Ann Arbor Oct. '73

PROCEEDINGS —

Fourteenth Annual Meeting

Theme:

"Search For New Transportation Horizons"

October 15-16-17, 1973
Hollenden House
Cleveland, Ohio

Volume XIV • Number 1 1973

TRANSPORTATION RESEARCH FORUM

Modeling of Aircraft Movements at Airports

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SUMMARY

This paper provides a general overview of the mathematical models that are available to assist the decision-making process in airport planning. Some of the problems facing aircraft operations at an airport are considered. The airport airside is then discussed, together with the factors influencing duplicate aircraft operations. Different modeling techniques are described and five classes of models are presented. These are:

- Capacity Models
- Delay Models
- Controller Workload Models
- Collision Risk Models
- Pollution Models

INTRODUCTION

The airport is a key element in the total air transportation system, and is a facility for the movement and temporary storage of passengers, vehicles, baggage, cargo, and aircraft. Its basic function is to permit the transfer of people and goods between air and ground transport vehicles and from one aircraft to another. The airport airside consists of the runways, taxiways, and gates within the airport confines plus approach and departure airspace. Figure 1 illustrates the relationship between the airport airside and other elements of the air transportation system.

The 1960s saw the appearance of a phenomenon that is now one of the most critical problems confronting the air transportation industry: widespread airport congestion. Airport congestion is manifested in many ways; it is most apparent in, and is characterized primarily by, delay to aircraft resulting from insufficient capacity of the airfield system. Congestion is of major concern to the air transportation industry because delay not only causes passenger inconvenience but also leads to increased aircraft operating costs.

As traffic levels increase, the associated congestion and delays result in a greater probability of aircraft collision and a build-up of pollution levels. All of these factors contribute to the air traffic controller's workload. Therefore, in the future, the air transportation industry must either (1) provide more airport capacity, (2) achieve greater productivity by increasing load factors or by building larger and more environmentally compatible aircraft, or (3)

**Peat, Marwick, Mitchell & Co.*

AIR TRANSPORTATION SYSTEM

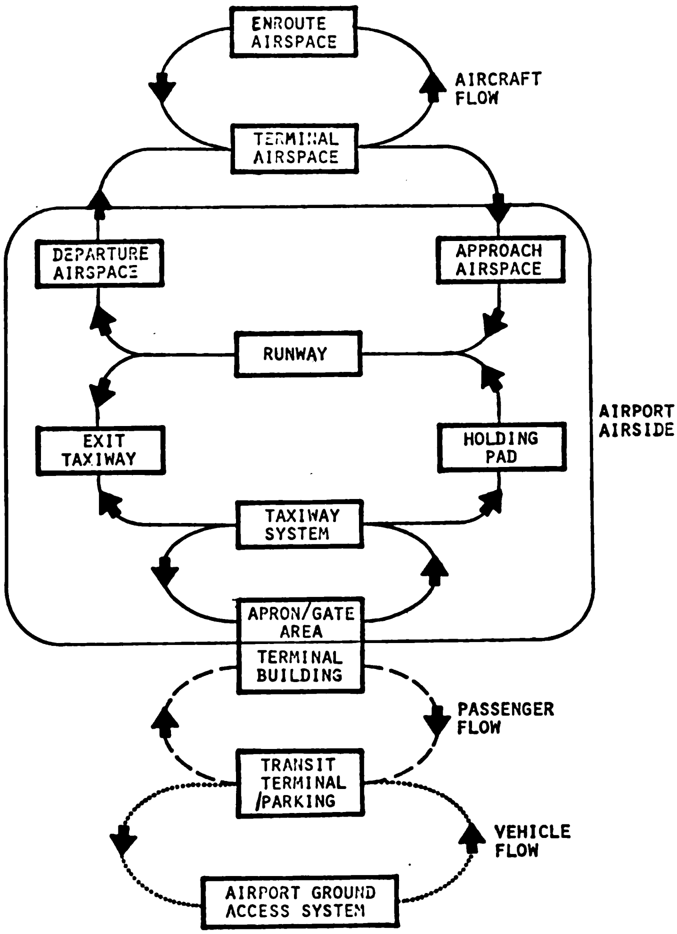

FIGURE 1

restrict traffic levels in order to minimize congestion costs. It appears that one of the best hopes for solving the problems of congestion is to devise new and improved methods of increasing airport capacity. A major step toward this goal is the development of reliable and generally usable planning tools which will not only provide accurate advance warning of impending congestion problems, but more importantly, will provide a basis for determining how best to minimize congestion and its related effects.

It is important to establish the operational feasibility of the airport airside in the early stages of the physical planning process by using appropriate models. It is also essential to integrate environmental, economic, and financial feasibility analyses with physical planning evaluations, prior to selection of an airport master plan. The models which are described in this paper can be used as effective planning tools to provide necessary inputs for these analyses.

A general overview of models of aircraft movement is presented to show both the range of models available and the applications to which these can be put. Further details of individual models can be found in the selected references given in this paper.

FACTORS AFFECTING AIRCRAFT MOVEMENT

As noted above, the term "airport airside" is used to refer to the areas on the airport surface designated for the operation of aircraft, namely the runways, taxiways, and gates plus the airspace in the immediate vicinity of the airport. The following factors influence the operation of aircraft on the airport airside:

Aircraft Operating Characteristics. This factor is the result of the interaction between pilot and aircraft. The pilot operates the aircraft within guidelines set by the aircraft manufacturer, the airline, and the regulating agencies. Parameters such as emission levels and the ability to perform certain maneuvers within space and time limits, evolve from these characteristics.

Physical Components of the Airside. This factor consists of the number, size, shape, and arrangement of the runway, taxiway, and gate components of the airside. Also included are electronic devices such as navigational aids, and radar used to locate aircraft on the airport airside.

The Environment. This factor consists of the air in which the aircraft operate. Meteorological conditions, wake and noise transmission, and chemical composition are each important elements.

Demand for Service. This factor specifies the type of aircraft to be served, whether they are arrivals or departures, the number of aircraft to be served, and the times and locations at which service is requested.

Aircraft Operating Rules and Procedures. This factor consists of the rules and procedures developed to achieve safe, efficient, and environmentally sound aircraft operations. Air traffic control procedures and separation standards set by the Federal Aviation Administration, noise and pollution standards, and airline schedules are typical of the rules and procedures affecting aircraft movement.

The way that aircraft move on the airport airside is a function of all of the above factors. The mathematical models described below account for the factors and produce appropriate output information regarding the aircraft movements.

MODELING TECHNIQUES

It is convenient to divide mathematical models into two sub-groups: analytical models and simulation models. By an [illegible] model, we mean a series of mathematical expressions that produ[illegible] value when all significant input parameters are specified. By a simulation model, we mean a series of mathematical expressions that describe the movement of individual aircraft or groups of aircraft through parts of the airfield system. The mathematical expressions allow simulated aircraft movements to occur for a defined time period, and measurements of the appropriate output parameters are taken in a fashion similar to measurements which would be performed in the real world.

In either case, computations using the models can be performed manually or by using computers. If the model is relatively simple, and the number of results required is relatively small, then a manual approach would be suitable. However, if the model is complex, or the number of outputs required is large, then it is often convenient to use a computer to reduce computation time and cost.

For both types of model, the accuracy is a function of the care taken in the specification of the mathematical expressions and the selection of appropriate accurate input parameters. There is no essential difference in accuracy between the various model types, and their level of accuracy can only be proved by comparison with real-world information. There is often a trade-off between the level of complexity of the model that is required and the cost of modeling. Good judgment by model developers can produce sufficiently accurate results at minimum costs. Theoretically, there are no bounds to the complexity of situations that can be modeled, or the accuracy achieved. However, cost considerations usually dictate the degree of sophistication. Above certain levels of complexity, it is often easier to use simulation than to attempt to prepare complicated analytical equations.

Model validation is an appropriate test to apply to airport models before accepting and using the results. The validation process consists of a comparison of the values of model outputs with values of the same information observed in the real world. The model inputs used in the validation process should reflect the operating conditions observed in the real world at the time output parameters are measured. Under these circumstances, validation occurs when model outputs and observed values agree within the required accuracy limits of the model.

CAPACITY MODELS

In its relation to aircraft movements, capacity is considered as a flow rate; that is, the number of operations passing a particular point in unit time.

At the current state of the art, no modeler, to our knowledge, has attempted to produce an analytical model of aircraft movements for the whole airport airside. However, simulation models do exist and will be described later in the Delay Model section of this paper. Analytical models have been developed for different components of the airfield. The use of the models depends on the assumption that the capacity of one component is not reduced by aircraft operations on another component when this other component is operating at capacity. This assumption could loosely be termed one of independence, and analytical evidence for the assumption is available.[1*] The

*References appear at end of paper.

components of the airfield that have been modeled are the runway system (including approach and departure airspace), the taxiway system, and the gate system. Because of the complicated air traffic control rules and procedures governing aircraft movements in terminal area airspace and on runways, runway models soon become complex, and only the simpler models are described here (Reference 1 gives details of more complex models).

The first major work on analytical capacity models was done in the early 1960s and used a definition of practical capacity that included acceptable delay levels. Current capacity model work is based on a definition of ultimate capacity that is independent of demand or delay.[1,2]

Each model of an airport airside component computes capacity as the inverse of a weighted average service time. In symbols, this could be expressed as

$$C = \frac{1}{\overline{T}}$$

where C represents capacity and $\overline{T}$ represents weighted average service time. The service times for individual aircraft or groups of aircraft are computed. These service times, based on the previously described factors influencing aircraft operation, are then averaged, using weights for the proportion of individual or groups of aircraft that require service.

In symbols,

$$\overline{T} = \sum_{i} p(i)T(i)$$

where p(i) is the proportion of aircraft class i requiring service and T(i) is the service time for aircraft of class i.

Runway Models. Models to compute runway capacity have been developed for single runway and combinations of up to four runways in different configurations.[1] The factors affecting aircraft movement that are of interest in this instance include runway use configuration, air traffic controller procedures, operating strategies, weather conditions, navigational aids, aircraft mix, and operating characteristics.

As an example, a model of the operation of a single runway with arrivals only is given below.

If R(i), runway occupancy requirement, represents the time allowed by controllers for arrivals of aircraft of class i to leave the runway, an A(ij) represents the time separation allowed by controllers to satisfy the air separation standards between aircraft of classes i and j, then

$$T(ij) = \text{Maximum of } [R(i), A(ij)]$$

where T(ij) is the time between aircraft of classes i and j. Then the w
average service time

$$\overline{T} = \sum_{ij} p(i)p(j)T(ij)$$

where p(i) is the proportion of aircraft of class i requiring service, then

$$\text{Capacity } C = \frac{1}{\overline{T}}$$

The formulation of such models includes the effect of random deviations in the time intervals and becomes quite complex when factors such as wake turbulence and mix distortion occur.

Taxiway Models. In general, taxiway capacity is not a problem except at the most basic airports. Certain exceptions to this exist, especially the situation where taxiways cross active runways. Models of this situation have been developed using techniques similar to those described for runway models. In this case, gaps between the operations on the runway are examined to determine the number of aircraft that may cross the runway. In simplified form this may be represented by N(ij) aircraft crossing the runway in the gap between aircraft i and j which are separated by time T(ij). Then the crossing capacity is:

$$C = \frac{\sum_{ij} p(i)p(j)N(ij)}{\overline{T}}$$

Taxiway crossing models have also been developed for crossings of parallel runways.

Gate Models. Models to compute gate capacity have been developed that depend on the following factors: the number and type of gates, gate occupancy times, and the mix of aircraft requiring service. The methodology is again similar to that of the runway model. If G is the number of gates, if p(i) the proportion of aircraft of class i in the mix, and if T(i) is the gate occupancy of class i, then

$$\text{Capacity } C = \frac{G}{\sum_{i} p(i)T(i)}$$

A more sophisticated version of this model—one that ensures gate sizes are adequate for the aircraft being served—is also available.

In each of the above models, once the methodology has been developed, the most important requisite for accurate capacity determination is adequate input data for the service times. Field observations, historical records, and further analysis can produce these input data.

DELAY MODEL

Delay is the difference in time for an aircraft movement to take place between two fixed points, under two different conditions. Condition one is the actual time experienced by the aircraft (i.e., after interference from any other aircraft). Condition two is the time that would be experienced by that aircraft if there were no interference from any other aircraft. (Thus, in uncongested conditions, the times are equal and the delay is zero.)

Analytical models to compute delay generally rely on queueing theory which has the following limitations: most queueing models estimate average delay, assuming the system has reached a steady-state condition. The assumption of steady state may not be appropriate and the measurement of average delay may not be the required information. Currently, the application of queueing theory to delay models is limited to only a few statistical distributions concerning aircraft operations. This means the models do not accurately reflect the complex distributions that occur due to aircraft scheduling. At the current state of the art, it is extremely difficult to model complex interactions such as occur with multiple runway configurations to produce delay information. For this reason, the authors believe that simulation models are more appropriate for delay information.

The simulation models developed to predict delay information[3] use Monte Carlo sampling techniques (i.e., clock time is advanced to cause the next event to occur, and time intervals are sampled from the distributions of random variables).

The model operates by tracing the path of each aircraft through space and time on the airport airside. The airside is represented by a series of links and nodes depicting all possible paths an aircraft could follow.

Arriving aircraft data are generated via a demand-generating mechanism at the entry gate to the common approach path. The classes of the arriving aircraft are assigned on the basis of the desired mix. Approach speeds are then assigned from an empirical distribution. For each arrival pair, interarrival times, approach speeds, and wake turbulence characteristics are checked so that sufficient separation exists on the common approach path. This procedure sets up the arrival demand process on the final approach.

As each aircraft arrives over the threshold, the exit taxiway and associated runway occupancy time are assigned to the aircraft. These assignments are based on empirical distributions which take into account such factors as exit location and type, aircraft class, condition of the runway, and weather. The aircraft's routing to the gate or basing area is established in the following manner: as the aircraft exits the runway, a check is made on the availability of a gate of the correct size. If an appropriate gate will be available by the time the aircraft reaches the apron/gate area, the aircraft's route to the gate is assigned on the basis of the exit taxiway used and the basis of gate location.

Once an aircraft's route to the gate has been established, the aircraft is moved along its route from link to link on the airfield network. Checks are made at each link to determine whether the next link on the route is [illegible] able or occupied by another aircraft. If the next link is occupied, th[illegible] is delayed until the link is vacated. When the aircraft reaches its gate, a gate occupancy time is assigned from empirical distributions and is added to the gate arrival time. This information determines the earliest time at which the aircraft could leave the gate. The empirical distributions for gate occupancy time reflect the typical schedule bunching of air carrier departures, where appropriate. When an aircraft is ready to leave the gate, a check is made to ensure that the ramp area is clear for push-back. The route to the departure runway is determined by the gate location, the aircraft class, and the departure runways in use at that particular time.

The traces of the paths of all aircraft through the airport airside are made by continually advancing clock time and recording the new location of the aircraft. The records of aircraft movement are then processed by the model to produce desired output information including delays and flow rates.

To ensure the accuracy of the outputs, the simulation model is run several times with the same inputs. The average of the output values for several runs is then used.

AIR TRAFFIC CONTROLLER WORKLOAD MODELS

In order to assess controller workload, one must consider the Air Traffic Control (ATC) system as a whole. The operational objective of an ATC system is a safe, expeditious, and orderly flow of traffic. The ATC system might be described as one in which a decision-making element (the controller) receives information about a given external environment and then exercises a control action on that environment to achieve a particular objective. This control action is exerted in the presence of external agents which can modify the system independently of the decision-making element.

In the ATC system, the external environment is made up of the human or mechanical elements which controllers are able to influence:

- pilots of aircraft operating within the ATC system
- the position of aircraft in time and space
- the technical means available to controllers to enable them to receive and exchange information

The external agents comprise the elements liable to influence the system and act on the controllers.

- Flight plans and pilots' intentions (including the times at which aircraft request admission to the airport airside).
- Random factors such as errors and position, speed, time at reporting, altitude, failures.
- Meteorological factors which are subject to random deviations, such as wind.

The basic function of the Air Traffic Controller is to monitor traffic and, if necessary, to intervene to keep traffic flowing safely. This means that information processing is one of the main tasks of the controller. For information gathering and for instructions transmission, a considerable amount of technical equipment is needed to maintain contact between the controller or ATC system and aircraft. Information processing is still mainly performed manually. The controller gets information about the situation of aircraft and checks the situation by comparing it with safety criteria. If the avoidance of unsafe conditions demands intervention, the controller gives the necessary instruction to the aircraft pilot. The confirmation of these instructions by the pilot is a closed communication loop. The pilot changes the course of his aircraft in accordance with the given instructions and the change of course gives new information to the controller.[4]

There are two different means of evaluating controller workload tasks in the ATC system. The role which the controller plays in the whole ATC system and his share in the task completion can be evaluated. This will show, for example, his responsibility for safety and will lead to criteria such as work quality, errors and their consequences, and response times to different situations. Alternatively the demands of the controller's job and the effect on the controller can be evaluated. The job demands of the controller can be described in terms of skills and stress. Skills refer to the controller's ability to execute tasks. Stress is concerned with the way demands are made on these skills by the job. The objective description of job attributes derived from the tasks can be set against subjective descriptions of the job demands on the controller. Skills relate to the individual abilities of the controller. Stress leads to strain in the controller related to his individual working capacity.

There are three possible ways of evaluating controller workload:

- Full scale real life experiments
- Analytical Models
- Simulation Models

Full scale real life experiments are generally not acceptable because of the cost and safety factors involved. Analytical models are very useful for studying certain special limited aspects of the ATC system, but do not permit an overall analysis which would be sufficiently realistic. The inability of analytical models to permit overall analysis derives from the difficulties in breaking the problem down into a series of simple subproblems.

The remaining possibility is a simulation model. Such a model consists of reproducing in a "laboratory" the operating conditions of the ATC system, by means of various techniques and devices. There are two general types of simulation models: dynamic or real time simulation models, and arithmetical or fast time simulation models. The terminology is expressive and conveys the idea that in real time simulation models the time dimension is retained in the simulation process, whereas in fast time simulation models the operations involved take place quickly so that the time sequence of events is unrelated to the rhythm of real life.

In a real time simulation model, the human operators (controllers and pilots) can participate and carry their functions in conditions similar to those in real life. This enables maximum realism to be introduced into laboratory studies of the controller's behavior in various operational circumstances, and also into the man/man and man/machine interfaces, within the ATC system (exchange of information).

With real time simulation models, controllers and pilots can perform their own roles, with only the nonhuman elements of the ATC system artificially reproduced to provide the essential dynamic information for human action.

Real time simulation models remove the restraints of space while retaining those of time. If one wishes to be rid of both types of restraints in the simulation process, then the human factor must be eliminated by artificially simulating all of the human decision-making processes. This occurs in the fast time simulation model. The result is achieved by substituting logical mechanisms for the human involvement in decision processes.

Having replaced human decision by logical processes, it remains to simulate time itself, which corresponds to delays, response times, periodicities, and speeds. This is achieved by considering time as a mathematical parameter, in the same way as the other quantities involved in the general logic of the model. The whole system, with its dynamic properties is expressed in purely logical and arithmetical terms, which can be assimilated by an electronic computer. Consequently, the only equipment needed to use a fast time simulation model is an electronic computer, together with a program of the necessary data.

The use of fast time simulation, and the use of logical decision mechanisms, require the following conditions to be satisfied:

- that the simulated decisions are logical
- that the logical rules governing these decisions are known
- that only one simulated decision is possible in a given situation

In the case of ATC controllers, ambiguities sometimes exist and controllers choose between options for control actions. Therefore the third condition is only partially satisfied.

For this reason, the authors believe that real time simulation models are the most appropriate means of investigating controller workload. In a real time simulation, the accuracy of the model depends on the closeness to reality that the situations are portrayed to controllers and pilots involved in the model. Therefore, care has to be taken to give adequate sensory cues, including appropriate headsets, instrumentation and visual displays where appropriate. The techniques of visual presentation are one of the most difficult aspects of accurate real time simulation and motion pictures; electronic displays and physical models have all been used. (Note that such real time simulation models are also used for pilot training.)

Several measures of performance can be made from a real time simulation model. Objective measures of workload, such as number of aircraft handled and amount of information processed, can readily be obtained. Studies of errors made and physical movements of the controllers can be performed. Interviews with controllers after the simulation and other subjective measures of stress can be performed by human factors specialists.

COLLISION RISK MODELS

Accidents occur when an aircraft collides with a stationary object or with another aircraft. In general, causes of accidents are of two types. The first is a blunder on the part of one of the humans in the system—for example, the pilot or the air traffic controller. Blunders can also occur due to sudden and significant failures of mechanical or electrical equipment (such as the wave guide localizer or rudder control). The second type is an accumulation of small random errors of the various components in the system. For example, small piloting errors coupled with controller errors and a number of mechanical and electrical deviations can accumulate to produce a significant deviation of the aircraft from its intended path.

As the occurrence of accidents is of low probability, it is difficult to collect significant data to accurately predict the probability of future accident occurrence. This is particularly true because corrective measures are taken as soon as the cause of an accident is evident.

However, risk analysis methods are available that use distributions of tracking error to calculate the probability of collision with another aircraft or a fixed object. The analysis of most interest is the computation of probability of collision with other aircraft. Using analytical models, the effect of changes in ATC rules and procedures or the introduction of new navigational aids on safety can be investigated. A collision risk model has been developed that demonstrates the importance of system characteristics in determining safe operating conditions.[5] Inputs to the model are as follows:

- aircraft size
- length of the common approach path
- ATC separation requirements
- aircraft performance characteristics

The model, which is based on previous work including that of the Department of Transportation and the Royal Aircraft Establishment, uses normal distributions to compute collision risk given the above inputs. The model computes total collision rate as the sum of three components: collision rate from front or rear, from above or below, and from left or right. Then collision risk for a particular segment of flight is the sum of the collision rates for different time intervals;

$$\text{Collision Risk} = \sum_{t} \text{Collision Rate} \times \text{Time}$$

This computation is performed for all aircraft in the area under consideration and the risks summed. The collision rates for different time intervals are computed by considering error distributions in the equations of motion of the aircraft. As these computations are lengthy, computer programs for the mo[illegible] are available for single and parallel runway systems. The model methodology can also be applied to other configurations such as intersecting runways.

Within the state of the art of the modeling techniques available for collision risk prediction, the effectiveness of the various systems in terms of collision risk should be measured on a relative rather than an absolute basis.

POLLUTION MODELS

In this paper, the term "pollution" refers to both air pollution by gaseous and particulate matter, and noise pollution.

Air Pollution. Aircraft engines emit hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter, and other emissions. The amount emitted by any particular aircraft is a function of the engine design, the type of fuel used, the throttle setting and the length of time the engine is operated. Consequently, aircraft moving under their own power in and around the airfield system cause air pollution. Knowledge of the operating conditions will allow computation of the amount of pollutants emitted in unit time.

Two steps are necessary to compute the amount of air pollution caused by aircraft in a particular time period at an airport.

The amount of pollution emitted in unit time by various aircraft types, engine classes, etc., has to be determined, and the amount of time spent by each aircraft at each speed (and therefore throttle setting) during operations on the airport airside has to be determined. One source of information on taxiing times, speeds, etc., can be obtained from the airfield fast time simulation model (described previously) that provides delay information. The simulation could be extended to incorporate the unit pollution factors mentioned above and would compute the amount of pollutants emitted by the aircraft in any time period under consideration.

Comparisons of the amounts of various gases and particulate matter emitted under different conditions obtained from different model runs would then provide a measure of the effectiveness of these different conditions in terms of air pollution.

It should be noted that air pollution emissions in themselves are not a measure of air quality. The meteorological and topographical conditions in the area influence the quality level as do the presence of other sources of air pollution in the vicinity. The relationship between emissions and air quality can be described by a dispersion model. Wind and turbulence effects and the effect of the motion of the pollution source are considered in a dispersion model, and air quality measures produced.

Several basic diffusion mechanisms have been developed that can be used in such a model including the Gaussian Plume Model[6] (which has been shown to accurately describe diffusion from a point source). Extensions of this model to strip sources have been made that allows computations for the airport airside with many aircraft in operation simultaneously. This analytical model computes air pollution concentration at different points for varying emission rates wind speeds and aircraft tracks.

Noise Pollution. Noise has been recognized as a major constraint to airport development since the widespread introduction of commercial jet aircraft in the early 1960s. Considerable study has been devoted to both the measurement and the interpretation of aircraft noise with respect to its effect upon people living in communities near airports. From these studies, various models have evolved that relate the noise of an aircraft flyover to community response. Various methods have also been developed for estimating community response to the noise environment created by multiple aircraft operations occurring over an extended period of time.

The model that has been used in recent years to describe aircraft sound levels for areas in the vicinity of airports uses an index called the Noise Exposure Forecast (NEF). An NEF value at a given ground position provides an estimate of the integrated noise exposure resulting from aircraft operations. NEF values are determined in three major steps. In the first, the noise levels at the ground position are determined for each aircraft classification and for each aircraft operation along each flight path in the vicinity of the ground location. This first step requires knowledge of the aircraft noise characteristics and the takeoff of landing profiles for the different aircraft classifications, and knowledge of the location of the flight paths with respect to the ground position.

In the second step, the noise level estimate for each aircraft classification and for each operation and flight path is adjusted by factors based on the number of operations occurring per daytime or per nighttime period. This second step results in NEF values for each aircraft classification, operation, and flight path. The third step involves the addition of the individual NEF values to arrive at a final value for the given ground position.

Thus, the total noise exposure at a given point caused by aircraft operations is composed of the effective perceived noise level (EPNL) produced by different aircraft classes flying along different flight paths. For aircraft class i on flight path j, the NEF(ij) can be expressed as:

$$\text{NEF(ij)} = f \begin{bmatrix} \text{EPNL(ij), number of daytime operations.} \\ \text{number of nighttime operations} \end{bmatrix}$$

The total NEF at a given ground position is then determined by the summation of all the individual NEF(ij) values.

At the time of writing, the NEF noise environment analysis represents the best available technique for estimating aviation-generated noise and its impact upon human activities. However, it is likely that in the near future a new methodology called the Aircraft Sound Description System (ASDS) will be made available by the FAA.[7] The basic premise of the concept is straightforward: exposure to aircraft noise is described in terms of the total amount of time that sound levels exceed a pre-selected threshold value. As applied to airport area analyses, then for any desired location a noise exposure quantity is specified which states the exposure as "X" minutes of total exposure to sound levels in excess of 85 dB(A) (a sound level similar to that emitted by some common home appliances).

This concludes the presentation of the models of aircraft movement a airports chosen for discussion in this paper. A number of other models exist that are used in structural design, accounting, etc., but these have not been reviewed herein.

REFERENCES

1. Douglas Aircraft Company; Peat, Marwick, Mitchell & Co.; American Airlines, Inc., *Procedures for Determination of Airport Capacity; Interim Report,* 1973.
2. Harris, R. M., *Models for Runway Capacity Analysis,* (Mitre Corporation MTR 4102 Rev. 2), 1972.
3. Maddison, D. M., *A Model of the Airfield Surface System,* University of California ITTE, (Thesis), 1970.
4. Ergonomics Vol. 14, Number 5, September, 1971.
5. Hockaday, S. L. M., *A Model to Investigate the Separation of Landing Aircraft, with Special Reference to Collision Risk,* University of California ITTE, (Thesis), 1969.
6. United States Atomic Energy Commission. *Meteorology and Atomic Energy,* 1968.
7. Cruz, J. E., *Aircraft Sound Description System; Background and Application,* FAA Office of Environmental Quality EQ-73-3, March, 1973.