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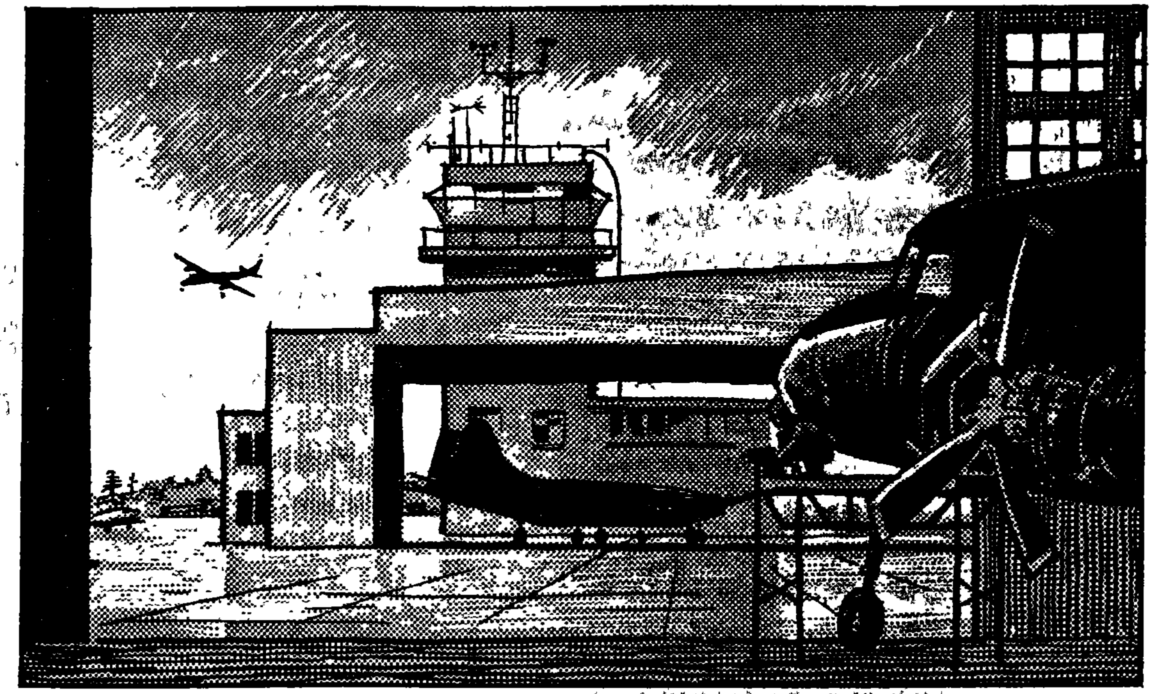

A REPORT ON

# A METHOD FOR DETERMINING THE ECONOMIC VALUE OF AIR TRAFFIC CONTROL IMPROVEMENTS AND APPLICATION TO ALL-WEATHER LANDING SYSTEMS

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# A METHOD FOR DETERMINING THE ECONOMIC VALUE OF AIR TRAFFIC CONTROL IMPROVEMENTS AND APPLICATION TO ALL-WEATHER LANDING SYSTEMS

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# I

# INTRODUCTION

This report summarizes the results of a study concerned with the development of a method for determining the economic benefits to civil users of the airways associated with Air Traffic Control improvements and the application of the method to an evaluation of the benefits associated with all-weather landing systems.

In addition to this introductory section, the report deals with the following subjects in the parts indicated: II. Summary and Conclusions, III. The Method of Benefit Determination, and IV. Application of the Method to an Evaluation of All-Weather Landing Systems. This summary report is supported by Technical Notes, presented in a separate volume, which provide further detail regarding theory underlying the evaluation method and describe the work performed by United Research in fulfilling the study contract.

## A. The Role of Economic Benefit Evaluation in the FAA Program

The FAA is charged with the task of modernizing the airways system in order to, 1) increase the utility of the system to potential users, 2) improve the efficiency of the system, and 3) increase the margins of safety.

In fulfilling this task, the FAA is called upon to recommend and administer the investment of government funds in the development, installation and operation of system improvements. It must advise the President and the Congress concerning funds to be appropriated to carry out its program. Once funds are appropriated the FAA is further obligated to administer their use so as to best promote the objectives of its task.

In the administration of a large investment program in the airways, the relative benefits which would flow from the devotion of funds to airways improvements as opposed to alternative governmental or private investment programs are a prime consideration. It is equally important to have a proper basis for evaluating the relative benefits to be derived from investment in alternative airways programs. Furthermore, to the extent that sound economic policy dictates that government funds invested in the Air Traffic Control system should be recapturable through charges on the users, it is desirable to determine that such charges are fair and reasonable, that they do not exceed the value of the services made available, and that they do not unduly limit the use made of the available services. All of these considerations point to the need for a method of estimating economic benefits associated with airway improvements in monetary terms which permit comparison with the costs of providing the services.

## B. Limitations on the Scope of the Study

This study has been confined to an analysis of the economic benefits of ATC improvements to the civil users of the airways. This is not meant to suggest that important economic, as well as military, benefits do not accrue to the military users as a result of ATC improvements. On the other hand, in evaluating the benefits of improvements in the ATC system to military users, non-economic considerations are often of overriding importance. Considerations surrounding changes which affect civil users, while they are not entirely free of non-economic aspects, are principally economic.

Although the user benefits determined in accordance with the method recommended in this report provide guide posts for "user charge" policy, user charges are outside the scope of this report. The design of specific user charges should consider the effects upon benefits of the charges themselves, as well as the effects of the improvements.

## II
## SUMMARY AND CONCLUSIONS

### A. The Method

The method developed by United Research for the determination of economic benefits associated with Air Traffic Control improvements is based on:

1. The measure of the effects of these improvements in dollar terms on the demand for and the cost 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 property and life) prevented by the improvement.

In order to determine the annual net return from any selected improvement, the dollar values determined for each of the above measures are summed and the annual operating costs of the improvement are then subtracted. A present value formula which takes into consideration the applicable interest rate and the number of years the improvement can be expected to be in operation is then applied to determine the investment in an improvement which can be justified by the FAA.

### B. Application of the Method

In applying the method to a selected improvement such as an all-weather landing system two preliminary steps are necessary. These are:

1) Determination of the physical effect of the improvement (e.g., 0-0 ceiling and visibility conditions, number of operations per runway); and,

2) Calculation of the annual reduction in the physical units of disruption, delay, cancellation and diversion.

Economic benefits associated with an improvement can then be computed.

Thus, the method as applied to an all-weather landing system concludes the following:

| | | |
|---|---|---|
| 1. | Additional demand leading to increased revenues to air carriers | $11,500,000 |
| 2. | Cost savings to air carriers | $ 9,379,000 |
| 3. | Cost savings to general aviation | $ 292,000 |
| 4. | Value of accidents prevented | $ 3,791,000 |
| | Total | $24,962,000 |

Since the annual operating costs of an all-weather landing system were not available, the annual net return of this ATC improvement was not calculated.

A further conclusion based upon a detailed study of the installation of all-weather landing systems at 22 airports (a stratified sample of all approach control airports in the United States) shows that: 50% of the total dollar benefits would be realized if installations were made at only 14 airports.

## III

## THE METHOD OF BENEFIT DETERMINATION

There are three principal types of economic benefits associated with ATC improvements--namely: 1) benefits from improvements in utility of the airways which result in an increased demand for their use, thereby allowing either an increased price to be charged for the same volume of traffic or creating a higher incidence of use at the same price; 2) benefits from improvements in efficiency which result in reduced cost to the users, part or all of which might be recoverable as a charge for the improvement; and 3) benefits from improvements in the margins of safety which result in fewer accidents, thereby reducing the premature and costly loss or damage of human and physical resources. The method for determining the economic benefits of ATC improvements is designed to assign dollar values to each type of benefit so that the total economic benefits of a contemplated improvement may be derived.

### A. The Effects of ATC Improvements on Demand

In the method developed, the demand for airways is derived from the demand of passenger users of common carrier air transport services. There is further demand on the airways by shippers, including the U. S. government, and general aviation users. However, for reasons later discussed, the demands of shippers have not been specifically considered in the method and the demands of general aviation users are separately treated.

The demand for airline passenger transportation at varying prices, expressed in terms of the quantity of air passenger miles (all other contributing factors being held constant at 1957 levels), is represented by the solid line in Figure I. This demand relationship was derived from data for the years 1947-1957 through the technique of multiple regression. The method of computing the demand relationship is described in detail in Section III of the Technical Notes, Volume II, of this report. In addition to price, significant variables in the time series used to derive demand were the Gross National Product and data which described seasonal variations in air travel. The increase in speed of air travel during the period was so highly correlated with the increase in Gross National Product that it was impossible to make a separate estimate of the influence of speed increases on the demand for air travel.

Of the several factors which might be changed by ATC improvements, the reliability of air transportation proved to be the only factor investigated which had both a significant and quantifiable effect on demand for air travel. During the winter months of each year, the unreliability of air travel is typically greater than unreliability in the summer months. For purposes of the method, the percentage of scheduled miles not completed is used as the measure of unreliability. A more precise and sensitive measure of unreliability would have been desirable (as for example the percent of trips delayed more than thirty minutes) but data are not available to derive such a measure. Characteristically, during periods when air services experience greatest unreliability, the percent of first class travelers (users of air and first class rail services) who travel by air declines. In part this results from a shift from air to rail travel and this shift can be ascertained from the relationship shown graphically in Figure IV for the years 1947-1957. When quarterly unreliability (U) is expressed in

FIGURE I

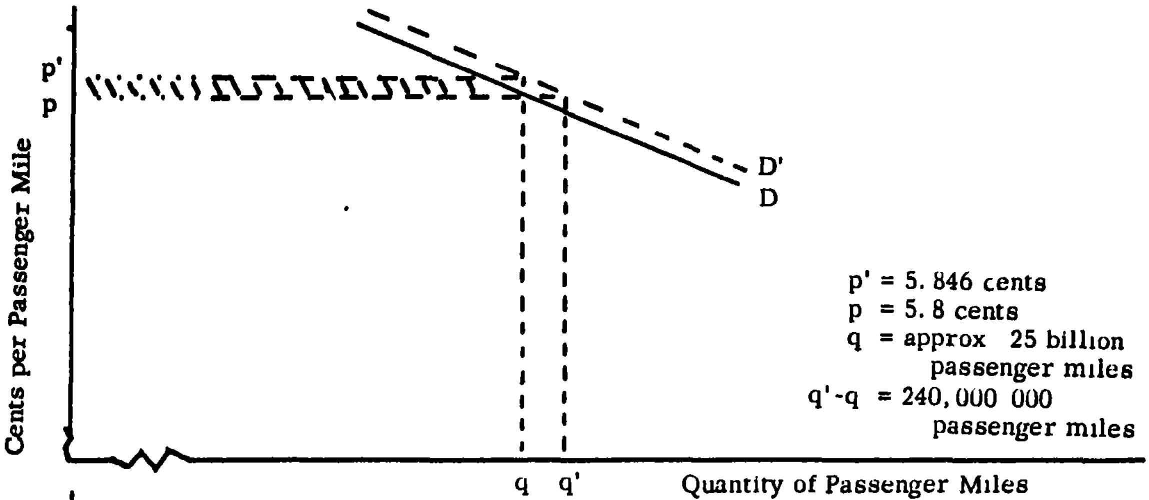



FIGURE II

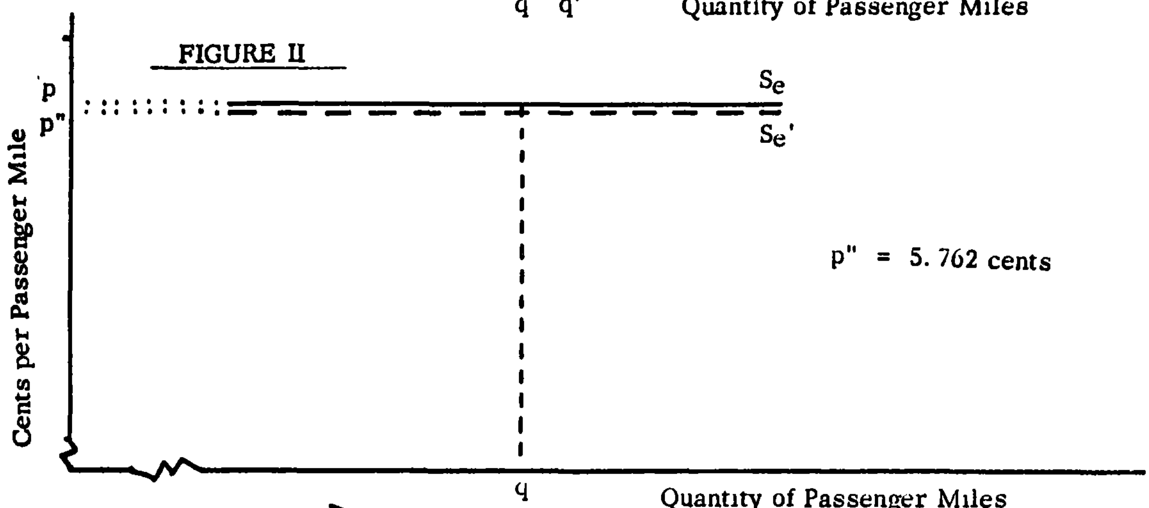
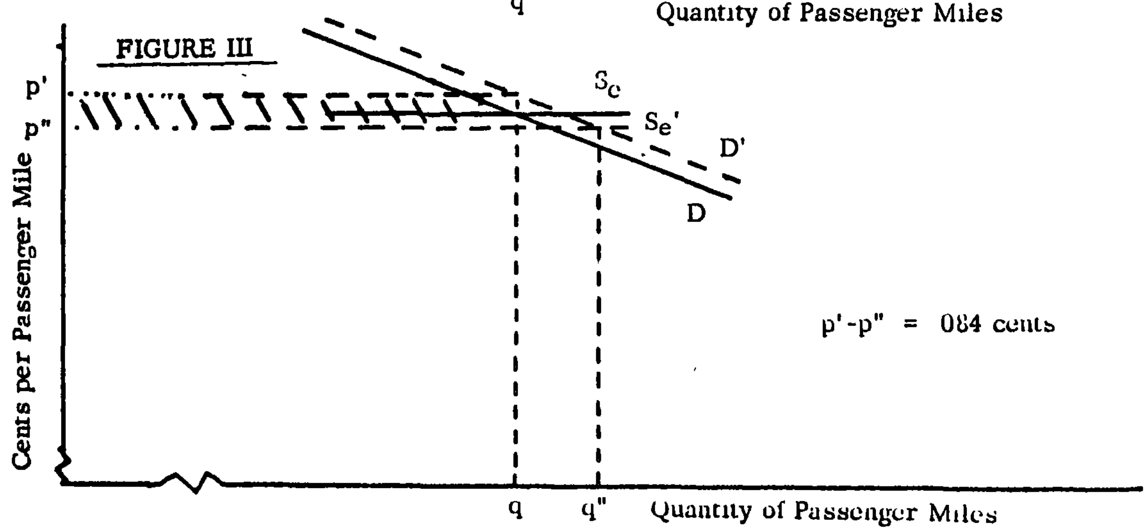


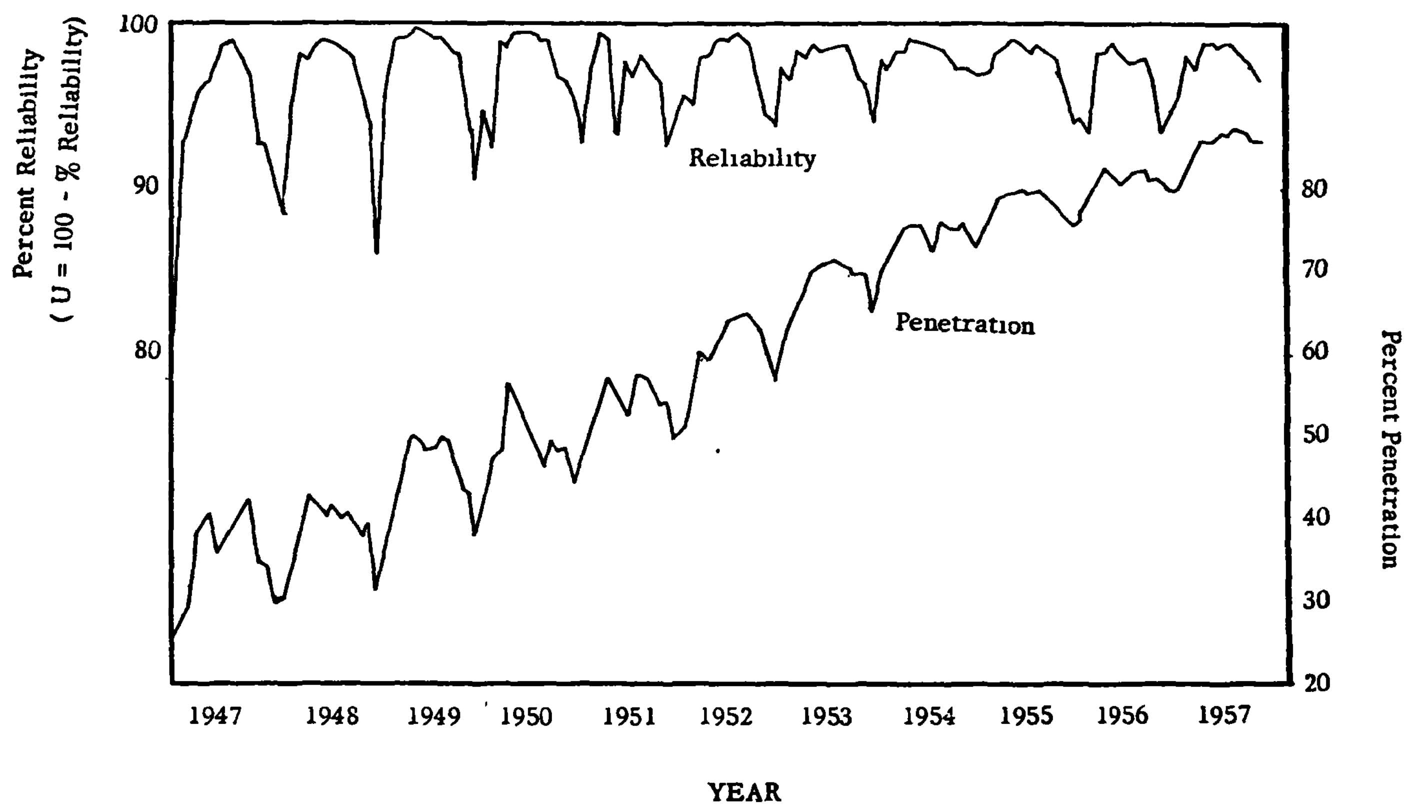

FIGURE III



## FIGURE IV

VARIATION WITH TIME OF RELIABILITY OF AIR TRANSPORT AND THE

PERCENTAGE PENETRATION BY AIR TRANSPORT OF THE TOTAL PASSENGER MARKET



percentage points, and the quarterly drop in air travel percentage of total air and first class rail travel is expressed in terms of air passenger miles, a high correlation is found, as can be seen in Figure Vb. The same data are plotted on a semi-log scale in Figure Va to point up the tapering effect on traffic of successive levels of improvement.

The average annual level of unreliability of the last three years has been about 3%. As can be seen from Figure Va, a reduction in U to 2% could be expected to increase annual passenger-miles by 320,000,000, while a further reduction to 1% would only increase passenger miles by an additional 200,000,000 annually.

From the relationship between changes in unreliability of air transport services and demand, it is possible further to determine the effect of an ATC improvement on demand by estimating its effect on the unreliability of air service. In other words, an ATC improvement which reduces unreliability by permitting relatively more flights to be completed will increase the utility of the airways and, hence, increase demand by an amount that can be determined from the established relationship. It is also possible to reflect the greater reliability provided by an ATC improvement in an adjusted demand function, as shown by the dotted line in Figure I (in this illustration the increase in demand associated with all-weather landing systems is depicted). From the adjusted demand function, it is then possible to ascertain the amount by which the price of air transport services may be increased without reducing the level of demand below current experience. In the case of the all-weather landing systems it is estimated, for example, that the same level of demand would exist at a price of 5.846 cents per passenger mile, as was actually experienced under existing reliability conditions at a price of 5.8 cents per passenger mile. The difference between 5.846 cents and 5.8 cents represents additional revenue which could be recovered from the passenger without reducing the total demand for air service.

Figure I illustrates the method for computing the potential additional revenue available as a result of the shift in demand when an ATC improvement increasing reliability has been made. The difference in unit price which might be charged (p' -p) times the original quantity (q) equals potential additional revenue available to apply to the cost of the improvement without changing the level of passenger travel.

It is pertinent to note that demand shifts are computed solely in regard to airline passenger traffic, the principal civilian sector in which demand shifts are likely to involve substantial dollar values. Airline cargo traffic contributes only to a limited extent to total airline revenues and is believed still to be in a status where only substantial price reductions would add greatly to demand. Schedule reliability in the sense used here appears to be of relatively little significance in determining the demand for cargo operations. Data are unavailable from which to construct a reliable demand curve for general aviation. Consequently, the impact of ATC improvements on this group has been measured in terms of cost savings (including an estimate of the value of time saved) alone.

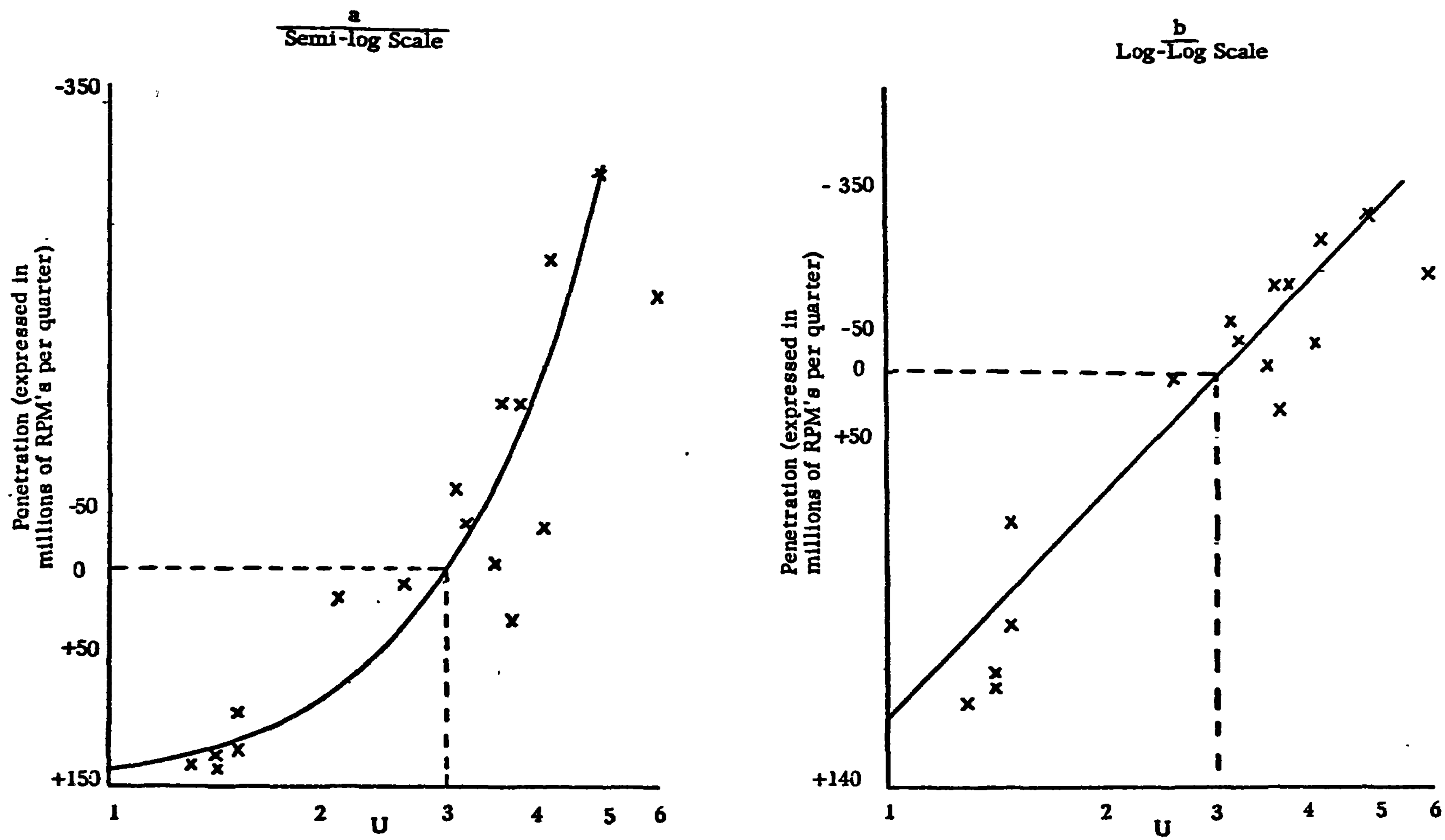
B. Determining Effect upon Cost of Supplying Air Transportation

For purposes of economic benefit evaluation, the supply curve can be considered to be a horizontal straight line, as depicted in Figure II. This is to

FIGURE V

VARIATION OF AIR TRAVEL WITH

UNRELIABILITY FACTOR



say that, within the range of demand shifts which might result from ATC improvements, increased air transport services will be made available to the extent demanded at an unchanged price. The impact of ATC improvements on three types of disruptions of airline services make possible reductions in costs of providing air transportation: aircraft delays, flight cancellations, and flight diversions to an alternate airport.

1. Delay adds to operating costs by requiring additional aircraft operating time to accomplish a given trip. Airline delay has been assigned a cost of $170 per hour, the average direct aircraft operating cost of airline planes in 1957, exclusive of depreciation.

2. Cancellations have a mixed effect on airline costs and revenues. A cancelled flight "saves" some operating expense, but "costs" some revenues. Additionally, some out-of-pocket expense to the airline (Interrupted Trip Expense) is likely to be occasioned by a cancellation. The method of costing cancellations is to consider lost revenue as a cost, subtract from it the direct operating cost saved, and to add average interrupted trip expense per cancellation. The costs of cancelled flights will differ, depending on the passenger capacity of the aircraft involved and length of haul. Taking these factors into account, each cancellation of a local service flight was estimated to cost $24, short-haul trunk $86, and long-haul trunk $326 for 1957.

3. Diversions are, in effect, a mixture of delays and cancellations. Because diversions are more likely to involve large aircraft (since smaller aircraft operated over shorter stage lengths are more likely to be cancelled) costs associated with diversions are likely to be high. The cost of an average diversion used in this study was $691, made up of one hour of delay (at the average cost for four-engine equipment, or $210), one-half hour ferry flight, a resulting long-haul cancellation, and an amount of interrupted trip expense equal to twice that applicable to a cancellation.

In order to determine the effect of an ATC improvement upon costs of providing air transportation, it is necessary to determine its effects in terms of the reduction of delays, cancellations, and diversions. The costs of hours of delay and numbers of diversions and cancellations avoided by the improvement is the gross reduction in costs resulting from the improvement. If there is some operating or investment cost (such as airborne instrumentation) which must be borne by airways users, this cost should be subtracted from the gross cost reduction to arrive at the net reduction in costs attributable to the improvement. The net reduction in costs, when divided by the quantity of passenger miles provided, determines the amount per passenger mile by which the supply curve can be lowered (dotted line, $S'_e$, Figure II). This is not a reduction in price, but of cost, of air transport. Again, however, the amount (p-p") q is a sum which might be recoverable as a charge for the ATC improvement.

Figure III shows the combined effects of shifts in demand for and in the cost of supplying airline passenger transportation. The total amount of potential additional revenue from the airline sector is represented by (p'-p")q. This means that an improvement for which a service charge totalling (p'-p")q is exacted would leave the airlines with the same number of passenger miles and the same net revenues, if a higher fare (equal to p'-p per passenger mile) were charged. The amount of potential additional revenue so determined (p'-p")q represents the economic benefits of the improvement to the airline users of the airways. The difference between this amount and the cost to the government of operating the improvement is the "net return" which can be evaluated against the cost of developing and installing the improvement, if user charges in the amount of the economic benefits are exacted.

It may be noted that the economic benefits determined from the relationship $(p' - p'')q$ are not necessarily the maximum benefits or the maximum recoverable revenues associated with a particular improvement. At some different price the quantity of demand may be such that the recoverable revenue is greater.

General aviation costs are affected by improvements in the ATC system in much the same way as airline costs. Lacking a demand function, however, a specific value has been assigned to time savings afforded by ATC improvements to the general aviation user, in lieu of computing the additional amount passengers would be willing to pay for improved service. The costs assigned to disruption of general aviation activity are:

1) An hour of delay--average direct operating costs of $34, and two passenger-hours of delay at $10 per hour, total, $54;

2) A cancellation--five passenger hours of delay, $50; and

3) A diversion--one and one-half hours' direct operating costs, $51, plus six passenger-hours of delay, $60, a total of $111.

## C. Determining Effect on Accidents

Since the economic loss associated with accidents can not be adequately treated in the context of demand-supply relationships, the economic benefits of accident avoidance are determined separately in the method developed. The determination of the economic benefits associated with ATC improvements which reduce the probability of accidents is approached in two steps: 1) The type and number of accidents which will be avoided as a result of the improvement is estimated and 2) a dollar loss is assigned to each avoidable accident based on the amount of property damage and personal injuries and/or loss of life generally associated with the type of accident involved.

In the initial stages of assessing the benefits of accident avoidance, it is useful to make the assumption that a particular ATC improvement will be 100% effective in preventing accidents of a specific type. 1/ An examination of the records of accidents will show how many accidents of that type occurred. The number of each type of accident is related to some appropriate measure of "exposure" (For example, landing accidents under instrument conditions are related to the total number of instrument landings). The effect of a particular installation on the probable number of accidents in a given time period can be determined from the accident and exposure data.

Accidents result in two types of economic loss, loss or damage to property and loss or injury to human life. The economic loss attributed to loss

1. The assignment of a lesser degree of effectiveness should follow an engineering evaluation of the reliability of the equipment involved in the improvement.

of a human life is computed by placing a present value on the future income payments of an average airline passenger, the concept of loss being the loss to the economy of the productivity of the accident victim. Other bases for assigning a value to the loss of a human life may be used. For example, the value may be based on court awards to accident victims or the average insured value of the deceased. However, it is clear that no basis of valuation can satisfactorily reflect the full implications of a premature death. The basis used indicates that a substantial loss is involved and this is believed to be sufficient for purposes of benefit evaluation.

The average severity of accident varies with the stage of the flight at which the accident occurs. Thus, average costs of different types of accidents differ materially. For landing accidents, which would be reduced by all-weather landing systems, the average costs were determined to be as follows:

1. airline--$311,000 (including value of 0.81 lives and 0.75 serious injuries),

2. general aviation (planes over 12,500 gross weight)-- $267,000 (including value of one life), and

3. general aviation (planes 12,500 gross weight and under)--$155,000 (including value of 0.75 lives).

## D. Use of the Present-Value Formula

The net potential revenue (N) which should be used to determine the capital cost which the government would be justified in paying for the improvement can be computed by adding potential revenues available from air carriers and general aviation because of increased demand and reduced operating costs to the economic loss avoided by reducing accidents, and then subtracting the annual additional cost of operating the ATC system after an improvement has been made. The formula for determining the justifiable level of capital costs for an improvement is:

$$C = N \cdot \frac{1 - (1+r)^{-T}}{r}$$

where

C = the capital cost of the improvement
N = annual net return
r = applicable interest rate, and
T = the number of years the improvement can be expected to provide the net return.

Example: For an ATC improvement which would provide a net return over operating cost of $500,000 per year for 10 years, with an applicable interest rate of 12%, the justifiable investment would be:

$$C = \$500,000 \cdot \frac{1 - (1.12)^{-10}}{.12}$$

$$= \$500,000 \quad 5.65$$

$$= \$2,825,000$$

It should be noted that this is the simplest form of the present value formula, in that it assumes that the annual net return will remain constant. In air transportation it is likely that savings from many improvements will increase each year. To reflect an increasing annual net return would require a slightly different formula, but would not materially change the results. The alternate formula is discussed in Section II of the Technical Notes. The resulting present value is the amount of imvestment which can be justified now in order to obtain future dollar benefits.

The interest rate deserves particular comment since the level of the interest rate used greatly influences the results. For example, had 3% been used, rather than 12%, in the above example, the justifiable investment would have been $4,265,000, rather than $2,825,000. The implication of a high interest rate is not only to provide for the "cost of the money" devoted to a project in the strict accounting sense but to take account of the average return which would accrue from the alternative investment of the money in the civilian sector of the economy and to place a relatively high value on the desirability of making investments in alternative government programs. Whereas the "cost of the money" to the government might be in the order of 3%, the same amount of money invested in the private sector of the economy would yield, on the average, a good deal more--say 12%. (Reference is made in Section II of the Technical Notes to the body of theory which has grown up concerning this question.) A project which is justified by use of a high interest rate (such as 12%) is clearly a more defensible investment than one which can only be justified on the basis of a lower rate, such as the government borrowing rate.

## IV

## APPLICATION OF THE METHOD TO AN EVALUATION OF ALL-WEATHER LANDING SYSTEMS

The economic evaluation method developed in Part III has been applied to all-weather landing systems. This application requires an analysis of the physical effects of the change which an all-weather landing system could be expected to bring about. An all-weather landing system was assumed, on the basis of consultation with representatives of FAA/BRD Systems Analysis Directorate, to introduce the following improvements at any airport where it might be installed:

1) Allow operations at the airport under ceiling and visibility conditions of 0-0, [1] whereas such operations are now generally not conducted below 200-1/2,

2) Allow 60 operations per single independent runway (where not limited by some more restrictive factor peculiar to an individual airport) under any operating conditions, and

3) Reduce the probability of IFR landing accidents to zero.

Clearly the area of influence of an all-weather landing system is centered on the airport at which it may be installed. It would be feasible, but expensive, to analyze the effects of all-weather landing systems at all towered airports in the United States. A carefully selected stratified sample of airports was chosen for study, instead, in order to permit a more detailed analysis of each. The criteria for selection of the sample were traffic volume and incidence of IFR weather. [2] The fourteen airports which experienced both high traffic volumes and a high incidence of IFR weather were included in the sample to be studied. Eight other airports, judged to be typical of other towered airports grouped in order of decreasing traffic and lesser incidence of IFR weather, were also chosen for analysis. The 22 airports chosen are those listed in Table I.

It was necessary to estimate for each of the sample airports the incidence of the physical units of disruption suffered in 1957, which would have been avoided had an all-weather landing system been installed. In the absence of recorded data concerning such disruptions, a model was found to be useful in making these estimates. In this model the incidence of disruptions in the area of the airport was related to:

1) The rate at which an airport can handle landings and take-offs, stated in operations per hour, which has been designated the "acceptance rate": this rate will vary from 0 under present 0-0 conditions to whatever the top capacity of the airport may be in VFR conditions;

---

1. An idea of the relative amounts of benefits from a lesser system, such as one which allowed operations until conditions worsened below 100-1/4, can be had from reference to Volume II, Appendix II, which gives occurrences of weather at each of a sample of airports.
2. The selection criteria are described in the Technical Notes.

2) The rate at which aircraft are scheduled (or planned) to land and take off at the airport, which has been designated the "arrival and departure rate", or more simply the "arrival rate"; and

3) The incidence and duration of adverse weather conditions.

These relationships are depicted graphically in Figure VI, which shows, for the 24 hours of a sample day, the IFR "arrival rate" (solid line) and the "acceptance rate" (dashed line) at Midway airport. The dotted line at 90 operations per hour shows the estimated hourly acceptance rate at this airport with an all-weather landing system.

For each of the sample airports a "typical" hour-by-hour arrival rate pattern for IFR weather periods was constructed, using airline schedules for airline flights and a one-month sample of IFR flight strips for general aviation and military flights. Maximum acceptance rates in IFR conditions were estimated by CAA personnel at each sample airport. The weather pattern for each airport during all of 1957 was supplied by the Weather Bureau.

## A. The Analysis of Disruptions.

As can be seen in Figure VI, there are three types of relationships between arrival rates and acceptance rates, only two of which are important to an analysis of the effect of all-weather landing systems. These are:

a) VFR weather, when acceptance rate is at the maximum, and an all-weather landing system could not improve acceptance rate. Delays may occur during such periods, but these delays are not pertinent to the present study;

b) Times of restricted acceptance rate, which could be improved by an all-weather system, during which acceptance rate is higher than arrival rate; and

c) Times of restricted acceptance rate, which could be improved by an all-weather landing system, during which arrival rate exceeds acceptance rate. The most important case of this relationship is the time when the airport is closed, and acceptance rate is zero.

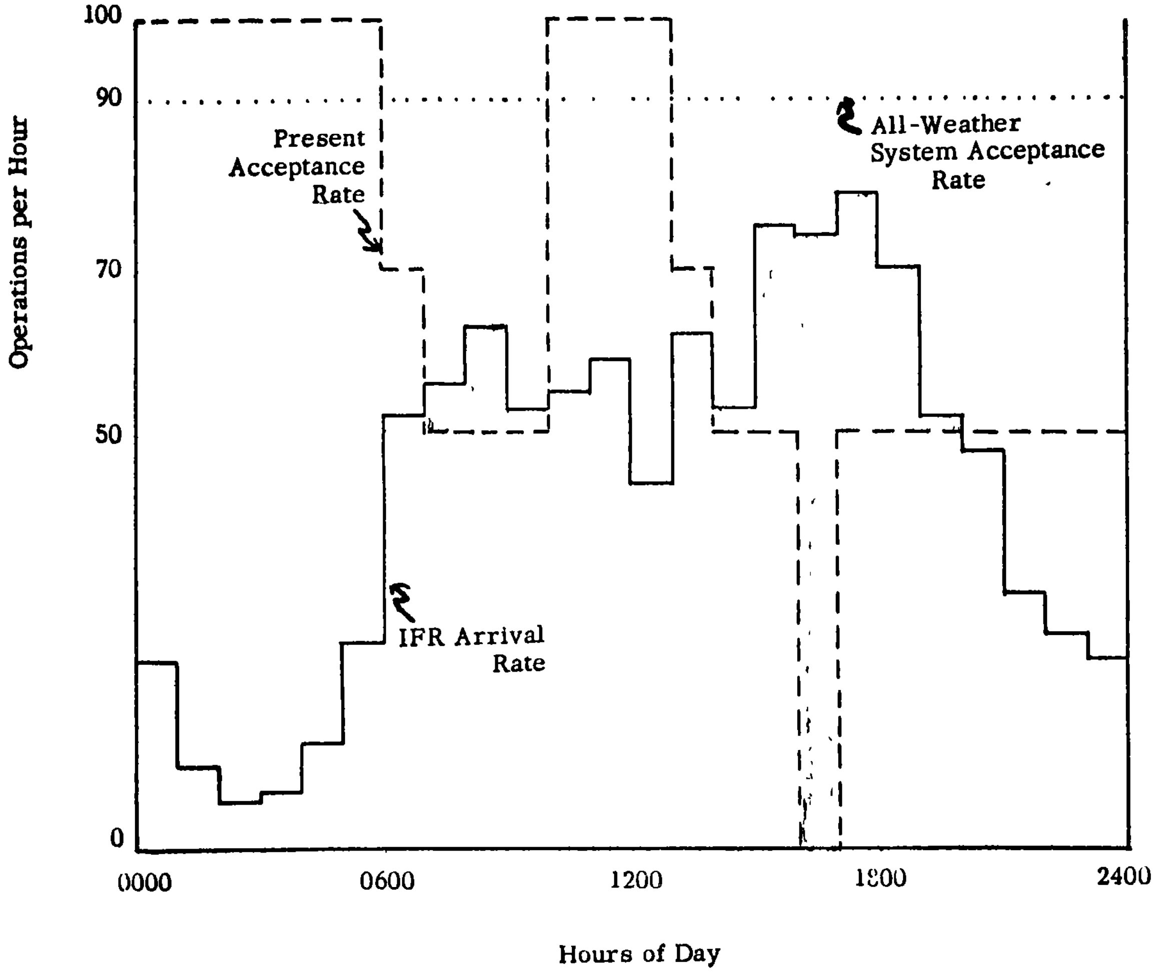
1. Disruption during periods when acceptance rate is restricted, but exceeds arrival rate. Delays occur even when the hourly acceptance rate exceeds the hourly arrival rate. The reason is that aircraft do not present themselves for take-off and landing at perfectly spaced intervals. Even if schedule operations were evenly spaced, the minor deviations from schedule caused by differences in winds aloft or, for planes departing, by excessive time in loading passengers, would cause some "bunching" of aircraft to be handled, and thus some delay to provide the needed spacing between aircraft.

Clearly this type of delay will be less as fewer planes must be handled in a given hour, and less as more planes can be handled (and thus less space or time needed between operations). The average delay is a function of the relationship between arrival rate and acceptance rate. Figure VII shows graphically this relationship as it was used to estimate delays in this study.

FIGURE VI

HOURLY ARRIVAL AND ACCEPTANCE RATES

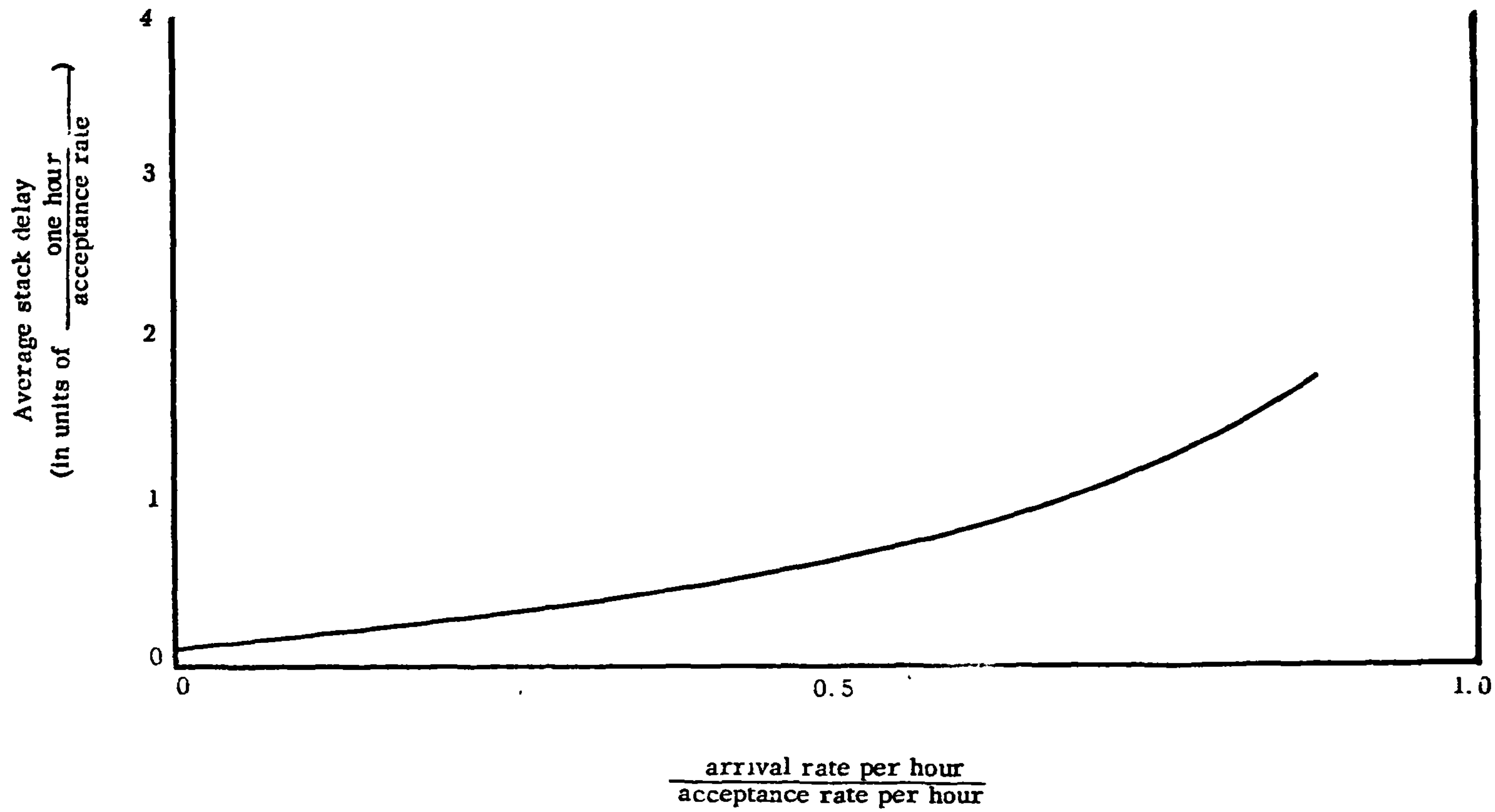
DURING A SAMPLE DAY AT CHICAGO MIDWAY AIRPORT



## FIGURE VII

RELATIONSHIP OF AVERAGE DELAY PER AIRCRAFT

TO ARRIVAL RATE / ACCEPTANCE RATE



The effect of an all-weather landing system being to raise the acceptance rate, the improvement in delay can be measured as the difference between the delay experienced with the lower acceptance rate and that which would have been experienced with an all-weather system installed.

The computation of delay of this sort was made for each sample airport for the year 1957, using Weather Bureau records of the number of occurrences of IFR operating weather for each hour of the day. The resulting estimates of plane-hours of delay are included in Table I. At most sample airports the hours of delay computed in this way were substantially less in number than hours of delay when the airport was closed. Ground delay and airborne delay are totalled, since the ground delay will have occurred on the flight line with engines running, and differences in cost between airborne and ground delay of this sort are slight.

2. Disruptions during periods when arrival rate exceeds acceptance rate. It is clear that disruptions pyramid during periods when the airport is closed, or when more planes present themselves for landing or take-off than can be handled over extended periods. 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 reached which reduce delays by 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, described in Section VII of the Technical Notes, 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. These are reported in Table I.

B. Evaluating Physical Units of Disruption.

1. Effect on air carrier demand. As was noted in Section III, the one ATC improvement which has been shown to have a quantifiable effect on demand for passenger air travel is reliability, measured in terms of scheduled flights completed. The avoidance of 16,640 cancellations of trunk airline flights, included in the total cancellations shown in Table I, represents approximately 1/5 the flights cancelled annually by trunk airlines,[1] and thus could be expected to have the effect upon demand shown by dotted line D' in Figure I. The implication of this shift in demand is that 240,000,000 additional passenger-miles could be sold at current fares, or that .046 cents additional fare per passenger mile could be charged for the same number of passenger miles as were provided in the base year. For the 1957 total of approximately 25 billion passenger miles, this amounts to an additional potential revenue of $11,500,000 attributable to nationwide installation of all-weather landing systems.

1. As reported in "Airport Activity Statistics of Certificated Air Carriers," Air Transport Association of America, Washington, D. C.

# TABLE I

## ESTIMATES OF AVOIDABLE AIR CARRIER AND GENERAL AVIATION DISRUPTIONS AT SAMPLE AIRPORTS - 1957.

| Airport | Hours of Delay | | Diversions | | Cancellations | |
|---|---|---|---|---|---|---|
| | Air Carrier | Gen. Aviation | Air Carrier | Gen. Aviation | Air Carrier | Gen. Aviation |
| LAX Los Angeles | 471 | 42 | 281 | 12 | 489 | 42 |
| MDW Chicago, Midway | 9072 | 498 | 861 | 23 | 1557 | 84 |
| LGA New York | 372 | 47 | 111 | 7 | 241 | 30 |
| DCA Washington, D. C. | 479 | 42 | 254 | 11 | 584 | 52 |
| SFO San Francisco | 195 | 6 | 111 | 1 | 229 | 6 |
| Total, Stratum I | 10589 | 635 | 1618 | 54 | 3100 | 214 |
| IDL New York | 460 | 18 | 640 | 12 | 892 | 34 |
| PIT Pittsburgh | 312 | 55 | 127 | 11 | 321 | 56 |
| CLE Cleveland | 138 | 21 | 57 | 4 | 149 | 22 |
| ATL Atlanta | 452 | 10 | 366 | 4 | 948 | 22 |
| EWR Newark | 319 | 40 | 236 | 14 | 808 | 100 |
| YIP Detroit | 422 | 38 | 441 | 20 | 1183 | 106 |
| PDX Portland, Ore. | 176 | 5 | 221 | 3 | 857 | 24 |
| PHL Philadelphia | 254 | 19 | 149 | 6 | 453 | 36 |
| DAL Dallas | 226 | 20 | 119 | 5 | 367 | 32 |
| Total Stratum II | 2759 | 226 | 2356 | 79 | 5978 | 432 |
| BOS Boston | 372 | 33 | 67 | 3 | 229 | 20 |
| HOU Houston | 205 | 63 | 132 | 20 | 402 | 122 |
| MSP Minneapolis | 61 | 8 | 48 | 3 | 104 | 14 |
| CVG Cincinnati | 190 | 20 | 127 | 6 | 347 | 36 |
| Total | 828 | 124 | 374 | 32 | 1082 | 192 |
| Total, Stratum III | 2898 | 434 | 1309 | 112 | 3787 | 672 |

TABLE I (cont.)

| Airport | Hours of Delay | | Diversions | | Cancellations | |
|---|---|---|---|---|---|---|
| | Air Carrier | Gen. Aviation | Air Carrier | Gen. Aviation | Air Carrier | Gen. Aviation |
| ORD Chicago, O'Hare | 118 | 13 | 86 | 5 | 158 | 18 |
| FWA Fort Wayne | 12 | 8 | 7 | 2 | 35 | 24 |
| Total | 130 | 21 | 93 | 7 | 193 | 42 |
| Total, Stratum IV | 976 | 157 | 698 | 52 | 1448 | 316 |
| ROC Rochester, N. Y. | 38 | 4 | 8 | 0 | 54 | 4 |
| LEX Lexington, Ky. | 26 | 5 | 15 | 1 | 99 | 20 |
| Total | 64 | 9 | 23 | 1 | 153 | 24 |
| Total, Strata V, VI, VII & VIII | 3233 | 455 | 1161 | 50 | 7727 | 1212 |
| NATIONAL TOTAL | 20455 | 1907 | 7142 | 347 | 22850 1/ | 3000 1/ |

1. Includes adjustments for coincident weather patterns at nearby stations. See Technical Notes.

Because the decisions regarding all-weather landing systems will be made individually regarding each airport, it is desirable to determine this demand effect on an individual airport basis. It is impracticable to construct separate demand functions for different airports; therefore the national total $11,500,000 has been divided among airports in proportion to the airline costs saved by all-weather installations. The resulting figures are shown in Column 2, Table II.

2. Effect on air carrier and general aviation costs. The physical units of delay at each airport were evaluated, in terms of their cost to airlines and general aviation, at the rates applicable to 1957, as listed in Section III. Table II, Columns 1 and 3 show the dollar values at each airport which resulted.

## C. Estimating and Evaluating Avoidance of Accident

The type accident which all-weather landing systems should avoid is a landing accident occurring during an instrument approach. Examination of accident records for 1956 and 1957 revealed 16 such accidents to airline planes at approach control towers, and two to general aviation planes of over 12,500 lbs. gross weight. The 1957 total of such accidents among smaller general aviation planes was four; no examination was conducted of previous years' records for the smaller planes.

When these accidents were related to the amount of "exposure" represented by instrument approaches during the years in which they occurred, the accident rate for airline planes proved to be .000015 per instrument approach, while the larger general aviation planes showed a rate of .000013, and smaller general aviation planes of .000041. Columns 1,2, and 3, Table III, show the probabilities of an avoidable landing accident to each type of plane at each of the sample airports, based on 1957 instrument approaches at those airports. Column 4 shows the dollar cost of the avoidable accidents, while columns 5 and 6 show the loss in lives and serious injury which would be avoided by an all-weather landing system at each airport.

## D. The Sum of Dollar Benefits.

Table II shows the major categories of dollar benefits and their totals for each sample airport, and for the nation as a whole. It should be noted that the benefits at fourteen large airports total over one-half the nationwide benefits.

The wide disparity between benefits at Chicago Midway airport and any of the other stations deserves discussion. The method of estimating physical units of disruption which was described earlier in this Section demonstrated the substantial penalties in disruption which are paid at an airport during periods when the "arrival rate" exceeds the "acceptance rate". Chicago Midway was the only airport at which the arrival rate exceeded the tower-estimated maximum IFR acceptance rates for extended periods of time. In view of the importance of the ratio between arrival and acceptance rate, the present IFR capacities of all busy airports should be the subject of specific empirical study.

## E. Examples of the Use of Dollar Benefits.

No judgment is possible regarding at which airports all-weather landing systems should be installed until information on annual operating and installation

TABLE II

DOLLAR VALUES OF POTENTIAL BENEFITS FROM ALL-WEATHER LANDING SYSTEM INSTALLATIONS AT SAMPLE AIRPORTS - 1957

| Airport | Air Carrier Costs (000) | Air Carrier Potential Added Revenue (000) | General Aviation Costs (000) | Dollar Cost Of Accidents (000) | Total Dollar Benefits (000) |
|---|---|---|---|---|---|
| LAX | $ 288 | $ 357 | $ 6 | $ 158 | $ 809 |
| MDW | 2177 | 2690 | 34 | 153 | 5054 |
| LGA | 151 | 186 | 5 | 95 | 437 |
| DCA | 283 | 350 | 6 | 62 | 701 |
| SFO | 115 | 143 | 1 | 87 | 346 |
| IDL | 542 | 669 | 4 | 59 | 1274 |
| PIT | 152 | 188 | 7 | 73 | 420 |
| CLE | 69 | 85 | 3 | 76 | 233 |
| ATL | 380 | 469 | 2 | 87 | 938 |
| EWR | 260 | 321 | 9 | 64 | 654 |
| YIP | 414 | 511 | 10 | 75 | 1010 |
| PDX | 230 | 284 | 2 | 78 | 594 |
| PHL | 169 | 208 | 3 | 48 | 428 |
| DAL | 133 | 163 | 3 | 103 | 402 |
| BOS | 122 | 151 | 3 | 40 | 316 |
| HOU | 149 | 184 | 12 | 53 | 398 |
| MSP | 45 | 56 | 1 | 40 | 142 |
| CVG | 136 | 168 | 4 | 39 | 347 |
| ORD | 84 | 104 | 2 | 35 | 225 |
| FWA | 9 | 12 | 2 | 40 | 63 |
| ROC | 15 | 18 | * | 25 | 58 |
| LEX | 19 | 23 | 1 | 18 | 61 |

NATIONAL TOTAL $24,962,000 [1/]

* Less than $500

1. Includes adjustment for coincident weather patterns at nearby stations. See Technical Notes.

TABLE III

PROBABILITY AND VALUE OF AVOIDING LANDING ACCIDENTS AT SAMPLE AIRPORTS - 1957

| Airport | Probability of Avoiding One Accident: Air Carrier | Large G. A. 1/ | Small G. A. 2/ | Dollar Value (000) | Lives | Serious Injuries |
|---|---|---|---|---|---|---|
| LAX | .43 | .03 | .11 | $158 | .46 | .32 |
| MDW | .44 | .02 | .07 | 153 | .43 | .33 |
| LGA | .24 | .03 | .08 | 95 | .28 | .18 |
| DCA | .17 | .01 | .04 | 62 | .18 | .13 |
| SFO | .26 | .01 | .02 | 87 | .24 | .20 |
| IDL | .17 | .01 | .02 | 59 | .16 | .13 |
| PIT | .17 | .03 | .08 | 73 | .23 | .13 |
| CLE | .19 | .02 | .08 | 76 | .23 | .14 |
| ATL | .26 | .01 | .02 | 87 | .23 | .20 |
| EWR | .15 | .02 | .08 | 64 | .20 | .11 |
| YIP | .20 | .02 | .05 | 75 | .22 | .15 |
| PDX | .23 | .01 | .02 | 78 | .21 | .17 |
| PHL | .13 | .01 | .03 | 48 | .14 | .10 |
| DAL | .28 | .02 | .07 | 103 | .30 | .21 |
| BOS | .10 | .01 | .04 | 40 | .12 | .08 |
| HOU | .10 | .03 | .09 | 53 | .18 | .08 |
| MSP | .10 | .01 | .04 | 40 | .12 | .08 |
| CVG | .10 | .01 | .03 | 39 | .11 | .08 |
| ORD | .07 | .02 | .05 | 35 | .11 | .05 |
| FWA | .05 | .03 | .10 | 40 | .15 | .04 |
| ROC | .06 | .01 | .02 | 25 | .07 | .05 |
| LEX | .04 | .01 | .02 | 18 | .06 | .03 |

1. General aviation plane over 12,500 lbs. gross weight.
2. General aviation plane under 12,500 lbs. gross weight.

costs can be entered into the formula shown previously. As examples of how the formula would work, however, the results of several computations for Los Angeles, Pittsburgh, and Fort Wayne are shown in Table IV, using various assumptions concerning annual additional operating cost of the all-weather system. It can be seen that the justifiable capital cost varies greatly from city to city. The justifiable investment at each airport can be compared with the installation cost to determine at which stations an all-weather landing system, once developed, should be installed. The sum of the justifiable investment figures at those airports where installations will be made, minus the sum of the installation costs at those airports, gives the figure which FAA would be justified to spend in the successful development of an all-weather landing system.

## TABLE IV

## SAMPLE VALUES FOR JUSTIFIABLE INVESTMENT IN ALL-WEATHER LANDING SYSTEMS - THREE AIRPORTS

| Assumptions | Justifiable Investment | | |
|---|---|---|---|
| | Los Angeles | Pittsburgh | Fort Wayne |
| 1. System operation costs $50,000 annually, lasts 10 years, interest rate 12% | $4,288,000 | $2,090,000 | $73,000 |
| 2. System operation costs $150,000 annually, lasts 10 years, interest rate 12% | $3,723,000 | $1,526,000 | 0 |
| 3. System operation costs $50,000 annually, may last only 5 years, interest rate 12% | $2,679,000 | $1,306,000 | $46,000 |