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This paper describes work being done at NASA, Langley Research Center and at the Research Triangle Institute on advanced, ground-based guidance and control for the near terminal area. Large-scale computer traffic simulations in conjunction with flight experiments with a Boeing 737 aircraft will be used to evaluate various concepts for automated terminal area metering and spacing. The all-digital real-time air traffic simulation model is described. Facilities for aircraft tracking and for interfacing the aircraft with the digital simulation are discussed, along with possible application to other types of experiments.

I. Introduction

In order to provide for more efficient and safe operations in airport traffic areas, there is an urgent need to develop and thoroughly evaluate new and proposed system concepts prior to implementation. Beginning in 1970, NASA embarked upon an advanced technology development program with the objective of increasing the productivity of the aircraft/airport/ATC system with primary concentration on the airborne elements of the system. The research program includes analyses, large scale computer simulations, development of suitable ground facilities, and flight tests with a modified Boeing 737 airplane. Research is being conducted at the present time to evaluate new concepts in the ground and airborne systems and in operational flight procedures.

This paper provides an overview of the research work and facilities developed or under development at NASA and the research being conducted by the Research Triangle Institute (RTI) in support of this effort. The major effort at RTI has been associated with the development of a comprehensive computer simulation model to realistically represent the terminal area air traffic control situation. This model has now been developed and has been used in the batch mode to conduct trade-off studies as discussed in the following sections and in Reference 1.

The simulation model simulates the major features of the terminal area, including aircraft performance characteristics, controller/pilot communications, ground controller decisions, navigation capabilities, and surveillance accuracies. The outputs of the simulation model have been found to compare favorably with associated characteristics in the real terminal area. The simulation is fully dynamic and operates in real-time. Potential conflicts are detected and resolved as the simulation progresses and the simulation model has the ability to handle certain non-routine situations such as simulated aircraft that are inserted into the flow pattern by the computer console operator. As aircraft are inserted, they are integrated into the normal terminal area flow pattern, properly sequenced, and spaced for landing.

The dynamic nature of the computer model algorithms that have been developed permit the generation of near terminal area guidance data from the computer in the real-time mode. Navigation and guidance algorithms have been programmed which are not intended to be optimum but are intended instead to reflect present day controller decisions as closely as possible. In addition, advanced instrumentation and control techniques have been programmed such that it is possible to replace the simulated present day controller decision algorithms with different techniques and control strategies and to compare performance under realistic conditions in both simulation and flight demonstrations. Since controller/pilot communications are included in the simulation, the computer programs have the capability of providing command guidance information for evaluation of operational procedures and associated airborne instrumentation and displays.

The following sections describe the overall NASA program and facilities and the simulation model in more detail. In addition, the uses of the simulation model in real-time experiments using a simulated cockpit and the actual Boeing 737 airplane are discussed.

II. NASA Terminal Configured Vehicle (TCV) Program

The Department of Transportation and the Federal Aviation Administration have undertaken the upgrading of the air traffic control system in order to increase safety and to handle expected future increases in air traffic density with reduced noise pollution and congestion. This revision of the system, known as the Upgraded Third Generation, has as major features; 1) Intermittent Positive Control (IPC), 2) Discrete Address Beacon System (DABS), 3) Area Navigation (RNAV), 4) Microwave Landing System (MLS), 5) Upgraded Air Traffic Control Automation, 6) Airport Surface Traffic Control (ASTC), 7) Wake Vortex Avoidance System (WVAS), 8) Aeronautical Satellites for Transoceanic Flight (AEROSAT), and 9) Automation of Flight Service Station (FSS)⁽²⁾. Needless to say, the full potential system improvement will not be realized unless the airborne systems are capable of fully utilizing the features listed above. The airborne systems include the basic airframe and equipment, the flight-control systems (manual and automatic), displays for either active control or monitoring, navigation and communication equipment, and the crew as the responsible manager and operator of the aircraft.

In formulating the joint DOT/NASA Civil Aviation Research and Development Policy Study Report⁽³⁾ the question of U. S. Government conduct or support of demonstration programs in civil aviation is introduced with: "Demonstration programs are needed to prove out new systems and technologies, to assess market potentials, or to

remove major institutional constraints temporarily. Demonstration programs are experiments designed to embrace new concepts, procedures, regulations or the blending of new technology into existing systems. These programs should collect information and required data in a real-world environment involving the ultimate users of the system."

Responding to this need, the NASA Langley Research Center has implemented the Terminal Configured Vehicle (TCV) Program (4). Its goal is to identify, evaluate, and demonstrate aircraft and flight management technology that will improve the efficiency and acceptability of conventional aircraft in terminal area operations because this region is recognized as the system bottleneck and is also the major area of possible unfavorable impact with the community environment. Figure 1 shows pictorially the area of emphasis of the program.

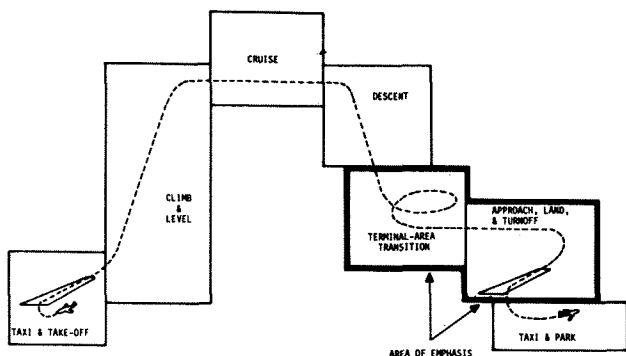


Figure 1. Area of Emphasis of the NASA Terminal Configured Vehicle (TCV) Program.

The TCV program is conducting analytical, simulation and flight test research which will support improvements in 1) terminal area capacity and efficiency, 2) approach and landing capability in adverse weather and 3) reduction of noise impact through operating procedures. In this research, the test facilities described in the next section will be used to examine very carefully the flight characteristics of conventional commercial aircraft and their control systems, avionics, and displays when operating under procedures made possible by advanced air traffic control systems.

One example of this effort is the participation of the TCV research aircraft in the demonstration of the U. S. national microwave landing system to the All Weather Operation Panel of the International Civil Aviation Organization (ICAO). Using guidance information from the phase-2 scanning beam MLS installed at FAA's National Aviation Facilities Experimental Center, the aircraft flew 3° descending curved approach paths with 130° intercept turn and 3-mile final approach. The approach also included automatic flare and touchdown(5).

III. Experimental Facilities

Ground-Based Simulations

For ground based simulations, the terminal area simulation model on the NASA CDC Cyber 175 computer will be used in conjunction with a fixed base cockpit simulator to conduct experiments with the human pilots in the control loop. Several fixed base cockpit simulators are available at NASA-LRC including a cockpit which simulates the aft flight deck in the NASA TCV aircraft. In addition, a general purpose transport aircraft cockpit equipped with a Collins ANS-70A Mark II area navigation system will be used in planned experiments. The computer program for the aerodynamics and controls for the fixed base simulators are programmed for the CDC Cyber 175 and include gust/wind models, non-linear actuator models, detailed aerodynamics, and automatic flight control and navigation control functions.

Data transfer between the terminal area simulation model and the simulated cockpit will be provided through analog to digital and digital to analog interfaces available on the CDC real-time complex. Voice messages from the terminal area simulation will be generated on an Adage AGT/130 computer for transmission to the pilots in the simulated cockpit.

Flight Experiments

Figure 2 is a pictorial view of the test facilities that will be used to provide a realistic ATC environment for the 737 aircraft. Information from the terminal area computer simulation on the CDC Cyber 175 computer will be transmitted to the airport at NASA (Wallops Island, Va.) over a two-way data link. At NASA-Wallops, the data are transmitted to the TCV aircraft over a two-way ground/air microwave data link. Additional facilities consist of a terminal area display research van which contains an Adage AGT/130 interactive graphics display system and TV equipment with the capability of transmitting high resolution television pictures to the research aircraft. A runway control center has been constructed at Wallops Island to provide for project control and communications for the experimenter. Figure 3 is a block diagram indicating the interconnections between the various computers, tracking systems and data links in the overall aeronautical research complex.

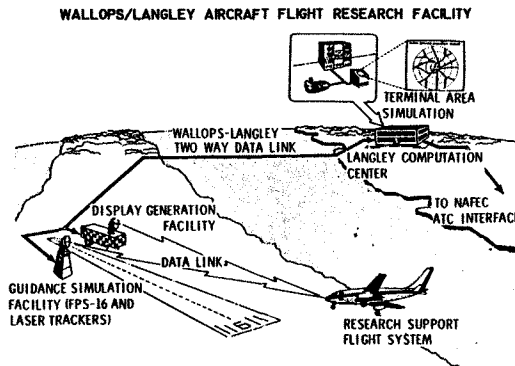


Figure 2. Pictorial Diagram of the NASA Experimental Facilities.

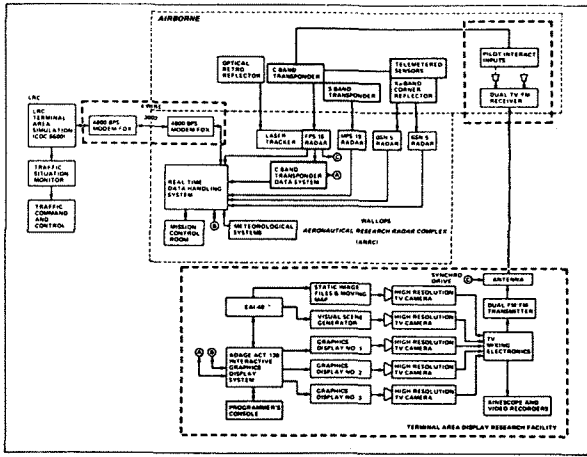


Figure 3. Block Diagram of NASA-Wallops Experimental Facilities Indicating the Various Tracking Systems and Data Links in the Overall Aeronautical Research Complex.

The modified Boeing 737 aircraft is equipped with advanced digital flight control, navigation and guidance systems and associated electronic displays. An aft flight deck provides a second cockpit installed in the passenger cabin from which the aircraft can be flown in a fly-by-wire mode. This second cockpit is a limited authority system which can be either disconnected or overridden by safety pilots in the forward flight deck. In addition, a real-time data acquisition system operates on board and acquires and records signals representing variables pertinent to the experimental conditions. The recorded data are stored on magnetic tape or may be downlinked to the ground via an L-band telemetry downlink to a mobile ground station data recording system.

Electronic display systems installed in the aft cockpit include dual electronic attitude director indicators (EADI) and electronic horizontal situation indicators (EHSI). Presentations on these displays are modified by changes in software programs on the display processor or in the navigation computer. Figure 4 shows the internal arrangements in the 737 research aircraft.

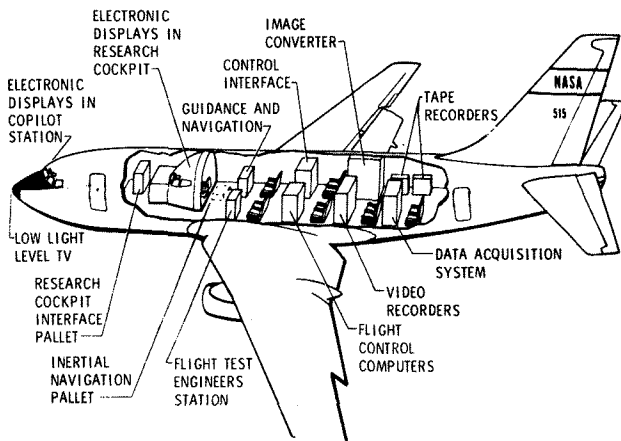


Figure 4. Internal Arrangements of the B-737 Research Aircraft.

Other facilities available at NASA-Wallops include a precise laser/radar tracking system, meteorological sensors, and optical position measuring equipment. In addition, a simulation of the national microwave landing system is under development. This simulation will use information from the laser/radar tracking system to generate data with MLS accuracies and format which will be then transmitted over the air/ground data link to the research aircraft. This simulation will be used until such time as an actual MLS system becomes available.

IV. The Terminal Area Simulation (TAS) Model

The terminal area model is a flexible simulation of the airborne, ground control and communication aspects of the terminal area environment which is, with input data changes, adaptable to existing terminal areas and which can be and is being expanded to incorporate advanced concepts of instrumentation and control. The airborne aspects modeled include aircraft dynamics, performance capabilities of 20 different classes of aircraft, traffic samples depending on desired operations per hour and probabilities of aircraft types and route loadings, aircraft load factors, intended flight plans, flight path errors, and meteorological effects. The ground control aspects include control procedures (both current ATC procedures and advanced control techniques), control options (i.e. speed control, alternate paths, altitude change, holding patterns), separation standards, navigational aids, terminal area geometrics, air-route structuring, runway handling constraints and surveillance errors. The communication aspects reflect only controller to pilot communication and include message content, delays associated with the actual delivery of a message, delays associated with controller work load, and priority delivery of messages.

The TAS model, which can be run in both a real-time or a fast-time mode, outputs overall performance measures for trade-off evaluation of various navigational or control techniques as they relate to the terminal environment as a whole. In addition, the real-time mode offers a visual and audio environment for a realistic real-time simulation of traffic in the terminal area and is capable of providing automatic guidance information for real aircraft. The overall TAS model is composed of three independent units, including a traffic generation program, the terminal area simulation, and post analysis routines.

Traffic Generation

The traffic generation program is responsible for supplying traffic samples to be input to the terminal area simulator. These samples describe the initial conditions for arrival aircraft on a prescribed perimeter about the runway or for departing aircraft on the runway apron. Inputs to this program include limitations and deviations on initial speeds and altitudes for different performance classes of aircraft and on headings and lateral positions for the entry points on desired routes. Depending on the desired operations per hour and probabilities of aircraft types and route loadings, the program outputs offer times, initial positions, headings and velocities of aircraft which comprise the traffic sample. Realistic traffic samples can be generated based on

known probabilities of aircraft in a particular terminal area, or special purpose samples can be generated by varying the input parameters. Such a special purpose sample might consist of all similar type aircraft or a modified distribution of aircraft on the terminal area routes.

Terminal Area Simulation

The terminal area simulation was designed to be adaptable to both existing and advanced concepts of instrumentation and control. The needed versatility and flexibility were accomplished through the identification of the various functions performed within the terminal area into three groups: airborne functions, communications and ground control. These three groups correspond to the three bracketed sections of the flow chart in Figure 5: TRACK (update of aircraft position data considering aircraft dynamics, performance capabilities of different classes of aircraft, and use of particular navigation aids), COMMUNICATIONS (communication of ground control with aircraft, considering channel loads and priority of messages to be sent), and CONTROL (ground control procedures used to control the flow of aircraft and to resolve potential conflicts between aircraft). Unit organization of the functions within these three groups permit the use of or exclusion of any subset of functions as is required by a particular data set. The data set for a particular run must fully describe the desired terminal environment including such information as types and locations of navigational aids, the terminal area route structure, performance data for desired classes of aircraft, a master traffic sample, intended flight plans, separation standards, navigation and surveillance errors, types of control techniques to be used and the criteria for determining when to utilize them, a wind profile, controller message content, and delays associated with the delivery of messages.

When the simulator is initialized, all traffic is assumed to be on the runway or outside the perimeter of the terminal area of interest, waiting in the master traffic sample to enter the terminal area. Examining a four second incremental clock (corresponding to a four-second radar scan rate), the control section of the simulator determines if the offer time associated with an aircraft in the master traffic sample has been reached. If this time has been reached, initial control procedures are performed for the aircraft and it is either entered into the "active" traffic of the terminal or held in an enroute delay queue outside of the terminal area perimeter.

Movement of the aircraft within the terminal area is based on predefined intended flight plans which can be modified for a particular aircraft by the control section of the program in order to facilitate the traffic flow. Modifications to a flight plan must, however, be communicated to the pilot through the communications section of the program. The intended flight plans and any optional flight paths are described by the data in terms of the navigational aids to be used to fly each portion of the path ("flight modes" such as a VOR radial, a DME radius, a vector, an ADF beacon, an ILS system, an MLS system, or RNAV) and in terms of the navigational aids used as the objective at the end of each portion of the path ("flight mode objectives" such as VOR radial intersection, a DME radius, a new altitude, RNAV turn anticipation, etc.). The position of each aircraft in "active" traffic is updated every four seconds based on the navigational algorithms which describe each navigational aid being used by the aircraft and on the aircraft dynamic model. Each updated position reflects the impact of current winds and navigational errors. In addition to the actual calculated position, a radar tracking position is calculated which reflects surveillance errors.

The control routines in the program are called on as necessary during the simulation, depending on the criteria for determining when to utilize control. Each possible route has associated with it a set of control procedures to be performed for each aircraft at various points or regions on the route. Given the position of an aircraft and current clock time, the criteria for performing a particular control procedure for an aircraft can be: movement past a boundary line on the route, existence of an aircraft within a certain region on a route, or time elapsed since the last control procedure was performed. An example of a predefined control point might be fixed path fixed point speed control where the determination of the optimum speed is calculated for an aircraft. This speed control decision might be based on ETA's (Estimated Times of Arrival) of this and other aircraft at a point and the anticipated delay capability of the aircraft further ahead on the route and must be based on the performance capabilities of the aircraft. An example of a control procedure which is executed based on an elapsed time from a previous control calculation might be a dynamic vectoring routine which determines the optimum time to vector an aircraft, using continually updated status information on other aircraft. In addition to the predefined control points or regions, immediate control procedures for a particular aircraft can be requested when a potential conflict exists which must be resolved by a second aircraft.

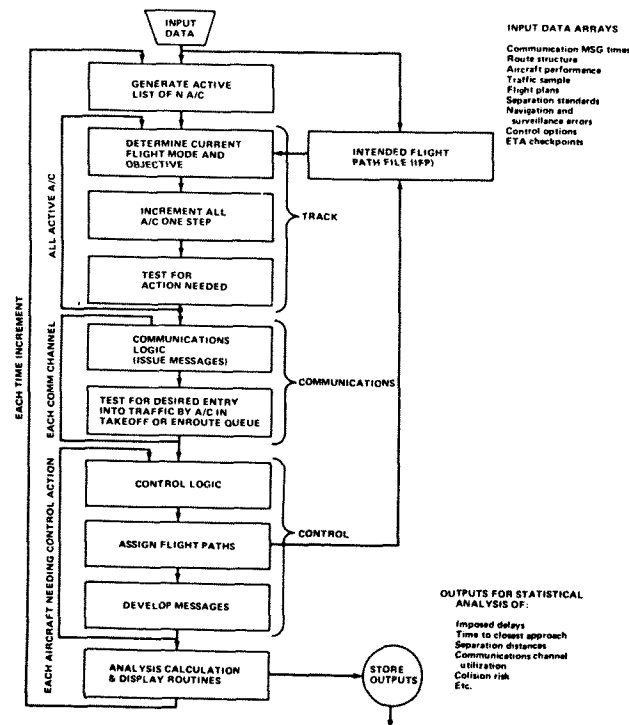


Figure 5. General Flow Chart of the Terminal Area Simulation Model.

The control section of the simulator consists of control modules which are called upon as needed according to the status of the aircraft in the terminal area and according to the desired degree of control defined by the input data. Current ATC procedures define control sectors where a controller is responsible for handing aircraft in his/her sector to another controller with adequate separation. This control philosophy permits limited look ahead capability into future sectors and concentrates on separating aircraft within a sector with little knowledge of the impact on the entire terminal area. This philosophy is handled in the simulator by establishing an ETA point within a sector just prior to a handoff point to a new controller. The control algorithms then simply maintain separation between aircraft in the sector up to this point. An optimum control philosophy might be one in which each aircraft is assigned an ETA at the runway considering separation requirements. Control is then responsible for maintaining the schedule of aircraft or reassigning schedules when necessary. The simulator handles this logic with an initial scheduling module as each aircraft is entered into "active" traffic and dynamic speed control and path control modules as an aircraft proceeds on its path to the runway. When a schedule can no longer be maintained due to flight errors, a rescheduling module is called.

The control section of the program is capable of simulating both the controller decisions and the computer aided decisions which might be offered to a controller to assist in the resolution of the traffic flow problem. In either case the results of the decision are transmitted from a controller to a pilot via a voice communications channel. Simulation of the communication aspects of terminal area environment is accomplished through the use of two message arrays per channel, one ordered on the earliest time of delivery (future messages) and one ordered on the latest time of delivery (current messages). As a control decision is made, a time envelope is associated with each message containing the results of the decision. This time envelope corresponds to the earliest and latest times a controller can deliver the message to a pilot such that the control decision remains valid. Initially, all messages are ordered on earliest time of delivery and placed into a future message array. As the time associated with a message in this array comes up, the message is moved into a current message array and ordered on latest time of arrival. These two arrays enable a priority delivery of messages. Message delivery delays are simulated by assigning an elapsed time for the delivery of each message and by permitting only one message to be delivered at a time by a controller. At present, the simulator handles up to 10 message channels.

Real-Time Graphics Displays

Operating in the real-time simulation mode, the air traffic flow is monitored on a simulation console display (CRT). Information displayed includes nominal route structures, controller message information, and data for each aircraft such as a symbol for its position and a tag containing flight identification, speed, altitude, and hold status. The display, updated every four seconds, may be oriented with respect to arbitrary geographic coordinates and scaled as chosen by the

observer. The origin of coordinates may also be referenced to a chosen aircraft to produce a moving aircraft centered display.

Figures 6 and 7 are examples of full terminal area simulation displays of the Atlanta (40 n.mi. radius) and Denver (55 n.mi. radius) terminal areas. The Atlanta display illustrates the current nominal Atlanta arrival and departure routes for runways 8 and 9R, with arrival vectoring areas both to the north and south of the runways. The Denver display shows a proposed fixed path route structure associated with a metering and spacing control concept under study by the Mitre Corporation for the FAA.

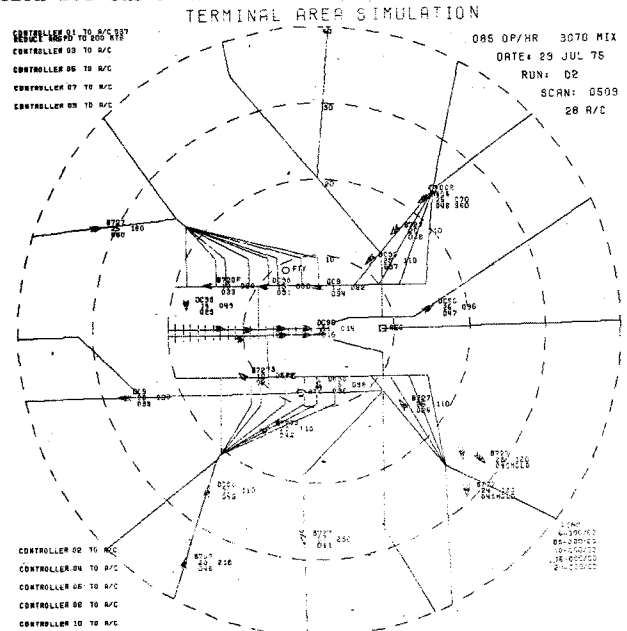


Figure 6. Real-Time CRT Display of a Simulation of the Atlanta Terminal Area. This display is updated every four seconds in the real-time mode.

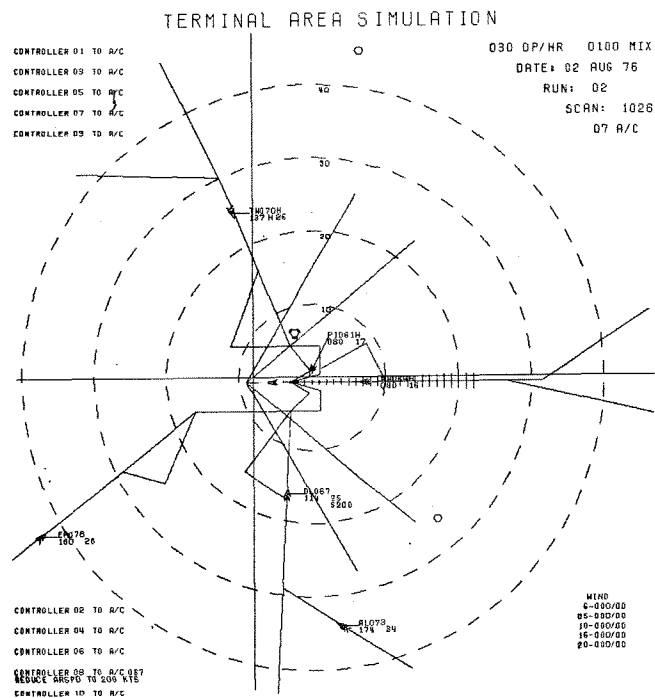


Figure 7. Plot of CRT Display Similar to That of Figure 6 for the Denver Terminal Area.

Real-Time Synthesized Audio Commands

Controller message information, in addition to being displayed on the display CRT at the appropriate time, are sent simultaneously in coded number form to the Adage Graphics Terminal (AGT). The Adage computer then uses the coded numbers to retrieve voice phrases in digital PCM form from disk storage. The analog equivalent of the message is then composed and output through an audio amplifier and speaker system.

An example of an arrival clearance message format used in the simulation of current procedures at Atlanta is:

(Aircraft identification), proceed to (Norcross, Dallas, Hampton, or Tyron) intersection. Descend and maintain (1 or 2 digits) thousand.

The basic phraseology of the message is precoded, and the control section of the program fills in the data in parentheses and tailors the message to a particular aircraft.

Batch Mode Analyses

In the batch or fast-time mode of operation, data from the terminal area simulation are output on a data tape containing scan by scan information which is in turn used as input to post-processing analysis programs. These post-processing programs include a statistical analysis program, a position plotting program, and a noise exposure forecast (NEF) computation and plotting program. In addition, provision is made for analysis of fuel consumption by accumulating data on fuel consumption during the execution of the simulation program in the fast-time mode. The accumulation of data for post processing analysis is usually accomplished by running the simulation for a simulated two-hour time period after the simulation stabilizes to a steady state operational condition.

A summary of the types of output data available from the simulation programs are given in Table 1. Examples of the type of output obtainable from the simulation programs are given in Figures 8 through 11. Figure 8 is a plot of the average flying time in the terminal area for arrivals vs. scheduled operations per hour. The solid line indicates the average flying time in the terminal area statistic obtained using the present day Atlanta traffic mix under IFR conditions while the dotted line indicates the average flying time for aircraft assuming all similar type aircraft (DC9-30). The relative improvement in capacity of the terminal area can be seen from this plot. Figure 9 is a plot of the average total fuel consumed per aircraft vs. operations per hour for a normal traffic mix and for all similar type aircraft. The average fuel consumption due to delay maneuvers is plotted separately as shown.

Figure 10 is a plot of NEF noise contours for the Atlanta terminal area under IFR conditions and near capacity traffic loads. This plot is an experimental plot taken under a particular set of operational conditions and should not be interpreted as representing the noise environment at Atlanta at the present time. Rather, it is intended as an example of the type of output obtainable from the simulation model. Figure 11 shows an aircraft density plot of the aircraft flow pattern used to generate the NEF contours of Figure 10.

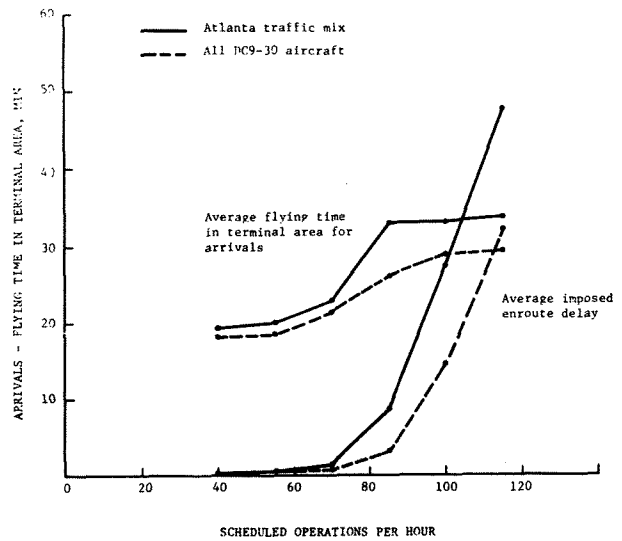


Figure 8. Plot of the Simulation Program Output Showing Average Flying Time in the (Atlanta) Terminal Area for Arrivals vs. Scheduled Operations Per Hour. This plot compares average flying time using the present day Atlanta traffic mix under IFR conditions with a traffic sample consisting of all similar type aircraft.

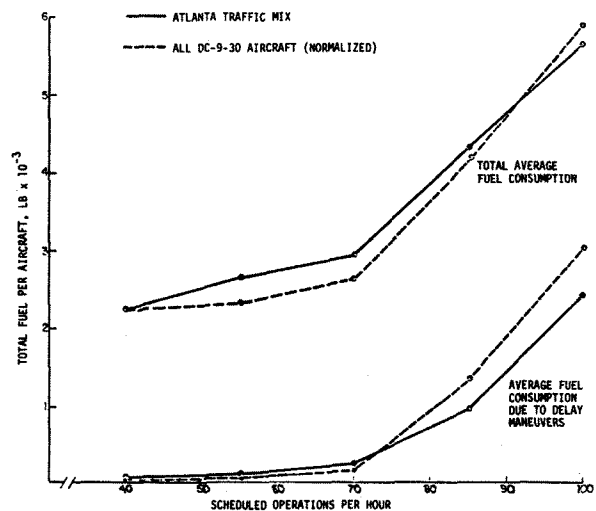


Figure 9. Example of the Simulation Program Output Showing the Average Total Fuel Consumed Per Aircraft for Atlanta Under IFR Conditions. The plot compares fuel usage of a normal traffic mix with a traffic sample consisting of all similar type aircraft.

Statistical Analyses - histograms, sample means and standard deviations of the following parameters.

time between entries in take-off queue--departures
actual time between departures
imposed delay in take-off queue--departures
time between successive departures from terminal area
actual flight time in terminal area--departures
total time in terminal area--departures
time between entries in enroute queue--arrivals
actual time between arrivals
imposed delay in enroute queue--arrivals
time between successive touchdowns--arrivals
actual flight time in terminal area--arrivals
total time in terminal area--arrivals
range to closest aircraft for the five closest aircraft

Plots of aircraft positions and density plots

Fuel consumption data - total fuel used by aircraft in the following categories.

awaiting departure clearance
departing the terminal area
enroute holding
terminal area holding
approach phase
arriving aircraft (total)
delay maneuvers (total)
total fuel (arrivals and departures)

Noise Contours - noise exposure forecasts (NEF) or peak tone corrected perceived noise level (PNDB).

Table 1. Output Data From the Simulation Programs in the Fast-Time (Batch) Mode.

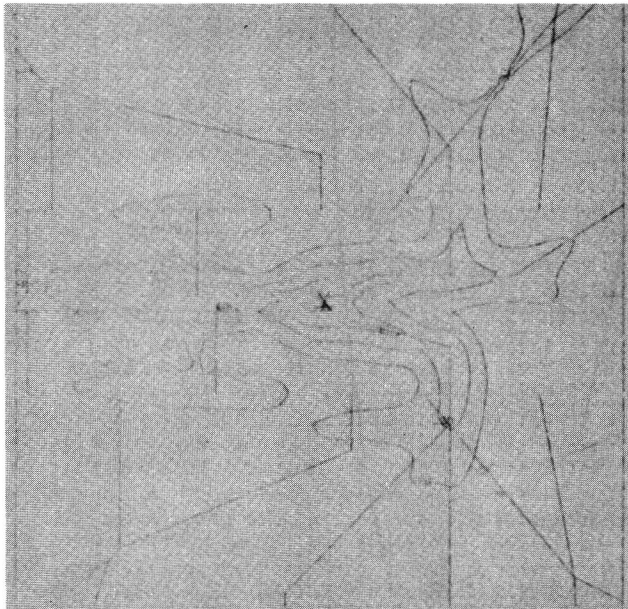


Figure 10. Example of Noise Exposure Forecast Contours from the Simulation Model. These contours are predicted on the basis of 1300 operations per day on Runway 9R and 8 at Atlanta. The contours were taken under a particular set of experimental conditions and should not be interpreted as representing the present Atlanta noise environment.

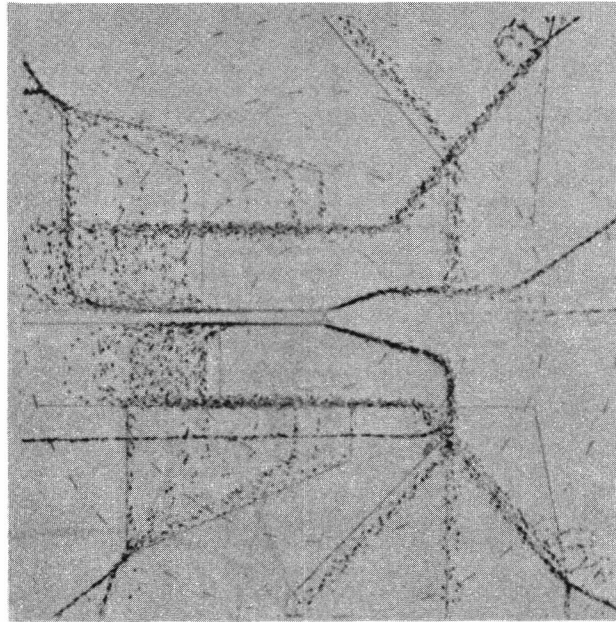


Figure 11. Density Plot of Air Traffic Flow into and out of Runway 9R and 8 at Atlanta International Airport. This particular flow pattern was used to generate the noise exposure forecast contours of Figure 10.

The large amount of output data obtainable from the simulation in the batch mode permits determination of the effects of changed instrumentation and procedures on numerous overall measures of the terminal area efficiency. Quantitative data is obtained to permit the evaluation of trade-offs and benefits to be obtained from changes in the overall ATC ground and airborne system.

V. Experiments in Ground Based Guidance and Control

A joint NASA/FAA/Mitre Corporation/RTI program has been implemented to more completely evaluate the application of the proposed microwave landing system to an automated terminal area metering and spacing system concept. One concept for ground based metering and spacing that has been developed is that of a fixed-path speed control where the ATC aids an aircraft in achieving a scheduled landing time by issuing indicated airspeed commands to the pilot at prespecified locations in the airspace. A first order evaluation of this technique has been conducted (6) and indicated that such a system is feasible with navigation accuracies obtainable with the MLS system. It is necessary, however, to determine if the theoretical results will be confirmed with human pilots in the control loop. In addition, it is necessary to determine if the speed control algorithms and path stretching maneuvers will prove acceptable to the pilots. Initial analyses did not fully consider the interactions between multiple aircraft in the terminal area and the possible human errors in utilizing available navigation techniques.

Figure 12 indicates the control procedures necessary for the metering and spacing concept under evaluation. A tentative schedule and ETA

computation is made upon entry of the aircraft into the terminal area and this schedule is adjusted during the approach maneuver as indicated in the figure. The final dynamic schedule adjustment is done using a direct-course-error readout technique (DICE) which determines the error at the runway which will occur if an aircraft immediately initiates a turn to a predetermined point on the path.

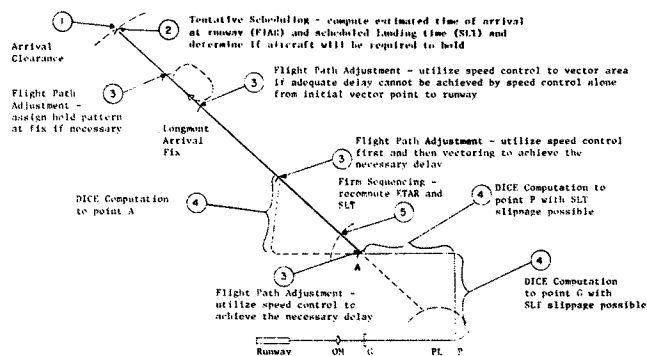


Figure 12. Control Procedures for the Metering and Spacing Concept Under Study.

For experimental purposes it will be assumed that all aircraft have capability for utilization of the microwave landing system and use area navigation.

The terminal area simulation will be integrated with a presently existing transport simulator configured with conventional avionics equipment and a Collins ANS-70 area navigation system. It is anticipated that the primary link between the transport simulator cockpit and TAS model will be through a voice circuit. Voice commands generated by the TAS model will be presented to the simulator pilot who then carries out the specified control command. Figure 13 shows a block diagram of the experimental set-up.

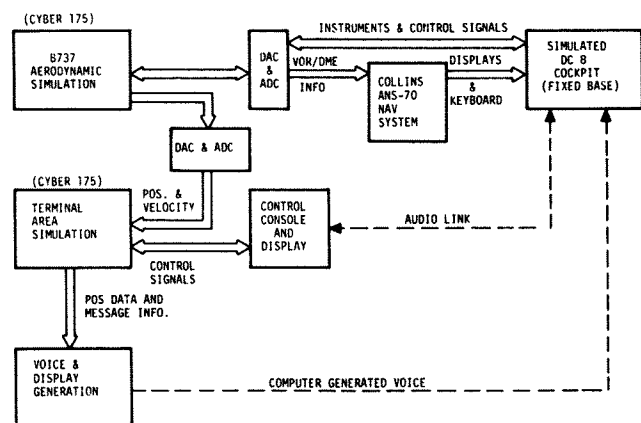


Figure 13. Block Diagram of the Experimental Set-Up for Integration of the Terminal Area Simulation with a Fixed Base Cockpit Simulator.

The real-time simulations will be conducted with various pilots in the loop. It will be desirable to use pilots actually familiar with transport aircraft and high density terminal area procedures. In addition, it will be highly desirable for the simulator pilots to have familiarity with the usage of the Collins ANS-70 navigational system. The simulations will be conducted to determine statistics on delivery error to the runway threshold and to other specified points along the approach path. In order to keep the number of experimental variables to a minimum, wind models and piloting techniques will be consistent from data run to data run. The primary experimental variables are expected to be MLS configuration (2 configurations), traffic density (2 traffic samples) and approach route (2 routes).

The actual number of data runs required will be determined after initial cockpit integration experiments are conducted to determine the required set-up time and simulated flying time required for a simulated approach. Because of the relatively large number of experimental variables, it will be desirable to obtain as many simulated approaches as is feasible under the constraints of available computer time and effort.

Outputs of the real-time simulations using the various control techniques and navigation systems are expected to provide data on: statistics on delivery error to the outer marker, amount of control activity required, amount of time of arrival control remaining at each control point, effects of communications delay, statistics on aircraft profile following deviations, and differences in pilot workload and avionics system complexity in using present day techniques vs. the automated ground based system.

In addition to the experiments discussed above, the simulation model will be used in other experiments as described in the following section.

Future Plans and Uses

The TAS model will be integrated with the simulated TCV cockpit and with the TCV aircraft to provide a realistic environment to study the effectiveness of on board aircraft traffic situation displays. This display will have the positions of surrounding air traffic relative to one's own position, together with other data such as flight number, altitude and velocity, viewable by the pilot on a cockpit monitor. This information could be used in various ways depending on the particular ATC strategy - aircraft interaction considered. For instance, it may prove useful in aiding the acceptance of reduced parallel runway separation for independent landings, or provide needed information on surrounding traffic with a data link replacing voice to relay ATC instructions. Figure 14 shows an example of a planned display for the TCV aircraft.

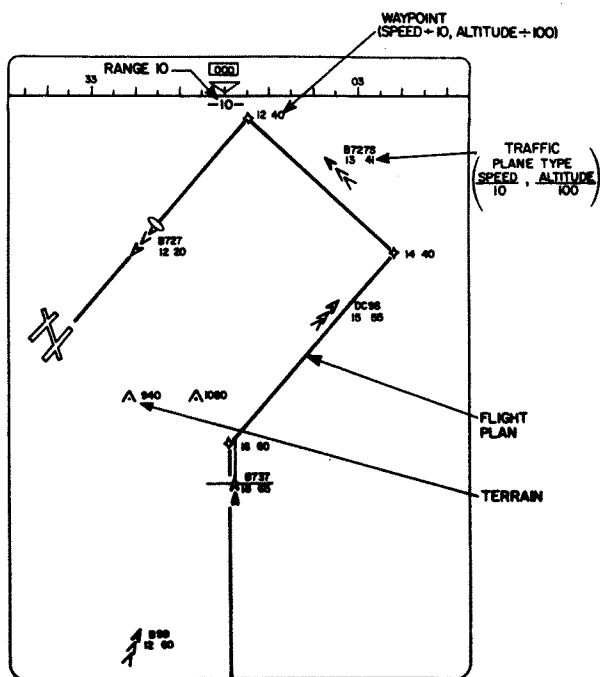


Figure 14. An Example of a Traffic Situation Display Which Will Be Used in Future Studies.

The simulator will also serve as a tool to study the feasibility of advanced terminal area air traffic control systems employing forms of closed loop control to obtain more precise time of delivery accuracy. This type of system working together with algorithms to optimally schedule aircraft have the potential of significantly increasing terminal capacity. Various strategic and tactical techniques of flight path specification have been advanced as candidates for these advanced ATC systems. In tightening the control process to obtain levels of performance desired, the effect of flight dynamics of the aircraft and also the response provided by advanced airborne flight control and display systems must be considered. The air traffic simulation can be programmed to provide the scenarios which will enable an evaluation of the sources and the effects of errors when various proposed advanced ATC systems interact with advanced airborne systems.

References

1. Britt, C. L., et al: "Potential Reduction of Aircraft Fuel Consumption in the Terminal Area with Advanced Instrumentation and Procedures" presented at the National Aerospace and Electronics Conference (NAECON), Dayton, Ohio, May 1976.
2. Department of Transportation, Federal Aviation Administration: "An Overview of the FAA Engineering and Development Programs," Report No. FAA-EM-73-2, March 1973.

3. Department of Transportation and National Aeronautics and Space Administration: "Joint DOT-NASA Civil Aviation Research and Development Programs," DOT TST-10-5, NASA SP-266, March 1971.
4. Reeder, J. P., Taylor, R. T., and Walsh, T. M.: "New Design and Operating Techniques and Requirements for Improved Aircraft Terminal Area Operations," NASA TM X-72006, December 1974.
5. Aviation Week and Space Technology: "Microwave Landing System Demonstrated," pp. 96-99, June 14, 1976
6. Gados, R. G., Mohleji, S. C., and Gabrieli, H.: "A Proposed Metering and Spacing System for Denver," MITRE Technical Report MTR-6865, March 1975.