figures 2 through 5 and are stated as objectives with their associated research and development activities.

Figure 2. Minimum separation of arrivals and departures.

MINIMUM SEPARATION OF ARRIVALS AND DEPARTURES

OBJECTIVE	R & D
-Wake Vortex Solutions	-Alleviation - Aircraft Design Methods (NASA/FAA/Industry) -Avoidance - Operational Solutions (FAA/NASA/Industry) -Sensors -Flight path profiles & tracks -Ground Alleviation methods
-Improved Cockpit Displays	-CDTI, DABS, TCAS, Printout in the cockpit Human Factors, Communication (FAA/NASA/Industry)
-Accurate, Timely Weather Information	-Enroute & terminal area, along flight paths, in aircraft and on the ground
-Improved Navigations & Guidance	-MLS, IFR procedures for various A/C types and technology levels

Figure 3. Optimized runway and taxiway configuration.

OPTIMIZED RUNWAY AND TAXIWAY CONFIGURATIONS

OBJECTIVE	R & D
-Improved runway and taxiway layouts	-Traffic simulation of alternative HUB airport configurations
-Separate runways for GA and Commuters	-Configuration studies, procedure development, simulations, cost/benefit studies

STANDARDIZED AIRPORT EMERGENCY PROCEDURES, STANDARDS, AND EQUIPMENT

-Develop crash fire & rescue procedures, standards, and equipment for projected requirements.	-Studies of equipment requirements for various A/C accident situations. Size of operation.

Figure 4. Maximum gate utilization.

MAXIMUM GATE UTILIZATION

OBJECTIVES	R & D
-Sharing of airline gates	-Feasibility studies of alternative passenger loading and unloading systems
-Use of transportation vehicles from a/c to terminal	-Studies of multi-layer terminal operations. Arrivals on one level departures on the other

COORDINATED SERVICING OF AIRCRAFT

-Centralization of a/c servicing equipment and personnel	-Standardization studies of a/c servicing requirements

STREAMLINED PASSENGER HANDLING

-Consistent passenger check-in procedures	-Standardization studies of passenger check-in requirements
-Off-site check-in	-Automation methods

Figure 5. Environmental compatibility solutions.

ENVIRONMENTAL COMPATIBILITY SOLUTIONS

OBJECTIVE	R & D
-Land use planning	-Investigate conversion methods and insulated structures
-Retirement of old, noisy 727's, DC 9's, 737's	-Develop alternative incentives, noise tax in landing fees, etc.
-Quieter operational procedures	-Develop technizues to encourage the use of decel approaches and high glide scopes

General Comments

It can be seen that a number of pressing research and development activities were identified by the group. Many of these recommendations require the cooperative efforts of many organizations, associations and agencies, as well as industry participation. This being the case, the group recommended that TRB Committee A3A16 take the initiative to transmit these research recommendations and others developed at the workshop to the various organizations that are active in this field.

As an example it was suggested that it would be essential to have in place by the year 2000 the necessary standards, operating procedures and facilities to accommodate aircraft at present and projected congested hub airports at a level to meet demand. Specifically, the following items should receive high priority:

Independent IFR landing systems and procedures to:
- a. Reduce centerline parallel runways (4300')
- b. Separate short runways for GA/Commuters
- c. Converging runways
- d. Triple runways
- e. Closely spaced parallels (to 1000')
- f. Other strategies including staggered thresholds and variable glide slopes to 6°.

Also enroute and terminal area automation should be pursued as quickly as possible so that significant aircraft and airspace system productivity gains can be realized by the third decade, if not sooner. And finally, an overall system such as an Integrated Flow Management System should be implemented as quickly as is feasible at the national, enroute and terminal levels.

The workshop group concluded its deliberation with the overwhelming concern that much work is required to meet the challenges of the 2000's. Much will depend on what we do in the last two decades of the 1900's. The key will be careful, but innovative planning, reduction of instutional constraints, rapid integration of high technology and a "can do" attitude on the part of everyone in the air transportation business.

Group 5 - INSTITUTIONAL ISSUES IMPACTING AIRCRAFT/ AIRPORT COMPATIBILITY

Participants

David J. Sheftel, Chairman
Technology Development Associates
Philip H. Agee, Manager, Airport Planning, Air Transport Association of America
G. A. Champniss
British Airports Authority
Ken Eldred
Ken Eldred Engineering
Raymond Fowler
Pavements Division, FAA
A. Robert Kuhlthau
Department of Civil Engineering, University of Virginia
William Leder
Dallas/Ft. Worth Airport
John Molloy
NASA/Langley Research Center
Leonard E. Mudd, Acting Deputy Director, Office of Airport Standards, FAA
John Reynolds, FAA
Norman D. Witteveen, Greiner Engineering Sciences, Inc.

Procedures

The group adopted the following procedure for addressing its assignment within the short time allotted. First, an hour or so was spent in a synthesis mode, with the group essentially "brainstorming" to identify all the factors which might be anticipated to impact the problems of aircraft/ airport compatibility. At this stage no effort was made to reject any suggestions, nor was there any attempt to justify the topic as an institutional issue. The main objective was to get as many thoughts as possible before the group.

The second stage was that of review. The brainstorming list was reconsidered carefully, and decisions were made about the appropriateness of keeping the thought, combining it with another, expanding it, or dividing it into two or more components. Also, at this point inputs from the other groups were incorporated into the lists and subjected to the same examination.

Stage three was a classification phase. The items which survived the review of stage two were subjected to further scrutiny from the viewpoint of grouping them under collective headings which represent major institutional issues of concern to aircraft/airport compatibility. At this point, although the final output of the group was beginning to take shape, it was still organized in outline form.

Next, each major topic from step three was discussed more thoroughly by the group. In some instances it was felt that the outline form was sufficient to define the problem. For other areas it was judged that further elaboration or comment might be helpful to others when considering the conclusions and the recommendations of the group. In these latter instances, small subcommittees were formed to prepare a brief position statement for each such issue.

Finally, the group addressed the task of distilling its work into a series of recommendations for study, research and development or other actions.

The remaining sections of this report are concerned with the final three stages of this procedure. The third section contains the classified outline of institutional problem areas. The fourth section presents the brief position statements to clarify some of the problem areas, and the final recommendations of the group are listed in the last section.

Problem Area Outline

Under each problem area, various descriptors or phrases are used to identify specific component problems. Neither the areas nor the components are listed in any order of importance.

Lack of Funds for Airport Research
- ways to reduce pavement costs
- lighting
- runway/taxiway layout
- minimize downtime
- improved operations at reduced visibility

Noise
- future regulatory levels
- the effect of noise in limiting capacity
- credibility
- descriptors
- curfews versus soundproofing
- land use
- special procedures
- preferential runways
- mechanisms for community relations

Economic-Financial Aspects of Airport Operation
- airport finances
- defederalization
- taxation (trust fund, head tax, etc.)
- economic impact of airport on community
- tax exemption
- deregulation

Operator Costs
- effect of noise abatement procedures
- fuel conservation
- landing fees
- terminal facilities
- curfews
- peak hour spreading
- slots and allocations
- common gate usage
- user charges
- compatibility at secondary or air carrier reliever airports

Jurisdictional
- land use
- legislative/regulatory
- block grants versus categorical grants
- standards and enforcement
- safeguarding against obstructions
- new sites and expansion
- ground access
- bilateral negotiations
- customs control
- secondary airports
- long term policy planning

Discussion of Selected Topics

a. Airport Related Research Requirements.

Since the airport is a critical element of the air transportation system, it is essential that it perform at its optimal level with minimum service disruptions. Therefore, to assure maximum utilization of airport facilities at minimal costs, and to insure the highest degree of safety, reliability, capacity and performance, incorporating the latest state of the art, the following airport related research is required.

(1) Airport Pavements
   (a) Investigate longevity of various pavement systems under high usage conditions by live load testing and analysis.
   (b) Develop low cost pavement design by:
      - utilizing recycled materials.
      - substituting new materials that are available either nationally or locally
   (c) Continue the development of evaluation and design methodologies for the non-destructive testing of pavement.
   (d) Validation of surface friction and hydroplaning techniques by test track procedures.

(2) Improved Design of Airport Geometric Configuration

   To be accomplished by use of simulators and analytical techniques.
   (a) Location and geometry of high-speed runway exits.
   (b) Minimize centerline separation distances of runway-to-taxiway and taxiway-to-taxiway, and their relationships to aprons and structures.

(3) Improved Design of Visual Landing and Airfield Surface Guidance Systems
   (a) Enhance the conspicuousness of visual approach lighting systems
   (b) Enhance ground guidance by improved pavement lighting and signing which will provide maximum clarity and directional information.

Because these research topics are applicable to all airports, and the results should be uniform and consistent with international systems and coordinated with the military, they are of national interest and, therefore, should be financed through the user trust fund.

b. Economic and Financial Issues.

A timely and thorough analysis of various economic and financial issues could influence their resolution with a resulting salutory effect on the airport system. As one example, consider the topic of airport economic impact.

What is needed is to develop a good methodology and procedure to identify and quantify both direct and indirect economic benefits that the airport generates for the community. The problem needs to be properly defined and sources of funding explored for an academic research program to achieve the following:

(1) Search, identify, and review existing reports and methodologies relevant to this subject.
(2) Based on this effort, develop a methodology and procedure which has the most persuasive impact to communicate the economic benefits of the airport to local citizenery.
(3) Perform an actual case study to demonstrate its effectiveness.

c. Noise.

(1) The noise from aircraft/airport operations is the single most important impediment to the continued operation and future expansion of the national civil aviation system.
(2) The only long-term solution to the problem is the availability of quieter aircraft and the achievement of compatible land use control around the airports. Research and development is essential to assure the production of quieter aircraft that will meet certification standards that are more stringent than those presently in force. Likewise, means must be found to establish and maintain compatible land use around airports.
(3) In the short term it is necessary to use all known procedures and techniques to minimize noise impact. Failure to do so will inevitably result in ever increasing local restrictions on aircraft and airport operations. Such restrictions reduce the efficiency of the national air transportation system, its financial viability, and its ability to serve the public and the business community.
(4) A process must be established to define the combination of procedures, techniques, and controls most appropriate to minimizing the noise impact around specific airports while maintaining the desired level of

service. The process must assure participation by all directly affected interests and provide for the agreements necessary to assure the implementation of the package selected. Procedures, techniques and controls which might be used include

- flight path optimization,
- preferential runway utilization,
- take-off and approach profile management,
- control of noise from ground operations,
- airport use regulations, such as noise limits and numerical restrictions which may vary with time of day,
- control of land use,
- soundproofing,
- transfer of some traffic to secondary airports.

(5) Establishment of compatible land use today and assurance of future land use compatibility is an essential element in the overall acceptability of continued airport operations at many locations. In most circumstances land use control is out of the hands of the airport operator, and in all circumstances it is out of the federal jurisdiction. Because at many large airports adjacent communities have already developed with existing non-compatible uses, innovative and feasible alternatives need to be developed to change these existing land uses from non-compatible to compatible. This should include the financing of acquisition programs with concurrent re-development for compatible uses. Also, methods to encourage the preservation of existing compatible land uses should be investigated.

(6) A strong research program is needed with the goal of producing in the future an aircraft that is perceived as quieter, and is operationally more efficient. The program should include:

(a) Research to define the certification noise goals required to establish varying degrees of compatibility between the noise from aircraft/airport operations and adjacent communities. The planning horizon for these goals should be the year 2000 and beyond. The research should also include assembly of data that would enable a more precise description of the noise from aircraft operation with respect to its effects on airport neighbors, including the effects of the time of day, seasonality, frequency weighting, duration, background noise from other sources, and other factors.

(b) Research to define the interrelationships among low speed aerodynamic performance of aircraft, engine performance, and noise control technology with respect to developing methodology for optimizing the design of aircraft. Additional consideration should be given to

- methods to increase low speed L/D,
- effects of increasing maximum lift potential,
- effects of take-off thrust/weight and engine cycle,
- methods to increase noise reduction at thrust reduction,
- development of higher by-pass ratio engines,
- approved acoustic treatment concepts and materials,
- number and positions of engines,
- performance under crosswinds and tailwinds,
- ATC procedures that restrict achievement of optimum climb performance,
- minimum altitudes for safe execution of maneuvers for noise abatement.

(7) National conferences and other mechanisms are needed to assist in the development of national consensus relative to the long range research, development and implementation plans for achieving compatibility between airports and their neighbors.

Recommendations

This section summarizes the recommendations of the group for future action. Eight of the recommendations refer to actions that could be taken by the TRB Committee A3A16, and two are for more general research and development programs.

TRB Committee Activities

a. Underfunded R & D for Airports - the Committee should keep abreast of current airport research and development plans, particularly in the areas of pavement, layout, and lighting, so as to be in a position to make comments, if requested.

b. Airport Noise - the Committee should keep abreast of current airport noise research and development plans so as to be able to offer comments, if requested. The review should include aircraft design and both operational procedures in the air and on the ground.

c. Dissemination of Airport Noise Information - the Committee might consider sponsoring a forum for information transfer on all aspects of noise reduction.

d. Long Term Planning - policy planning at the federal level should be more comprehensive in relation to future trends in traffic, aircraft and airport design and operation. The Committee should identify the major issues bearing on long term policy planning and give them widespread distribution.

e. Land Use Practices Around Airports - the Committee might stimulate the formation of broad and innovative ideas concerning land use policy around airports.

f. Airport Surface Access Planning - there seems to be poor planning as far as relating airport access with passenger load is concerned. TRB Committees should study the issues involved, particularly those concerning local coordination and consideration of alternative modes and community impact.

g. Block Grant Policy - there are many unknowns and uncertainities regarding block grants policy and administration. Before these become a reality these issues should be resolved. The Committee should become familiar with the problems involved in order that it might be able to comment on them if requested to do so.

h. Poor Public Relations at the Local Level - when issues arise at the local level concerning the expansion or construction of a new airport, the ability to handle these issues at the local level varies widely. It would be very beneficial if the Committee would document case studies of airport experiences in handling land acquisitions, zoning, building code issues, etc., and then translate the results into guidance for future actions.

Research Recommendations

1. Study alternative means to reduce institutional constraints on airport expansion such as tax incentives, FHA interest rates, building codes, etc.

2. Develop quantification of both direct and indirect economic and social benefits which accrue to a community from the presence of a modern and efficient airport.

WORKSHOP PARTICIPANTS

Aaronson, Robert, The Port Authority of New York and New Jersey
Adams, Richard J., Systems Control Inc.
Adil, Anees, Federal Aviation Administration
Agee, Philip H., Air Transport Association of America
Bates, George P., Jr., Falls Church, Virginia
Bigler, William, University of Virginia
deBoer, Eric, Schipol Airport Authority, Netherlands
Bonaventura, Vincent E., Port Authority of New York and New Jersey
Branstetter, James, National Aeronautics and Space Administration
Bushee, James W., Federal Aviation Administration
Champniss, G.A., British Airports Authority, England
Clancy, M.B., Aer Rianta, Dublin Airport, Ireland
Conner, D. William, Yorktown, Virginia
Cox, William E., Talbert, Cox & Associates, Inc.
Donoghue, J. Larry, Ralph Burke Associates
Driver, Cornelius, National Aeronautics and Space Administration
Eldred, Kenneth McK., Ken Eldred Engineering
Ericksen, Walter P., Lockheed-California Company
Fowler, Raymond, Federal Aviation Administration
Galloway, Thomas, National Aeronautics and Space Administration
Gehman, William E., Michigan Aeronautics Commission
Greene, George C., National Aeronautics and Space Administration
Greene, Lawrence P., Manchester Center, Vermont
Guth, Herbert J., Transportation Research Board
Hanchet, David, Transport Canada
Harris, Andrew S., Harris, Miller & Miller, Inc.
DerHohannesian, Armen, Hoyle, Tanner & Associates,Inc.
Holder, Stuart, Landrum and Brown
Horne, Walter B., Williamsburg, Virginia
Hubbard, Harvey, National Aeronautics and Space Administration
Jacobson, Ira D., University of Virginia
Kuhlthau, A. Robert, University of Virginia
Lange, Roy, Lockheed-Georgia Company
LeCroy, Roy C., Lockheed-Georgia Company
Leder, William, Dallas/Fort Worth Airport
Maglieri, Domenic J., National Aeronatuics and Space Administration
McQueen, Roy, NATC-Yang and Associates
Millen, Ernest, National Aeronautics and Space Administration
Molloy, John, National Aeronautics and Space Administration
Mudd, Leoanrd E., Federal Aviation Administration
Newton, Floyd, Douglas Aircraft Company
Paris, George T., Hayes, Seay, Mattern & Mattern
Larsons, William E., Douglas Aircraft Company
Perkins, Porter, National Aeronautics and Space Administration
Reaveley, Peter, Miami International Airport
Reynolds, John W., Federal Aviation Administration
Roskam, Jan, University of Kansas
Shea, William F., Federal Aviation Administration
Sheftel, David J., Technology Development Associates
Sinha, Agam N., Mitre Corporation
Smetana, Harold, Federal Aviation Administration
Stephens, David G., National Aeronautics and Space Administration
Stickel, Joseph W., National Aeronautics and Space Administration
Stone, Ralph, University of Virginia
Swanson, Curtis, Western Michigan University
Tackaberry, Charles C., Transport Canada
Webb, Chess, Transport Canada
Williams, Louis, National Aeronautics and Space Administration
Witteveen, Norman, Greiner Engineering Sciences,Inc.

SPONSORSHIP OF THIS CIRCULAR

GROUP 3--OPERATION AND MAINTENANCE OF TRANSPORTATION FACILITIES
Patricia F. Waller, Highway Safety Research Center, University of North Carolina, Chairman

Committee on Aircraft/Airport Compatibility
D. William Conner, Yorktown, Virginia, Chairman
Walter P. Ericksen, Secretary
Richard J. Adams, Philip H. Agee, Donald M. Arntzen, George P. Bates, Jr., Ronald F. Birk, Vincent E. Bonaventura, Robert L. Bowles, C. W. Carpenter, Jack E. Clark, Jack D. Downey, Leo F. Duggan, Willard M. Fletcher, William E. Gehman, Aaron J. Gellman, A. Robert Kuhlthau, Lawrence Langweil, Francis X. McKelvey, Leonard E. Mudd., J.J. Ruddy, Jr., R. John Sanders, Paul M. Schonfeld, David J. Sheftel, George P. Vittas, Norman D. Witteveen

Herbert J. Guth, Transportation Research Board, Staff Representative