Operational Constraints for STOL Aircraft

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The Short Takeoff and Landing (STOL) transportation system has been proposed as a solution to short-haul transportation congestion, because it 1) operates independently of the existing Conventional Takeoff and Landing (CTOL) system; 2) offers more convenience to short haul travelers; and 3) relieves congestion at major airports. However, the STOL transportation system encounters operational constraints which differ from current CTOL aircraft. These constraints are: economics, short-haul market characteristics, operating environment, and community acceptance. This paper discusses how these constraints influence the STOL aircraft's size, speed, propulsion system, takeoff/landing performance, and maneuverability.

Introduction

THE prospect for introduction of STOL service during the 70's depends on the availability of convenient sites, an acceptable STOL aircraft, and operations independent of CTOL aircraft and airports. Obviously, the most convenient sites would be the traveler's origin or destination. The service to the top of the Pan-Am building typified this type of operation on a miniature scale. The extension of this type of service to millions of annual passengers requires a much larger facility than the typical rooftop can accommodate.

The term STOL has been applied to many vehicles with takeoff/landing performance varying widely among them. Usually, vehicle descriptions are accompanied by curves to illustrate significantly lower seat-mile costs with just a few hundred more feet of runway. Extension of this logic, of course, will produce a vehicle with operating characteristics quite similar to today's short-haul jets, in the process ignoring the basic deficiency in short-haul air transportation today; long runways are usually a long way from town. The alternative is a vehicle with surface and near-surface operating characteristics compatible with land availability in densely populated areas, a true STOL.

The STOL concept has evolved during the 60's in an era of explosive growth of the entire economy. Urban sprawl has consumed vast tracts of land adjacent to core cities for low density residential use which might have been available for close-in airports. The existing airports in most cities are now surrounded by development and are constrained from growing physically as they approach or exceed their practical annual capacity (PANCAP) during the 70's. Efforts to increase PANCAP center around parallel IFR runways to increase aircraft acceptance rates, together with increased capacity per unit as found in the wide-bodied jets. These prospective increases may be deterred by lack of space for gates, surface access to the airport, and increased noise opposition caused by increased flight frequency. As airport planners look for new sites, the realities of land-use planning and jumbo-jet runway needs require space of 15 to 25 square miles which, at residential densities, consume living space for 100,000 to 200,000 people.

It is, therefore, clear why new airport sites are usually proposed in remote, relatively distant areas which unfortunately add more time to the trip and produce even less appeal to the short-haul traveler. While the long-haul traveler may not like this development, he has no practical alternative. The short-haul traveler, however, can select surface modes as alternatives to air transportation. This practical selection between modes, based on time, separates short-haul air travelers from air travelers in general. Thus, the term short applies again to STOL in the context of passenger trip length. This preamble to the STOL concept sets the stage for identifying the constraints imposed on the STOL aircraft. These real-world constraints are necessary to answer the question confronting the planners for STOL, "How long is short?"

Evaluation Criteria

Figure 1 represents the evaluation process to which a candidate aircraft design is subjected. It is represented as a wheel-like machine which produces an acceptable aircraft. The four problem components shown on the wheel rim are filters through which this aircraft design must pass or be rejected. In reality, the filtering process is highly iterative within the wheel, and each component requires recognition of the other or an infinite number of designs will require evaluation. In short, the process of selecting trial aircraft requires the expertise of engineering, marketing, management, and operations personnel to reduce the problem to a scale suitable for mathematical analysis with models and methods that can be understood by decision makers. In addition, input data must be used that are credible and obtained from reliable sources.

The experience gained by McDonnell Douglas (MDC) in STOL system development has ranged across the entire spectrum of the system. MDC has been involved in the analysis and flight testing of parts of a system that are not traditionally identified with an airframe manufacturer. However, it became apparent early in the STOL effort that this new concept required understanding of the total system to define a suitable aircraft, and unfamiliar territory would have to be explored. This was accomplished by close coordination with airlines, federal and local officials, and community groups with responsibility for, or involvement with, air transportation.

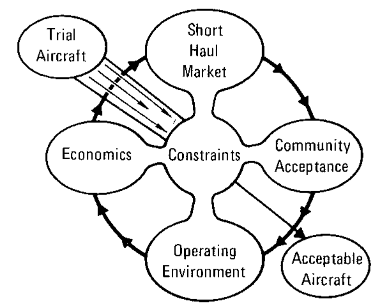

Fig. 1 Aircraft evaluation process.

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Fig. 2 Existing short-haul passenger market.

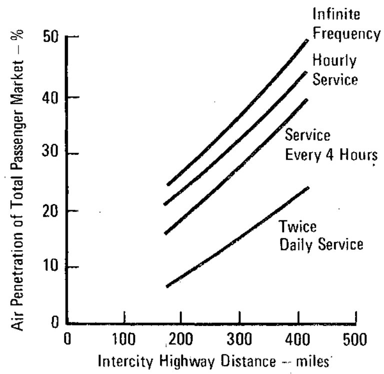


Fig. 4 Effect of frequency on market penetration.

Short-Haul Market

The initial constraint facing the STOL aircraft is the short-haul market. The short-haul market is usually described as trip distance of 500 miles or less with particular interest in the 200 mile distance which characterizes the two giant, city-pairs, New York-Boston, and New York-Washington D.C. In addition, the high density, short-haul routes are not particularly dependent on connections to long-haul routes and can therefore be treated as a transportation system in their own right. Figure 2 shows a map of the U.S. with all routes of 250 miles or less with 50,000 origination and destination (O&D) passengers per year in 1968. This map shows a distinct radial pattern about major hubs, making the term hub very appropriate. The routes shown in the California Corridor do not include intrastate traffic which would add lines to the map if included. The point is, there are highly developed short-haul markets where the established demand provides a solid base for air travel. However, some of these markets have shown decaying growth rates as improved freeways develop and/or air traffic congestion increases. Thus, the short-haul traveler appears to be evaluating the surface/air travel alternatives and opting increasingly for surface modes. The causes and effects have been mentioned. The question is should the aviation community forfeit the short-haul passenger to the surface modes or should it seek solutions to the problems? The STOL concept developed from cause and effect analyses centering on value-of-time/total trip cost concepts. The establishment of convenient terminals for the passenger at both ends of his trip is an important part of this concept.

The phrase "city-center to city-center," because of oversimplification, has been misunderstood. It actually means, "connect two points which produce enough traffic to make it worthwhile" and while this statement seems trite, its significance cannot be ignored. There are airports in the U.S. that are conveniently located and STOL aircraft can certainly use them. The STOL aircraft's contribution at these airports will be congestion relief and reduction of Air Traffic Control delays. In many cities, suburban airports are convenient as an origin but inconvenient as a destination, making both suburban and downtown airports desirable to the passengers. By designating each city as at least two points rather than one the result is route proliferation. To illustrate, assume that three cities are connected to each other with a nonstop routing. Obviously, only three nonstop routes are possible (Fig. 3, solid lines). If a downtown airport is added at each city, 12 possible routes result, omitting connections between airports in the same city. In general, adding an airport at each city produces four times as many potential inter-city routes. Ignoring for the moment the time of day variation of passenger flow along the various segments, if the same flight frequency is maintained on all four segments, an aircraft one-fourth as large is indicated. The actual ratio must be larger because: 1) the flow along the suburb to downtown link is predominantly toward the downtown in the morning and predominantly toward the suburbs in the evening; 2) the markets are growing as a function of time; and 3) the service frequency and passenger travel along the major airport to major airport segment are to a degree independent of the city-pair because of the interconnections required with the total airline system. In general, multiple delivery points will require smaller aircraft. At least for the present, then, short-haul aircraft should reverse the trend of ever increasing size in new aircraft.

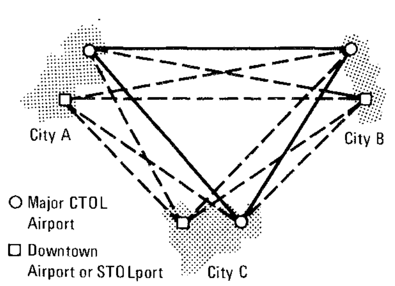


Fig. 3 Route proliferation in a three city system.

Frequency of Service

The issue of frequency of service is central to any discussion of the short-haul market. Frequency of service and its relationship to air traffic stimulation has been, and remains, a controversial topic. It is generally agreed that it does influence traffic and short-haul traffic in particular. In order to study this problem, MDC developed a patronage model for use in estimating modal splits between surface and air transportation. This model, as well as many others, is based on the value-of-time concept which attaches a cost to each time component of a total trip (portal-to-portal). It also includes cost penalties for intangibles such as: inconvenience of no auto; mode change; on-time dependability; and similar hard-to-quantify items. Since time is money in this model, frequency-of-service is expressed as an expected waiting time (cost). Figure 4 shows an example of this type of analysis for selected city-pairs in the Great Lakes Region. The two key assumptions here are that the traveler values his time at $6 per hour and that he has access to any existing commercial airport and a downtown STOLport in each city. Some significant results from this analysis provide the first quantitative demonstration of intuitively expected trends. First, aircraft market penetration increases with distance and at 350 miles it is about twice as high as at 175 miles. This is entirely caused by automobile competition at short distances which begins to fade rapidly with distance. At 400 miles,

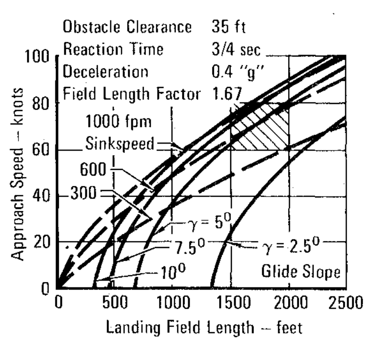


Fig. 5 Landing field length.

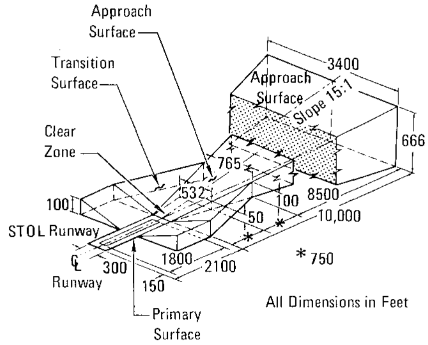


Fig. 6 STOLport protection surfaces.

twice-daily service provides the same market penetration as nominal hourly service does at 175 miles. Thus, the primary implication for short-haul aircraft design resulting from consideration of frequency effects is that an aircraft which is twice as large flying half as often will not attract the same total market as a smaller aircraft flying twice as often. Direct operating cost comparisons based on a constant load factor are not valid. For long-haul aircraft, where the traveler does not have a choice, frequency of service becomes much less important.

Thus, the consideration of the short-haul market has produced the dual constraints of frequency of service and aircraft size resulting from the demand of the short-haul traveler for more convenient service. These factors must be considered if the short-haul air system is to compete effectively with the surface mode alternatives.

Operating Environment

The constraints imposed on STOL aircraft by the operating environment are, to a large degree, influenced by the requirements for community acceptance as discussed in the next section. This section will cover the areas of airspace requirements, air traffic control, and ground facilities.

Airspace Requirements

The need for STOL aircraft to operate into densely populated areas with many high-rise features produces a requirement for steep approach and departure gradients. Figure 5 illustrates the relationship of approach speed to landing field length for various approach slopes. The lines of sink speed are particularly important since the opinions of various professional pilots for MDC, Eastern Airlines, American Airlines, NASA, and FAA concur in advocating sink speed limits in the 800 fpm to 1000 fpm range in IFR operations. This opinion is shared by FAA and U.S. Army personnel in testing of rotary-wing aircraft. If passenger deceleration effects are considered, the field length falls out in the 1500 to 1800 ft range. It should be emphasized that this finding applies to STOL and VTOL vehicles alike because the calculations for this chart are simple geometric and kinematic relationships.

The FAA draft advisory circular on STOLport criteria has considered these pilot opinions on sink speed as well as statistical correlation of flight test data for various STOL aircraft operations at the FAA NAFEC test facility. Photo-theodolites were used for accurately recording aircraft trajectories relative to an ILS flight path. Figure 6 shows the spatial relationships of the proposed criteria. Of particular interest is the approach clearance plane of 15:1. For CTOL aircraft this clearance plane is 50:1 and for VTOL (helicopter) VFR operations it is 8:1. These slopes are not randomly produced but are directly related to the nominal glide path of approaching aircraft. In general, the approach clearance plane slope must be approximately half the aircraft approach slope. This relationship is obtained from statistical analysis of vertical dispersion about the nominal flight path induced by instrument error, wind effects, and simple human error. The STOL aircraft minimum practical operating area is thus defined by the realities of IFR operations and the physical laws of kinematics.

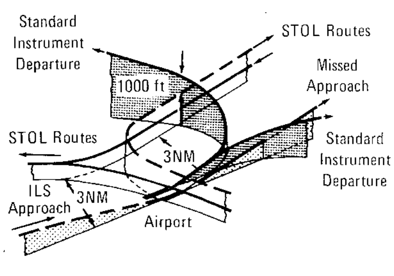
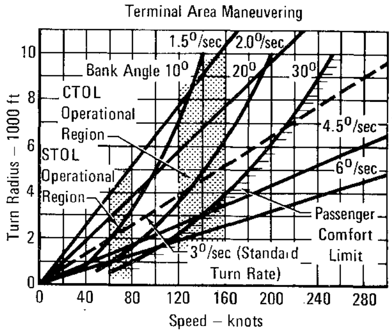


Fig. 7 CTOL-STOL traffic separation.

Fig. 8 Terminal area maneuvering.



Air Traffic Control

The air traffic control problem looms large in any STOLport siting exercise. This topic is very complex and has been subjected to considerable study by MDC analysts using the avionics data collected from the joint American Airlines/MDC STOL evaluation program. These data provide proof of the acceptable accuracy of several area navigation systems relative to the criteria specified in the FAA Advisory Circular 90-45. The area navigation system plus the slow speed maneuvering capability of the STOL aircraft permitted penetration of so-called congested airspace by flying "inside and beneath" the crowded airspace without violating vertical and lateral separation criteria established by FAA. Figure 7 schematically illustrates this point with the key assumptions being 1000 ft vertical separation and 3 miles lateral separation for co-altitude routes. Through the use of 2500 ft separation for parallel runways, 20° to 30° offset approaches, 2.5° CTOL glide slopes compared with 7.5° STOL glide slopes, and staggered runway thresholds, IFR STOL strips can be placed at most major airports with the possible exception of La Guardia, Washington National, and Lindbergh Field (San Diego). STOL strips for VFR operations at these airports are feasible under current rules and, in fact, La Guardia already has one. Figure 8 compares typical STOL and CTOL maneuvering capabilities. Note that STOL turn radii are from one-fourth to one-half of those of CTOL for reasonable bank angles and turn rates. In some cities, near city-center airports exist which could be used for STOL aircraft operations. Examples

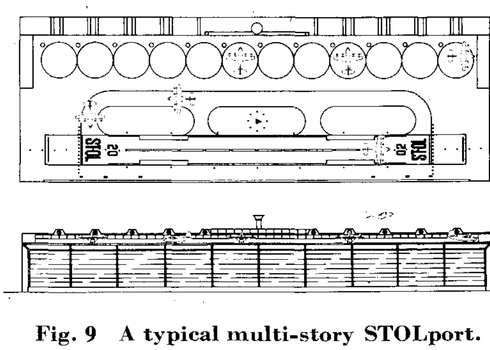


Fig. 9 A typical multi-story STOLport.

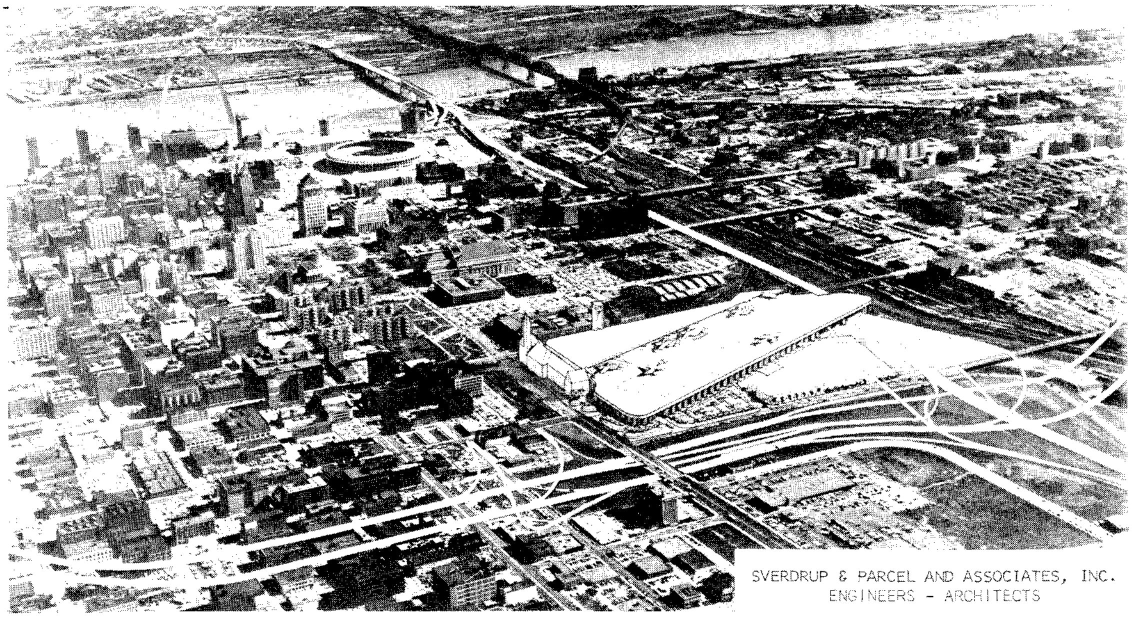


Fig. 10 Proposed St. Louis Union Station STOLport.

of these are Meigs Field (Chicago), Detroit City, and Cleveland Lakefront. Other cities have nearby airports which are not ideal but could serve as interim facilities pending STOLport construction. Examples are: Teterboro (New Jersey) and Parks Bi-State (St. Louis).

Ground Facilities

The STOL passenger market under consideration will consist largely of high-density, short-haul routes which, from a facilities point of view, result in a requirement to handle millions of passengers per year at most major hub cities. The facilities requirements include gates for handling aircraft and space for passenger processing. Another major consideration is automobile parking. If further amenities are included such as baggage handling, concessions, snack bars, and restrooms, considerable space is required independent of the vehicle carrying the passengers. MDC has analyzed the operational surface/gate capacity with a Monte Carlo simulation of daily flight operations including allocation of space for unscheduled aircraft maintenance. These studies place the capacity of a STOLport in the 4 to 8 million annual passenger range for a single-runway, 12 gate STOLport. A multistory structure is required to accommodate passenger processing and parking space beneath the flight deck (Fig. 9). The broad range of capacity estimates arises from variations of turnaround time, aircraft capacity, and arrival rate (ATC rules). It should be pointed out that if VFR heliport criteria are applied only one-seventh of the total area requirement is eliminated for a two landing pad heliport because passenger service space requirements are independent of vehicle type. If the IFR operations considerations are incorporated into heliport criteria, the area reduction will be very small and the V port area requirements will be very near STOL area requirements. Thus facility area and, therefore, cost requirements should be virtually the same for high density STOLports or V ports. However, to assure continuous operations, STOLports with a single runway will require STOL aircraft which can operate in high crosswinds.

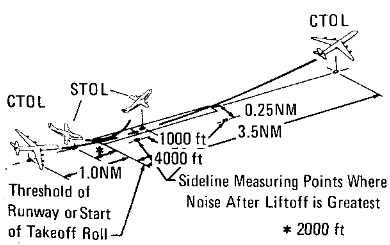


Fig. 11 FAA existing CTOL and proposed STOL noise measuring points for aircraft type certification.

Community Acceptance

The next constraint, community acceptance, is linked with the problem of locating convenient sites and outlining the characteristics of the facility. When the term community is used, it means the community-at-large including the local political entity providing the facility, the local nonusing populations, and local and visiting users. The controversy surrounding commercial airports today, either existing or proposed, hinges almost entirely on community sensitivity to noise and the availability of real estate acceptable for aircraft operations, suitable for economical construction, and ecologically compatible. The overriding constraint is noise and, fortunately, the operating characteristics of STOL aircraft lend themselves to noise abatement.

The approach to low noise taken by MDC in first generation STOL aircraft development has been to propose the use of low tip speed propellers (600 to 700 fps) on an aircraft in the 50 to 70 passenger size. This combination of tip speed and installed power points toward an aircraft compatible with ambient noise levels in commercial and industrial areas where most STOLport locations have been proposed. Flight operations of the Breguet 941S (950 fps tip speed) in demonstrations with Eastern Airlines and American Airlines did not produce a single noise complaint even, in some cases, with prior notification to antinoise groups.

Figure 10 shows a STOLport proposal for installation at the St. Louis Union Station. This site was selected by joint effort between the St. Louis City Planning staff, MDC STOL project personnel, local FAA personnel, and American Airlines personnel. Actual approaches to this site endorsed its selection and noise monitoring recorded virtually no increase in sound levels above street level ambient noise. Similar studies of sites in other major metropolitan areas indicate that STOLports of the size discussed here can be located conveniently and within noise tolerant zones. The proposed FAA STOL aircraft noise criteria suggests noise measurements be taken at the points shown in Fig. 11. It is expected that the allowable STOL noise levels will be published in an FAA Advanced Notice of Proposed Rule Making (ANPRM) early in 1971. However, conformance to these rules will be no guarantee of local acceptance, and careful use of noise con-

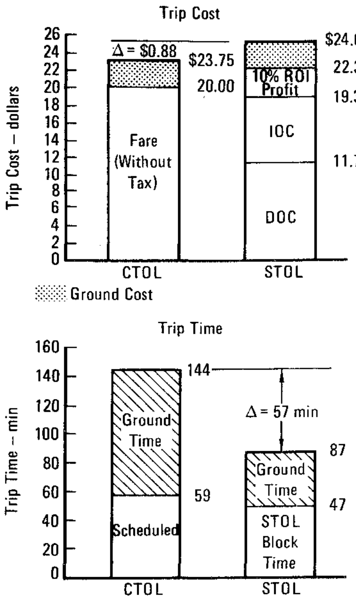


Fig. 12 STOL-CTOL trip time and trip cost comparison New York to Boston.

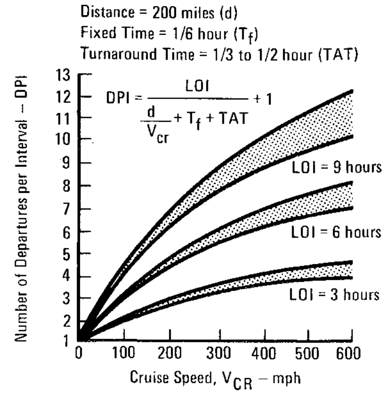


Fig. 13 The effects of passenger demand peaking on the relation of aircraft capability as a function of cruise speed.

tour overlays must be a major input to a STOL site selection study.

Economics

This paper has dealt at some length with three major constraints of the four shown in Fig. 1. The last constraint, economics, is the ultimate test to which any commercial venture must be submitted, and the STOL system must be economically viable or it will not come into existence. Economic viability, however, is a much maligned term, widely used and frequently misunderstood. STOL aircraft will have increased direct operating costs over contemporary short-haul jets by as much as 1 cent per seat mile or a \$3 or \$4 air trip cost increase over theoretical jet costs. However, if the STOL aircraft relieves crowded runways to expedite traffic for larger long-haul jets and their \$10+ per minute delay costs are reduced, an over-all cost benefit is certainly obtained by the air carrier. Further, if STOL strips at existing airports defer facility saturation for just two years, the time value of deferred spending could more than offset the cost of the STOL strip. So, two indirect cost benefits are likely to result from STOL system operations in the form of over-all congestion reduction and deferment of expenditures for major airport development.

It is not necessary, however, for these benefits to be attributed to the STOL system to provide economic justification. The STOL system can be justified on the basis of value-of-time and consideration of the total trip on a time and cost basis. Figure 12 compares STOL and CTOL trip time and trip cost between New York-Boston where a West Side Manhattan STOLport is assumed to exist. The CTOL trip time and trip cost are taken from the Official Airline Guide for both air fares and limousine fares. The STOL cost is estimated and includes a 10% pre-tax return-on-investment profit increment as part of its fare structure. Note the nearly equal trip cost and approximately one-half of the trip time. To reduce CTOL trip time, cab times and cab fares could be used. However, this increases CTOL trip cost and still takes longer than the STOL system. This example used a 67 passenger STOL with a 300 mph cruise speed.

Cruise Speed in the Short-Haul Market

Any discussion of aircraft economics must include the consideration of productivity which is largely determined by aircraft size and cruise speed. Aircraft size has already been discussed. Cruise speed must be considered in the context of the short haul market and the fixed times inherent in each flight. The phenomenon of diurnal peaking in passenger demand is very common in short-haul travel: high passenger load factors occur on aircraft available during peak periods, and load factors fall off during nonpeak periods. Short-haul traffic also occurs in a time interval spanning only 12 to 16 hours and significant late night/early morning (10:00 p.m.–6:00 a.m.) demand is rare. Figure 13 shows the flights per given time interval for various cruise speeds for peak periods of 3, 6, and 9 hours. The width of the bands is determined by ground turnaround time (TAT) varying from 20 to 30 min. Thus, the traditional desire for higher speed is not as important as it is in long haul economics. The 9-hr peak corresponds to a uniform demand situation, since two 9-hr peaks are equivalent to the whole operating day. For a length of interval (LOI) of 3 hr, there is no difference in the number of departures performed by a 300 mph or a 500 mph machine, unless the faster machine can attain a faster TAT. Each aircraft can achieve at least three departures. If peaks occur over a 6 hr interval, the 500 mph aircraft can achieve at least one more departure over the 300 mph aircraft. In high density markets this influences the number of aircraft required. The high load factor flights in the peaks are more important than the low load factor flights during nonpeaks. The costs, both from an investment and operating standpoint, of providing the higher cruise speed must be balanced by the reduced requirements for aircraft and/or increased efficiency of operations. In many cases the slower aircraft may prove to be more economical.

Conclusion

This paper has covered a wide range of subjects related to STOL system development. Constraints have been discussed which should influence the design criteria for STOL aircraft. These constraints indicate that a 50–70 passenger, quiet propeller driven aircraft with 300 mph cruise speed approaches first generation STOL system requirements. The capacity and cruise speed of this STOL aircraft are smaller and slower than traditional analysis techniques would normally recommend.

The small capacity STOL will fit the expanded system with its route proliferation produced by additional operational sites (STOLports). The lower gross weight coupled with low tip speed propellers promises to be a tolerable vehicle from the noise standpoint. The lower cruise speed than conventional jets is a small penalty for short stage lengths. The operational criteria for STOLports set down by the FAA are compatible with sites available in densely populated areas and the 1500 to 1800 ft field length is compatible with the obstacle clearance criteria. The space requirements in the STOLport for passengers and parking are approximately equal to the areas required for flight operations. V ports for high-density all weather operations will be nearly the same size as STOLports.

Thus, the design criteria for STOLports and the proposed noise criteria do not produce operational constraints that degrade the STOL concept's basic objective of providing convenient, independent short-haul transportation without increasing total trip cost.