A View of Air Traffic Control in Future Terminal Areas

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A view of the nature of future terminal-area ATC operations is proposed by reasoned consideration of the FAA's ten year plan. The crucial, decision-making role of the air traffic controller in this environment is investigated. An analytical model of the ATC-pilot-aircraft control loop is presented and shown to meet certain a priori requirements of such a model. Application of the model indicates several characteristics of aircraft flow.

Nomenclature

B = stall speed or lower bound on velocity
D = desired nose-to-tail separation
L = length of each aircraft in a platoon
t = current time
T = system response delay
U = maximum velocity permitted in terminal area
$v_n(\cdot)$ = velocity of nth aircraft at time $(\cdot)$
$x_n(\cdot)$ = position of nth aircraft at time $(\cdot)$
$x_{n-1/n}(\cdot)$ = relative separation at time $(\cdot)$ $= x_{n-1}(\cdot) - x_n(\cdot)$
λ = "sensitivity" coefficient $= 1/\tau$
τ = time duration over which a separation deviation is to be corrected $= 1/\lambda$ (assumed constant for a given platoon)

Introduction

THE air traffic controller plays a crucial, decision-making role in air terminal operations. He must make the decisions which essentially determine level of safety and efficiency of aircraft flow. His primary job is, of course, to maintain adequate separations between aircraft to provide an acceptable level of safety against the risk of midair collision. A "byproduct" of meeting this responsibility is the control he exercises over the efficiency of aircraft flow which determines runway capacity.

Achievement of either the primary objective or "byproduct" is a difficult task. Yet, the controller's job is made even more complex by the fact that the two tasks are in opposition to each other. Aircraft flow could be increased by decreasing longitudinal separations as aircraft approach the runway. However, safety could be improved only by increasing separations. The controller must, therefore, establish a satisfactory tradeoff or balance between these two important objectives within constraints provided by operating rules.

The new generation of air traffic control will not change the need to provide safety and efficient flow in the future. It will, however, modify the environment in which the controller operates, both in terms of the system he must control and the aids available to him. The general nature of the future system is well documented in the Federal Aviation Administration's "Ten Year Plan."[3] In fact, it may be assumed that this document fully describes the hardware and procedures of the future system:

"The pattern for change is clearly set. The need now is for a concerted drive to expedite implementation."[3]

"Industry should know what areas are and are not prime targets for productive debate. It serves no useful purpose to expend energy re-evaluating old issues which have been resolved and are now under implementation."[3]

Many questions about the future system are, of course, unanswered at this time. What new problems might be created by changes which are thought to be the answers to the problems of today? What new opportunities for further improvement will be present? Indeed, how will the controller operate in the new generation of ATC?

The current study seeks to grapple with these challenges by investigating a proposed view of the future. Specifically, inquiry is initiated into analytically modeling the decision-making role of the air traffic controller. The objective of this modeling approach is to describe the level of safety and the efficiency of flow (runway capacity) which might be achieved in the future system.

A Proposed View of Future Operations

In the attempt to visualize the nature of operations in the future system, one is led to question the applicability of previous analytical concepts since the basic characteristics of the system will be changed in a number of ways. By such reasoning, one is led to consider two important developments which appear likely to occur: that airport capacity will be increased by a reduction in the longitudinal separation standard[3] and that the traditional 40-naut-mile definition of the terminal area must be expanded.

The separation standard may be reduced without degrading the safety level as a result of implementation of improved equipment.[3] Such action appears mandatory to providing the basic capability to accommodate the marked increase in demand for air travel[3] which is currently predicted. Improved scheduling techniques[3] and, perhaps, some form of demand leveling may result in sustained periods of high demand. Over-all, the orderly flow of aircraft will be more critical because of scheduling sophistication and because of much denser flow of aircraft. For these reasons, even small perturbations about the separation standard may assume new importance in terms of

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providing acceptable safety levels with increased capacity. If airside separations are reduced significantly, runway usage times could become the bottleneck which limits capacity. However, high-speed exits[3] are proposed to allow corresponding reduction of runway usage times. Use of such exits will cause the airside separation standard to remain the primary capacity-limiting factor. Blumstein[2] first studied this relationship of glide slope separation to runway capacity. However, aircraft fly nearly independently of each other under tower control on the glide slope. Separations achieved at the ILS gate, therefore, appear to determine separations along the glide slope. The ability of Approach Control to maintain a desired, constant separation between aircraft throughout approach is thus seen to be important to the future system.

Existing concepts of the terminal area may be revised since forces may tend to increase the area in which approach control functions are performed. Complete implementation of advanced flow control[3] will divert some congestion problems at the destination terminal back to the origin terminals. Holding patterns may be located much further away from the terminal,[3] perhaps 90–120 naut miles out, so that jet aircraft may realize the economies of holding at higher altitudes. Routine use of computerized, speed class sequencing[3] will allow a number of aircraft of similar flight characteristics to depart holding stacks for platoonlike approaches. Landing sequence may be determined when aircraft depart holding stacks rather than near the glide slope as is done in today's system.

Two other changes appear to be key factors in determining the nature of future operations. Controllers will be assisted by the automated radar terminal system (ARTS) which will give them more information to use in controlling aircraft and reduce certain workloads so they may concentrate more effectively on important duties. Secondly, the advent of improved navigation equipment[3] will allow a restructuring of airways. Because the use of prede-

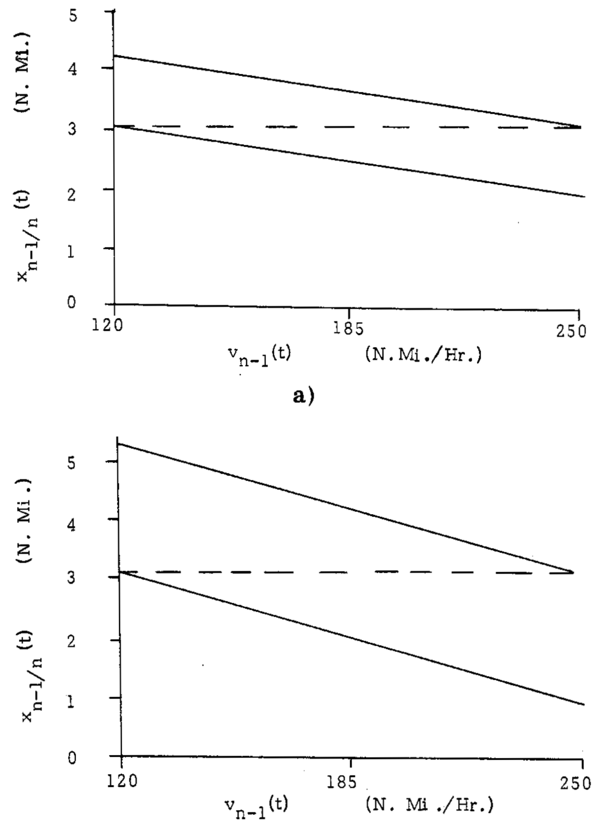

Fig. 2 Range of model applicability.

fined airways will result in improved efficiency, large deviations from these paths under manual control will be undesirable. The combination of speed class sequencing

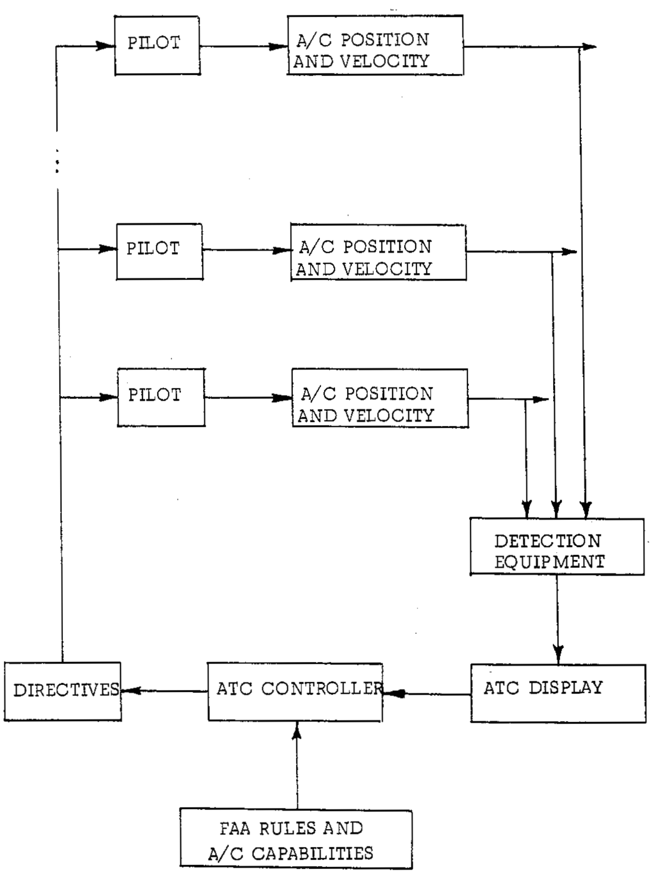

Fig. 1 ATC-pilot-aircraft control loop.

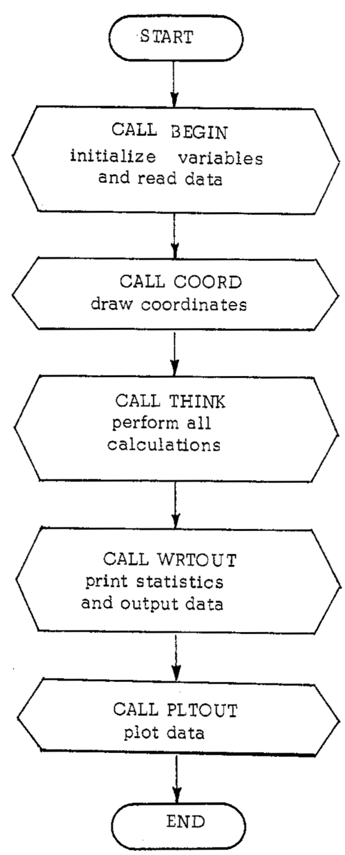

Fig. 3 Main program flow of operation.

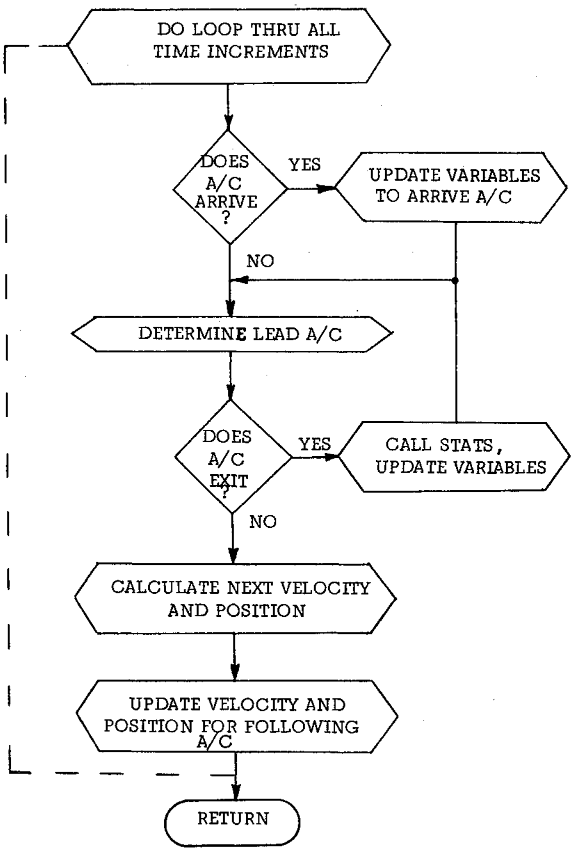

Fig. 4 Logic of flow in subroutine THINK.

and the need for an aircraft to fly some optimal approach envelop indicates that aircraft in a platoon will "compete" for the use of certain airways. This configuration is also stressed by Schriever and Seifert[7]:

"The number of aircraft in use today ... Is such that any inefficiency, particularly in the terminal areas, immediately results in delays in aircraft movements and other adverse effects. With the projected increase in numbers of aircraft, efficient airspace use becomes more imperative each year.

Ideally all aircraft should be operated along the optimum route and at the optimum altitude for the particular flight in question. Deviations from this ideal lead to a commensurate derogation in the efficient use of the aircraft. Some planes, for example 707's and DC-8's are so similar in operational characteristics that the optimum route and altitude on a given flight for one is usually the optimum route and altitude for the other. Congestion thus increases for that particular route and altitude and stringently requires the efficient use of airspace."

These, as well as other changes, result from numerous studies directed at existing problems implicitly included in the discussion. Even with these important improvements, the "Ten Year Policy Summary"[4] shows that terminal area delays will grow exponentially in the future. It appears mandatory to increase the number of runways to handle the traffic. However, this is a difficult, and in many cases impossible, undertaking. Each runway must, therefore, be operated at peak efficiency to accommodate dense aircraft flow.

Stated succintly, one may envision long platoons, each with similar aircraft following rather closely together on predefined paths and in a defined sequence on approach. This is a statement of an aircraft following situation in which each aircraft must be continuously controlled to maintain a desired separation with the aircraft directly ahead to balance safety and capacity needs. Over-all scheduling and timing will be computer controlled, so the question arises as to whether relatively small separation pertubations may cause safety/capacity inefficiencies. Small deviations in separation may be corrected by velocity and/or minor heading changes. If large deviations develop, definite course changes and sequence changes will be necessary and inefficiencies will result.

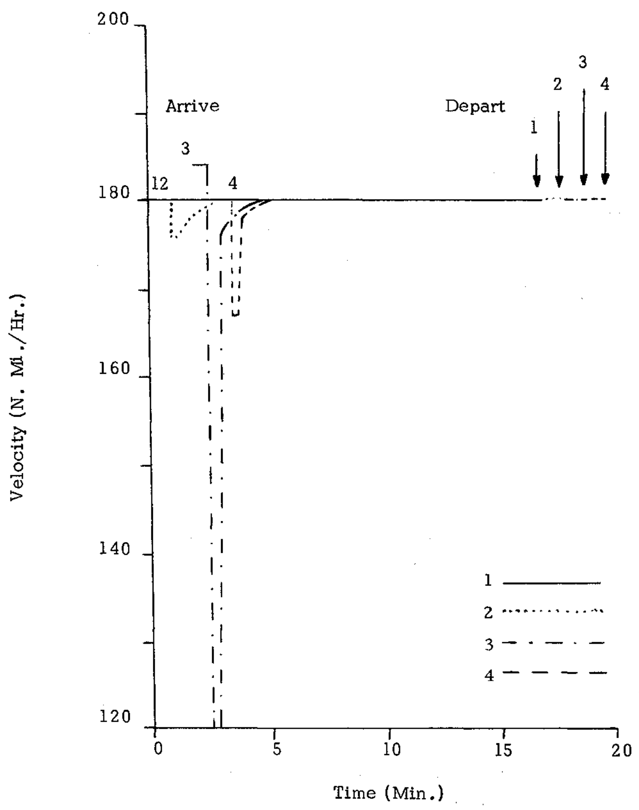

Fig. 5 Velocity profiles—stable model control.

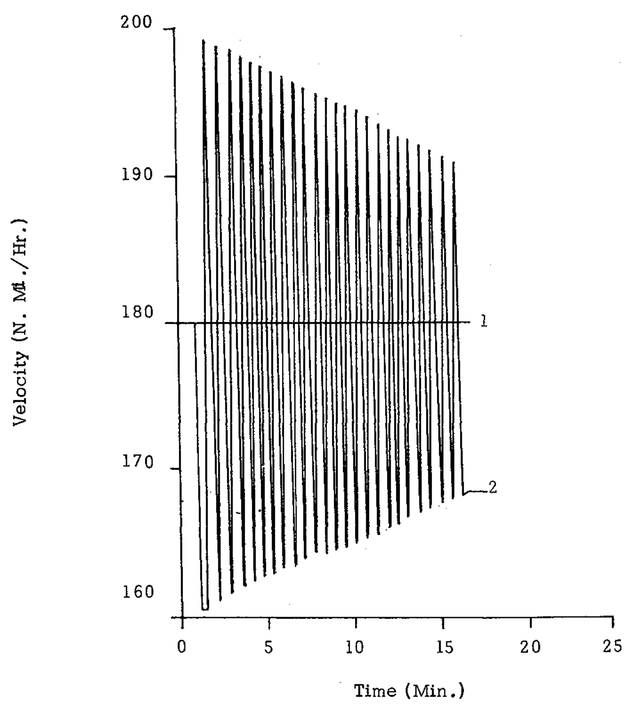

Fig. 6 Velocity profiles—unstable model control.

A Priori Conditions a Model Must Satisfy

A model of the future system cannot be validated with respect to actual data, since none exists. Therefore, it is important to establish a priori conditions which a model of this nature must satisfy so that it may be validated with respect to these conditions.

Most importantly, the model must reflect the actual variables in the ATC-pilot-aircraft control loop and must cause the control objective to be realized. The control loop for each aircraft is shown in Fig. 1. A single controller, operating within the deterministic constraints of FAA rules, will be responsible for directing the flight of several aircraft to achieve the control objective which is to maintain a desired (nose-to-tail) separation, D, between successive aircraft. The ARTS display will provide the data, range ($x_{n-1/n}$) and range rate ($v_{n-1/n}$), upon which the controller will base his control decisions. The variable which may be used to control aircraft flight is that of ground speed of the aircraft with respect to the flight path. In general form, the desired model may be written as

$$\text{ATC directive} = f[\text{range, range rate}, D] \quad (1)$$

Five additional requirements which may be discerned are: 1) the desired steady state of model operation is that nose-to-tail separations of D naut miles are maintained; 2) ATC directives (new velocities) must be within the limits of aircraft capabilities and passenger comfort needs; 3) for relative separations approaching zero [$x_{n-1/n}(t) \to 0$] a very drastic control directive (a course change) should be prescribed since this implies a collision situation; 4) a large or small deviation in separation (or in relative velocity) should be compensated for with a large or small value of the control directive; and 5) control directives should be of the sign (direction) given in Table 1.

The Model and its Justification

Assumptions upon which the proposed model is based are summarized below: 1) aircraft in a platoon are of similar flight characteristics and follow one another on a predefined path to the glide slope; 2) one dimensional analysis is sufficient since coordinates are located with respect to the flight path; 3) ARTS continuously displays the position and ground speed of each aircraft for use by the controller; 4) equations of rectilinear motion adequately describe the flight of aircraft with respect to the path; 5) aircraft are controlled by adjusting ground speed with respect to the flight path; 6) the control objective is to maintain the desired separation, D, between successive aircraft in a platoon; 7) the control process is continuous and an existing deviation from D is to be corrected over time duration τ; and 8) response of the system is such that the velocity of an aircraft will take a step jump to the directed velocity T time units after a directive is issued.

Table 1 Sign of control directives

Range, or separation	Range rate	Control directives decrease velocity (−) increase velocity (+)	Implied condition
< D	< 0	−	Too close, overtaking
	= 0	−	Too close
	> 0	− (or no change)	Too close, but separation increasing
= D	< 0	−	Overtaking
	= 0	0	No change
	> 0	+	Separation increasing
> D	< 0	+ (or no change)	Too far apart, closing
	= 0	+	Too far apart
	> 0	+	Too far apart, separation increasing

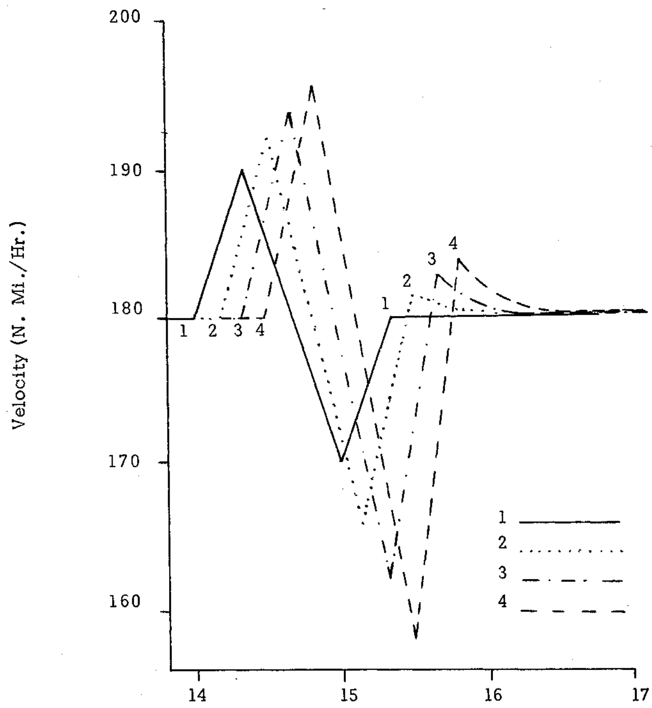

Fig. 7 Velocity profiles—following sawtooth velocity change.

The reader will note that several of these assumptions are approximations of the real system. Nevertheless, similar approximations have been employed to advantage in a parallel approach to modeling highway traffic. This approach, car following theory, has been developed by a number of researchers over a period of some 20 years and is, today, an accepted theory of traffic flow. Although many variations have been reported, car following models[9] typically assume that a driver adjusts the velocity of his vehicle in proportion to the relative velocity of the vehicle ahead. Models apply only to the restricted situation of dense traffic on long, straight roads. It is interesting to compare the characteristics of car following to those assumed for the aircraft situation (Table 2):

Consider the model of controller directives

$$v_n(t + T) = v_{n-1}(t) + \lambda[x_{n-1/n}(t) - (D + L)] \quad (2)$$

This model represents the velocity directed to the nth aircraft at time t (because of system response, T, the velocity is not assumed until time $t + T$). The control directive is based on a combination of the leading aircraft velocity and existing deviation from D. To show explicitly that it is of the form desired, add and subtract $v_n(t)$ to the right

Table 2 Characteristics of car and aircraft following situations

Item	Cars	Aircraft
Control directive	Acceleration	Ground speed along path
Control based on	Relative velocity	Range, range rate, D
Decision maker	Each driver	Single controller
Rules	Individual, variable	Strict, deterministic
Variables perceived by decision maker	Cars	Radar display
Type of flow	Dense	Dense
Situation	Long, straight road	Long, predefined path
Objective	Zero relative velocity	Constant separation

Table 3 Stability analysis

Parametric value	Response type
$T/\tau > \pi/2$	Velocity is oscillatory with increasing amplitude
$T/\tau = \pi/2$	Velocity is oscillatory with undamped amplitude
$1/e < T/\tau < \pi/2$	Velocity is oscillatory with damped amplitude
$T/\tau \leq 1/e$	Velocity is nonoscillatory and damped

side of Eq. (2) and divide throughout by $v_n(t)$ to obtain

$$\text{ATC directive} = v_n(t+T)/v_n(t) = 1 + \frac{v_{n-1/n}(t)}{v_n(t)} + \frac{x_{n-1/n}(t) - (D+L)}{\tau \cdot v_n(t)}$$

which is of the desired form stipulated a priori in Eq. (1). It is assumed that this model represents the controller's decision logic in combination with the physical laws governing aircraft flight. A more thorough development of the model is included in Ref. 9, but is beyond the scope of this particular article. Steady-state and stability analyses are also documented in Ref. 9; only the results are reported below. The steady-state analysis indicates that nose-to-tail separations of D are actually achieved by continued operation of the model, satisfying the first of the five a priori requirements.

The stability analysis is predictive of the safety of the proposed flight configuration. Two types of stability are involved: local and asymptotic. Local stability deals with the response of an aircraft to a velocity change of the aircraft ahead. Nonoscillatory, damped response represents the safest, stable type of response. Responses which are oscillatory with increasing amplitude are unstable and would cause rear-end collisions. Oscillatory responses with or without damping are also unstable and represent hazardous following conditions. Asymptotic stability is concerned with the manner in which a velocity perturbation of the lead vehicle is propagated down a line of traffic. Again, nonoscillatory, damped response is stable and, therefore, indicative of a safe following situation. Other response types may cause rear-end collisions. In both cases, stability criteria place bounds on acceptable values of λ and T. Parametric values found[9] to describe each response type are given in Table 3. Thus, for $T/\tau \leq 1/e$ the model is stable both locally and asymptotically.

Another type of "instability" might result if a priori condition 2 is not met. If it be assumed that only velocity changes (rather than minor heading changes) are to be made to correct separation deviations, velocity constraints must also be considered. That is, the velocity of an aircraft cannot be less than or equal to its stall speed, B, nor can it be permitted to exceed the maximum allowable terminal area velocity, U. If an ATC directive violated one of these constraints, "instability" would result since aircraft could not travel at such a velocity. Mathematically this concept may be expressed as

$$B < v_n(t+T) = v_{n-1}(t) + \lambda[x_{n-1/n}(t) - (D+L)] \leq U$$

A somewhat more interesting view of these constraints is through the limitations they place on $x_{n-1/n}(t)$. After appropriate manipulations, it is possible to write the acceptable bounds on $x_{n-1/n}(t)$

$$\tau[B - v_{n-1/n}(t)] + [D+L] < x_{n-1/n}(t) \leq \tau[U - v_{n-1/n}(t)] + [D+L] \quad (3)$$

If the velocity constraints are not to be violated, $x_{n-1/n}(t)$ must lie within these limits. The slanting lines in Fig. 2 graphically show these acceptable limits on $x_{n-1/n}(t)$ as a function of $v_{n-1}(t)$. The dashed line in the figure represents the desired separation, $(D+L)$. Parametric values used to obtain the graph are

B = 120 naut mile/hr U = 250 naut mile/hr
D = 3 naut mile L = 200 ft
τ = 0.5 min

A value of $x_{n-1/n}(t)$ outside the bounds given by Eq. (3) might occur as an aircraft enters the terminal area and comes under initial control of the model. Such a violation might also occur because of error while aircraft are on approach. In any event, a separation violation would cause the aircraft following model to call for a velocity outside the permissible velocity range. If $x_{n-1/n}(t)$ were greater than the upper limit in Eq. (3), a velocity greater than U would be directed. For $x_{n-1/n}(t)$ less than the lower bound, a velocity less than stall speed, B, would be indicated. Such an infeasible directive could be viewed as a course change to affect the velocity of the aircraft with respect to the flight path. A course change would, of course, destroy the collinear following situation and inefficiencies would result. This does, however, meet the priori requirement that $x_{n-1/n}(t) \to 0$ should call for a drastic control directive.

These constraints show that the allowable range of $x_{n-1/}(t)$ is not a function of T, D, or L. Thus, no penalties are incurred by reducing D to enhance runway capacity. However, the allowable range of $x_{n-1/n}(t)$ changes in direct proportion to changes in τ, the time duration over which a separation deviation is to be corrected. Figure 2b shows this sensitivity to τ by depicting a τ equal 1.0 min instead of 0.5 min shown in Fig. 2a. Since a larger τ permits a greater allowable range of $x_{n-1/n}(t)$, it appears tactically attractive to use a larger τ at great distances from a terminal and to reduce τ as the aircraft continue on approach. This tactic would permit the model to accept aircraft with large separations into the terminal area, and to provide more accurate control of flight near the glide slope. Theoretically, safety hazards would be reduced as the following situation approaches steady state, so this process could be used to the advantage of increasing landing rate.

Additional constraints on $x_{n-1/n}(t)$ could be formulated by considering the acceleration/deceleration capabilities of a particular type of aircraft. The parameter τ would also affect these constraints: the time to accelerate/decelerate to a directed velocity must be well less than τ.

Table 4 Input data for computer experiments

A. System parameters:

D = 3 naut miles
L = 200 ft = 0.0329 naut miles
T = 8 sec
T = 30 sec

B. Arrival data

Aircraft	Initial velocity (naut mile/hr)	Time to next arrival (sec)
1	180	60
2	180	50
3	185	70
4	180	50
5	175	60
6	175	50
7	180	70
8	185	60
9	185	70
10	175	60
11	180	...

Model Operation

A computer program was developed to study the model so that a better intuitive appreciation of its operation could be obtained and to confirm that a priori requirements 4 and 5 are met. Since data on the future system are not available, care must be taken in drawing quantitative conclusions from the program results. However, it does provide a qualitative picture of aircraft flow under such a decision strategy. This section describes the logic of the computer program and presents the results of several experiments performed with it.

Description of Computer Program

The program operates on an incremental time basis. That is, the position and velocity of each aircraft in the terminal area are updated according to the model each TINCMT time units, where 2 sec was used for TINCMT in this study to approximate continuous control.

Input data required by the program include the system parameters: D, L, τ, and T, the velocity of each aircraft as it becomes subject to control by the model, and the time between a current arrival and the next. Aircraft are "flown" a distance of 50 naut miles (also a variable) under control, then exit the modeled area. Program outputs include statistics (mean, standard deviation, minimum value, and maximum value) on the velocity of each aircraft as it departs and on the separation achieved between a departing aircraft and the one immediately behind it. Several graphs are provided to allow a visual understanding of the operation of the model over time. These graphs plot velocity, relative velocity, location, and deviation from desired separation—all versus time and for each aircraft.

The program is written in modular format so that each subroutine performs a single function. The main program merely calls appropriate subroutines in succession; a flow chart is shown in Fig. 3. The names and functions of the subroutines are detailed in this figure. The flow of operations in the most important subroutine, THINK, is shown in Fig. 4. THINK accepts arriving aircraft into the terminal area, control flight according to the model, and departs aircraft as they reach the glide slope and are no longer subject to model control. Constraints are provided in THINK so that velocity directives never exceed the maximum allowable terminal area velocity (250 naut mile/hr) or go below aircraft stall speed (120 naut mile/hr).

Experiments with Program

The point of departure from the modeled area is interpreted as the location $(D + L)$ naut miles down the glide slope from the gate, or entrance to the glide slope. Actual flight on the glide slope is such that aircraft fly independently of each other so the best possible separations at the gate may be obtained by this definition of the departure point. Thus, as each aircraft departs from the modeled area the succeeding aircraft is (at least approximately) at the gate. As each aircraft becomes the leader of the platoon, it maintains the velocity as directed in the last model directive.

The first experiment was designed to study model operation under stable conditions and in a situation in which the first aircraft maintained a constant velocity of 180 naut mile/hr throughout approach. Input data for this test are shown in Table 4; 11 aircraft were flown with the stable parametric ratio (T/τ) of 0.266. The resultant velocity-time profiles for the first four aircraft are shown in Fig. 5. These profiles are typical of all, but only four are shown for clarity.

Separation deviations which existed when aircraft arrived were essentially corrected within about 2 min. The initial velocity correction is rather abrupt and could be viewed as a heading change rather than an actual velocity change. Use of a large τ at the outer limits of the terminal area appears desirable since this would allow initial deviations to be corrected less drastically. Initial separation deviations were eliminated in an exponentially decreasing manner without overshooting and within the first two minutes in the system. After initial corrections were made, only insignificant velocity changes were directed during the remainder of flight.

Nose-to-nose separation between all successive aircraft at the departure point was 3.0329 naut miles; this is precisely the desired separation of $(D + L)$. This experimental steady-state result confirms the analytic solution presented earlier.

A second experiment was performed to study the results of operating with an unstable parametric ratio. The same input data was used but with T equal to 10 sec and τ equal to 6.35 sec so that the parametric ratio (T/τ) was 1.57. Such a ratio is near that for which the stability analysis predicted an oscillatory response with an undamped amplitude. Figure 6 shows the test results. The straight line at 180 naut mile/hr represents the velocity profile of the second aircraft. Clearly, such a response is undesirable. The period of oscillation is approximately 6.45 sec/cycle, or approximately equal to τ.

The final experiment was designed to study the stable response of the platoon to a velocity change of the first aircraft. The first four aircraft and the parametric value shown in Table 4 were used; however, the velocity of the first aircraft was programed to increase to 190 naut mile/hr, then decrease to 170 naut mile/hr, and then increase to 180 naut mile/hr in a short time period as shown by the solid line in Fig. 7. While such a drastic change in velocity would probably not occur in an actual case, this test was devised to indicate the effectiveness of the model in "following" velocity perturbations. The system response maintained insignificant separation deviations during this situation. Even though the velocity change was programed to occur near the time at which the first aircraft departed, the model made corrections such that departure separations between successive aircraft were (in naut miles): 3.0331, 3.0329 and 3.0330. The range of this data indicates that steady-state was reachieved for all practical purposes after the programed velocity change.

In each of these experiments, model application to each aircraft has been assumed continuous. Obviously, a single controller must communicate at discrete time intervals with each of the aircraft in his sector. However, for the situations tested, there appeared to be little difference between what a discrete process would have achieved and what the continuous process did achieve. Points of inflection in the velocity-time curves could be viewed as the only times a discrete control directive would be necessary. Such points were relatively few in number and, even with a number of aircraft under control, were well spaced in time indicating that explicit consideration of the discrete nature of control was not critical to these experiments.

Conclusions

The proposed view of operations in the future ATC system resulted from a rather abstract consideration of the many changes planned by the FAA. There appears to be little support for the view beyond the arguments presented. A strategy which permits aircraft to approach the glide slope in a collinear configuration is somewhat different from the path control strategy in use today. Nevertheless, such a configuration appears to offer certain improvements in the efficient flow of aircraft while maintaining a satisfactory level of safety. Furthermore, a modeling approach such as that employed in this study suggests the capability for more detailed analysis of the controller's role in the air terminal system.

References

[1]Alexander, B. (chairman), "Report of Department of Transportation Air Traffic Advisory Committee," Vols. 1 and 2, Dept. of Transportation, Washington, D.C., Dec. 1969.

[2]Blumstein, A., "The Landing Capacity of a Runway," *Operations Research,* Vol. 7, No. 6, 1959, pp. 752–763.

[3]FAA, "The National Aviation System Plan, Ten Year Plan 1972–1981," (71-01686), March 1971, FAA, Washington, D.C.

[4]FAA, "The National Aviation System Policy Summary 1971," (7-10686), March 1971, FAA, Washington, D.C.

[5]Lister, S. F. and Raisbeck, G., "Approach to the Establishment of Practical Air Traffic Control Safety Goals," Contract No. FA70WA-2141, Little, Cambridge, Mass., May 1971.

[6]Raisbeck, G., Koopman, B. O., et al., "Air Traffic Control System Capacity," Contract No. DOT-FA70WA-2141, Little, Cambridge, Mass., Aug. 1970.

[7]Schriever, B. A. and Seifert, W. W., *Air Transportation 1975 and Beyond: A Systems Approach,* The MIT Press, Cambridge, Mass., 1968.

[8]Simpson, R., "Evaluation of Air Traffic Control Models and Simulations," Contract No. DOT-TSC-77, June 1971, MIT, Cambridge, Mass.

[9]Wilhelm, W. E., "Following Theory With Applications," Ph.D. dissertation, 1972, Virginia Polytechnic Inst. and State Univ., Blacksburg, Va.

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An Interactive Real Time Simulation for Scheduling and Monitoring of STOL Aircraft in the Terminal Area

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An interactive real time terminal area simulation has been developed to investigate performance requirements for STOL aircraft operations. Consideration is given to the interaction of the ground system with STOL aircraft using an onboard 4D guidance system. The simulation consists of four parts: 1) a scheduling algorithm which schedules conflict free arrival times at critical points; 2) a trajectory synthesizer which determines the reference trajectory from feeder fix to final approach; 3) a simultaneous simulation of all aircraft using 4D guidance along the synthesized reference trajectories; and 4) a graphic display used to present simulation results and interact manually with the simulation. This paper describes the simulation and presents results obtained to date.

Introduction

IN support of research on STOL terminal area operation, Ames is studying a promising new guidance concept, generally known as a "4D" guidance system.[1] The 4D guidance system synthesizes a curved three dimensional flight path and generates command inputs to fly along the path according to a time schedule specified by the ground system.

The 4D guidance system has the potential for enabling precise control of aircraft in a terminal area with low pilot workload provided accurate navigation data is available. An important problem arising in the use of a 4D guidance system is its interaction with the ground system. A ground system based on the time synchronized approach control concept considered by the FAA for terminal operation in the 1980's would generate sequencing, spacing, and time control commands which the aircraft must obey. The impact of such a ground concept on future STOL 4D guidance systems raises complex questions. These can only be investigated by a total system simulation that includes elements of both the airborne and the ground system.

This paper describes the current simulation and outlines the criteria used in developing it. First a description of the over-all system is given followed by a more detailed discussion of the individual components. Next the use of the simulation and display is described followed by a brief discussion of the results to date.

General Description of Simulation

This section gives an overview of the complete simulation showing the interaction of the various components. These components will be examined in more detail later.

The complete simulation is illustrated in block diagram form in Fig. 1. Once the system has been initialized the only function of the executive program is to provide the time control necessary for real-time operation. The aircraft scheduler accepts arriving aircraft generated at random time instants or from the keyboard associated with the graphic display. The mode of operation is determined by the operator. An aircraft can be one of three types; for example, CTOL, STOL, or VTOL. The type is also chosen randomly from a specified statistical distribution. The operator can also decide whether the arriving aircraft will be scheduled automatically or manually with computer aid. In either case, the scheduler transmits the set of waypoints describing the desired approach route to the trajectory synthesizer which develops a three-dimensional trajectory together with the maximum and minimum times required to travel between each pair of time-critical points.

The scheduler then selects appropriate times for the aircraft to pass through the time-critical points and calls upon the synthesizer to specify the trajectory in the form

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