FORECAST OF LOSSES INCURRED BY U.S. COMMERCIAL AIR CARRIERS DUE TO INABILITY TO DELIVER PASSENGERS TO DESTINATION AIRPORTS IN ALL-WEATHER CONDITIONS: 1959 - 1963

(Contract No. FAA/BRD-309)

Prepared for

THE BUREAU OF RESEARCH AND DEVELOPMENT
FEDERAL AVIATION AGENCY

March, 1961

Prepared by

UNITED RESEARCH INCORPORATED
808 Memorial Drive
Cambridge 39, Massachusetts

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

Section I

INTRODUCTION AND SUMMARY OF CONCLUSIONS

This report was prepared pursuant to the terms of a contract (FAA/BRD-309) with the Bureau of Research and Development, Federal Aviation Agency, under which United Research Incorporated was assigned the task of preparing a forecast for the period 1959-1963 of the losses incurred by U S. commercial air carriers due to their inability to deliver passengers to destination airports in all weather conditions

Definitions

Under the terms of this contract, the dollar losses to be considered include

1 Costs incurred because flights scheduled into certain airfields are unable to land due to weather which is below authorized minimums and as a consequence are diverted to alternate airports.

2 Costs incurred because flights are delayed at departure or are unable to depart because weather at destination airfields is below authorized minimums.

3 Costs incurred because flights are delayed or unable to depart because weather at point of departure is below authorized minimums

4 Costs incurred due to the limited flow capacity and operational criteria associated with the present landing system, such as delays en route, time in stacks, cancellations due to congestion

Costs incurred by commercial air carriers in these various situations fall into three general categories and are so considered in this report. These categories are

1 Additions to normal direct aircraft operating expense and passenger handling costs incurred as a result of flight diversions delays, and cancellations in periods when weather is below authorized minimums.

2 Additions to total operating expense incurred as a result of loss of life personal injuries, and property damage resulting from landing accidents.

3 Losses in passenger revenue resulting from the inability of airlines to complete scheduled flights in periods when weather is below authorized minimums, and from a general inhibition in the demand for air travel in bad-weather months.

Method

The basic methods of cost determination used in this study were developed by United Research in a previous report to the Bureau of Research and Development Federal Aviation Agency, under Contract FAA/BRD-17, "A Method for Determining the Economic Value of Air Traffic Control Improvements and Application to All-Weather Landing Systems." In that study emphasis was placed upon the development of techniques which could be used to measure the economic benefits to users of the Federal Airways System of any given improvement in air traffic control systems. Methods developed were based on (1) The measure of the effects of these improvements in dollar terms on the <u>demand</u> for and the <u>cost</u> of airline passenger transportation, (2) the measure of the effects of these improvements on the costs of general aviation transport, including value of passenger time, and (3) the annual value of the accidents (loss of life and property) prevented by the improvements.

In order to determine the net economic benefits from any selected improvement in the air traffic control system, the dollar values computed for each of the above measures were totaled and any associated operating expenses were subtracted. In applying the methods to a selected improvement such as an all-weather landing system, two preliminary steps were considered necessary (1) determination of the physical effect of the improvement upon present operating restrictions and limitations and (2) calculation of the reduction in the physical units of flight delay, cancellation, and diversion Through the application of the methods enumerated above to the data derived by these preliminary procedures, it is possible to compute the economic benefits of any specific air traffic control improvement.

In addition to the development of the basic methods of determining the economic benefits, the previous study (FAA/BRD-17) included an application of these methods to a measurement of the benefits accruing as a result of the installation of all-weather landing systems The level of aviation activity considered was in terms of a past period, 1957

In this report the research effort is directed to a measurement of the losses incurred by commercial airlines as a result of a lack of all-weather landing systems, with most of the effort directed toward a future period.

Measuring the costs or losses incurred by users of the airways as a result of an existing deficiency in the airways system is tantamount to determining the economic benefits accruing to the same users as a result of an improvement which eliminates the system deficiency. The methods previously developed to measure the economic benefits of all-weather landing systems can be utilized, therefore, in the present problem of determining the losses incurred as a result of an inability to operate without schedule interruptions in bad weather

Essential to this study is a forecast of future commercial airline passenger traffic providing the level of aviation activity for which carrier losses are computed. Such a forecast of domestic passenger traffic through 1963, together with the methods used, is given in Section IV of this report

Limitations

Commercial airline activity considered in this study is limited to operations at airports within the Continental United States

As aviation activity considered is limited to that of commercial airlines, it is appropriate to note that general aviation activity and the operations of military aircraft are excluded from consideration in this study. Furthermore in determining the costs incurred by commercial airlines, losses in revenue from nonpassenger sources were not considered, nor were the economic costs incurred by airline passengers.

It is obvious that users and operators of general aviation aircraft, particularly executives and professional personnel transported in corporate aircraft, incur substantial economic costs as a result of flight disruptions in bad-weather periods. Also, the military forces incur some measure of economic cost as a result of their inability to land aircraft at civil airports when weather is below authorized limits.

At the present time, the omission from consideration of non-passenger traffic (represented by mail, express, and freight) results in only a minor understatement of the total costs incurred by airlines as a result of schedule disruptions. Although substantial increases may be expected in the operation of cargo services due to the recent conversion of piston aircraft from passenger to cargo configuration and the availability of new all-cargo aircraft, it appears that revenue from cargo will still remain a small portion of the total operating revenues of the domestic airlines in the period prior to 1964. Also, the nature of cargo traffic, which makes it far less susceptible than passenger traffic to diversion to other modes of transportation in periods of bad operating weather, tends to minimize the losses of this class of traffic.

Losses now incurred by airline passengers as a result of flight disruptions are substantial, however. The amount of productive time lost by airline passengers as a result of flight diversions delays and cancellations represents not only a personal inconvenience to individuals but an actual economic loss as well

Conclusions

The findings in this report indicate that U.S airlines incur losses of approximately $55 million a year due to flight disruptions in periods when weather conditions are below authorized limits Due to increased traffic and increases in the costs of operating aircraft, these losses will increase to over $65 million by 1963 The growing proportion of jet aircraft in the carriers' fleets is one of the major factors accounting for the cost increases since costs of delay are far greater for jet aircraft than for piston aircraft because of the higher hourly operating expense of the former.

The losses take the form of (1) cash losses when airlines are forced to cancel, delay or divert their schedules, (2) short and long term costs resulting from landing accidents, and (3) losses from reduction in the demand for air travel due to its present unreliability in bad-weather periods. The costs considered in this report were of an incremental and direct nature only If flight depreciation expense and all indirect and overhead expense were allocated to the aircraft time consumed in delays, diversions and cancellations the costs would have been considerably higher than those shown

The summary table below lists the estimated dollar losses for the above three categories. The variation shown for 1960 in comparison with both the previous year, 1959, and subsequent years is accounted for primarily by the combined effects of (1) the fact that the accident rate in 1959 was abnormally high, (2) the increase in aircraft capacity which tended to hold down growth in aircraft movements in 1960, and (3) the low rate of traffic growth in 1960. A stable pattern of cost increase is established for the 1961-1963 period through the influence of normal factors.

	(Dollars in Thousands)			
Year	Increased Costs Due to Flight Delays Cancellations and Diversions	Costs of Landing Accidents	Losses in Passenger Revenue Due to Decreased Demand	Total Costs
1959	$13,104	$27,738	$17,343	$58,185
1960	12,450	15,022	23,340	50,812
1961	14,259	16,434	24,576	55,269
1962	17,157	17,957	25,974	61,088
1963	20,519	19,730	27,456	67,705

Estimated carrier losses are presented in Table 1 (Appendix A) for 22 airports selected in the previous study on the basis of traffic volume and incidence of IFR weather.

Section II

INCREASED OPERATING COSTS INCURRED AS A RESULT OF FLIGHT DELAYS, CANCELLATIONS AND DIVERSIONS DUE TO ADVERSE WEATHER

Under existing landing systems the scheduled operations of air carriers become disrupted in periods when weather conditions are below authorized operating limits. Under these adverse weather conditions, occurring at either the airport of destination or departure, airlines are forced to delay or cancel scheduled flights or divert them to alternate airports.

In so doing, the airlines incur additional operating expenses.1/ In the case of delayed flights, direct aircraft operating expenses are increased as a result of aircraft holding in stacks or on the ground while waiting for weather conditions to improve Flight cancellations involve reductions in direct aircraft operating expense but increases in passenger handling costs as well as losses in passenger revenue. Flight diversions represent a combination of delays and cancellations They entail a delay component when the scheduled flight time is exceeded due to the necessity of landing at an alternate airport. Since the diverted aircraft must be brought back into the normal aircraft rotation scheme, it may be necessary

1/ Over the long run, these costs constitute a normal cost of doing business and thus are borne by the public through payment of passenger fares or subsidy Inasmuch as the Civil Aeronautics Board considers carrier profit in relation to a reasonable rate of return on investment when deciding carrier requests for increased fares or subsidy, it may be argued that the added costs are transferred directly to the public In short run periods, however, when the fare level does not provide a fair and reasonable rate of return over and above normal operating expense, this transfer of burden to the public is not so obvious.

to operate nonrevenue ferry flights or to cancel revenue flights at other airports In addition, the landing of passengers at an airport other than their scheduled destination creates added passenger handling expense

Set forth in this section is a determination of the magnitude of these costs in the 1959-1963 period together with an explanation of the methods and assumptions used.

Measurement of Delay

Basic to the problem of cost measurement is a determination of the incremental aircraft time when flights are delayed or diverted as a result of the inability to land or to take off when weather conditions are below limits Actual aircraft delay data attributable to this source are not available Although the deviations of actual aircraft time from scheduled aircraft time can be computed from recorded data, these deviations would represent delays from all sources rather than those occurring only from the inability to land promptly in all weather conditions

A further consideration is the fact that the standard of measurement, scheduled air and ground time, is itself affected in part by the incidence of weather delay so that its use would result in an understatement of true delay time Scheduled block-to-block times in current airline schedules are in excess of that actually required for taxi, take off, gain-to-altitude, cruise, let down, landing, and taxi to terminal facilities by reason of air traffic control delays, of which delays in instrument weather are a part

In the absence of recorded data it was necessary, therefore, to estimate the hours of aircraft time accumulated as a result of flight delays, diversions and cancellations. This had been done in the previous study through the use of a mathematical model, an explanation of the model, shown in Appendix B of this report, describes the methods used to estimate hours of aircraft delay incurred because of schedule disruptions due to IFR weather conditions In the previous study, these estimates were used as a basis for determining the economic benefits of airways improvements; in the current study, comparable data are required in order to estimate the costs incurred by airlines because of flight delays.

In the model the incidence of flight disruptions is related to:

1. The rate at which an airport can handle landings and take-offs, stated in terms of operations per hour (acceptance rate) With present landing systems this rate will vary from zero in zero-visibility weather to whatever the top capacity of the airport may be in VFR conditions

2 The rate at which aircraft are scheduled to land and take-off at the airport (arrival rate).

3 The incidence and duration of adverse weather conditions.

Delays at airports occur (1) when a restricted acceptance rate is higher than an arrival rate, and (2) when the arrival rate exceeds the acceptance rate, the most important case being when the airport is closed and the acceptance rate is zero.

1. Disruption during periods when acceptance rate is restricted, but exceeds arrival rate Delays occur even when the hourly acceptance rate exceeds the hourly arrival rate because aircraft do not present themselves for take-off and landing at perfectly spaced intervals Even if scheduled operations were evenly spaced, the minor deviations caused by differences in winds aloft, by planes departing and by excessive time consumed in loading passengers would cause some bunching of aircraft and thus create some delay in order to provide needed spacing between aircraft. The average delay is a function of the relationship between arrival rate and acceptance rate. As the effect of adverse weather is to

lower the acceptance rate, attributable delay can be measured as the difference between the delay experienced with the lower acceptance rate and that which would have been experienced if scheduled operations were possible in zero-zero ceiling and visibility conditions.

In the previous report a computation of aircraft hours of delay from this source was made for each of 22 airports, for the year 1957, using Weather Bureau records of the number of occurrences of IFR operating weather for each hour of the day. An hour-by-hour arrival rate pattern for IFR weather periods had been constructed through the use of estimated acceptance rates, actual airline schedules and airport weather patterns.

2. Disruptions during periods when arrival rate exceeds acceptance rate. It is clear that disruptions will pyramid during periods when the airport is closed, or when more planes present themselves for landing or take-off than can be handled. During the early stages of such conditions the excess can be handled by stacks in the air and waiting lines on the ground. Theoretically, the effects of such periods could be expressed purely in terms of very extended delays. As a practical matter, decisions are made by airline personnel which reduce delays by flight cancellations and diversions.

In determining the behavior of individual flights during periods of adverse weather, a decision-making framework was established, embodying certain physical and legal constraints on aircraft operations This framework was used to determine when flights would be cancelled and diverted and when flights would be held in a delayed status until landing was possible Through the use of this model each single period of an hour or more when each of the sample airports was closed due to ceiling and/or visibility criteria in 1957 was separately analyzed to arrive at estimates of delays, diversions, and cancellations at that airport.

Airport data considered in the previous report represented 1957 experience, whereas the current study calls for consideration of the 1959-1963 period. After discussion with airline operating personnel and air traffic controllers at selected airports, it was concluded that the relationship existing between hours of delay and instrument approaches in 1957 could be accepted for the later period Thus, average delay per instrument approach is assumed to be the same for the 1959-1963 period as that established in the 1957 period. The total number of aircraft delays will increase, of course, as the number of instrument approaches increases with the general level of commercial carrier operations.

Cost of Flight Delay

Determining the costs of aircraft delay for any given period is a matter of applying average aircraft operating costs per hour to the total hours of delay.

Costs incurred by airlines as a consequence of en route delays are incremental costs directly associated with operating aircraft, such as flight crew salaries and traveling expenses, fuel, and direct maintenance. Flight equipment depreciation charges and flight equipment insurance expense have been excluded from flying operations expense, as they do not increase (in the short run, at least) when aircraft are forced to operate additional amounts of time due to en route traffic delays. It might be argued that these expenses do not apply over the long run, however, as the additional aircraft time consumed in delays adds to aircraft requirements and thereby constitutes a normal cost of doing business. There is merit to this argument and in the long run there is no reason why depreciation and insurance charges should not be charged against en route delays The inclusion of flight equipment depreciation as incremental expense would have increased the cost estimates by approximately $2 million a year.

A portion of overhead maintenance burden has been excluded on the theory that a sizable proportion of such supervision expense is fixed in nature and does not increase when additional aircraft time is expended because of en route delays. Again, this is a short-run treatment of burden costs for, over the long run, maintenance burden expense is a function of direct maintenance expense

It was assumed that the average hourly operating costs of the combined fleets of U.S domestic carriers would be typical for those aircraft subjected to delay. In order to determine the average hourly costs for the combined fleets it was necessary to apply estimated hourly costs for each equipment type to the number of hours flown by each type, and divide the total expense for all equipment types by total hours flown.

Annual costs experienced in 1959 and available 1960 monthly data were used as a base and it was assumed that inflationary labor and material cost increases would account for an average annual increase of two per cent in the future periods Aircraft hours data used to determine the weighted average cost figure were computed from 1959 and available 1960 data together with estimates of hours to be flown in future periods by flight equipment now on order and required to meet future traffic demands. In computing annual aircraft hours flown an average annual utilization of 3,000 hours per aircraft was assumed, with long-range aircraft utilization set 20% higher than the average, and short-haul aircraft 20% lower.

The average hourly costs used in computing aircraft delay costs are shown below. It should be noted that these are incremental costs only and carry no allocation of indirect and overhead expense.

Year	Average Operating Costs per Hour
1959	$205
1960	245
1961	265
1962	285
1963	310

The number of hours of aircraft delay (see Appendix A, Table 11) was estimated by applying the average amount of air and ground delay per instrument approach in 1957 (as derived in the previous study) to the estimated number of instrument approaches by commercial airlines for the 1959-1963 period (see Appendix A, Table 7). The number of instrument approaches was considered to be a function of the number of aircraft departures required to handle passenger traffic volumes in the 1959-1963 period

The dollar loss to commercial airlines as a result of aircraft delay in periods when weather conditions are below authorized limits (shown for 22 selected airports and total U.S in Appendix A, Table 12) is summarized below

Year	Annual Cost of Delays Due to Weather
1959	$3,926,000
1960	4,588,000
1961	4,910,000
1962	5,253,000
1963	5,695,000

Costs of Flight Cancellations

When airlines are forced to cancel flights because of adverse weather conditions they are subjected to increased expense and to losses in revenues. Some direct flight expense is saved as a result of not flying the cancelled mileage, but, on a net basis, flight cancellations result in losses to airlines Normal operating expense is increased when a flight is cancelled because (1) of a need to provide hotel facilities, meals or another form of transportation to inconvenienced passengers, (2) accommodating passengers on other flights involves duplicate reservations and ticketing costs, and the handling of ticket-refund requests involves additional accounting costs, and (3) positioning of aircraft in order to work them back into a normal rotation schedule scheme is often necessary after flights have been cancelled, involving nonrevenue ferry flights and additional flight operation and maintenance expense.

1. Interrupted Trip Expense. The expense of providing accommodations to passengers inconvenienced by flight cancellations is reflected in this category. Unit expenses (i e., interrupted trip expense per cancelled aircraft departure) have been analyzed for past periods in order to project a reasonable rate for the future. Despite increases in aircraft capacity, interrupted trip expense per aircraft departure showed some decline in the 1957-1959 period. In projecting unit costs it was assumed that the rate would have stabilized by 1960 and would increase by two per cent annually through 1963. Estimated annual interrupted trip costs are shown in Appendix A, Table 13

2. Duplicate Passenger Handling Expense. The increased expenses associated with duplicate handling of passengers at ticket counters and by reservations offices as well as the handling of ticket refunds are assumed to be a function of traffic handled The incremental costs of ticketing and making reservations for air passengers were recently submitted by carriers participating in the Passenger Credit Plan Investigation, CAB Docket 10917 These estimates range from one to four per cent of passenger revenue. A rate of two per cent has been selected for the purposes of this study, although it is recognized that the figure may be conservative for the experience of certain carriers The rate has been applied to the revenue represented by passenger bookings on the flights cancelled because of weather conditions Annual costs for duplicate reservations, tickets and accounting are shown in Appendix A, Table 13

3. Ferry Mileage Expense. Ferry mileage accounts for approximately 10% of total nonrevenue mileage operated by domestic airlines. Of this mileage, a portion is flown in order to relocate aircraft after flight cancellations have disrupted normal aircraft distribution.

Recorded data are not available from which to determine precisely the amount of nonrevenue ferry mileage flown for the purpose of relocating aircraft after cancellation due to weather. In the absence of actual data, it is assumed that 50% of total ferry mileage is flown for this purpose.

In projecting ferry mileage it was assumed that a ratio of 1.6% would apply between nonrevenue and revenue miles and a ratio of 10% between ferry mileage and total nonrevenue miles. With the assumption that 50% of all ferry mileage is generated as a result of weather cancellations, it follows that ferry mileage operated to relocate aircraft after weather cancellations will be equal to 08% of total revenue miles. Revenue miles are based upon the passenger traffic forecast shown in Section IV.

The incremental flight operation and direct maintenance costs incurred by airlines in operating nonrevenue ferry flights are identical to the flight costs incurred in weather delays (see p. 12). The application of these hourly flight costs to the number of hours required to fly the estimated ferry mileage results in total costs incurred by airlines in positioning aircraft after weather cancellations. These costs (see Appendix A, Table 13) are given below

Year	Cost of Ferrying Aircraft
1959	$605,000
1960	596,000
1961	595,000
1962	628,000
1963	658,000

In addition to the costs involved in cancelling flights, airlines are subjected to losses in passenger revenue as booked passengers turn to other modes of transportation in order to complete journeys. Not all of the traffic booked on cancelled flights is lost to air transportation, however, for a shift of passengers from cancelled flights to operating flights does occur in some degree. The portion of traffic booked originally on a cancelled flight and retained on other flights varies in direct proportion to the length of the passenger journey involved The shorter the passenger trip, the less will be the shift of traffic to other flights; conversely, the longer the passenger trip, the higher will be the percentage of traffic retained on other flights. When a short-haul flight is cancelled because of weather conditions, it is much simpler for a passenger to find an alternative mode of transportation and still reach his destination within a reasonable length of time. In long-haul services such possibilities do not exist and the passenger is more likely to try to find accommodations on a later flight and still travel by air.

Although this shift from cancelled flights to operating flights does occur, it is impossible to identify the traffic involved and to measure the shift precisely. Theoretically, this traffic shift could be identified by means of a name search and a comparison of airline reservations cards and passenger lists The process would be a laborious and unmanageable task at the best, however, and the statistical findings would remain suspect. To account for the passengers holding reservations on a cancelled flight of a given airline, it would be necessary to determine how many of the passengers were accommodated on flights of another airline, how many were diverted to another mode of transportation, and how many gave up their travel plans entirely. To account for the numbers of passengers involved in cancelled flights by <u>all</u> carriers would be impossible, for all practical purposes

It is necessary, therefore, to make assumptions regarding the percentage of booked passengers who would continue to travel by air in the event their flights were cancelled due to weather conditions After discussions with operating personnel at airlines with both long-haul and short-haul characteristics, it was decided to use the following assumptions in regard to traffic retained.

Length of Passenger Journey	Per Cent of Booked Passenger Revenue Retained
0- 500 miles	25%
501-1,000 miles	50
1,000 miles or over	75

When these assumptions were applied to traffic volume by mileage groups in the CAB Origination-Destination Air Traffic Survey for 1958 (latest published data available) and consideration paid to differing fare yields, the weighted average rate of traffic retention for all domestic air travel was 47%. This is the average retention rate applicable to total travel and not to individual carriers, however. It is obvious that carriers whose traffic is primarily short-haul in nature will retain a much lower rate of traffic and will incur severe passenger revenue losses in periods of bad operating weather. Also, it should be noted that the assumed rate of traffic retention applies to trunk and local service carriers as a whole. The portion of an individual carrier's own traffic that is retained would be lower. When a carrier cancels a flight because of bad weather, some of the booked passengers may transfer to later flights of another carrier. While this constitutes a loss to one airline, it does not represent a loss to air transportation as a whole.

It was assumed that the average cancelled flight carried traffic with passenger-journey and load-factor characteristics of the national average; i.e , if the load factor for all domestic trunk and local service carriers is 60% for any given year, it was assumed that the average flight cancelled because of weather reasons would also have a load factor of 60% Also, the assumption that the average journey of passengers on cancelled flights is equal to that of all domestic air travel means that the loss to air transportation will be 53% (in terms of the 1958 traffic distribution by length of passenger journey) A similar assumption was made in regard to fare yields, the determination of which considered recent trends in first class/coach traffic relationships

The application of these assumptions in regard to load factor, length of passenger journey, fare yield, and traffic loss to actual and projected average seats per aircraft departure results in the estimates of the passenger revenue lost to air carriers per average flight cancellation shown below.

Year	Average Passenger Revenue Loss Per Flight Cancellation Due to Weather Conditions
1959	$273
1960	302
1961	337
1962	372
1963	408

It has been determined that the number of flights cancelled for weather reasons amounts to 1 14% of annual flight departures The application of this factor to the total number of airline flight departures required to handle traffic volumes in the 1959-1963 period produces the number of flights cancelled by airlines because of adverse weather conditions (see Appendix A, Table 14)

Passenger revenue losses (shown in Appendix A, Table 13) are summarized below.

Year	Annual Passenger Revenue Losses
1959	$14,989,000
1960	18,930,000
1961	20,694,000
1962	22,730,000
1963	24,858,000

While airlines suffer substantial losses in passenger revenues when flights are cancelled, they are able to save some operating expense as a result of not flying the cancelled mileage. Short-run cash savings occur primarily in the categories of flight crew salaries and expenses and in fuel costs. As direct maintenance expense is a function of aircraft hours flown, costs are saved in proportion to the reduction in flying hours; these savings are spread over the entire maintenance and overhaul period, however, and are not realized immediately.

Because of the influence of fixed components in flight and maintenance crew scheduling, it has been concluded that the unit costs saved as a result of <u>not</u> flying a scheduled trip are less than the incremental increased costs of <u>overflying</u> a trip. The unit flight costs derived for use in computing delay costs have been discounted, therefore, in determining cost savings from flight cancellations.

Generally speaking, no ground and indirect cost savings are possible when scheduled flights are cancelled Reservations and ticketing costs have been incurred and are usually duplicated in attempts to accommodate passengers on other flights. Ticket refunds are a source of additional expense and no savings are possible in aircraft handling expense; the only expense saved therefore, is in direct aircraft operating costs and in the in-flight passenger service categories of hostess salaries and food.

Total savings accruing to airlines as a result of cancelled mileage are reflected in the product of the hourly unit costs described in the preceding paragraphs and the number of aircraft hours cancelled. The number of aircraft hours cancelled is derived by applying a weighted average speed to the number of miles cancelled for weather reasons. The method of estimating cancelled revenue mileage has been explained in the discussion of revenue losses.

The cost savings resulting from flight cancellations are shown below.

Year	Annual Cost Savings in Aircraft Operating Expense
1959	$12,165,000
1960	18,433,000
1961	19,036,000
1962	18,941,000
1963	18,704,000

The net losses incurred from flight cancellations, represented by the total additional operating expense incurred plus the amount of passenger revenue loss less the costs saved as a result of not flying the cancelled mileage, are given below.

Year	Net Costs of Flight Cancellations
1959	$6,524,000
1960	4,817,000
1961	6,122,000
1962	8,511,000
1963	11,138,000

Cost of Flight Diversions

When an aircraft on a scheduled flight is diverted to an alternate airport as the result of inability to land at the scheduled destination airport, airline operating expenses are increased because of delay and disruption.

1 Costs of Delay. Because aircraft must fly on to an alternate airport, additional flight costs are incurred in proportion to the amount of delay involved Such delay is measured by the difference between the amount of block-to-block time scheduled and that actually required to fly between the departure airport and the alternate airport used.

The identification of aircraft delay time due to diversions is not possible in recorded airline operating statistics In order to recognize the additional flight costs incurred as a result of diversions, it is necessary to estimate the average delay time per diversion. After discussions with airline operating personnel, it has been concluded that an assumption of one hour delay per flight diversion would be reasonable. This average delay time recognizes the possibility of spending some time holding over the scheduled destination airport, flying on to an alternate airport and the possibility of holding over that airport before landing. Despite the increased speed of modern jet aircraft, the assumption of one hour per diversion appears reasonable

The total dollar cost to the airlines from this source of delay may be measured by applying the estimated number of flight diversions to the average cost per delay. The average hourly cost applicable to aircraft delay and the methods used in its determination have been discussed under Costs of Flight Delay. The number of flight diversions are assumed to be a function of instrument approaches (see Appendix A, Table 17).

2. Costs of Disruption. Flight diversions disrupt scheduled aircraft distribution as well as passenger journeys. Additional flight costs are involved as a result of aircraft disruptions and passenger service expense ("Interrupted Trip Expense")

As in the case of cancellations, the landing of aircraft at an airport other than its scheduled destination results in a disruption of the normal aircraft rotation used in flight scheduling. When weather clears at the original destination airport, the resumption of scheduled operations there depends upon the availability of aircraft. These can be furnished through the use of spare aircraft (and there is a rigid limitation on the number of airports at which an airline can now station expensive jet aircraft as spares) or the ferrying of aircraft

The possibilities involved in re-positioning aircraft after schedule disruptions are such that it is not always necessary to ferry an aircraft from the alternate airport to the original destination airport. As the airline will take advantage of the most efficient way to re-position the aircraft, it is assumed that the time spent in ferrying the aircraft will be less than the delay due to the diversion. No recorded data are available upon which to base ferry mileage due to this cause, it appears, however, that an assumption of ferry time equal to one-half the delay time due to diversions would be reasonable. Accordingly, an assignment of one-half hour of block time is assigned to each diversion to recognize aircraft disruption costs. Dollar costs to the airlines are represented by the estimated number of flight diversions times the incremental direct aircraft operating costs for thirty minutes.

The expenses involved in accommodating passengers on diverted trips are substantial The problem of providing accommodations and surface transportation are far more severe when flights are diverted to alternate airports than when flights are cancelled In the event of cancellations, the flight may have been scheduled to originate at the home city of a substantial number of the passengers. In the case of a diverted flight, the alternate airport is neither the origination nor the destination city of the inconvenienced passengers.

No studies were available upon which to evaluate the interrupted trip expense for flight diversions with that resulting from flight cancellations. A judgment evaluation set the diversion costs at twice those of cancellations. The average interrupted trip expense incurred per flight cancellation was determined in the paragraphs above relating to Costs of Flight Cancellations. Total dollar costs incurred in diversions were determined by doubling these unit costs per cancellation and applying this cost to the number of flight diversions.

Costs per diversion are shown in Table 16 (Appendix A), and total annual costs (see Appendix A, Table 18) are summarized below.

Year	Annual Costs of Flight Diversions
1959	$2,661,000
1960	3,021,000
1961	3,208,000
1962	3,411,000
1963	3,675,000

Section III

COSTS INCURRED AS A RESULT OF LANDING ACCIDENTS

The inability of aircraft to land safely in all weather conditions is reflected in accidents — from landings that are too short, too long or off the runway These accidents result in loss of life and in property damage to aircraft The payment of claims arising from these accidents results in increased airline costs in the form of direct payments (in the event the carrier is self-insured) or in insurance premiums which reflect both the accident rate and the amount of settlement

The number of landing accidents in adverse weather bears a relationship to the number of instrument approaches to which the airlines are exposed The number of instrument approaches at any airport is determined by the volume of aircraft operations and the time periods in which IFR operations are necessary.

In determining the costs to carriers of landing accidents during the 1959-1963 period, accident data for the years 1956 through 1959 were analyzed in terms of number of landing accidents, types of aircraft involved and the degree of aircraft damage (whether totally or partially destroyed) An investigation was made in regard to the amount of awards for death and personal injury benefits After analysis of these data, an estimate was made of the average aircraft damages incurred in a landing accident and the average amount of injury and death benefits paid per accident.

In estimating costs for the period, 1961-1963, the following procedure was followed

1 The 1956-1959 rate of instrument approaches per aircraft operation was applied to the forecast number of air carrier operations in order to estimate the number of instrument approaches to be made by air carriers (The number of instrument approaches is shown in Appendix A, Table 7.)

2. The 1956-1959 rate of landing accidents per instrument approach, .0000145, was applied to the number of instrument approaches in order to determine an estimate of the number of air carrier landing accidents (See Appendix A, Table 8)

3. Estimates of the average aircraft damage incurred per accident (see Appendix A, Table 9) and the average payment per accident for death and personal injury benefits (see Appendix A, Table 10) was applied to the number of landing accidents. In determining the amount of aircraft damage per landing accident attention was paid to the increased value of aircraft units in carrier fleets This ranged from $824,000 in 1959 to $1,963,000 in 1963 as a result of the transition to fleets composed primarily of jet aircraft. The amount of aircraft damage per landing accident was set at 25% of the aircraft value (carrier experience during the 1956-1959 period) This resulted in average aircraft damage of $206,000 in 1959, increasing to $491,000 in 1963.

In estimating the amounts paid to satisfy claims resulting from loss of life and personal injury, consideration was given to increased passenger loads resulting from increased aircraft seating capacity. The breakdown between fatalities and serious injuries per landing accident were estimated on the basis of the ratio between substantially damaged aircraft and demolished aircraft in the 1956-1959 period. The amount of costs for injuries and deaths was based upon an analysis of claims paid in the recent past The costs per landing accident for injuries and fatalities was estimated to be $2,134,000 in 1959, to decline to $1,669,000 in 1960 (reflecting the 1956-1959 rate), and to increase to $2,466,000 in 1963

The estimated total costs incurred by carriers as a result of landing accidents are shown below.

Year	Annual Landing Accident Costs
1959	$27,738,000
1960	15,022,000
1961	16,434,000
1962	17,957,000
1963	19,730,000

Although carriers may be reimbursed by insurance companies for damages resulting from landing accidents, the face amount of these damages must be recognized as economic costs in the long run, as insurance premiums must be sufficient to cover the damages on an industry-wide, year-in, year-out basis.

The higher costs in 1959 reflect an abnormally high accident rate in that year. Costs in future periods have been estimated on the basis of the rate existing in the 1956-1959 period.

Section IV

LOSSES INCURRED BY COMMERCIAL AIRLINES RESULTING FROM AN INHIBITION IN DEMAND DUE TO UNRELIABILITY OF AIR TRAVEL

A significant source of economic loss incurred by airlines is the reduction in demand for air travel resulting from unreliability in bad-weather months This reduction in potential passenger revenue is in addition to the losses incurred when airlines are forced to cancel flights on which passengers are already booked It exists because of the knowledge on the part of the traveling public that air travel is unreliable in bad-weather months and the fact that the public makes greater use of other modes of transportation during these periods of bad weather

The seasonal variation in the airlines' performance factor (scheduled miles flown as a per cent of scheduled miles) is an indication of unreliability of air travel in the bad-weather months.[1/] The percentage of scheduled mileage flown is at a high plateau during the late spring and summer months, declines in the fall, and drops to a low point in January and February Conversely, the percentage of scheduled miles cancelled rises to a peak during the winter months and is at a low point throughout the spring and summer months. This ratio, the percentage of scheduled miles that are cancelled, may be considered a measure of the current unreliability of air travel.

1/ Monthly performance factors for the U.S domestic trunk and local service airlines in the period 1952-1960 are shown in Table 5 of Appendix A.

It is recognized that this ratio of scheduled miles cancelled is not the sole measure of unreliability of air travel. Other schedule disruptions having an effect on demand, such as long delays and diversions, are not considered in this measure. Until recently, however, this factor has been the only public statistic available with which to measure schedule disruptions. At the present time the domestic carriers are submitting to the CAB monthly reports of the per cent of trips arriving on time or within 15 minutes of scheduled arrival time While these data will provide a means of measuring seasonal variation in delays, at the present time there are insufficient data with which to construct an adequate seasonal variation index.

That the public has recognized the unreliability of air transportation during the bad-weather months is evident in the seasonal relationship between air and rail travel. An analysis of the penetration of air travel in the total first class air and rail market indicates a peaking in the spring and summer months, a decline in the fall and low point in January and February. (These market penetration data for the 1952-1960 period are shown in Appendix A, Table 6.) These seasonal fluctuations in penetration bear a strong resemblance, of course, to the seasonal fluctuations of the reliability of air travel.

The seasonal relationship between the market penetration of air travel and air reliability over the 1952-1960 period has been plotted and is shown in Chart 1. Over this period the penetration of air travel into total first class air and rail travel has been substantial. This growth has been due to many factors, including the influences of fare changes, the increasing speed of aircraft, changes in the reliability of air travel, and the important intangible factor of a growing awareness on the part of the traveling public of the advantages of air travel in the conduct of business and social activity.

While it is impossible to measure satisfactorily the discrete effects of each of these factors on the demand for air travel, it is possible to measure the influence of seasonal changes in the reliability of air travel on seasonal changes in the market penetration of air travel, once annual trend values have been removed. This is accomplished by determining monthly deviations of reliability and market penetration data from their respective twelve-month moving averages and then comparing the two series These deviations have been plotted by month for the 1952-1960 period and are shown in Chart 2. As the chart indicates, there is a close relationship between the monthly deviations for reliability and those for penetration. Deviations increase in the summer months and decrease in the winter months for both series of data.

The establishment of this close seasonal relationship between reliability and penetration indicates that the monthly changes in market penetration have come about as a result of the monthly changes in reliability since none of the other factors affecting air travel — changes in fares, speed, volumes of service, etc — occur on a regular monthly seasonal pattern.

These observations of the changing relationships over time of reliability and penetration data can provide a measure of the influence of the reliability of air travel on the demand for air travel If past changes in reliability have brought about changes in demand, then the relationships between these changes can be used to predict future changes in demand

In the problem at hand, that of measuring the losses in passenger revenue incurred by airlines as a result of the present state of unreliability of air travel, the economic benefits to accrue as a result of improving reliability can be regarded as the economic cost of the existing state of unreliability That is, if it is possible to improve the reliability of air travel by a given amount through an improvement in the air traffic control system and thus increase the demand for air travel, then the economic cost of the existing state of unreliability can be measured by the dollar value of the change in demand.

Measuring the dollar costs to air carriers of the effect on demand of the existing state of unreliability of air travel due to weather conditions involves the following procedure.

1 Determining the existing degree of unreliability of air travel due to weather conditions

2. Establishing that a relationship exists between unreliability and demand.

   Estimating the degree of change in demand that will be brought about by an elimination of unreliability.

3. Applying the estimated change in demand to the level of air carrier traffic (and revenue) existing in any given period.

1 Degree of Existing Unreliability The degree of existing unreliability in air travel that is due to weather factors can be measured by the differences between the percentages of scheduled mileage cancelled in bad-weather months, the peak period of flight cancellations, and that cancelled in good weather months, when cancellations are low. The residual cancellations in good-weather months are assumed to be the result of nonweather factors, principally mechanical failures.

This is not strictly a true measure, for it understates slightly the influence of weather on cancellations in the summer months and overstates slightly its influence in winter months The understatement arises from the assumption that all flight cancellations in summer months are due to nonweather factors While this is generally true, nevertheless it is a fact that some flight cancellations occur in summer months as a result of weather conditions

On the other hand, however, the assumption that, with an improvement in the existing landing system, the same percentage of flights will be cancelled in winter months as in summer months overlooks the fact that heavy snowfalls will continue to cause flight cancellations in winter months because of runway snow removal problems While it is impossible to measure precisely the influence of these factors, it is reasonable to assume that they will have offsetting characteristics so that the difference existing between the percentage of scheduled mileage cancelled in winter months and that cancelled in good-weather months may be considered an adequate measure of the degree of unreliability chargeable to adverse weather conditions

The percentage of flights cancelled in peak performance months has been increasing since 1954.

Year	% of Scheduled Mileage Cancelled in Peak Performance Month
1952	0.80%
1953	1 26
1954	0 97
1955	0.99
1956	1.03
1957	1 19
1958	1.52
1959	1 67
Average	1 14%

This increase in the degree of unreliability in peak performance months has been due to increased congestion at airports, to maintenance difficulties associated with specific aircraft types, and to a change in the statistical reporting by carriers which may distort recent performance factors slightly in comparison with past periods In prior periods it was the airlines' procedure to continue to designate a delayed flight with the same flight number, at the present time, there is a tendency for airlines to cancel a flight that is delayed and to reinstate it with a different flight number In comparison with previous periods, this change in procedure has the effect of lowering the performance factor and increasing the number of miles reported as extra-sections to the Civil Aeronautics Board.

It is assumed that the influence of these factors will not continue to increase and that the average rate of cancellation during the peak-performance months of 1957, 1958 and 1959 — 1 46% — is a reasonable measure of unreliability due to nonweather factors for the 1959-1963 period The amount of unreliability due to weather factors is measured by the difference between unreliability due to all factors and that due to non-weather factors The average percentage of scheduled mileage cancelled for all reasons during the 1952-1959 period is 2 60%; annual data have shown little variation in that period, with the exception of 1956.

Year	% of Scheduled Mileage Cancelled (Annual)
1952	2.83%
1953	2 53
1954	2.18
1955	2.17
1956	3.32
1957	2 54
1958	2.61
1959	2.63
Average	2 60%

With 2 60% representing the degree of unreliability due to all factors and 1 46% to nonweather factors, it can be concluded that a factor of 1 14% represents the degree of unreliability due weather factors alone

2 Establishing Relationship between Unreliability and Demand. The existence of a relationship between the unreliability of air travel and the demand for air travel has been established previously in the discussion of the seasonal changes in schedule reliability and the penetration of the total first class air and rail travel market The existence of a close

relationship is an indication that changes in reliability have had an influence on changes in demand

It is necessary to determine the degree of change in penetration associated with a given change in reliability. This may be accomplished by relating the sum of monthly deviations from twelve-month moving averages for the market penetration data to the sum of reliability deviations. (See Chart 2) These ratios for each year in the series are shown below.

1953	2 11
1954	1 76
1955	1 65
1956	0.79
1957	0.87
1958	1 14
1959	1.03

From these data one may conclude that an increase in air travel reliability in the 1952-1955 period produced substantially more than a proportionate increase in market penetration In the 1956-1957 period, a change in reliability brought about a less-than proportionate change in air travel's share of the market; in 1958-1959 the change was slightly more than proportionate For the period as a whole, it appears that an assumption of a one-to-one relationship would appear to be reasonable

Thus, it appears that a given percentage increase in reliability will bring about the same percentage in the demand for air travel As the change in reliability being considered in this study is the total elimination of unreliability due to weather conditions (1 14%), one may conclude further that elimination of this source of unreliability would bring about an increase of 1 14% in the demand for air travel. This 1 14% factor, when related to a given level of traffic, may be considered as a measure of the loss being incurred by the airlines as the result of an inhibition in demand due to unreliability

3 Applying the Estimated Change in Demand to a Given Level of Traffic. With the determination of a 1.14% factor as a measure of the effect of existing unreliability on the demand for air travel, it remains to apply this factor to the level of demand existing in any period. This level of demand may be measured in terms of passenger revenue, the product of revenue passenger miles and the average fare yield per passenger mile.

To determine losses to air carriers in the 1959-1963 period it is necessary to forecast the level of demand (passenger traffic) for the period 1961-1963. Methods used in forecasting passenger traffic were developed in the "Curtis Report."1/ The basis of the forecasting method is the relationship between economic activity, as measured by Gross National Product, and first class air and rail travel. (The definition of first class air travel includes one-third of coach and family fare travel, on the assumption that this traffic has been diverted from first class travel.)

With the establishment of a relationship between first class travel and Gross National Product (this relationship was determined to be 65 first class passenger miles per $1,000 of Gross National Product in 1947 dollars), total first class travel may be projected through the use of a forecast of Gross National Product

The first class air market was determined by projecting the penetration of air travel into the total first class market for 1953-1958 by mileage groups A penetration limit of 90% was placed on passenger journeys of 100 miles or less and 95% on journeys of 500 miles or over Coach air travel

---

1/ United Research Inc., National Requirements for Aviation Facilities: 1956-1975, Volume IV, prepared for Edward P Curtis, Assistant to the President.

was predicted on the basis of its penetration of the total air travel market by journey length. The CAB Airline Traffic Surveys for March and September 1953 and March and September 1958 were used to compute the percentage of coach travel in each mileage group The trend of this percentage between 1953 and 1958 was projected on semi-logarithmic scale paper to a maximum of 75% in mileage groups under 1,500 miles, and 80% in mileage groups of 1,500 miles and over An exception was made in the case of the 1,100-1,199 mileage group, which includes the predominantly coach New York-Miami market, where the penetration was allowed to reach 80% This boundary limit on coach penetration was based on the theory that such factors as the prestige value of first class travel would be a deterrent to the complete absorption of the market by coach

Based upon the forecast of first class travel and the estimated coach penetration, the size of the total market was determined after making allowance for the traffic-generating effect of jet aircraft which were not operative in past periods. Data are not yet available upon which to base any conclusive findings as to the ability of jet aircraft to generate new traffic, however, it is reasonable to assume that there will be such traffic generation as a result of the increased business and personal travel opportunities created by the greater speeds inherent in jet aircraft As these benefits will accrue principally to long-haul traffic, it is assumed that the traffic-generating effect of jet aircraft will be on the order of 10% for travel in the 1,000-1,499 mileage blocks and 15% in the 1,500-and-over mileage blocks The resulting forecast of passenger miles for domestic trunk and local service carriers is shown in the following tabulation.

Year	Revenue Air Passenger Miles (billions)
1961	32 93
1962	34 97
1963	37 14

First class rail travel, which is the other component in the total market available to the airlines, has been decreasing steadily ever since World War II

Year	First Class Rail Passenger Miles[1/] (billions)
1946	16.93
1947	10 48
1948	9 42
1949	7 99
1950	7.98
1951	8 74
1952	8 13
1953	6 80
1954	5 86
1955	5 51
1956	5.37
1957	4.43
1958	3 63
1959	3 23

If the steady trend downward which has been evident since the end of the Korean war were maintained, there would be no first class rail travel after 1964 The first six months of 1960 show first class rail travel running at 96 48% of the first six months of 1959 If this ratio persists, the 1960 figure will be 3 12 billion passenger miles For the rest of the forecast period, the level of first class rail passenger miles is estimated to level off at 3 00 billion passenger miles a year The forecast of the combined market of total air plus first class rail follows

---

1/ Adjusted for 17% circuity

Source Association of American Railroads, Statistics of Railways of Class I

Year	Total Air and First Class Rail Revenue Pass. Miles (billions)
1957	29.76
1958	29 03
1959	32 55
1960	34.12
1961	35 93
1962	37 97
1963	40.14

A constant average yield of 6 0 cents per passenger mile has been assumed for the entire forecast period on the basis that the influence of an increasing proportion of coach traffic will tend to offset the effect of any future increases in the fare level. The application of this average fare yield to the forecast volume of passenger miles results in a dollar measure of the existing demand for air travel

As the influence of unreliability due to weather conditions on the demand for air travel was determined to be 1 14%, the dollar losses in passenger revenue resulting from the current degree of unreliability can be measured by applying the factor of 1.14% to current and forecast levels of passenger revenue The resulting revenue losses are shown below.

1959	$17,343,000
1960	23,340,000
1961	24,576,000
1962	25,974,000
1963	27,456,000

It is recognized that the net loss to the airlines of reduced demand is somewhat less than that indicated by passenger revenue losses alone There are some cost savings associated with <u>not</u> handling the traffic at the present time These are minor in comparison with the amount of revenue, however, and are limited to incremental costs incurred in reservations, ticketing and revenue accounting and in-flight passenger services. The volume of traffic involved, 1.14%, is so small and airline load factors (approximately 60%) are sufficiently low to warrant an assumption that the traffic resulting from the increased demand could be carried on existing flights. No direct aircraft operating costs are saved as a result of the 1 14% reduction in the demand for air travel resulting from the current state of unreliability of air travel.

An allocation to 22 selected airports is shown in Table 2 of Appendix A Total U S losses have been allocated to individual airports in the same ratio as that existing between individual airports and the U S total in cost savings.

APPENDIX A

Exhibits

Table 1

ESTIMATED TOTAL AIRLINE LOSSES INCURRED DUE TO INABILITY TO DELIVER PASSENGERS TO DESTINATION AIRPORTS IN ALL WEATHER CONDITIONS

1959 - 1963

(Dollars in thousands)

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif	$1,853	$1,240	$1,323	$1,463	$1,591
Chicago, Ill. (MDW)	4,106	2,790	2,763	2,703	2,665
New York, N Y. (LGA)	1,461	736	796	834	933
Washington, D C (DCA)	1,292	499	529	569	606
San Francisco, Calif	1,197	907	1,027	1,175	1,388
New York, N Y (IDL)	1,313	791	914	1,083	1,284
Pittsburgh, Pa	859	527	499	494	497
Cleveland, Ohio	842	442	483	494	497
Atlanta, Ga.	1,061	765	868	988	1,128
Newark, N.J. (EWR)	1,092	640	731	873	1,086
Detroit, Mich. (YIP)	1,023	431	387	360	303
Portland, Ore (PDX)	824	611	616	663	693
Philadelphia, Pa	822	449	499	568	606
Dallas, Texas	756	695	797	950	1,131
Boston, Mass	1,114	582	684	834	1,042
Houston, Texas	496	373	421	494	563
Minneapolis, Minn	522	403	468	568	693
Cincinnati, Ohio	1,021	345	387	438	497
Chicago, Ill. (ORD)	525	316	387	476	563
Fort Wayne, Ind.	138	108	123	136	151
Rochester, N.Y	387	291	320	360	452
Lexington, Ky	174	137	136	153	168
Subtotal - Selected Airports	$22,878	$14,078	$15,158	$16,676	$18,537
Total U S	$58,185	$50,812	$55,269	$61,088	$67,705

Note: These figures represent the sum of estimated passenger revenue losses (see Table 2), estimated avoidable landing accident costs (see Table 3), and estimated operating costs incurred due to inability to operate (see Table 4)

Table 2

ESTIMATED PASSENGER REVENUE LOSSES DUE TO INABILITY TO DELIVER PASSENGERS TO DESTINATION AIRPORTS IN ALL WEATHER CONDITIONS: 1959 - 1963

(Dollars in thousands)

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif	$ 65	$ 91	$ 91	$ 96	$ 98
Chicago, Ill. (MDW)	326	356	324	285	249
New York, N Y. (LGA)	73	56	56	57	57
Washington, D. C. (DCA)	80	40	40	40	41
San Francisco, Calif	49	68	71	78	85
New York, N.Y. (IDL)	65	58	66	72	80
Pittsburgh, Pa	40	42	37	37	32
Cleveland, Ohio	38	35	52	37	32
Atlanta, Ga	49	58	62	65	68
Newark, N. J. (EWR)	56	49	54	59	68
Detroit, Mich. (YIP)	64	35	29	26	22
Portland, Ore. (PDX)	30	46	46	46	44
Philadelphia, Pa	42	38	37	39	41
Dallas, Texas	31	51	56	63	71
Boston, Mass	62	44	50	57	66
Houston, Texas	22	30	32	37	39
Minneapolis, Minn	21	32	37	39	44
Cincinnati, Ohio	24	28	29	31	32
Chicago, Ill (ORD)	26	26	29	33	39
Fort Wayne, Ind	9	12	13	13	14
Rochester, N Y	22	26	27	26	30
Lexington, Ky	10	14	15	15	14
Subtotal - Selected Airports	$1,204	$1,235	$1,253	$1,251	$1,266
Total U S	$17,343	$23,340	$24,576	$25,974	$27,456

Note: Derivation of total U S passenger revenue losses is explained in Section IV.

Table 3

ESTIMATED ANNUAL AVOIDABLE LANDING ACCIDENT COSTS: 1959 - 1963

(Dollars in thousands)

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif.	$1,302	$ 668	$ 698	$ 741	$ 764
Chicago, Ill. (MDW)	1,280	517	534	516	518
New York, N.Y. (LGA)	832	384	411	404	444
Washington, D C (DCA)	598	250	267	269	271
San Francisco, Calif	790	484	534	584	666
New York, N.Y (IDL)	747	417	472	539	617
Pittsburgh, Pa	512	267	246	225	222
Cleveland, Ohio	512	217	226	225	222
Atlanta, Ga	640	401	452	494	543
Newark, N J (EWR)	619	334	370	427	518
Detroit, Mich (YIP)	469	217	185	157	123
Portland, Ore. (PDX)	576	317	308	314	321
Philadelphia, Pa	469	217	246	269	271
Dallas, Texas	491	367	411	471	543
Boston, Mass.	576	300	349	404	493
Houston, Texas	299	184	205	225	247
Minneapolis, Minn.	341	200	226	269	321
Cincinnati, Ohio	299	167	185	202	222
Chicago, Ill (ORD)	299	150	185	225	247
Fort Wayne, Ind	64	33	41	45	49
Rochester, N.Y	213	134	144	157	197
Lexington, Ky	85	50	41	45	49
Subtotal - Selected Airports	$12,013	$ 6,275	$ 6,736	$ 7,207	$ 7,868
Total U. S	$27,738	$15,022	$16,434	$17,957	$19,730

Note: Data were computed by applying the estimated average cost per accident (see Table 10) to the estimated number of landing accidents Landing accidents were estimated by applying the national rate of avoidable landing accidents per instrument approach (see Table 8) to the estimated number of instrument approaches at each airport (see Table 7).

Table 4

TOTAL AIRLINE OPERATING COSTS INCURRED DUE TO INABILITY TO DELIVER PASSENGERS TO DESTINATION AIRPORTS IN ALL WEATHER CONDITIONS

1959 - 1963

(Dollars in thousands)

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif	$ 486	$ 481	$ 534	$ 626	$ 729
Chicago, Ill. (MDW)	2,500	1,917	1,905	1,902	1,898
New York, N Y (LGA)	556	296	329	373	432
Washington D C (DCA)	614	209	222	260	294
San Francisco, Calif	358	355	422	513	637
New York, N.Y (IDL)	501	316	376	472	587
Pittsburgh, Pa	307	218	216	232	243
Cleveland, Ohio	292	190	205	232	243
Atlanta, Ga.	372	306	354	429	517
Newark, N J (EWR)	417	257	307	387	500
Detroit, Mich (YIP)	490	179	173	177	158
Portland, Ore (PDX)	218	248	262	303	328
Philadelphia, Pa	311	194	216	260	294
Dallas, Texas	234	277	330	416	517
Boston, Mass	476	238	285	373	483
Houston, Texas	175	159	184	232	277
Minneapolis, Minn.	160	171	205	260	328
Cincinnati, Ohio	176	150	173	205	243
Chicago, Ill. (ORD)	200	140	173	218	277
Fort Wayne, Ind.	65	63	69	78	88
Rochester, N.Y	152	131	149	177	225
Lexington, Ky.	79	73	80	93	105
Subtotal-Selected Airports	$ 9,139	$ 6,568	$ 7,169	$ 8,218	$ 9,403
Total U S	$13,104	$12,450	$14,259	$17,157	$20,519

Note: Estimated operating costs represent the sum of costs accruing from reductions in flight delays (see Table 12), reductions in flight diversions (see Table 18) and reductions in flight cancellations (see Table 15) when weather is below operational limits

Table 5

RELIABILITY OF U S. DOMESTIC TRUNK AND LOCAL SERVICE AIRLINES
(Aircraft Miles Performed as Per Cent of Aircraft Miles Scheduled)

Month	1952	1953	1954	1955	1956	1957	1958	1959	1960
January	94.27%	93.48%	94 05%	97 09%	93.80%	94 18%	96 12%	94 98%	94 53%
February	95.71	97 09	97.90	96.78	94.83	95 53	94 60	94 71	95 33
March	94.84	96 23	97 06	97 25	93 89	98.25	97 08	97 60	94.37
April	97 90	98 26	98 33	98.18	98.23	96 85	98 13	98.20	98 54
May	98.11	97 80	98 39	98.83	98.39	98 44	98 09	98.15	98 18
June	98.70	98 64	99.03	99 01	98 97	98 72	97 03	98.32	95.17
July	99 12	98.39	98.97	98 77	98 37	98 47	97 83	98 31	
August	99 07	98.53	98 78	98 17	97 74	98 81	98 48	98 33	
September	99 20	98 73	98 43	98 82	97 93	98.51	98 06	98 33	
October	98 87	98 74	98.15	98 25	98.11	97 94	98 07	97.67	
November	95 85	97 10	97 35	96 93	96.60	97 06	97.61	97.26	
December	94 14	96 26	97.30	95.70	92 93	96.38	97.31	96 05	
Average for year	97.17%	97 47%	97 82%	97 83%	98 68%	97 46%	97 39%	97 37%	

Source: CAB, Monthly Report of Air Carrier Traffic Statistics

Table 6

AIR PENETRATION OF TOTAL AIR AND FIRST CLASS RAIL MARKET 1/

Month	1952	1953	1954	1955	1956	1957	1958	1959	1960
January	50 30%	58.32%	66 40%	73 88%	76 23%	80.81%	85 70%	86.64%	89 17%
February	52 29	62 77	70.52	75 05	76 67	80 82	85 94	87 58	88 81
March	56 50	65 74	72 95	77.29	79 88	85.07	87 79	89.74	89 46
April	61 61	68 86	75.65	79 38	81 42	84 77	88 45	90.72	91 23
May	60 59	70 47	75 91	79.64	82 96	86 39	88 28	91.36	91 82
June	63 62	71 49	76 45	80 19	82 25	86 45	88 40	90.78	90 76
July	65 07	71 09	76.82	80 48	81 07	86 48	88.27	90.46	
August	65 57	72.80	73.57	80 14	82 09	87.56	88 86	90.96	
September	65.95	72 96	76.78	80 95	82 95	87.65	89 46	91 73	
October	66 42	71 65	76.27	80 47	82 94	87 14	88 86	91.45	
November	64 77	70 65	76 16	77 76	81.85	86 60	87.54	91.27	
December	61.63	70.89	76 59	77 92	81 38	86 77	85.28	89.76	
Average for year	61.30%	69 00%	74.60%	78.70%	81 05%	85.62%	87 80%	90.28%	

1/ Total U S domestic airline revenue passenger miles as a per cent of combined air passenger miles and first class rail passenger miles (Note that the rail passenger mile data have been adjusted for 17% circuity)

Sources: CAB, Monthly Report of Air Carrier Traffic Statistics, ICC, Passenger Traffic Statistics (Other Than Commutation) of Class I Railroads in the United States, Statement No M-250

Table 7

ESTIMATED NUMBER OF INSTRUMENT APPROACHES: 1959 - 1963

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif.	26,876	25,275	23,895	22,665	21,490
Chicago, Ill (MDW)	26,718	19,658	17,782	16,031	14,327
New York, N.Y (LGA)	17,359	14,603	13,893	12,714	12,122
Washington, D C. (DCA)	12,407	9,548	8,891	8,292	7,714
San Francisco, Calif	16,453	17,974	18,338	18,242	18,735
New York, N Y (IDL)	15,589	15,727	16,115	16,584	17,082
Pittsburgh, Pa	10,835	10,110	8,336	7,186	6,061
Cleveland, Ohio	10,741	8,425	7,780	7,186	6,061
Atlanta, Ga	13,475	15,165	15,004	14,925	14,878
Newark, N J. (EWR)	12,700	12,357	12,781	13,267	14,327
Detroit, Mich. (YIP)	9,665	7,863	6,113	4,975	3,306
Portland, Ore. (PDX)	11,888	11,795	10,558	9,950	8,816
Philadelphia, Pa	9,947	8,425	8,336	8,292	7,714
Dallas, Texas	10,046	13,480	13,893	14,373	14,878
Boston, Mass.	11,752	11,233	11,670	12,714	13,776
Houston, Texas	6,089	6,740	6,668	7,186	7,163
Minneapolis, Minn	6,917	7,302	7,780	8,292	8,816
Cincinnati, Ohio	6,319	6,178	6,113	6,081	6,061
Chicago, Ill (ORD)	6,158	5,617	6,113	6,634	7,163
Fort Wayne, Ind	1,239	1,123	1,111	1,106	1,102
Rochester, N.Y.	4,559	5,055	5,001	4,975	5,510
Lexington, Ky.	1,934	1,685	1,667	1,658	1,653
Subtotal-Selected Airports	249,666	235,338	227,838	223,328	218,755
Total U S.	574,478	561,672	555,700	552,794	551,020

Source: FAA, Air Traffic Activity, 1959

Table 8

ESTIMATED AVOIDABLE LANDING ACCIDENTS: 1959 - 1963

	1959	1960	1961	1962	1963
Total Aircraft Operations 1/	7,118,000	6,960,000	6,886,000	6,850,000	6,828,000
Total Instrument Approaches 2/	574,478	561,672	555,700	552,795	551,020
Avoidable Landing Accidents per Instrument Approach	.0000226	.0000160	.0000144	0000145	0000145
Avoidable Landing Accidents	13	9	8	8	8

1/ Data from National Requirements for Aviation Facilities, 1956 - 1975.

2/ Projections for 1960 - 1963 are based on the 1959 ratio of instrument approaches to total aircraft operations.

Sources: CAB, Resume of U S. Civil Air Carrier and General Aviation Aircraft Accidents, 1956-1959; CAA, Federal Airways Activity Reports, 1956-1957, FAA, Activities at Air Traffic Control Facilities, 1958-1959, Airlift Magazine, May 1960, CAB, Monthly Report of Air Carrier Traffic Statistics, December 1950-1959

Table 9

ESTIMATED UNIT VALUE OF AIRCRAFT DAMAGED OR DESTROYED: 1959 - 1963

	1959	1960	1961	1962	1963
Number of Aircraft in Service 1/	1,508	1,484	1,386	1,241	1,128
Depreciated Value of Aircraft (in millions)	$1,037	$1,623	$1,815	$1,760	$1,845
Insured Value of Aircraft (in millions)	$1,244	$1,947	$2,178	$2,112	$2,214
Unit Value of Aircraft Destroyed (in thousands)	$ 824	$1,313	$1,571	$1,702	$1,963
Loss per Aircraft Damaged (in thousands)	$ 206	$ 328	$ 393	$ 426	$ 491

1/ Assumes full retirement of piston and Viscount fleets (with the exception of approximately 250 DC-3's) accomplished on a straight line basis to 1965. Current and anticipated turbine orders phased in 1961-1963

Sources: American Aviation, April 21, 1958, Airlift Magazine, May 1959-1960, Air Transport Facts and Figures, 1960, Boeing Transport Division, Airline Fleets of the World, January 1960, Boeing Transport Division, Turbine Transport Original Orders - November 1959, Aircraft Exchange, November 24, 1960, URI, The Market for Used Aircraft, 1957.

Table 10

ESTIMATED AVERAGE COST PER AVOIDABLE LANDING ACCIDENT: 1959 - 1963

(Dollar figures in thousands)

	1959	1960	1961	1962	1963
Number of Aircraft: 1/					
Substantially Damaged	9	7	6	6	6
Destroyed	4	2	2	2	2
Total	13	9	8	8	8
Number of Persons: 2/					
Seriously Injured	10	10	11	12	12
Fatally Injured	116	50	53	57	60
Value of Aircraft:					
Substantially Damaged	$ 1,854	$ 2,296	$ 2,358	$ 2,556	$ 2,946
Destroyed	3,296	2,626	3,142	3,404	3,926
Subtotal	5,150	4,922	5,500	5,960	6,872
Payments to Persons: 3/					
Seriously Injured 3/	$ 200	$ 250	$ 281	$ 312	$ 318
Fatally Injured 4/	22,388	9,850	10,653	11,685	12,540
Subtotal	22,588	10,100	10,934	11,997	12,858
Total Cost of Accidents	$27,738	$15,022	$16,434	$17,957	$19,730
Estimated Cost per Accident	$ 2,134	$ 1,669	$ 2,054	$ 2,245	$ 2,466
Fatalities per Accident	8 9	5 6	6 6	7 1	7 5

1/ Projections for 1960 - 1963 are based on the 1956 - 1959 ratio of substantially damaged aircraft to total aircraft involved in avoidable landing accidents

2/ Projections for 1960 - 1963 are based on the 1956 - 1959 experience and a growth rate equal to that of the average number of seats per aircraft (see National Requirements for Aviation Facilities, 1956 - 1975).

3/ Estimated to increase $5,000 per year per injury between 1958 and 1960, and 2% per year thereafter

4/ Estimated to increase 2% per year per fatality

Sources: Time, Inc , Fortune Airlines Study, Spring 1959, Port of New York Authority, New York's Domestic Air Travelers, 1956, CAB, Resume of Civil Air Carrier and General Aviation Aircraft Accidents, 1956 - 1959.

Table 11

ESTIMATED HOURS OF AIRCRAFT DELAY DUE TO WEATHER: 1959 - 1963

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif.	487	463	442	424	414
Chicago, Ill (MDW)	8,226	6,053	5,475	4,936	4,411
New York, N.Y (LGA)	344	303	292	275	266
Washington, D C. (DCA)	270	227	217	208	200
San Francisco, Calif	331	354	359	358	365
New York, N.Y. (IDL)	318	320	326	333	340
Pittsburgh, Pa.	247	236	209	192	175
Cleveland, Ohio	245	210	201	192	175
Atlanta, Ga	286	311	309	308	307
Newark, N J. (EWR)	275	269	276	283	300
Detroit, Mich (YIP)	229	202	176	159	134
Portland, Ore (PDX)	262	261	242	233	216
Philadelphia, Pa.	233	210	209	208	200
Dallas, Texas	235	286	292	300	307
Boston, Mass	260	252	259	275	291
Houston, Texas	175	185	184	192	191
Minneapolis, Minn.	188	194	201	208	216
Cincinnati, Ohio	179	177	176	175	175
Chicago, Ill. (ORD)	176	168	175	184	191
Fort Wayne, Ind	103	101	101	101	101
Rochester, N Y	152	160	159	158	167
Lexington, Ky	113	109	109	109	109
Subtotal - Selected Airports	13,334	11,051	10,389	9,811	9,251
Total U S	19,153	18,726	18,527	18,430	18,371

Note: Data were derived as a function of instrument approaches ($y = 84 + 015x$), for total U S. and Chicago (MDW) the 1957 relationship to total U S instrument approaches was used

Table 12

ESTIMATED COST OF AIRCRAFT DELAY DUE TO WEATHER: 1959 - 1963

(Dollars in thousands)

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif.	$ 100	$ 113	$ 117	$ 121	$ 128
Chicago, Ill. (MDW)	1,686	1,483	1,451	1,407	1,368
New York, N.Y. (LGA)	71	74	77	78	83
Washington, D. C (DCA)	55	56	58	59	62
San Francisco, Calif.	68	87	95	102	113
New York, N Y (IDL)	65	78	86	95	106
Pittsburgh, Pa	51	58	55	55	54
Cleveland, Ohio	50	52	53	55	54
Atlanta, Ga.	59	76	82	88	95
Newark, N.J. (EWR)	56	66	73	81	93
Detroit, Mich. (YIP)	47	49	47	45	42
Portland, Ore (PDX)	54	64	64	66	67
Philadelphia, Pa.	48	52	55	59	62
Dallas, Texas	48	70	77	86	95
Boston, Mass	53	62	69	78	90
Houston, Texas	36	45	49	55	59
Minneapolis, Minn.	39	48	53	59	67
Cincinnati, Ohio	37	43	47	50	54
Chicago, Ill. (ORD)	36	41	47	52	59
Fort Wayne, Ind.	21	25	27	29	31
Rochester, N Y.	31	39	42	45	52
Lexington, Ky	23	27	29	31	34
Subtotal-Selected Airports	$2,734	$2,708	$2,753	$2,796	$2,868
Total U S	$3,926	$4,588	$4,910	$5,253	$5,695

Note: Data are derived from the estimated hours of aircraft delay (see Table 11) and the estimated direct operating costs per hour of in-flight delay (see Table 16).

Table 13

ESTIMATED COST PER FLIGHT CANCELLATION DUE TO WEATHER: 1959 - 1963

(Dollars in thousands)

	1959	1960	1961	1962	1963
Passenger Revenue Loss Due to Flight Cancellations 1/	$14,989	$18,930	$20,694	$22,730	$24,858
Expense of Operating Nonrevenue Ferry Mileage 2/	605	596	595	628	658
Passenger Service - Interrupted Trip Expense 3/	2,443	2,917	3,009	3,116	3,290
Duplicate Reservations, Ticketing and Accounting Expense 4/	652	807	860	978	1,036
Gross Costs	$18,689	$23,250	$25,158	$27,452	$29,842
Less: Savings in Aircraft Operating Expense	12,165	18,433	19,036	18,941	18,704
Net Costs	$ 6,524	$ 4,817	$ 6,122	$ 8,511	$11,138
Number of Flight Cancellations	54,309	62,605	61,408	61,101	60,926
Cost per Flight Cancellation	$ 120	$ 78	$ 100	$ 139	$ 183

1/ Represents that portion (47%) of total passenger revenue booked on cancelled flights which is lost to other modes of transportation and to discontinuance of travel

2/ Estimated as 5% of nonrevenue mileage, nonrevenue mileage was estimated as 1 6% of revenue mileage projected for U.S. domestic carriers in National Requirements for Aviation Facilities, 1956 - 1975.

3/ Based upon 1956 - 1959 cost per flight cancellation

4/ Estimated as 2% of passenger revenue lost to airlines as a result of flight cancellations

Table 14

ESTIMATED NUMBER OF FLIGHT CANCELLATIONS DUE TO WEATHER: 1959-1963

Airport	Actual 1959	Estimated 1/ 1960	1961	1962	1963
Los Angeles, Calif.	2,081	2,793	2,641	2,505	2,376
Chicago, Ill (MDW)	4,188	2,172	1,965	1,772	1,584
New York, N Y (LGA)	3,248	1,614	1,535	1,405	1,340
Washington, D C (DCA)	4,046	1,055	921	917	853
San Francisco, Calif	1,661	1,986	2,026	2,016	2,071
New York, N.Y. (IDL)	2,906	1,738	1,781	1,833	1,889
Pittsburgh, Pa	1,579	1,117	921	794	670
Cleveland, Ohio	1,466	931	860	794	670
Atlanta, Ga.	1,957	1,676	1,658	1,650	1,645
Newark, N.J. (EWR)	2,393	1,365	1,412	1,466	1,584
Detroit, Mich. (YIP)	3,187	869	675	550	366
Portland, Ore. (PDX)	719	1,303	1,167	1,100	975
Philadelphia, Pa.	1,676	993	921	917	853
Dallas, Texas	1,024	1,490	1,535	1,589	1,645
Boston, Mass.	2,944	1,241	1,290	1,405	1,523
Houston, Texas	778	745	737	794	792
Minneapolis, Minn	602	807	860	917	975
Cincinnati, Ohio	770	683	675	672	670
Chicago, Ill. (ORD)	982	621	675	733	792
Fort Wayne, Ind	162	124	123	122	122
Rochester, N.Y.	682	559	553	550	609
Lexington, Ky.	218	186	184	183	183
Subtotal-Selected Airports	39,269	26,068	25,115	24,684	24,187
Total U. S.	54,309	62,065	61,408	61,101	60,926

1/ Projections for 1960 - 1963 were based on the 1956 - 1959 growth rate at each airport.

Source: CAB, Airport Activity Statistics of Certificated Air Carriers.

Table 15

ESTIMATED COSTS OF FLIGHT CANCELLATIONS DUE TO WEATHER: 1959 - 1963

(Dollars in thousands)

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif	$ 250	$ 218	$ 264	$ 348	$ 435
Chicago, Ill (MDW)	503	168	196	246	290
New York, N Y (LGA)	390	126	153	195	245
Washington, D C (DCA)	486	82	92	127	156
San Francisco, Calif	199	155	203	280	379
New York, N Y (IDL)	349	136	178	255	346
Pittsburgh, Pa	189	87	92	110	123
Cleveland, Ohio	176	73	86	110	123
Atlanta, Ga	235	131	166	229	301
Newark, N J. (EWR)	287	106	141	204	290
Detroit, Mich (YIP)	382	68	68	77	67
Portland, Ore. (PDX)	86	102	117	154	178
Philadelphia, Pa	201	77	92	127	156
Dallas, Texas	123	116	154	221	301
Boston, Mass	353	97	129	195	279
Houston, Texas	93	58	74	110	145
Minneapolis, Minn	72	63	86	127	178
Cincinnati, Ohio	92	53	68	94	123
Chicago, Ill. (ORD)	118	48	68	102	145
Fort Wayne, Ind	19	10	12	17	22
Rochester, N Y	82	44	55	77	111
Lexington, Ky	27	15	18	26	33
Subtotal-Selected Airports	$ 4,712	$ 2,033	$ 2,512	$ 3,431	$ 4,426
Total U.S	$ 6,517	$ 4,841	$ 6,141	$ 8,493	$11,149

Note: Data are derived from the estimated number of weather cancellations (see Table 14) and the average cost per flight cancellation due to weather (see Table 13).

Table 16

ESTIMATED COST PER FLIGHT DIVERSION: 1959 - 1963

	1959	1960	1961	1962	1963
Aircraft Operating Expense Due to:					
In-Flight Delay 1/	$205	$245	$265	$285	$310
Nonrevenue Ferry Flight 2/	103	123	133	143	155
Passenger Service - Interrupted Trip Expense 3/	90	94	98	102	108
Total	$398	$462	$496	$530	$573

1/ Based on average operating cost per aircraft for one hour of flight time.

2/ Based on average operating cost per aircraft for one-half hour of flight time

3/ Assumed to be twice the passenger service expense assigned to flight cancellations

Table 17

ESTIMATED NUMBER OF FLIGHT DIVERSIONS DUE TO WEATHER: 1959 - 1963

Airport	1959	1960	1961	1962	1963
Los Angeles, Calif	342	324	309	296	289
Chicago, Ill. (MDW)	781	575	520	469	419
New York, N.Y (LGA)	238	208	200	188	181
Washington, D. C (DCA)	184	153	146	139	133
San Francisco, Calif	228	245	249	248	253
New York, N.Y. (IDL)	219	220	225	230	235
Pittsburgh, Pa.	167	159	140	127	115
Cleveland, Ohio	166	141	134	127	115
Atlanta, Ga	196	214	213	212	211
Newark, N.J (EWR)	187	184	188	194	205
Detroit, Mich. (YIP)	154	135	116	103	85
Portland, Ore (PDX)	196	178	164	157	145
Philadelphia, Pa	157	141	140	139	133
Dallas, Texas	159	196	200	206	211
Boston, Mass.	177	171	176	188	199
Houston, Texas	115	122	122	127	127
Minneapolis, Minn	124	129	134	139	145
Cincinnati, Ohio	118	116	116	115	115
Chicago, Ill. (ORD)	116	110	116	121	127
Fort Wayne, Ind	63	61	61	61	61
Rochester, N.Y.	99	104	104	103	109
Lexington, Ky.	70	67	67	67	67
Subtotal-Selected Airports	4,256	3,953	3,840	3,756	3,680
Total U.S.	6,687	6,538	6,468	6,435	6,414

Note: Flight diversions were derived as a function of instrument approaches, (y = 49 + .0109x), for total U.S. and Chicago (MDW) the 1957 relationship to total U.S. instrument approaches was used.

Table 18

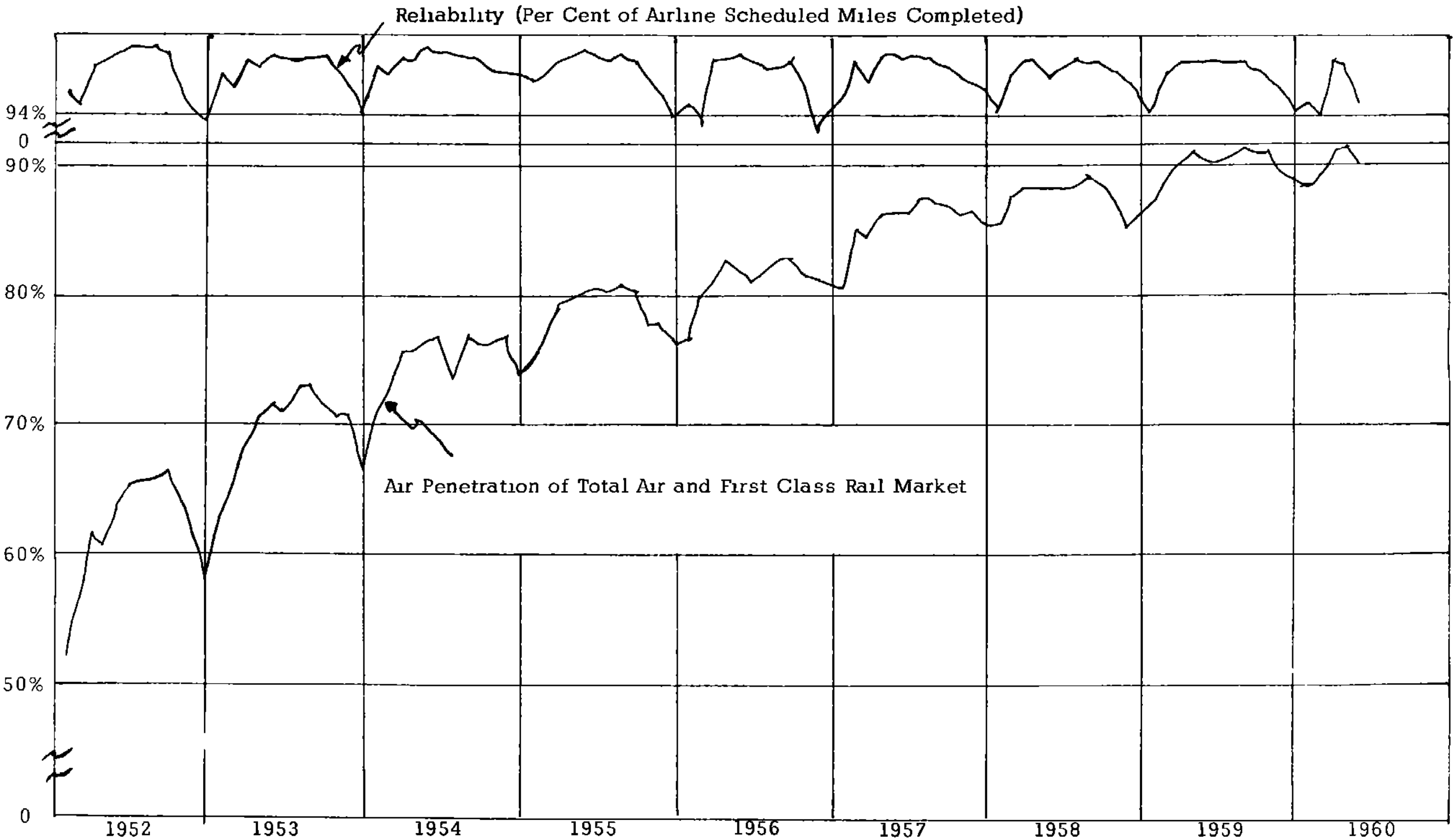
ESTIMATED COSTS OF FLIGHT DIVERSIONS DUE TO WEATHER: 1959 - 1963

(Dollars in thousands)

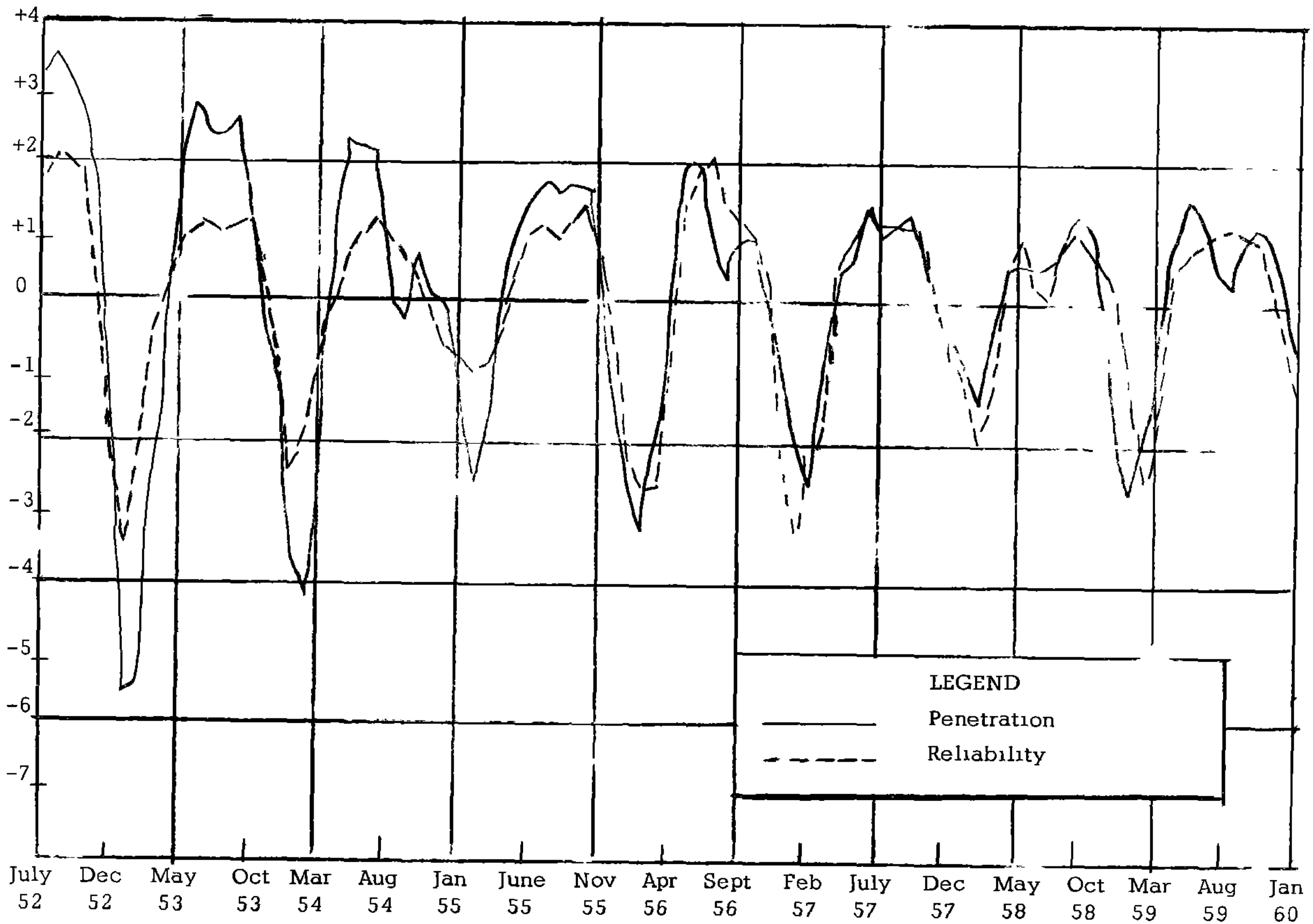
Airport	1959	1960	1961	1962	1963
Los Angeles, Calif	$ 136	$ 150	$ 153	$ 157	$ 166
Chicago, Ill (MDW)	311	266	258	249	240
New York, N Y (LGA)	95	96	99	100	104
Washington, D.C (DCA)	73	71	72	74	76
San Francisco, Calif	91	113	124	131	145
New York, N Y (IDL)	87	102	112	122	135
Pittsburgh, Pa	67	73	69	67	66
Cleveland, Ohio	66	65	66	67	66
Atlanta, Ga.	78	99	106	112	121
Newark, N J. (EWR)	74	85	93	102	117
Detroit, Mich (YIP)	61	62	58	55	49
Portland, Ore. (PDX)	78	82	81	83	83
Philadelphia, Pa	62	65	69	74	76
Dallas, Texas	63	91	99	109	121
Boston, Mass	70	79	87	100	114
Houston, Texas	46	56	61	67	73
Minneapolis, Minn	49	60	66	74	83
Cincinnati, Ohio	47	54	58	61	66
Chicago, Ill (ORD)	46	51	58	64	73
Fort Wayne, Ind	25	28	30	32	35
Rochester, N Y	39	48	52	55	62
Lexington, Ky	29	31	33	36	38
Subtotal-Selected Airports	$1,693	$1,827	$1,904	$1,991	$2,109
Total U S.	$2,661	$3,021	$3,208	$3,411	$3,675

Note: Data are derived from the estimated number of flight diversions (see Table 17) and the average cost per flight diversion (see Table 16).

SEASONAL VARIATIONS IN AIR PENETRATION OF THE MARKET AND RELIABILITY OF AIRLINE OPERATIONS. 1952 - 1960



DEVIATIONS FROM NORM FOR AIR-PENETRATION-OF-THE-MARKET DATA AND RELIABILITY-OF-AIRLINE-OPERATION DATA 1952 - 1960



Note. Deviations are measured from twelve-month moving averages

APPENDIX B

Methods of Estimating the Physical Gain from New Airway and Airport Facilities

In an idealized airway system there would be no limits on the attainable schedule or point to point times of air operations except the speed and performance characteristics of the aircraft employed. Under such circumstances flying could be properly likened to a continuous process operation.

Unfortunately, delays exist which break the continuity of flights. It is convenient to distinguish between two types of delay, those due to bottlenecks and those due to complete suspension of an operation.

To make this distinction properly the two basic parameters of a discontinuous process must be defined. These are 1) the theoretical or rated service capacity of the system, and 2) the actual demand for services. For example, an airport's capacity would be the total possible number of landings and take-offs that might be handled in any designated time period while the demand would be the actual number of landings and take-offs. It is common to call the service capacity per time period the acceptance rate and to designate it by the Greek symbol μ . Similarly, the demand per time period is usually called the arrival rate and labeled λ .

Obviously, if the arrival rate exceeds the acceptance rate (i e $\lambda > \mu$) the system cannot handle the traffic without cancellations or diversions In the limit the acceptance rate could fall to zero and it would be necessary for all service to be cancelled or diverted. However, even if $\mu > \lambda$, the probability of aircraft sometimes arriving at intervals less than the average landing or take-off time can cause waiting lines to form, creating a queuing or stacking delay. Therefore, the following two categories of delay can be distinguished

(a) delay observed when $\mu \bar{>} \lambda$, which we shall call bottleneck delay,

(b) and delay observed when $\lambda > \mu$ which will be accompanied by cancellations or diversions.

Bottleneck Delay

Bottleneck delays thus are delays that occur in discontinuous systems even though there is sufficient capacity to handle all demands on the system. Of course, if a properly spaced schedule could be established and rigidly enforced, there would be no bottleneck problem. In practice, however, such schedules are not readily feasible and are often impossible. Headwinds and other adverse weather conditions, mechanical and equipment difficulties, and coordination problems arise that, with present airway equipment and organization, prevent the realization of perfectly synchronized schedules. In short, bottleneck delays occur because there are breaks in the rhythm of the operation. At crucial bottlenecks in the system demand spasmodically exceeds capacity and temporary waiting lines appear.

The most important natural bottlenecks encountered in air operations are limits on air space and landing strips. These limits are of substance because safety requires that modern airplanes operate with a certain minimum "cushion" of unoccupied air space about them and that landing strips not be utilized for more than a certain maximum number of landings per time unit. The size of the needed space cushion and the number of tolerable landings per time unit is a function of the control facilities available and, with present equipment, of the weather. Investment in airways modernization is essentially a means of modifying airspace requirements and landing limitations.

To measure the physical effect of airway investments an analytical means is needed for relating the "characteristics" of the bottleneck to a performance standard, measured in time units. This is a problem in analyzing the sources, causes and extent of bottleneck delays in non-continuous systems or processes. Fortunately, rather extensive effort has recently been applied to the study of this general type of problem. The models resulting from these efforts are catalogued under the heading "waiting-line" or "queuing" theory.

It is beyond the space limitations and scope of this study to develop all the essential features of queuing theory. Moreover, the techniques are moderately difficult to understand and require some prior training in probability mathematics.1/ Thus, only an heuristic introduction and understanding of the subject will be developed here.2/

Using queuing theory a formula for estimating waiting time can be developed for the special case of "random" arrivals and service times. Randomness in this case means that the time intervals between arrivals and departures are unsystematically and independently distributed about some average or expected value. Clearly, this assumption may not be particularly true for airway operations that are rather rigidly scheduled. The random model is useful, however, and the "exceptions" can be handled by adaptations discussed later in this report. 3/

The essentials of the simple random case can be stated as follows 4/

Let $\bar{t}_w$ = the average waiting time in the queue before entering the facility,

$\bar{t}_s$ = the average time spent on servicing an occupant of the queue,

T = some arbitrary time interval to be used for purposes of measurement (for example, one hour),

---

1. A good introduction to queuing theory can be found in reference (6).
2. The crucial element in evaluating airway investments is, of course, reduction in waiting time. Queuing theory also can be used to estimate the optimum spacing of arrivals, service time, or other dimensions of a queue, assuming that waiting time is held constant. However, this appears irrelevant in an airways study in which reduction of delay is the obvious objective.
3. See also references (2) and (3).
4. The notation used here is essentially the same as that employed by Churchman, et. al., in reference (6).

λ = the average arrival rate, that is, the average number of arrivals in the same time interval T in which μ is measured,

μ = the acceptance rate or the average maximum number of units that can be served in the interval T,

and $\bar{N}$ = the average number of units in the queue, i. e. the average length of the waiting line, including the units being served.

It is important to be clear on the distinction between waiting time and service time. Service time is the time during which a member of the queue absorbs the full attention or use of the bottleneck facility, waiting time is all the other time spent in the queue so that $(t_s + t_w)$ = total time spent in the queue including time in the facility. This means, for example, that for an airport facility, service time in landing is simply the time that the plane being landed has exclusive use or control of the landing strip; it is thus the time between a plane being released from the stack and actually moving off the runway. Similarly, time spent in the stack would be the waiting time t_w.

To analyze waiting time, we initially observe that the average length of the queue divided by the average arrival rate must equal the average total time spent in the queue. That is,

$$\frac{\bar{N}}{\lambda} = \bar{t}_w + \bar{t}_s \qquad (1)$$

The necessity of this relationship can be shown by considering some hypothetical situations. For example, let $\lambda = 1.0$ (i. e. one more unit arrives at the queue during every interval T) and suppose for simplicity that the queue is always about 6 units long, that is, $\bar{N}$ is about equal to 6. Now for the queue to always remain approximately 6 units in length, one unit must be released from the queue in every interval T. If we make the usual assumption that the discipline of the queue is first come, first served, any new entrant to the queue must wait through 6 intervals before being able to proceed, so $t_w + t_s = 6$. However, let the arrival rate rise to 2. Now, it is obvious that if the queue is to remain 6 units in length, the total time in the queue must decrease. In fact, it must now be 6/2 or 3 units of time.

Equation (1) can, by algebraic manipulations, be rewritten

$$\bar{t}_w = \frac{\bar{N}}{\lambda} - \bar{t}_s \qquad (2)$$

Now it can be shown[1] that in the completely random case

$$\bar{N} = \frac{\lambda/\mu}{1 - \lambda/\mu} \qquad (3)$$

Moreover·

$$\bar{t}_s = \frac{1}{\mu} \qquad (4)$$

(For example, if $\mu = 2$, then it must, by definition, take 1/2 of a time interval

---

1. See reference (6), pp. 393-398 for a derivation of this equation.

to service each customer.) Equation (3) and (4) can be substituted into (2) so that:

$$t_w = \frac{1}{\lambda}\left[\frac{\lambda/\mu}{1-\lambda/\mu}\right] - \frac{1}{\mu}$$

which reduces to

$$t_w = \frac{1}{\mu-\lambda} - \frac{1}{\mu} \qquad (5)$$

Technically speaking this is an equation for expected or average waiting time at a single station (e.g. single runway airport) [1] in the random case.

The meaning of equation (5) can be illustrated by a table of values for t_w constructed under various assumptions about the values of λ and μ. Table I is such a construction. *The notable thing about the value of t_w is the way it* rises sharply as $\lambda \rightarrow \mu$ in value. The computation of the table was materially simplified by setting $T = \mu$ so that μ always equals 1, this does not at all affect the generality of the table. If the delay in conventional time units is desired--e.g. seconds, minutes or hours--it is only necessary to multiply t_w by T/μ as measured in such units. For example, say T= one hour and μ=30, the delay then would be 4/30 hours (4 x 1/30) when $\lambda =$ .8 of μ .

TABLE I

t_w	μ	λ
.25	1	.2
1	1	.5
4	1	.8
infinity	1	1.0

The ratio, therefore, of λ to μ is crucial in determining the amount of delay. This ratio is normally called the "traffic density."

Several questions immediately arise with regard to the applicability of this analysis to a real situation and specifically its applicability in evaluating an all-weather landing installation

(a) How realistic is this model, in view of its prediction of infinite waiting time as λ/μ approaches 1.0? Experience has shown instances of achieved arrival rates very close to theoretical maximum acceptance rates, without major delays. There is little doubt that the human beings who operate the present system can adapt to an increased acceptance rate for short periods of time.

(b) How does the assumption of completely random arrivals and take-offs agree with the typical airway busy-hour situations? Do *deviations from this random assumption markedly change the conclusions?*

---

1. The double station or dual runway case is discussed later.

(c) The model makes the assumption that the airport consists of a single landing strip, from which aircraft take-off and land. Are estimations using this model invalidated by the existence of multi-runway airports, or by the fact that the take-off interval is generally shorter than the landing interval?

These questions need to be dealt with before an analytical model for queuing delay can be used with some confidence.

Adler and Fricker (references 1, 2, and 3) have studied the "bottleneck" delays which result when one aircraft is scheduled to land in each "service period," and when "service times" are constant. Arrivals were assumed to be of less than Poisson randomness, deviations from the exact scheduled arrival time being due to aircraft speeding up or delaying en route. These deviation patterns or distributions were characterized by them as being "box", "triangular", or "parabolic" in shape, and by the maximum "spread", S, of this deviation, expressed in terms of the landing or "service" interval. Figure I illustrates these concepts (taken from Figure 2.2 of reference 1).

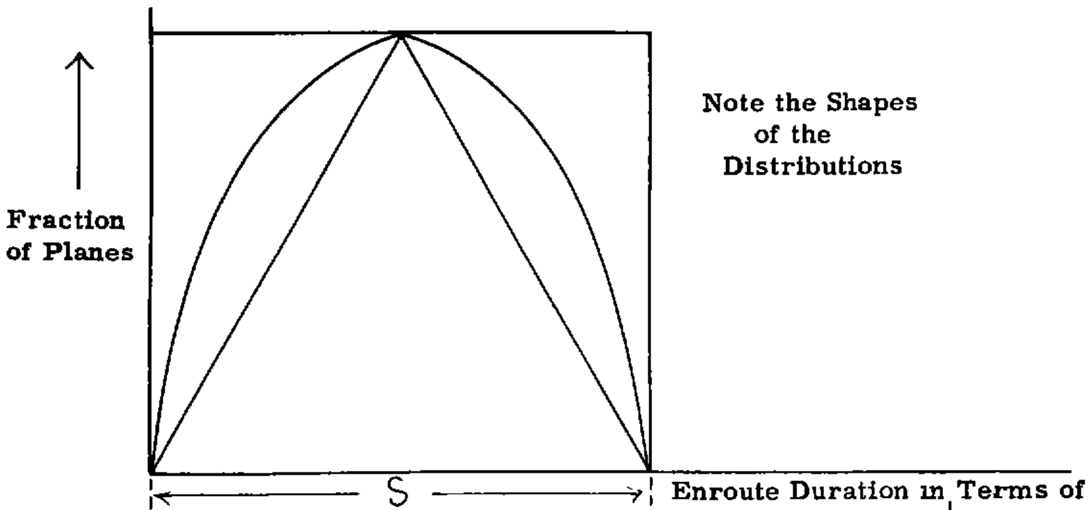


Figure I

Using random numbers, stack delays were computed for a range of S and for a range of λ/μ (called ϵ, or the traffic parameter, by Adler and Fricker, reference 1, 2 and 3 and e by Morse, reference 5). The method was to have an electronic computer "fly" each aircraft en route and through the landing procedure. The results are depicted in Figure II and Table II.

Figure II

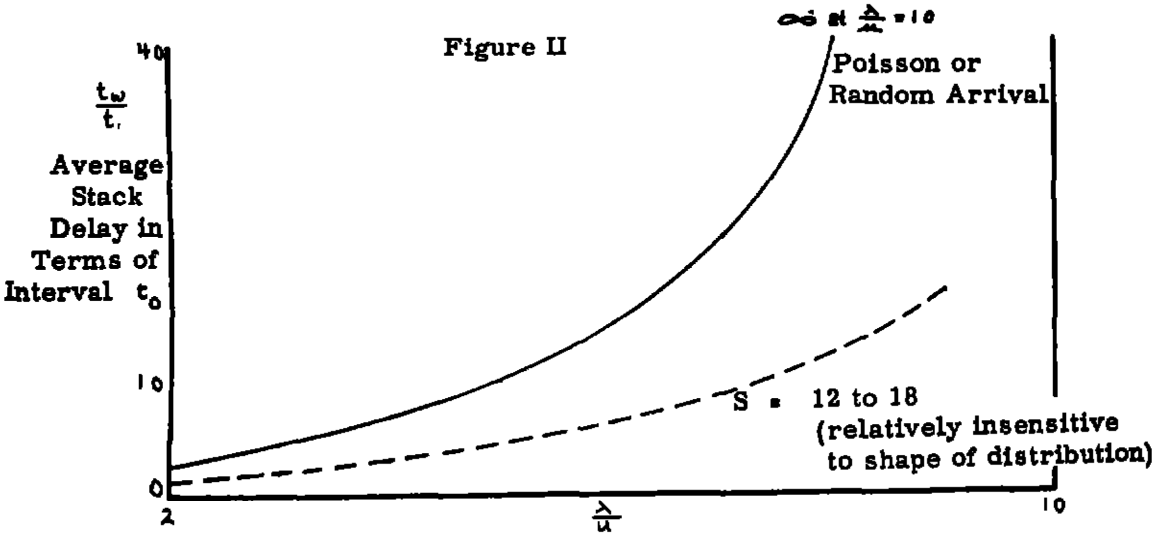


TABLE II

Values of t_ω / t_o Corresponding to

Values of λ/μ in Figure II

λ/μ	t_ω / t_o	
	Actual	Poisson
.2		.25
.3	.210	
.4	.30	
.5	.440	1.0
.6	.640	
.7	.870	
.8	1.10	4.0
.9	1.80	

Thus, from these results we conclude

(a) Variation of the shape of en route deviation does not seriously affect the results, for a given spread, S.

(b) The "spread", S, influences stacking delay. However, for $\lambda/\mu < 0.7$, the average delays are all less than one unit period (for example, two minutes) so that for the lower values of λ/μ, changes in S will have a slight effect.

(c) ATC modifications affecting en route time-keeping accuracy, will in effect change S. Thus, a source exists here by which the savings due to these measures can be computed.

(d) This bears on the "Randomness assumption" and its use in simulating reality. At $\lambda/\mu = 0.7$ there is a difference, but a small one, between the "random" model and the data generated by Adler and Fricker. Thus, the reliability of the model need be checked only for the high values of λ/μ .

Further, Adler and Fricker's data were generated by a sufficiently large number of "flights" to lend reliability to the results, and to the method used. The reason for the differences between their model and the theoretical results may lie in the transient form of the queue build-up, and the need for a long time period to pass before a steady state queue results. For these reasons it is concluded that the data of the form generated by Adler and Fricker can be relied upon.

It remains to determine the effects of airport configuration. Improved runway configurations essentially afford a reduction in delay due to an improved acceptance rate. Conceptually, there are three basic types of airport configurations. In the single runway type, arrival at the facility for landing or take-off is random. We have two queues feeding into the same facility without priorities, so that for the purposes of analysis we can consider one queue to be in operation.

In the independent dual runway type of airport, one runway can be used exclusively for landings and the other for take-offs, or, alternatively, each can operate as a parallel facility independent of the other, both being supplied from the same queues. In 1957, no major airport in the U. S. operated this type of facility.

A third type, which exists at several major airports (e.g. Chicago Midway), consists of interdependent parallel or intersecting runways. Here, one runway can be used for take-off while landing is proceeding on the other. Schematically for close parallel runways, the picture might be

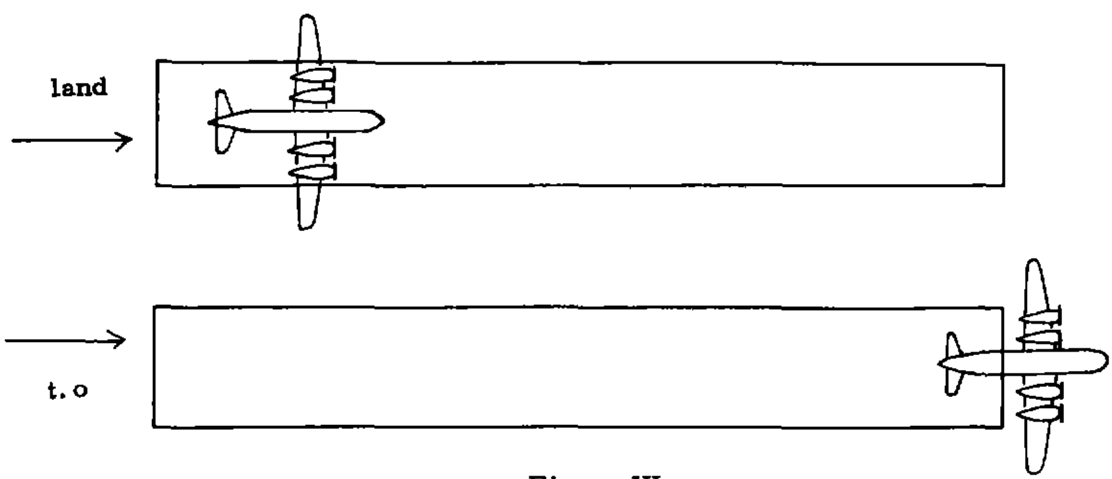


Figure III

An aircraft can take off, under IFR, only if the aircraft landing on the parallel runway has already touched down, or if a preceding aircraft taking off has had sufficient time to provide the spacing required. Similarly, an aircraft which is landing must allow a preceding landing aircraft to turn off the runway, and it cannot land, i. e., proceed below its wave-off altitude, if an aircraft taking off has not crossed the far boundary.

If there were no interdependence between the runways, then the acceptance rate for the whole airport would equal the individual landing rate plus the individual take-off rate. Interdependence causes an extension of the interval between the operations--to allow for the landing aircraft to get from its wave-off position to touch down, and to allow the aircraft taking off to cross the boundary.

As an example, an airport which can handle 120 aircraft per hour, VFR, (60 per runway), may be limited to 90 per hour IFR due to these extra "leeway" limitations. Under VFR, or with a "perfect control and spacing" IFR, 120 could be attained. But this would imply exact alternation of take-offs and landings as well. Under random arrival conditions, the lower or conservative figure is used, which assumes that a landing aircraft can be preceded by another landing aircraft as well as an aircraft taking off. Conceptually, the model is looked on as a single runway operation, where the acceptance interval is equal to the landing or take-off interval (assumed equal), plus the leeway time. If there were a serious disproportion between the numbers of take-offs and landings in a given period, the rate would go down. However, such serious disproportions do not frequently exist in busy periods.

Cancellations, Diversions and Curtailed Services

In the previous section it was assumed that the airport or airway facility always had sufficient capacity to handle the average demands made upon these facilities over any important period of time. Excess demands were experienced only spasmodically and very temporarily. More exactly, the average acceptance rate, μ , exceeded the average arrival rate, λ , and queuing occurred only because of temporary random deviations from these averages.

Although arrangeable on the same continuum, an obvious order of magnitude differentiates this case from situations in which the service facility must sharply reduce its operations and the service rate is forced below the arrival rate for a significant period of time. Under such circumstances, the traffic density is forced above unity and, as noted in the last section, such a traffic density implies an infinite queue under "random" assumptions. While there are good reasons for doubting that in practice the situation will completely degenerate, a traffic density greater than unity at any facility is clearly not tolerable for any prolonged period of time. There are, in fact, only three solutions to such a difficulty

(a) greatly increasing the length of the queue during the period of curtailed operations and using excess capacity which becomes available when things revert to normal to work-off the backlog,

(b) diverting demand away from the overtaxed facility to a facility that is not fully utilized, and

(c) outright cancellation of some operations.

These three solutions are not mutually exclusive, all three can be and are used in a real situation. Usually solution (a) is preferred, and (b) and (c) are last "resorts", used only after considerable deterioration in service has occurred. Similarly, solution (b) normally will be preferred to (c) by both airlines and passengers.

The concepts underlying the analysis of "closed" periods perhaps can be understood best by considering first a condition where no cancellations or diversions occur, and where λ, or arrival rate, is constant throughout the period considered. Two new concepts are here introduced,

(1) the time the facility's services must operate at a curtailed rate, which shall be denoted by T_o, and

(2) the percentage--let it be k notationally-- of normal capacity available during the period of curtailed services (e.g. if an IFR landing rate is .6 of the VFR rate, k=.6).

Assuming that there was no queue when the period of curtailed operations began and that no cancellations or diversions are made and ignoring random bunching of the traffic, the length of the queue at any point t time units after the curtailment begins will be given by the following expression

$$N = (\lambda - K\mu)\, t \tag{6}$$

where, as before, N represents the number of units in the queue. The term in brackets, $\lambda - K\mu$, represents the number of new arrivals who can't be served in any time interval, since t is the number of time intervals, the product of the two terms indicates the length of the queue.

To illustrate the concept, consider a hypothetical situation in which

μ = the acceptance rate = 20 landings per hr,

λ = the arrival rate = 10 landings per hr,

and $K = .25$ (7)

This means that during the period of curtailment, 5 planes per hour are added to the queue (10 - .25 x 20). Thus at the end of 2 hours of reduced operations, the queue should be 10 planes long, at the end of 3 hours, 15 planes long, etc.

Furthermore, it is obvious that the queue will be longest when the period of curtailed services finally comes to an end. Therefore, the maximum queue, N_m, is given by the following expression

$$N_m = T_o\,(\lambda - K\mu) \tag{8}$$

and the average queue, $\bar{N}$, will be one-half of this

$$\bar{N} = \frac{T_o}{2}(\lambda - K\mu) \tag{9}$$

(on the assumption that the arrival and acceptance rates remain constant) Such a relationship is depicted graphically in Figure 5 1 in Adler and Fricker, reference (3)

Similarly, the total delay for all planes during the period of curtailed operations will be equal to the average queue during the period multiplied by the number of time periods. Thus, if D_c represents total delay during the period of curtailment,

$$D_c = T_o \bar{N} = \frac{T_o^2}{2}(\lambda - K\mu) \quad . \tag{10}$$

It will take some time after full operations are resumed, of course, to eliminate the queue built up during the "down period." Therefore, a calculation also must be made of the delay incurred during this recovery period. Delay during the period of curtailed services was calculated by multiplying the average queue by the period the queue was in existence. An analogous procedure can be used to calculate delay during the recovery period. Thus, letting

D_r = delay during the recovery period

and T_r = the time required to eliminate or recover from the queue,

then

$$D_r = T_r \bar{N} \quad . \tag{11}$$

Since the queue to be "worked off" during the recovery period is the queue existing at the end of the period of curtailed services, the average queue during the recovery period will be the same as the average during the period of curtailment--that is, one-half of the maximum queue. Thus, as before,

$$\bar{N} = \frac{T_o}{2}(\lambda - K\mu) \quad . \tag{12}$$

It remains to calculate T_r which will depend on the amount of "excess capacity" existing in the system under normal conditions. This will be equal to $\mu - \lambda$.
The time required to eliminate the backlog will be the backlog divided by this excess capacity or

$$T_r = \frac{T_o(\lambda - K\mu)}{(\mu - \lambda)} \quad . \tag{13}$$

In other words, if the backlog or queue is 50 units when the recovery period begins, and if 10 units normally arrive per hour and 20 units can be served per hour under normal conditions, it will take 5 hours to work off the backlog since

$$\frac{50}{20-10} = 5 \quad .$$

Putting all this together,

$$D_r = \left[\frac{T_o(\lambda - K\mu)}{(\mu - \lambda)}\right]\left[\frac{T_o(\lambda - K\mu)}{2}\right] \tag{14}$$

$$= \frac{[T_o(\lambda - K\mu)]^2}{2(\mu - \lambda)} \quad . \tag{15}$$

Furthermore, total delay, D, will be equal to.

$$D_c + D_r = \frac{T_o^2(\lambda - K\mu)}{2} + \frac{[T_o(\lambda - K\mu)]^2}{2(\mu - \lambda)} \quad . \tag{16}$$

However, it is usually far easier and also more meaningful to work with average delay per aircraft than with total delay. Average delay can be obtained by dividing total delay by the number of planes involved. The number of planes will be equal to

$$\lambda t_o + \lambda t_r$$

that is, to the sum of arrivals in the period of curtailed service, λt_0, and the arrivals in the recovery period, λt_r. If we divide total delay by this figure, make appropriate substitutions and simplifications, the following expression for average delay is obtained

$$\bar{D} = \frac{T_o (\lambda - K\mu)}{2\lambda} = \frac{T_o}{2}\left[1 - \frac{K\mu}{\lambda}\right] \quad . \qquad (17)$$

In practice, however, diversions and cancellations become necessary. Practice varies from airline to airline, and from one part of the country to another. No two weather instances are identical, even as regards the weather itself, to say nothing of traffic loads or aircraft which are airborne at the time. Much of the decision-making about diversions and cancellations is dependent on uncertain weather forecasts, and relies heavily on the individual and collective experience of dispatchers and pilots. Hence, no specific overall rule can be developed.

A study of current trunk-line, general aviation and military practice, however, permits certain general courses of action to be described. From these a model can be constructed which estimates delay, diversion and cancellations.

For example, the following would appear to be a reasonably representative list of practices

A. For aircraft scheduled to arrive at a closed airport

(1) When weather conditions first fall below current take-off and landing criteria, all aircraft which are airborne at that time continue on their way and "hold" or "stack" in the vicinity of the airport for which they were originally destined.

(2) As long as the length of time of the "close-down" period is not known, aircraft already in the air will continue to "hold" until such time as they can land at original destination, or until they are forced by the danger of exceeding safety limits to divert to an alternate airport.

(3) No aircraft will wait in the air at destination more than one hour (i. e. after one hour in the "queue" the aircraft will leave the queue for an alternate airport), and flying time to the alternate airport is 1/2 hour, so that a total maximum delay of 1.5 hours is tolerated in each case.

(4) Aircraft which originate at a distance represented by more than one hour's flight time from destination continue to proceed to destination, regardless of conditions at destination.

(5) Aircraft one hour away or less from destination hold on the ground,

if destination is "closed", until cleared, hence, beginning with the end of the first hour, aircraft from points one hour's flying time away or less cease to arrive at destination.

(6) General and military aircraft do not arrive after the first hour of close-down, i. e. all such aircraft will divert or cancel.

B. For aircraft scheduled to depart from a closed airport

(1) General and military aircraft cancel all take-offs after the first hour of close-down.

(2) In cases of very long close-downs, air carrier aircraft will hold on the ground, at origination airports, for a period not longer than their flying time away from destination.

(3) When an airport "reopens" after a close-down, those aircraft which have been waiting for a period less than their flying time away from destination will not have cancelled, and will be ready to take off, in the order of their originally scheduled departures. However, these aircraft which were scheduled to land during the closed period, and which were diverted or cancelled at origin, will not be available for take-off. Hence, the number of aircraft ready for take-off is approximately equal to the number which have landed or were on the ground before the closed period began. The net result is to reduce delay after the airport opens, at the expense of increased cancellations.

There are certain questions which this model raises. The first is the validity of applying a general rule in cases where the decisions taken are so much a matter of judgment. This judgment must necessarily take into account the alternate surface transport available to the passenger, the number of passengers affected by cancellation of specific flights, the positioning of aircraft when schedules are resumed, the need for crews and the problems of exceeding "legal" crew hours or maintenance flight-hours and many other considerations. Similarly, the excess fuel carried varies among types of aircraft, as does dispatch policy. However, for the purposes of the present study, the assumptions are considered representative of the kind of decisions which would be made.

One basic assumption used, however, deserves more critical consideration. No exact knowledge is assumed of the length of the close-down period. Hence, aircraft tend to divert from the queue under conditions where they might not have to divert if the exact conditions could be forecast. In this manner, the model will overstate diversions, and by similar reasoning, will overstate cancellations of short-duration flights.

At the same time, aircraft have been assumed to arrive from more distant airports because of no knowledge of the duration of closedown. Such an assumption tends to raise the estimate of delay, since an increase in cancellation will reduce delay. Thus, it can be seen that the assumption that there is no exact foreknowledge of the weather produces effects which operate in opposite directions. The net effect is not known but is probably not large. A further question not adequately considered is that of the interaction of a number of airports which may be closed simultaneously. Under the present assumptions, aircraft one hour's flight time away or less are accounted for, since they receive "feed-back" from the destination airport. However, situations exist in which departures are cancelled or delayed at more distant airports as a result of receipt of information concerning closed conditions at the destination airport, or because of conditions at intermediate airports.

Delays due to take-off conditions, for all flights, are accounted for by assuming that an aircraft will hold on the ground a length of time equal to its scheduled flight time to destination. However, delay at destination, and the number of diversions, is somewhat overstated, since in reality fewer flights would arrive than predicted by the model. Contrariwise, it has been assumed that there will be no general of military arrivals after the first hour's close-down. In practice some military and general arrivals will occur after the first hour, thus offsetting this overestimation of delay and diversion. The net effect is probably small.

Application to All-Weather Systems

The installation of an all-weather system should have the following effects

(a) "Closed periods" which result from ceiling and visibility conditions alone will be eliminated. There will be no effect, however, on closure due to obstructions, snow on runways, etc., nor will the all-weather system reduce delays due to communications, airborne traffic clearance, or airspace arrangements and procedures

(b) The landing acceptance rate, on a single runway equipped with the all-weather system, becomes approximately 60 movements per hour Assuming a take-off rate of 60 movements per hour as well, the total on the runway would reach 60--as compared with whatever rate is currently obtainable on that runway, during the different IFR conditions

(c) On two interdependent runways, the effect of the all-weather system is to provide for sixty movements on any one runway As noted above, this figure is reduced in practice, because of interdependence between runways, to a figure somewhat lower than 120 The actual capacity is computed using "leeway" estimates plus the known single-runway all-weather capacity of 60 At such airports an estimated figure of 90 total movements per hour is used

Computation of Delay

Delay was computed separately for "closed" and "open-IFR" periods. The following detailed procedure was used for "open-IFR" conditions. At a given airport, the annual distribution of IFR weather was obtained from Weather Bureau records, prepared by the Records Center at Asheville, N. C. Similarly, landing and take-off at an airport were obtained from tower experience at that airport, and from IFR flight strips. Weather Bureau annual records were obtained for the entire calendar year 1957, and flight strips and hourly weather records for the period August 15 to September 15, 1958.

Arrival rates for scheduled airline aircraft were obtained from schedules for domestic trunk lines. August, 1958, airline schedules were used. VFR military and general aviation flights were estimated from annual averages, and attributed largely to those hours of the day (primarily the daylight hours) when these aircraft are most active. IFR military and general aviation flights were estimated from IFR flight strips, recorded at twenty-two airports, during the period August 15 - September 15, 1958.

As a result, for each airport studied the following table was derived:

Flight Conditions	No. of days/yr.[1]	Ceil / vis	μ	λ_L	$\lambda_{t.o}$
I	250	VFR			
II	60	1000-4500' 2 miles			
III	30	500-1000' 1-2 miles			
IV	15	200-500' 1/2-1 mile			
V	10	0-200' 1/2 mile			

At some of the major airports, IFR procedures apparently are used as a rule when ceilings are between 1000 and 4500 feet--not because of absolute technical necessity, but because of the scarcity of airspace and the long delays which might ensue if an aircraft not on IFR missed an approach. This is borne out by a study of the flight strips for August - September 1958. However, expressions of opinion by tower personnel tended to indicate that acceptance rates during such periods more nearly approximate VFR than IFR acceptance rates. Therefore, these periods were considered as VFR for the purposes of this study.

Knowing λ/μ for each hour of each day, average delay per aircraft, in terms of $t_0 \frac{\mu}{\lambda}$, is obtained from Figure II, using a combined λ/μ for landing and take-off. This is logical providing both landing and take-off arrivals are random, that priority is given to neither and that for practical purposes μ land = μ take-off. In a given unit time period, the total arrivals to use a facility are given by λ land + λ take-off whence,

$$\text{total } \frac{\lambda}{\mu} = \frac{(\lambda_{land} + \lambda_{t\text{-}o})}{\mu} \quad \text{for all types of aircraft.} \qquad (18)$$

Total annual delay for a given airport during the IFR conditions, with the all-weather system in operation, is the sum of hourly delays throughout the year based on $\frac{\lambda}{\mu}$ values that would exist with the all-weather system

1. For each hour of the day, for the 365 days of 1957, numbers given in this column are examples only.

Total annual weather delay for the periods when $\lambda < \mu$, as estimated from weather conditions for calendar year 1957, without an all-weather system, is the sum of hourly delays for conditions III and IV as they actually occurred. The total annual saving in delay for a given airport is computed by subtracting the delay which would have occurred with an all-weather system during those same periods from the delay estimated actually to have occurred.

It should be noted, however, that during condition V airports are considered to be closed, delay during such periods is calculated by a different method, described in the following section. Additionally, for a single airport in the sample (MDW) for certain hours of the day $\lambda > \mu$ during conditions III and IV, delay during these hours also required calculation by the following method rather than that described above.

Delay Saved Due to Elimination of Closing Due to Ceiling and Visibility

Certain assumptions have been made regarding the arrival, departure and cancellation of flights when weather conditions are below minima. Following these criteria, a typical "history" of a three-hour shut-down period could be as follows, for a given airport

HOUR	OCCURRENCE	RESULTS
I	Take-off 1. No take-offs made from closed airport.	1. Aircraft scheduled to take off in this hour suffer an average delay of one-half hour (delay at gate, engines not running--delay not attributed to any flights subsequently cancelled).
	Landing 2. All scheduled air carrier flights arrive and "hold".	2. Average holding delay is assumed 1/2 hr. per arrival.
	3. Military and general aviation flights divert on arrival or notification of closure.	3. Average additional flight time is one hr./plane.
II	Take-off 4. All military and general aviation flights cancel take-offs.	4. All military and general flights intended for closed period are now cancelled. (At this stage this includes flights intended for hour I and hour II.)
	5. Scheduled departures, whose destination is one hour or less away, and which were supposed to leave in hour I, cancel. All others hold at gate.	5. These flights removed from list of flights which will take off once airport opens.

HOUR	OCCURRENCE	RESULTS
II con't	Landing 6a. Military and general flights do not arrive. 6b. Scheduled carriers, one hour or less away, have held on ground in hour I, and do not arrive. If hour II is closed, these cancel.	6. Arrival rate during second hour is normal arrival rate less military and general and less flights scheduled to take-off in hour I from one hour or less away.
	7. Flights which arrived during hour I divert.	7. For conservatism, assume additional flight time delay of 1/2 hour per hour I arrival.
	8. Scheduled carrier aircraft from airports greater than 1 hr. away, arrive.	8. Assume 1/2 hr. delay per arrival.
III	Take-off 9. All military & general flights cancel take-offs.	9. Military & general flights intended for hour III are cancelled.
	10. Scheduled departures, from hour II, whose destination is one hour or less away, cancel. Scheduled departures from hour I, with destination less than 2 hours away, cancel.	
	Landings 11a. Military & general flights do not arrive. 11b. Scheduled carriers, one hour or less away, and held on ground in hour II do not arrive.	11. Arrival rate during second hour is normal arrival rate less military & general arrival rate less flights scheduled to take off in hour II from one hour or less away.
	12. Scheduled carriers, one hour or less away, and held on ground in hour II, cancel.	12. Cancellations of flights directed to the airport.
	13. Flights which arrived in hour II divert.	13. Add flight delay of 1/2 hour per airplane arriving in hour II.
	14. Carrier aircraft, from more than one hour away, arrive and enter queue.	14. Average waiting time, one half hour. Height of queue is arrivals scheduled for hour III (air carrier) less scheduled arrivals from less than one hour away.

HOUR	OCCURRENCE	RESULTS
IV Field Open	<u>Take-off</u> 15. Hold take-offs for one hour or less away. 16. Take-offs scheduled for hour I, for destinations three hours away, for hr. II, for destinations 2 hrs., and all hour III take-offs, wait in queue in this order. <u>Landing</u> 17. Arrivals in hour IV, even though field has opened, are similar to hour III, i.e. only scheduled carrier arrivals from distances greater than one hour.	16. Take-offs and landings are handled as time permits, assuming $\lambda/\mu <$ 1.0 for period IV. 17. Arrive and wait in queue behind hour III aircraft, (see no. 14 above).
V Field Open	18. Similar to period IV, except that one-hour flights from period III destined for the airport arrive. Also normal military & general t.o. and arrival ensue.	18. Queue is increased accordingly.
VI	19. If any aircraft are still left from previous periods, they continue in queue and land.	

Each occurrence, during and after closed conditions, as obtained from a comprehensive survey of U. S. Weather Bureau data for 1957, is then " worked through" individually, in accordance with these assumptions.

<u>Calculation of Total Delay for the United States--1957</u>

At the end of 1955 there were 143 airports in the United States at which the CAA maintained approach control towers. Itinerant activity at these airports, for the calendar year 1956, ranged from 389,399 total movements at Chicago Midway Airport, to 10,276 at Pocatello, Idaho (reference 8). Not only does the total traffic vary greatly from airport to airport, but the types of traffic and the weather conditions show great differences as well.

Obviously, considerations of time and expense preclude the taking of measurements at more than a small fraction of the airports involved. At the same time, statistical sampling theory and practice provide a method by which a sample of reasonable size will provide representative values of the needed parameters. In other words, total annual aircraft delay can be estimated from the delay computed for the airports included in the experimental sample, provided the sample is carefully selected. This selection involves choosing the size of the sample, deciding upon "strata" of the airport population from which the sample is to be taken, allocating the sample size between the strata, and selecting the specific airports to be included.

It has been noted that airports are extremely heterogeneous with regard to their rate of activity. One method of gaining precision in the estimates is to group the airports into strata of more homogeneous characteristics with regard to total annual delay. A sample can be taken from each stratum, and the delays for that particular stratum estimated from the sample. Total nation-wide delay is then equal to the sum of the delays measured for the strata.

The difficulty in this approach is to develop a method of ranking the airports, and to stratify them properly, before any measurements of delay have actually been made. To meet this difficulty, some parameter which can be used as an indicator of the total magnitude of expected delay must be selected from available data for each airport. The basic queuing model can again be used to guide in selecting such a parameter.

Average "bottleneck" delay, and to some extent cancellation delay, has been shown to be a function of $\frac{\lambda}{\mu}$. In other words,

$$\text{average delay} = f\left(\frac{\lambda}{\mu}\right) = K\left(\frac{\lambda}{\mu}\right) \quad (19)$$

Total delay is related to average delay and to $\frac{\lambda}{\mu}$ in the following manner.

$$\text{total delay} = k \ (\text{instrument movements/year}) \times \left(\frac{\lambda}{\mu}\right) \quad (20)$$

average delay

$$\sim (\text{instrument movements/year}) \times \left(\frac{\lambda}{\mu}\right) .$$

Since delay is assumed to occur primarily under IFR conditions, this reduces the problem to one of ranking the airports by their characteristic λ/μ on an a priori basis. Initially it was assumed that μ is constant for all airports. However, subsequent study showed that runway configuration had a substantial effect on μ . In order to reduce the error of the original assumption, a 100% sample was taken of the 14 largest airports, which fell in the top two strata, and could be expected to contribute the major portion of total delay. Although the smaller airports might have been ranked somewhat differently if varying μ had been used, these airports individually contribute so little to the total delay that the error resulting from treating μ as constant in selecting the sample may be considered small.

Since λ is dependent upon the intensity of movements under instrument conditions, a general expression for λ would be

$$\lambda = K \frac{\text{total IFR movements}}{\text{total time airport was under IFR conditions}} . \quad (22)$$

Since total IFR movements are known for each airport, it was only necessary to estimate the total time duration during the year that IFR conditions prevailed.

Obviously,

$$\text{total IFR time} = \left[\frac{\text{IFR time}}{\text{total time}} \quad \text{x total time} \right] \tag{23}$$

$$= K \left[\frac{\text{IFR time}}{\text{Total time}} \right] \tag{24}$$

since "total time per annum" is a constant. The ratio of IFR time to total time has been found to be indicated almost directly by the ratio of air carrier IFR operations to air carrier total operations. These data show that for the preliminary sample design we have in mind,

$$\frac{\text{IFR weather}}{\text{Total weather}} \sim \frac{\text{IFR movements, carrier}}{\text{Total movements, carrier}} \; . \tag{25}$$

The latter are available from published data. Substituting in equations (24) and (22),

$$\lambda \sim \frac{\text{IFR movements}}{\text{IFR movements carrier/ total carrier movements}} \; . \tag{26}$$

From equation (21), letting the sum of IFR movements = I, and (IFR movements/ total movements) = F, or weather factor,

$$\text{Total delay at an airport} = F\,(I^2/F) \; . \tag{27}$$

All of the 143 airports for which published 1956 data are available were ranked on the basis of I^2/F, so that a sample size and strata could be determined.

Sample Size and Strata

On ordering the airports according to I^2/F, it was found that the five having the largest a priori expectation of delay are Los Angeles, Chicago Midway, New York-La Guardia, Washington, D. C., and San Francisco. These are all major airports, for which we are specifically interested in finding delay, and they were accordingly assigned to one stratum as a 100% sample. This left a total of 138 airports to be stratified and sampled. Here, the list was inspected, and seven additional strata assigned in such a manner that twice the value of I^2/F at the dividing line equals the sum of the means of these two adjacent strata. If $I^2/F = Y$ and $\bar{Y}_n$ a mean of Y for stratum n,

$$2 \text{ x } (Y)_{\text{at dividing line}} = \bar{Y}_1 + \bar{Y}_2 \; . \tag{28}$$

This division rule is aimed fundamentally at achieving a proportional allocation of the size of the strata in relation to the amplitudes of the variable, I^2/F.

In selecting the number of strata, as Cochrane says (reference 7), "the more the merrier" are desired. However, a point of diminishing returns is soon reached where sample costs grow faster than the rewards from increased accuracy.

Sample Size

The larger the size of the sample, the greater the precision of predictions for the whole population made on the basis of that sample. The concept of "accuracy" here is an important one. It does not mean that for a given sample size, the result predicted or estimated for the population will definitely be accurate within a given per cent of the true value. Assume, rather, that sampling of this same "population" of airports is carried out several times in succession. Each sample would result in the calculation of a different value of total delay. Depending, however, on the size of the sample taken, and on the dispersion of the data for the basic population which is being sampled, an estimate can be made of the percent of the time that these samples will give a result within a desired accuracy.

In other words, we can decide, before choosing the sample size, what "confidence limit" can be accepted for a given accuracy in sampling total delay. This confidence limit and desired accuracy determine the maximum acceptable sample variance, and hence minimum sample size.

$$\bar{Y} - 1.96\, S_y < Y < \bar{Y} + 1.96\, S_y \qquad (29)$$

where Y= mean of I^2/F. To get this in terms of total delay, multiply through by N, or the total number of airports at which delay can be expected to occur, making the necessary substitution and transposing,

$$S_y = \frac{.10}{1.96} \times \text{total delay} = .05 \times \sum I^2/F \qquad (30)$$

and sample variance, $V = (.05 \times \sum I^2/F)^2$.

Using the methods outlined by Cochrane (reference 7), sample size is computed as follows

Ignoring for the moment the correction for finite population (fpc),

$$N_o = \frac{(\sum N_H S_H)^2}{V} = \frac{120 \times 10^{17}}{64 \times 10^{16}} = 19$$

where N_H = number of airports in a given stratum, and S_H is the standard deviation in a given stratum. Correcting for the fact that n , or sample size, is a fairly large fraction of N, or population size,

$$n = \frac{N_o}{1 + \frac{1}{V} N_H S_H{}^2} = \frac{19}{1 + \frac{33 \times 10^{16}}{64 \times 10^{16}}} = 13 \qquad (31)$$

The size of the sample taken in each stratum, for minimum variance, will be proportional to the product of the size of the stratum and the standard deviation of that stratum. In symbols,

$$n_H = \frac{n N_H S_H}{\sum N_H S_H} \qquad (32)$$

where:
- n_H = sample size for stratum H
- N_H = "population", stratum H
- S_H = standard deviation, stratum H .

Previously, it had been decided to sample the first stratum 100%.

Accordingly, the total sample size required is 13 + 5 or 18. Proportioning a sample of 18 in accordance with this principle, we obtain

Stratum	n'_H	N_H	n_h
1	5.00	5	5
2	5.86	9	6
3	3.44	14	4
4	1.21	15	2
5	.50	13	1
6	.50	13	
7	.67	29	1
8	.82	46	

n'_H is the first approximation. The column headed n_h shows the sample sizes finally selected, with the aim of emphasizing the strata having higher variance and which will, in any case, account for most of the delay.

Selection of Specific Airports for Inclusion

In order to avoid biasing the sample through a priori judgments, a random sample was taken, i.e., airports were selected such that every airport (except the five in stratum No. 1) had an equal chance of being chosen. The procedure was carried out for each stratum separately. The list of airports selected by strata is presented on a following page. After the preliminary selection of this sample, it was decided to sample the second stratum, consisting of the nine airports shown on the table, 100% as well, since additional personnel or activity were not required in gathering data at these airports.

To calculate total nationwide delay, each of the strata was computed (fully sampled strata by simple addition, partially sampled strata by proportion) the total delay being the sum of all strata.

The list of airports selected for the sample includes

Stratum #1 (100%)

(MDW) Chicago
(LAX) Los Angeles
(LGA) New York
(SFO) San Francisco
(DCA) Washington, D. C.

Stratum #2 (100%)

(ATL) Atlanta
(CLE) Cleveland
(DAL) Dallas
(YIP) Detroit
(EWR) Newark
(IDL) New York
(PHL) Philadelphia
(PIT) Pittsburgh
(PDX) Portland, Ore.

Stratum #3 (4 of 14)

(BOS) Boston
(CVG) Cincinnati
(HOU) Houston
(MSP) Minneapolis

Stratum #4 (2 of 15)

(ORD) Chicago
(FWA) Fort Wayne

Stratum #5 (1 of 26)

(ROC) Rochester

Stratum #6 (1 of 75)

(LEX) Lexington

REFERENCES

1 Adler, R B , and Fricker, S.J The Flow of Scheduled Air Traffic (1), Research Laboratory of Electronics, M I.T , T.R No 198, May, 1951.

2 Adler, R B., and Fricker, S J The Flow of Scheduled Air Traffic (2), Research Laboratory of Electronics, M I T., T.R No 199, August, 1951.

3 Adler, R.B., and Fricker, S J The Flow of Scheduled Air Traffic, Journal of Royal Aeronautical Society, July, 1954

4 Bell, G E Operational Research into Air Traffic Control, Journal of Royal Aeronautical Society, October 1949

5. Morse, Philip M Queues, Inventories and Maintenance, New York, John Wiley and Sons, 1958

6. Churchman, Ackoff and Arnoff, Introduction to Operations Research, New York,John Wiley and Sons, 1957

7 Cochrane, William G Sampling Techniques, New York, John Wiley and Sons, 1953

8 United Research, Inc , A Method for Determining the Economic Value of Air Traffic Control Improvements and Application to All-Weather Landing Systems, Vol II