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ENERGY IMPACT OF SHORT-HAUL STOL SYSTEMS

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ABSTRACT

An analysis has been made to evaluate the impact on fuel requirements of a segregated short-haul system. A comparison has been made between two alternate scenarios: one with STOL, and the other without STOL. For the New York to Washington, D.C. city pair the results show: (1) the modal efficiency approach, while indicating the "with STOL" scenario requires more fuel than the "without STOL" scenario, is of questionable validity because it does not account for various effects which exist in realistic scenarios; (2) evaluation of fuel requirements based on more detailed modeling indicates that while a STOL scenario requires more fuel than without STOL when an idealized CTOL system is postulated, the STOL scenario requires less fuel than without STOL when the CTOL system has even moderate delays. These results are due to a combination of effects: the closer and more convenient locations of STOL ports to the traveler, congestion at the CTOL airports, and the impact of the through passenger traffic. Sensitivity of results to STOL aircraft block fuel and to CTOL congestion delays are considered.

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INTRODUCTION

The investigation of STOL for providing improved short-haul transportation has received much attention in recent years (references 1 through 6). A variety of methodologies and criteria have been considered by which to judge and evaluate such systems. Studies such as references 5 and 6 are concerned with economic viability. References 7, 8, and 9 were more comprehensive in that they were concerned with not only economics but also the level of service provided and the environmental impacts of noise and pollution. However, not much has been done to examine the energy implications of such systems. In this paper we will give some preliminary results on the evaluation of energy or fuel requirements for a short-haul STOL system based on the segregation concept in which secondary airports are utilized to segregate the origin-destination passengers. In particular, we will compare the energy requirements for two alternate scenarios: one with an optimized STOL system and the other without STOL.

It might be expected that the introduction of STOL would automatically result in an increased fuel usage for that scenario since STOL aircraft generally require more fuel than conventional CTOL aircraft. However, such a conclusion does not account for realistic operational scenarios that bring into play forces or effects which could impact this energy conclusion. A realistic comparison should take into account:

1. the closer and more convenient locations of STOL ports to the traveler;
2. congestion at the CTOL airports;
3. the impact of the through passenger.

In the following, a rough-cut analysis will be made to account for these effects and to determine the trends involved. In this regard the results are considered preliminary in nature.

THE OPTIMAL STOL SYSTEM

The present study is based on the previous work of references 8 and 9 in which the characteristics of an optimum STOL system based on the segregation concept were derived. In order to relate it properly to the present study, it will be desirable to summarize the essential features of this previous study, its objectives, and how it was accomplished.

The scope of this study is seen by reference to figure 1 where the elements of the system are displayed. At the left of figure 1 is the transportation system with its major components, the traveler, the existing transportation, and the proposed new STOL system. The next block in figure 1 represents the analysis-phase of the transportation system. In brief, the analysis examines the competitive situation between the various combinations of travel modes and determines the least-cost alternative (including the value of time) for the individual traveler. By a Monte Carlo simulation, reliable statistics on the modal split are determined. With this information, a great many results of interest can be obtained. Main interest centers on the STOL system performance, in particular the criteria of merit shown in figure 1:

1. Service to the passenger
2. Economic viability
3. Terminal area environmental criteria
    a. Community noise
    b. Air pollution

The first item, service to the passenger, was measured in terms of the number of passengers the system will attract, and is of obvious importance if the system is to serve a useful purpose. Economic viability was measured in terms of return on investment. The environmental criteria included the impact of STOL system noise on the community surrounding the airport and the effect on air pollution.

The remaining portion of figure 1 is concerned with optimization. The three figures of merit, passengers carried, return on investment, and noise impact, are used as feedback to implement an optimization procedure in which all the available STOL system parameters (see reference 7) are altered so as to achieve a desired objective. This objective is to maximize the number of passengers carried with a constraint on the return on investment. The noise impact is included in the optimization by the cost of providing buffer zones to reduce noise impact.

Using the above methodology, the characteristics of the STOL system were determined and the "with STOL" scenario defined. These characteristics will be required to evaluate the energy needs of the STOL system and to compare the two scenarios, "with STOL" and "without STOL."

SCENARIOS FOR ENERGY EVALUATION

The energy question will be examined here for a specific case, the New York City to Washington, D.C. city pair. This city pair was one of the city pairs included in the Northeast corridor study of references 8 and 9. The situation to be considered is shown in figure 2 where the various modes of traveling between the two cities are diagramed. The various options for the traveler consist of a number of primary mode segments and car connecting segments in each city as shown. Two situations are to be analyzed. The first is the "without STOL" scenario (indicated by the solid lines) and the second is the "with STOL" scenario (indicated by the solid and dotted lines).

The passenger demand for the various modes of travel for both the "without STOL" and "with STOL" situations has been determined in references 8 and 9. This was accomplished by a projection of intercity travel demand to 1980 followed by a combined modal split and optimization analysis such that the STOL system would capture the maximum passenger patronage. The resultant passenger demand for each mode of the two scenarios is given in figure 3. It should be noted that no induced demand is assumed since the total number of passenger trips is the same for both scenarios. The data of figure 3 will be useful in later analysis for evaluation of fuel requirements.

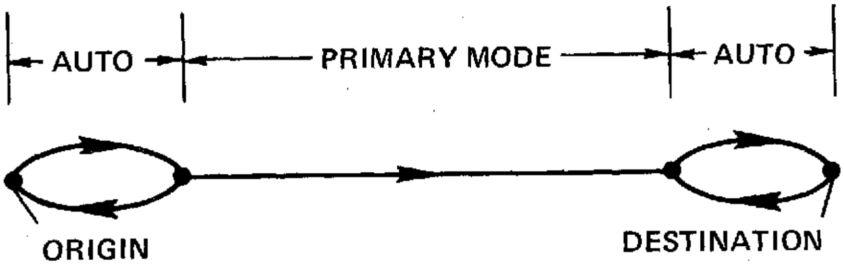
ENERGY REQUIREMENTS BASED ON MODAL EFFICIENCY DATA

One approach to evaluating energy requirements is based on utilizing average modal efficiency factors. Such data taken from reference 10 is given below.

Mode	Efficiency, E	
	Passenger - statute miles per gallon	(passenger - km per m^3)
Auto	30	(12,753)
Aircraft	16	(6,802)
Bus	110	(46,761)
Rail	100	(42,510)

These data are average figures over the country based on total modal activity and total fuel used by that mode.

The above modal efficiency data has been used to determine the fuel requirements for the 1980 "without STOL" and "with STOL" situations for travel between New York and Washington, D.C. The travel flow situation is as follows:



At the origin end, it is assumed that the auto is required to reach the primary mode and that a certain fraction will return to the origin. The primary mode carries the passenger to the destination end where a certain fraction of the autos are assumed to have traveled from the destination to meet the incoming traveler.

The fuel required for the primary segments (other than STOL) is given by

$$\text{Fuel for primary segment} = \sum_i \frac{N_i\ D_i}{E_i} \tag{1}$$

where: N_i = number of one-way passenger trips for the ith mode.

D_i = distance traveled by ith primary mode.

E_i = efficiency of the ith mode.

The D_i for various modes were categorized into two values. While the straight airline distance is 215 statute miles (346 km), the D_i for CTOL and STOL was taken to be 226 statute miles (364 km) to reflect slightly non-direct paths and terminal area maneuvering for a landing. The D_i for all ground modes were taken to be 248 miles (399 km) or about 15 percent greater than the airline distance.

The fuel for the STOL primary mode can be found from data given in references 8 and 9. There the optimized STOL system was determined to require 73 round trips, and the block fuel characteristics for the augmentor wing used in the study are shown in figure 4. These block fuel characteristics are somewhat greater than for other types of short-haul aircraft. Typical results for several other types taken from reference 11 are shown in figure 4: the externally blown flap (EBF), the over-the-wing/internally blown flap (OTW/IBF), and the mechanical flap (MF) designed for field lengths of 3,000, 3,000, and 4,000 feet respectively (914, 914, and 1,219 km). Because of the possible variations and uncertainty in fuel characteristics, we will take a reference aircraft with fuel requirements as shown in figure 4. Variations of ±20 percent from this reference are indicated in the figure and will be used for later comparisons.

The validity of replacing the augmentor wing by a reference aircraft is based on two ideas. First, it is clear that the results depend only on the costs and not explicitly on the aircraft concept itself. Second, since it can be shown that the sensitivity of total cost to block fuel is only about 0.1, it would be expected that moderate changes in block fuel could be made without affecting the modal split results of references 8 and 9. This value of sensitivity can be determined from data in reference 11 where it is shown that block fuel and oil costs are about 20 percent of the total DOC, and DOC is about equal to IOC.

The fuel required for the auto connecting segments is given by

$$\sum_i \frac{N_i}{MT_i}[D_{oi}(1+K_{oi})+D_{di}(1+K_{di})] \tag{2}$$

where: N_i = number of one-way passenger trips.

D_{oi} = auto distance from the origin to the ith primary mode.

K_{oi} = fraction of car trips returning to origin after delivery of traveler to the ith primary mode.

D_{di} = auto distance from the ith primary mode to the destination.

K_{di} = fraction of car trips from ith primary mode to destination that is required to pick up the traveler at the primary mode.

M = auto miles per gallon.

T_i = number of travelers per car.

The fuel required in equation (2) for the auto connecting segments is a random variable dependent on the particular traveler and his exact origin and destination locations. For this reason it would be necessary to obtain the expected value of the auto travel distance for a large sample of individual travelers. Suitable data for doing this were generated within the computer in obtaining the modal split data shown in figure 3, and so were not explicitly obtained. For this reason we will make, hopefully, some reasonable guesses at the required values. We will see that the results are not very sensitive to these values. Figure 5 itemizes the values used.

The results of fuel computations using equations (1) and (2) are given in figure 6. Here the components of fuel for both the "without STOL" and "with STOL" scenarios can be compared. The most significant comparison to notice is between the totals for both scenarios, and this comparison shows that the introduction of STOL would require about 18 percent more fuel.

Assuming the validity of this approach, one could rightly inquire as to the benefit that is achieved for this increased fuel. The benefit that has accompanied this fuel cost is a superior system as viewed by the traveler in terms of his generalized cost consisting of out of pocket cost and the cost of his time. The traveler's preference for STOL is substantiated by the modal split data of figure 3. Here we see that STOL was a preferred mode of travel in that: (1) it captured 96 percent of all the air travel (95 percent for the entire corridor), and it produced a 137 percent increase in air travel (87 percent for the corridor). The latter was accomplished by attracting substantial numbers of travelers from their cars as well as the bus and rail. Whether this superior mode of transportation is worth the increased fuel usage would require a value judgment to be made. Equally important is the question regarding the validity of this analysis.

It should be emphasized that the design of the STOL system was based only on providing a maximum of service in terms of the number of passengers with constraints on economic return and environmental noise impact. No consideration was given to including fuel in the optimization or as a constraint. Thus a reduction of the 18 percent could be expected if fuel were to be included in the design of the STOL system. This figure would also be reduced if the STOL share of the modal split were reduced.

Another thing to notice from the table in figure 6 is that the auto connecting fuel is a small fraction of the primary segment fuel. This means that the sensitivity of the total system fuel requirements to errors in estimating some of the parameters in equation (2) is low. For example, if the estimates of fuel for the connecting mode are too large by 100 percent, the error in the comparison between the "without STOL" and "with STOL" scenarios would be only 3 percent (i.e., the "with STOL" scenario would require 18 percent + 3 percent more fuel). Thus any reasonable estimates are satisfactory for revealing the major trends. The small auto connecting fuel also means that the importance of locating the STOL ports close to the traveler is not great.

The above results comparing the "without STOL" and "with STOL" options in terms of fuel usage can be questioned because this approach based on modal efficiency data is not very accurate in specific cases as will be discussed in the next section.

ENERGY REQUIREMENTS BASED ON FLIGHT DATA

The preceding results on fuel usage comparisons may be questioned for several reasons. First, the method of calculating fuel usage by means of the standard modal efficiency factors does not necessarily model the real-world situation very accurately especially for the CTOL usage. These average efficiency factors are based on total activity and total fuel usage in the country and hence may not be accurate at the major centers of CTOL traffic where congestion effects play an important role. It would be expected this method would give low fuel requirements for the CTOL mode. Second, it will be noted that the methodology for determining the CTOL and STOL fuel requirements is not the same. While the CTOL requirements were based on modal efficiency data, the STOL requirements were based on more detailed engine and flight profile calculations.

Third, the analysis does not account for the potential reduction in fuel due to the closer and more convenient location of STOL ports. Fourth, the preceding methodology does not account specifically for the impact on fuel usage of congestion at major CTOL hubs and the reductions in congestion and fuel requirements which could result from an independent short-haul system. Finally, there is no way of accounting for the effect on fuel of through traffic, that is, the coupling between delays to the origin-destination traveler and the through traveler. In the following, a rough-cut analysis will be made to account for these effects in order to get an idea of the trends involved.

To overcome the deficiencies just noted it will be necessary to begin by determining the actual performance data for the aircraft to be used in terms of fuel, time and distance. In references 8 and 9, the assumption has been made that in the 1980 time period: (1) the same schedule as in 1972 would be maintained and (2) the increased demand would be met by using larger aircraft, namely, 150 passenger 727-200's instead of currently used DC9's (125 passengers) or B727-100's (70-131 passengers). The performance data for this aircraft has been obtained from reference 12 and is given in figure 7 for each segment of the flight between New York and Washington, D.C. Two situations are given in figure 7. In the first, labeled (1), the performance is based on the manufacturer's flight profile data of reference 12. No allowance has been made for delays that could occur in the terminal area due to congestion. The allowance for taxi times given by the manufacturer agrees or slightly exceeds values given in unpublished FAA data. In the second situation, labeled (2), the performance is based on including the effects of current operational delays. A measure of the delay can be obtained from the difference between the total block time based on the manufacturer's data (given in (1)) and the published block time of 1.02 hours from the Official Airline Guide, reference 13. This time difference is assumed to be spent with the aircraft in its most efficient flight mode, the cruise condition, and the additional fuel is determined using the fuel consumption of .0355 n.m./lb (0.145 km/kgm) taken from reference 12. Note that the total block time agrees with the published value.

Next, it is necessary to determine the number of flights to be made by the CTOL aircraft. From the official Airline Guide, reference 13, it can be seen that there are 98 trips per day from New York to Washington, D.C. and 107 trips per day from Washington to New York, for a total of 205 one-way trips per day.

Now the fuel required for the "without STOL" scenario can be determined using estimates of the CTOL requirements based on actual flight data. The result is summarized in figure 8. Here the fuel requirements for modes other than CTOL are repeated from figure 6 for completeness. However, the CTOL requirements have been determined by combining the single-flight fuel data with the number of flights for the CTOL mode. Two CTOL situations are shown, without operational delays, and with current operational delays corresponding to the flight data in figure 7.

It can be noted that the normal operational delays result in significantly greater (22 percent) total fuel usage compared to the situation with no operational delays. It can also be seen that the CTOL fuel requirements are much larger than given previously in figure 6. This is because the calculations now include the impact of the through passengers as well as the origin-destination passengers, since the calculations are based on actual flights on which through passengers also ride. Thus, part of the cost of congestion in terms of increased fuel is due to the through passengers. This means that the "with STOL" scenario must also be charged with the cost of through passengers for a fair comparison to be made.

The "with STOL" scenario results have also been determined and shown in figure 8. The STOL fuel requirements are the same as in figure 6 where the calculations were based on actual engine and flight profile data. The CTOL fuel requirements, as noted in the previous paragraph, must take into account the through passengers as well as the origin-destination passengers. Since the number of CTOL passengers will be markedly reduced because nearly all of the origin-destination passengers are now traveling on the STOL system, it would not be appropriate to continue the use of the B727-200 aircraft. Rather than postulating another CTOL system with other aircraft and fuel characteristics, it is consistent with this rough-cut analysis to estimate the through passenger impact on the CTOL fuel requirements from the modal efficiency data given earlier, and the result is given in figure 8. With this calculation, we are not assuming any delays beyond that already inherent in the DOT modal efficiency data. It seems reasonable to not include additional delays since the number of CTOL passengers being processed in the "with STOL" scenario has been found to be reduced by a substantial 34 percent from the "without STOL" scenario as a result of segregating the origin-destination traffic by the STOL system.

The most important observation to be made from figure 8 is that the total system fuel with STOL (column (3)) is greater (about 12 percent) than without STOL for the no delay situation (column (1)), but less than (8.5 percent) without STOL for the current operating delay situation (column (2)). From these results it can be seen that the STOL system utilizes less fuel than the conventional CTOL system with even moderate delays.

The reasons behind these results are worth delineating. The first effect is due to the closer proximity of the STOL ports to the traveler and results in a somewhat smaller connecting segment fuel. The second effect is due to delays to the origin-destination passenger because of congestion in the CTOL system. Such delays are less with STOL because the STOL system operates from secondary airports. The third effect, due to the through passenger, is more subtle. This effect is concerned with the coupling between delays to the through passenger traffic and delays to the origin-destination traffic. The deleterious effect on fuel requirements of slight delays for the origin-destination passenger is amplified by the presence of the through passenger traffic which must necessarily share the same aircraft. Thus, because the "without STOL" scenario has inherently greater CTOL delays than the "with STOL" scenario (since the latter has desegregated nearly all the origin-destination traffic with the STOL system), the fuel required for the through passenger is also greater.

Another interesting observation from figure 8 is that the total air fuel for "with STOL" and for "without STOL" with current delays are about the same. This is in spite of the fact that the total number of origin-destination air passengers with the STOL scenario is 137 percent greater than the "without STOL" scenario (see figure 3). This surprising result is a consequence of the last two factors discussed in the preceding paragraph, that is, the delays in the CTOL system and the impact of the through passenger traffic.

Since CTOL delays and STOL aircraft fuel usage are important elements in the present analysis, it is of interest to examine the sensitivity of total system fuel to these variables. Figure 9 displays a comparison of the "without STOL" and "with STOL" scenarios in terms of fuel requirements for the total transportation system when the STOL system fuel is varied ±20 percent and the CTOL air delay is increased by 10 minutes in the "without STOL" scenario. It is seen that for +20 percent fuel usage and current CTOL delays the total system fuel for both "without STOL" and "with STOL" scenarios is about the same. Further, the effect of 10 minutes added CTOL delay is such that the "without STOL" option is considerably worse than the "with STOL" option.

CONCLUDING REMARKS

It is worth restating two of the main preliminary conclusions of this study. For an optimal segregated short-haul STOL system utilizing secondary airports, analysis for the New York to Washington, D.C. city pair shows:

a. The modal efficiency approach for evaluating fuel requirements indicates that the "with STOL" scenario requires 18 percent more fuel than the "without STOL" scenario. However the validity of this approach is questionable because it does not account for various effects which exist in realistic scenarios.

b. Evaluation of fuel requirements based on more detailed modeling using flight data indicates that while a STOL scenario requires 12 percent more fuel than without STOL when an idealized CTOL system is postulated, the scenario with STOL requires less fuel than without STOL by 8.5 percent when the CTOL system has even moderate delays.

These results are due to a combination of effects: the closer proximity of the STOL ports to the traveler, delays to the origin-destination passenger because of CTOL congestion, and the impact of the through passenger traffic by means of coupling between delays to the origin-destination and through passengers.

It should be emphasized that the results are based on a STOL system design in which fuel was not considered in the optimization process. Further, reductions would be expected, for example, if fuel were considered explicitly in the optimization process, if constraints were placed on the number of passengers to be carried by the STOL system, or if the STOL modal split data on which this report is based were too optimistic.

The results are considered to be preliminary in nature for several reasons. For example, there is a need to include in the analysis other city pairs and other corridors, changes in fuel costs, advanced and more costly CTOL aircraft designed for the same noise levels as for the STOL aircraft, and more data regarding delays for CTOL aircraft at specific ports. Inclusion of such effects would provide greater generality of the conclusions.

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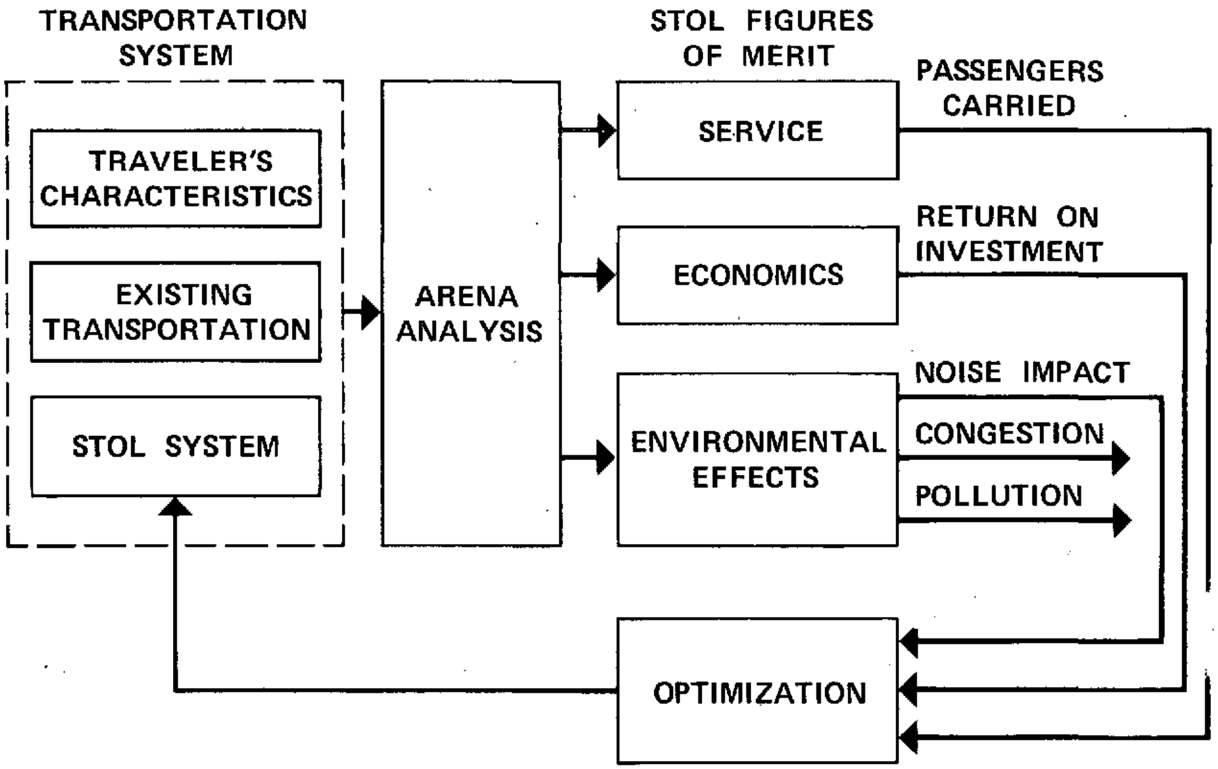

Figure 1.– Optimization of the STOL system.

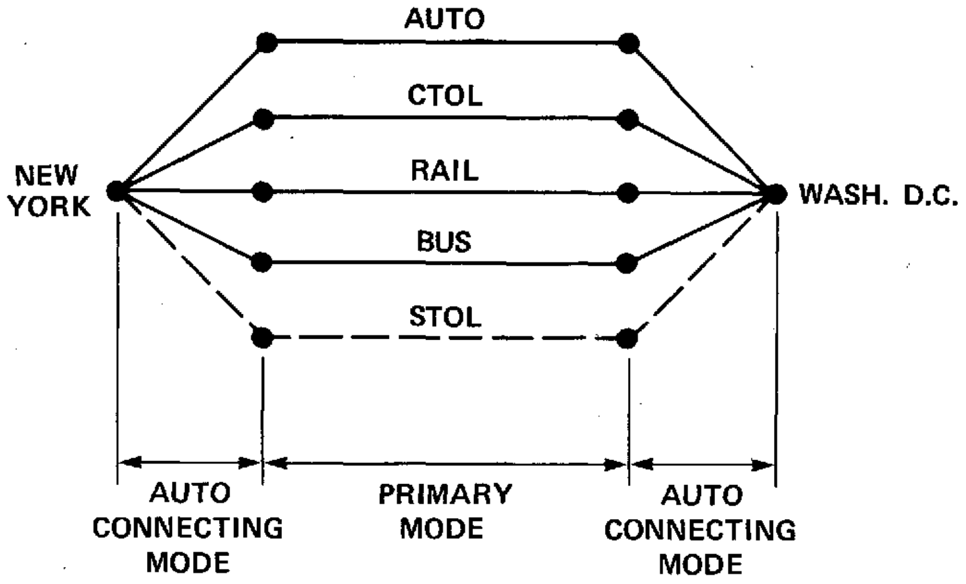

Figure 2.–Scenario for energy evaluation.

MODE	DAILY ONE-WAY PAX TRIPS	
	WITHOUT STOL	WITH STOL
AUTO	14,176	11,054
CTOL	6,302	660
BUS	2,456	1,348
RAIL	7,630	3,228
STOL	–	14,274

Figure 3.–1980 modal split for travel between New York and Washington, D.C.

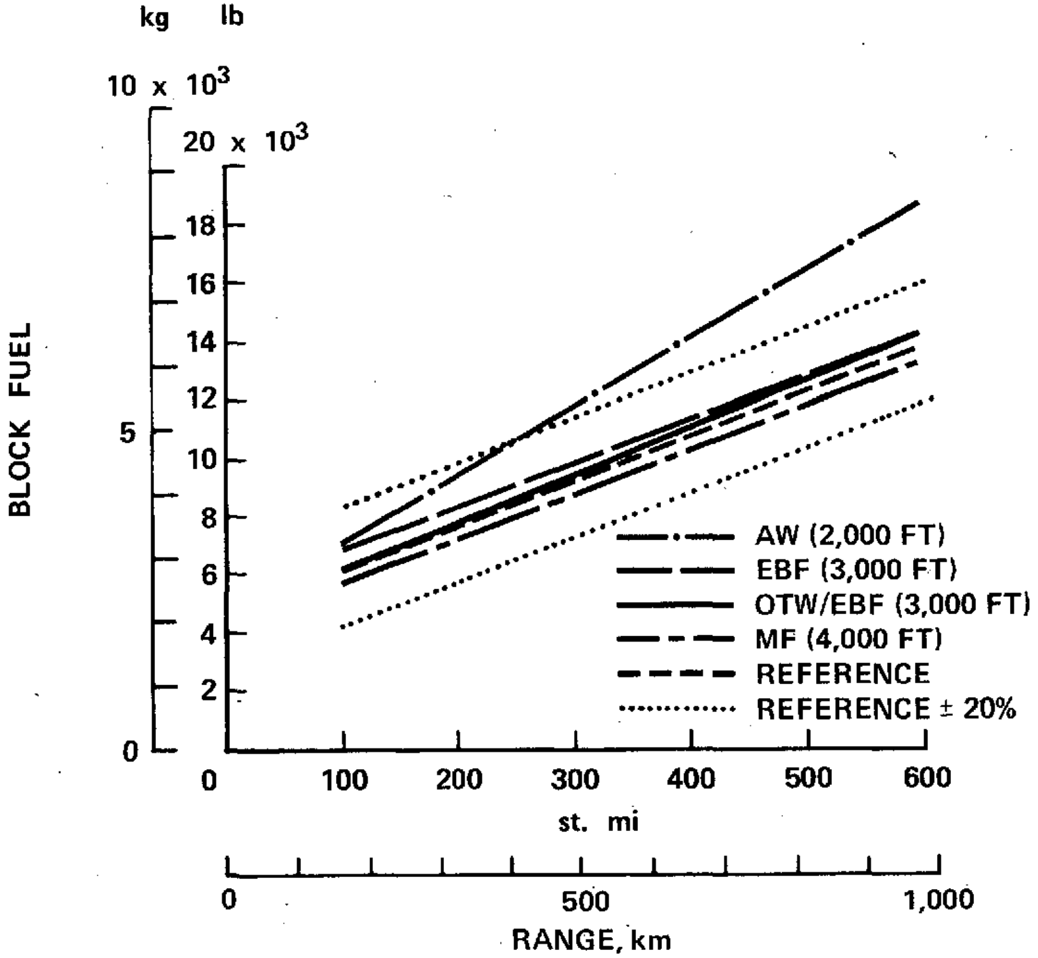

Figure 4.–Block fuel for STOL aircraft.

SCENARIO	CAR CONNECTING SEGMENT TO:	N_i 1-WAY PAX TRIPS	D_{oi} st. mi (km)	K_{oi}	D_{di} st. mi (km)	K_{di}	T_i
WITHOUT STOL	CTOL	6,302	20(32)	0.5	20(32)	0	1.0
	RAIL	7,630	20(32)	1.0	20(32)	1.0	2.5
	BUS	2,456	10(16)	1.0	10(16)	1.0	1.0
WITH STOL	CTOL	660	20(32)	0.5	20(32)	0	1.0
	RAIL	3,228	20(32)	1.0	20(32)	1.0	2.5
	BUS	1,348	10(16)	1.0	10(16)	1.0	1.0
	STOL	14,274	10(16)	0.5	10(16)	0	1.0

Figure 5.—Data for auto connecting segments.

SEGMENTS	MODES	GALLONS (cu m) OF FUEL PER DAY	
		WITHOUT STOL	WITH STOL
PRIMARY	AUTO	117,000 (443)	91,200 (345)
	CTOL	89,000 (337)	9,320 (35)
	BUS	4,800 (18)	2,635 (10)
	RAIL	18,950 (72)	8,000 (30)
	STOL	—	175,346 (664)
TOTAL PRIMARY		229,750 (870)	286,501(1,084)
CONNECTING	AUTO-CTOL	21,000 (79)	2,000 (8)
	AUTO-BUS	6,550 (25)	3,590 (14)
	AUTO-RAIL	16,300 (62)	6,870 (26)
	AUTO-STOL	—	23,260 (88)
TOTAL CONNECTING		43,850 (166)	36,260 (137)
TOTAL		273,600(1,036)	322,761(1,222)

Figure 6.—Comparison of fuel requirements based on modal efficiency data.

SEGMENT	(1) PERFORMANCE WITH NO OPERATIONAL DELAYS			(2) PERFORMANCE WITH CURRENT OPERATIONAL DELAYS		
	FUEL lbs (k gm)	TIME hrs	DISTANCE st. mi. (km)	FUEL lbs (k gm)	TIME hrs	DISTANCE st. mi. (km)
TAXI: OUT 9 min	405 (184)	0.150	0	405 (184)	0.150	0
IN 5 min	225 (102)	0.0833	0	225 (102)	0.0833	0
INITIAL CLIMB TO 1500 ft (457.2 m)	1,020 (463)	0.036	6 (9.6)	1,020 (463)	0.036	6 (9.6)
HIGH SPEED CLIMB TO 15,000 ft (4,572 m)	2,600(1,179)	0.128	47 (75.6)	2,600(1,179)	0.128	47 (75.6)
CRUISE AT 15,000 ft (4,572 m) M = 0.7	3,042(1,382)	0.2465	124.5(200.3)	6,081(2,758)	0.4927	124.5(200.3)
HIGH SPEED DESCENT	350 (159)	0.13	48.5 (78.0)	350 (159)	0.13	48.5 (78.0)
TOTAL	7,642(3,466)	0.7738	226 (363.5)	10,681(4,845)	1.02	226 (363.5)

Figure 7.—Block performance characteristics of B 727-200 for 226 statute miles (363 km).

MODES	GALLONS (cu m) OF FUEL PER DAY		
	WITHOUT STOL		(3) WITH STOL
	(1) CTOL WITH NO OPERATIONAL DELAYS	(2) CTOL WITH CURRENT OPERATIONAL DELAYS	
PRIMARY SEGMENT			
AUTO	117,000 (443)	117,000 (443)	91,200 (345)
CTOL: OD & THRU	233,822 (885)	326,807(1,237)	154,129 (583)
OD	89,013 (337)	124,413 (471)	9,320 (35)
THRU	144,809 (548)	202,394 (766)	144,809 (548)
BUS	4,800 (18)	4,800 (18)	2,635 (10)
RAIL	18,950 (72)	18,950 (72)	8,000 (30)
STOL	–	–	175,346 (664)
TOTAL AUTO CONNECTING SEGMENT	43,850 (166)	43,850 (166)	36,260 (137)
TOTAL	418,382(1,584)	511,407(1,936)	467,570(1,770)

Figure 8.—Comparison of fuel requirements based on flight data.

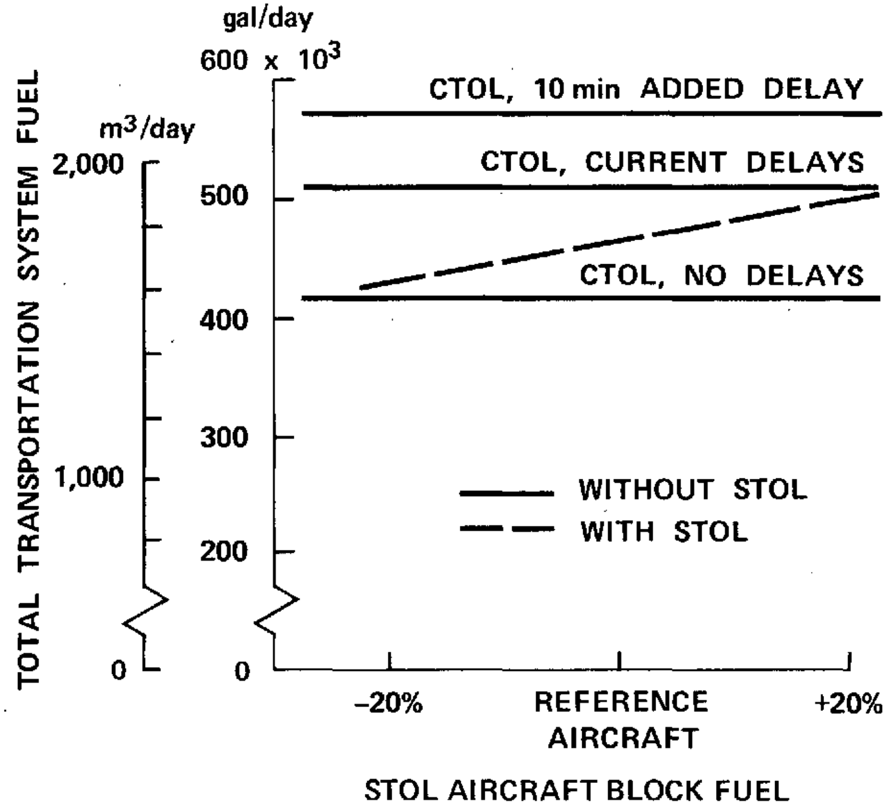

Figure 9.–Sensitivity of system fuel to STOL block fuel and CTOL air delay.