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A COMMUNICATIONS SYSTEM FOR THE TERMINAL AREA EFFECTIVENESS PROGRAM

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16. Abstract

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A COMMUNICATIONS SYSTEM FOR THE TERMINAL AREA EFFECTIVENESS PROGRAM

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SUMMARY

The Terminal Area Effectiveness Program has the broad scope of evaluating Air Traffic Control (ATC) procedures. One area of interest is pilot acceptance of complex ATC procedures. This report describes a means to measure this acceptance by studying the impact on pilots of meeting the ATC procedural requirements: a system which merges a piloted aircraft simulation performed at the National Aeronautics and Space Administration's Ames Research Center and an ATC environment simulation conducted at the Federal Aviation Administration's National Aviation Facilities Experimental Center. The concept-testing system configuration, its operation, and its performance are discussed in this report.

INTRODUCTION

The National Aeronautics and Space Administration's Ames Research Center (NASA ARC, located at Moffett Field, CA) is engaged in manned flight simulations using digital computer systems, high-fidelity motion simulators, visual scene simulators, and other research tools. The simulation systems operate in a real-time, closed-loop manner with the computer responding to pilot control inputs, solving the mathematical models that comprise the aircraft model, and simulating the state of the aircraft through the use of motion cues, a control force-feel system, flight instrumentation displays, sound cues, and visual cues. The pilot, located in a mock-up model of the aircraft cockpit, observes the aircraft state and "flies" the aircraft by actuation of flight controls which are representative of the simulated aircraft.

The ATC simulations conducted at the Federal Aviation Administration's National Aviation Facilities Experimental Center (FAA NAFEC, located near Atlantic City, NJ) utilize digital computer systems, data terminals, and large computer-controlled cathode ray tube (CRT) display units. The ATC simulations operate in a real-time mode with the computer calculating the arrival times, heading, altitude, and other pertinent information of the aircraft in accordance with a programmed algorithm and displaying the information along with ground reference points and/or ATC check-points on an ATC radar display unit (a computer-driven CRT). The simulations are managed by controllers who are stationed at the ATC displays and monitor the aircraft in the ATC environment. If a controller determines an aircraft course change is necessary, he communicates the new course via a voice link to an operator who enters the course data into the simulation computer via a data terminal.

The objective of this communications system is to make the manned simulated aircraft of ARC appear identical to the locally-generated aircraft in the NAFEC simulation. With the system's voice link, the ATC controller can make requests such as course changes, radio frequency changes, or position reports which instructs the ARC simulator pilot to maneuver or alter the "aircraft." Therefore, measurements can be described to calculate the workload on pilots in meeting the ATC procedures.

The communications system consists of the following connections between the ARC and NAFEC sites:

(1) A full-duplex serial data link between the simulation computers,

(2) A pilot-to-controller voice link,

(3) A telephone line between computer operators, and

(4) Back-up circuits for connections (1) and (2).

These connections provide: the computer-to-computer link to transfer position data and other aircraft information between the simulation computers (1), the necessary voice links (2), and a separate, status-reporting link between the simulation participants (3). The connections, their components, and their operational procedures are discussed in this report.

SYSTEM OBJECTIVES AND REQUIREMENTS

The objective of this system is to place the ARC simulated aircraft into the NAFEC simulated ATC environment. The Ames aircraft is to appear identical to the locally-generated aircraft and is to receive the ATC controller's voice directives in the same fashion as the other aircraft.

A major system requirement dictates that the ATC display symbol representing the Ames aircraft is to move in a continuous manner, not in unrealistic discrete jumps on the NAFEC controller's display unit. Discrete jumps can be caused by receiving incorrect aircraft position data or by not receiving the aircraft data fast enough to correctly update the CRT display. Therefore, the system must be designed to minimize or eliminate these occurrences.

Another requirement, which tends to increase the necessary transmission rate, is the need to display multiple ARC simulated aircraft on the NAFEC ATC displays. This feature allows the conduction of more realistic simulations, but results in transferring more data between sites because each aircraft has its own position data.

The facilities of ARC contain several real-time computer systems, simulator cabs, visual scene generators, and other simulation equipment. These components are merged into combinations which best meet the specific requirements of the research aircraft being simulated. In a similar manner the NAFEC facilities contain several simulation stations, each with unique capabilities to meet a particular experiment's requirements. It is desirable that each site be able to independently form any simulation and still retain the capability of merging. This objective has obvious far-reaching consequences as it is nearly impossible to merge every possible simulation system at each site. Therefore, this requirement is relaxed and only selected simulation facilities (described below) at each site can be merged. This still creates special-system's demands. For example, the voice communications (for the pilot-to-controller voice link) must be switchable between simulation cabs at ARC and between ATC stations at NAFEC, and digital computer input ports must be available on various real-time computer systems.

An obvious objective is to design a reliable system. This requirement particularly applies to specific components which could develop frequent problems. For example, the primary transcontinental circuits may become unavailable due to a higher priority application, to weather interference, or to some other failure. Also, since some components such as the modems are susceptible to occasional hardware failures, it is important that the system remains operational, despite minor component failures.

SYSTEM CONFIGURATION

A simple block diagram of the overall system is shown in figure 1. Notice that there are three types of links connecting to two sites. The top link, a voice connection, allows a computer operator at either site to talk with the operator at the other site (and, in fact, with other persons at his site). This connection is a switch network telephone circuit using the Federal Telephone System (FTS). Speaker phones are attached at each end so that hands-off communications can occur. The purpose of this connection is to allow communications independent of the simulation, that is, a "hot line" circuit between sites.

The second link shown in figure 1 is for data transmission. This connection is a data quality circuit for full-duplex, serial data transmissions between simulations. On this circuit, the aircraft position data is transferred between sites. Even though the function of the data link is primarily simplex (position data originates at ARC and is transmitted to NAFEC for display), a full-duplex data link is supplied. The three reasons for this are: (1) the return circuit can be used for error detection, reliability tests, and fault isolation; (2) the ARC simulated aircraft may need the position data of other aircraft in its vicinity such as for radar proximity device simulation, and only the NAFEC computer can supply this information; and (3) the standard available transcontinental circuits are full-duplex. The primary circuit used for this data link is a NASA Communications System (NASCOM), data quality, leased-line telephone circuit. The data communications devices, shown in figure 1 as the terminations of the data link, consist of computer input ports, data switching equipment, and modems and are described later in this report.

The bottom voice connection shown in figure 1 is the pilot-to-controller communications link. This circuit is attached to each site's intercom system so that the voice link can be routed to the proper simulation cab at ARC and to the proper ATC station at NAFEC. Like the data link, a NASCOM circuit is used as the primary connection.

For system reliability, back-up connections are included for the data link and the pilot-to-controller voice link. The data link has two possible back-ups: the NASCOM pilot-to-controller voice circuit; or a direct distance dial (DDD), switch network line from the commercial telephone company. The voice link has one possible back-up, a FTS circuit. If the data link uses the only available NASCOM circuit, the voice link must use the FTS circuit.

One of the system objectives listed is to allow each site to develop any simulation configuration and still retain the capability of merging. The primary limiting factor in meeting this objective is deciding which digital computer to select as the simulation digital computer. At NAFEC a Xerox SIGMA 5 computer is available for ATC simulations. At ARC there are several possibilities including Xerox SIGMA 7 or SIGMA 8 or SIGMA 9 computers, or an Electronic Associates, Inc. (EAI) 8400 computer. In the present configuration it was decided to use the SIGMA 7 computer because (1) the digital input port for the data link is easiest to design for the SIGMA computers, (2) any hardware designs for the SIGMA 7 computer are easily adapted to the SIGMA 8 or SIGMA 9 computers, (3) most of the ARC simulations operate or can be easily converted to operate on a SIGMA computer, and (4) the SIGMA 7 computer has the maximum amount of computer time available for the TAE program. A description of the Xerox SIGMA computers is contained in references 1 and 2.

The selection of the SIGMA computers as the digital simulation computers defines the requirements necessary for the data link. In addition, since the pilot-to-controller voice link enters each site's intercom system, this communications path can be made from any ARC simulator cab to any NAFEC ATC station. Thus, any simulation facility which can be attached to the SIGMA 7 computer at ARC or the SIGMA 5 computer at NAFEC can be considered as a component in the total system.

Data Link

The data link consists of the components shown in figure 2. A description of each of these components follows.

The Serial Communications Interface (SCI, described in ref. 3), shown below the SIGMA 7 computer, is a device which performs the parallel/serial translations on the data transmitted over the data link. In this application, eight-bit parallel data quantities are passed between the SIGMA 7 processor and the SCI in an interrupt-driven mode using a programmed input/output interface, the SIGMA's Direct Input/Output system (refs. 1 and 2). The SCI serially transfers the eight-bit quantities to and from the modem shown in figure 2 in an asynchronous format (transmission formats are described in ref. 4), but the transmission clocks are generated by the modems. This mode of operation is called an isonchronous transmission format. An advantage of the isonchronous format is that the SCI can use the simple control logic necessary for asynchronous transmissions and still obtain the higher reliability of synchronous transmissions by using synchronous modems.

The next component in the data link is the synchronous modem. A modem (an acronym for modulator/demodular) is a device which converts between signals that use voltages to define the logic levels and signals that use frequencies to define the logic levels. The logic level frequencies are compatible with the bandwidth of telephone circuits (NASCOM or DDD). In addition, various signals such as data and clocks can be defined with different frequencies and transmitted over one telephone circuit. The modems used in this program are synchronous modems; they generate the clocks which dictate to the transmitter when to place data on the line and inform the receiver when to sample the incoming data. The modems used for this application are Vadic Corporation 3410 series modems which operate at a standard rate of 1200 bits per second; they are described further in reference 5.

The communication signals between the SCI and the synchronous modem conform to the Electronics Industries Association (EIA) standard RS232-C defined in reference 6. This standard is widely used by data terminal equipment (such as computer data terminals, the SCI, or other computer serial input/output ports) and by data communications equipment (such as modems).

The synchronous modems shown in figure 2 are designed to transmit and receive on a two-wire, leased-line circuit, thus a two-wire circuit connects the modem to the ARC Central Switching Facility (a distance of approximately 1 km). At the ARC Central Switching Facility, the two-wire circuit is bridged to a four-wire circuit to be compatible with the NASCOM network. The four-wire circuit is then patched into the NASCOM network.

The NASCOM network consists of four-wire, leased-line telephone circuits which run between NASA installations. The NASCOM data circuits are optimized to operate at the standard 4800 bits per second rate but can function well at the slower 1200 bits per second speed used by these modems. The particular route chosen to connect ARC and NAFEC is:

(1) a NASCOM circuit from ARC to the Jet Propulsion Lab (JPL) in Pasadena, California;

(2) a NASCOM circuit from JPL to the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland; and

(3) a specially installed leased-line circuit from GSFC to NAFEC.

The circuits are scheduled on a weekly basis, at least 1 week before each intended use. Because priority conflicts can arise and the circuits may become unavailable, backups to the circuits are provided as described below.

At the NAFEC site, the four-wire circuit is converted back into a two-wire circuit and connected to the NAFEC modem. This synchronous modem is identical to the ARC modem.

The NASA-Ames Interface, shown near the NAFEC SIGMA 5 computer in figure 2, is a device designed specifically for this program and performs functions analogous to the operations of the SCI. However, instead of using a program-initiated, eight-bit data path as the SCI does, this device stores thirty (30) eight-bit quantities in a buffer and transfers this buffer to or from the SIGMA 5 computer. The transfer media between the SIGMA 5 computer and the NASA-Ames Interface is Xerox's automatic data channel, the Input/Output Processor (refs. 1 and 2). Data is transferred directly to and from SIGMA 5 memory and bypasses the SIGMA 5 central processing unit. This device interfaces to the synchronous modem using EIA RS232-C Standard signals and transmits and receives in the isonchronous mode.

It was stated earlier that various back-up systems are provided for the data link. The data back-ups must be invoked only if there are no operative NASCOM circuits available. If at least one NASCOM circuit is available, the data link is as shown in figure 2. The data link has priority over the voice link because the NASCOM circuits are better data-quality circuits than DDD circuits.

The data backup system involves replacing the leased-line synchronous modem shown in figure 2 with a switch network (DDD telephone) synchronous modems. A switch network modem is constantly powered-up at each installation so that if the need arises, it is easily switched into the data path and a dial-up telephone link can be made.

The data link just described is extremely modular in design to facilitate reliability and upgrading. Features which allow upgrading include (1) using the EIA RS232-C Standard for signals between the computer interfaces and the modems so that a different, faster modem (including a different manufacturer's modem) can be fitted easily into the system; (2) using four-wire circuits where two-wire circuits are shown in figure 2 to allow faster four-wire modems to be installed if desired (obviously, if four-wire modems are used, the bridge networks are not needed); and (3) the NASCOM network has multiple circuits which can be selectively patched into this system to provide faster or better-quality circuits.

Many of the components in the data link have duplicates to ensure system reliability. If one of the components fails, a quick swap can be made to remedy the problem; the SCI can be replaced, for example. Each modem shown in figure 2 is actually two modems, an active modem and a powered-on backup, which are easily swapped. Finally, certain links in the NASCOM path from ARC to NAFEC can be selected from a large number of possible circuits.

Voice Link

The voice link is shown in figure 3. At ARC each simulator cab has an intercom patch station for entry into the intercom system. The dial-less telephone shown in figure 3 also has an intercom patch station; therefore, any simulator cab and the telephone can be switched to the same intercom channel, and persons at each location can talk to each other. A four-wire circuit connects the telephone to the ARC Central Switching Facility where the circuit is patched into the NASCOM circuit.

The NASCOM voice circuit takes the same route to NAFEC as does the data link, that is, ARC to JPL, JPL to GSFC, and GSFC to NAFEC.

At NAFEC, the NASCOM circuit enters a switch specially built for this project which demultiplexes the one voice circuit onto one of six intercom voice circuits and onto the selected ARC display station. This switch unit is a set of relays which are controlled by the NASA-Ames Interface device shown in figure 2. The control proceeds as follows: ARC transmits via the data link a one of six voice select code, a six-bit quantity with only one of the six bits in the logic one state. NAFEC receives the data and flags it as the voice select code. The six bits are transferred to the switch unit where the selected relay is activated and a voice channel is selected.

The purpose of this switch unit is to simulate radio frequency changes. The operation could proceed as follows: the ATC controller, using the voice link, instructs the pilot to change his radio frequency. The pilot manually changes the radio frequency, and the ARC simulation computer determines the new radio frequency setting. This new switch setting is transmitted to NAFEC via the data link as a new voice select code. The NASA-Ames Interface inputs the new voice select code and transfers the information to the switch unit. The new voice select code will select a new ATC station for the pilot-to-controller voice link. Hence, a radio frequency change has occurred and the pilot is talking to a new controller.

Because the NASCOM circuit shown in figure 3 may be usurped by the data link, a backup voice link is necessary. This link, provided by a FTS circuit, is always available because a telephone set is installed at each site. At ARC, this FTS telephone has a patch cord input into the intercom system; at NAFEC, the FTS telephone connects to the one-of-six voice channel select switch. The backup circuit is activated by ARC personnel dialing NAFEC. Once an acceptable circuit is achieved (if a circuit is unacceptable, merely hang up and dial again until one is acceptable), the FTS circuits are patched into the intercom systems and the backup circuit is operational.

SYSTEM OPERATION

This section describes the operations of the three links which permit the merging of the two simulations.

The "hot line" voice link is a status reporting link for the simulation participants, experimenters, and operators. For instance, this connection is activated (personnel at one site merely dial the other site on the FTS line) before the simulation begins and remains active throughout the simulation's operation. Uses include (1) aiding the activation of the NASCOM data and pilot-to-controller voice links, (2) reporting equipment failures (e.g., a computer crash), and (3) reporting results.

The pilot-to-controller operation is straightforward. Once the voice circuit from the controller at the ATC display station to the pilot in the simulator cab is operational, communications proceed in a manner identical to the real-world pilot-to-controller communications. The simulation of pilot radio frequency changes was described earlier.

The operation of the final link, the data path, is obviously the most complex. On this link, position data, aircraft identification, synchronization characters (to determine the validity of the data), and other information must be transmitted. The data must be transferred at a rate sufficient to smoothly update the ATC display. The time constraint to be met is the ATC display update rate (one update every 4 sec).

The method of operation for the data link is continuous transmission of pertinent data. Each site blocks the pertinent data in a buffer of thirty (30) eight-bit quantities, transmits the buffer to the other site, and when the transmission is complete, a new buffer is formed with current data and a new transmission is initiated. The format of these buffers is contained in Appendices A and B. Operating at the modem rate of 1200 bits per second, the system transmits approximately three buffers from each site per second.

This transmission procedure delivers twelve blocks of aircraft positional data to NAFEC every four seconds. If no errors occur, the system could display twelve different aircraft originating at ARC. However, errors do occur and redundant data is needed. Current experiments transfer data on only one ARC aircraft to NAFEC; consequently, 11 of the 12 blocks transferred contain redundant data.

The present system is designed to allow the merging of up to three ARC aircraft into the NAFEC ATC simulation; a four-to-one ratio of redundant data is desired. The number three was selected because if three aircraft simulations were operating simultaneously at ARC, a large percentage of the ARC simulation facilities would be utilized, limiting the usefulness of merging additional aircraft. However, if more than three simulations are to be merged, 4800 baud rate modems could replace the present 1200 baud rate modems and allow up to 12 ARC aircraft to be merged into a NAFEC ATC simulation.

The over-transmit strategy described above reduces the changes of not receiving enough data to update correctly the ATC display and allows incorrect data to be ignored. If an error is detected in a received block, the entire block is thrown out and the system waits for the next block. The error detection operation includes:

(1) a parity check on each eight-bit quantity,

(2) a framing error check which occurs if the transmission line "hangs up" such as when caused by a "circuit hit" (i.e., the circuit momentarily goes dead),

(3) a synchronization character match check, in which the received synchronization characters must match with the known correct values (see appendices A and B for the location of the three synchronization characters), and

(4) a counter value (locations 23 and 24 of the transmit buffers) check. This location is incremented on each transmission by the transmitting computer so that each site can verify its accuracy.

The reliability of this transmission scheme is described in the Systems Performance section.

A great deal of flexibility is built into the data transmission system. As described above, the bandwidth of the data system can be increased by changing the modems. The system is full-duplex allowing additional features such as error detection and possible future simulation enhancements. Also, the buffers transferred between sites include several blank locations (see Appendices A and B) for future expansion.

SYSTEM PERFORMANCE

This section describes the test configuration of the system. An ARC aircraft simulation was merged into the NAFEC simulation and displayed on an ATC display unit. The results and comments on this experiment follow.

In these feasibility studies, the system was configured as shown in figure 4. The flight simulation was executed on the Systems Engineering Laboratories (SEL) 840 real-time computer system (ref. 7). This particular simulation involved short-take-off and land (STOL) aircraft equipped with four-dimensional area navigation (4D RNAV); a description of this simulation is contained in reference 8.

The operation of the data link was as follows: The SIGMA 7 computer requested aircraft position data from the SEL 840 simulation each time it was ready to transmit a new buffer to NAFEC. The SEL 840 computer responded to this request but otherwise ran independent of the ATC simulation. The SIGMA 7 computer compiled the buffer as described in Appendix A; to simplify the operation some data was left blank, including V_a, V_i, and the transponder code. In addition, the voice select control was fixed at one value (no radio frequency change simulation). The SIGMA 7 computer ensured that each buffer had a unique counter value (locations 23 and 24 of the buffer) and then transmitted the buffer. The NAFEC SIGMA 5 computer received the data, inspected the values it needed (X, Y, and Z positional data), and returned the buffer in the format shown in Appendix B if no errors were detected. (If an error was detected, the SIGMA 5 computer would ignore the data and wait for the next buffer.) The ARC SIGMA 7 computer inspected the received blocks for errors and compiled an error log.

The reliability of the data link was excellent; greater than 95% of the blocks transmitted were received back by the ARC SIGMA 7 computer with no detectable errors. A buffer received by the ARC SIGMA 7 computer was considered in error if (1) the counter value was not sequential, (2) at least one synchronization character did not match, or (3) if a hardware error (parity or framing error) was detected. The cause of nearly all incorrect buffers was "circuit hits," that is, moments when the NASCOM circuit went dead. These hits are unavoidable and the specified error rates of the circuits (one bit in error for every million bits transmitted) account for the incorrect buffers.

During the 6 months of development, checkout, and testing of this system, only NASCOM data circuits were used during experiments. The only component failure was a leased-line modem which was replaced by its backup, repaired by the manufacturer, and then placed back online.

The voice link used for these experiments utilized the FTS circuit rather than the NASCOM circuits because the FTS circuits were better matched to enter each site's intercom system and therefore produced louder audio levels (loud enough for pilot-to-controller voice communications for these experiments). However, future work must be done to achieve a more usable voice link by better matching impedances between the NASCOM circuit and intercom systems and possibly by installing voice amplifiers on the circuit.

The "hot line" link was an invaluable aid in the system's operation. Activated first each day to ensure that all components of the system were ready for operation, this link remained active throughout the experiment for reporting status and results.

The most important evaluation criteria was the observation that the ARC aircraft performed similarly to aircraft of local origin when displayed on the NAFEC ATC controller's display. The ARC aircraft symbol moved smoothly about on the ATC display, indicating that reliable data was received at a sufficient rate by the NAFEC computer.

An experiment to test the system's accuracy included instructing the ARC pilot to fly a particular 4D RNAV route (see ref. 8) and to arrive at a designed wait point at a certain time. These wait points were displayed at both the ARC simulator cab and the ATC controller's display, and the clocks at each site were synchronized. The ATC controller could verify correct position data since he knew when the ARC aircraft was to be at a designed point on his ATC display. This experiment was successful each time it was attempted; thus, the voice link was tested (when the NAFEC ATC controller dictated the particular flight path to the ARC pilot) and the data link operation was verified (by visual inspection of the ATC display).

CONCLUSIONS

The communications system described in this report is designed for use in the Terminal Area Effectiveness program and provides the capabilities of merging a complex aircraft simulation into an Air Traffic Control simulation. With this system, pilot workload, caused by elaborate ATC procedures, and ATC controller workload, due to such things as pilot errors or equipment failures while operating in an ATC or Terminal Control Area environment, can be determined. In addition, safety considerations of future ATC procedures and other ATC operational research areas can be studied using the realistic simulation provided by this system.

The communications system consists of a pilot-to-controller voice link for radio communications and a data link to transfer aircraft position information. In the preliminary experiments conducted, an ARC simulated aircraft was successfully merged into the NAFEC ATC simulation and "flown" through the simulated terminal control area. The ARC pilot was able to respond to voice directives from the NAFEC ATC controller and maneuver his aircraft in compliance with ATC commands. The ATC controller was able to verify the operation visually by instructing the ARC pilot to fly a particular route and observing the ARC aircraft symbol following the selected flight path on the ATC display unit.

APPENDIX A

DATA BUFFER

ARC TRANSMIT - NAFEC RECEIVE

Character	Contents	Description
1	Synch	Synchronization character 1.
2	Synch	Synchronization character 2.
3	X	Most significant 8 bits (0-7) of the X position coordinate. X is a 32-bit floating-point quantity and is referenced from the radar position. X is measured in feet.
4	X	Next most significant 8 bits (8-15) of X.
5	X	Next most significant 8 bits (16-23) of X.
6	X	Least significant 8 bits (24-31) of X.
7	Y	Most significant 8 bits (0-7) of the Y position coordinate. Y is a 32-bit floating point quantity and is referenced from the radar position. Y is measured in feet.
8	Y	Next most significant 8 bits (8-15) of Y.
9	Y	Next most significant 8 bits (16-23) of Y.
10	Y	Least significant 8 bits (24-31) of Y.
11	Z	Most significant 8 bits (0-7) of the Z position coordinate. Z is a 32-bit floating point quantity and is referenced from the radar position. Z is measured in feet.
12	Z	Next most significant 8 bits (8-15) of Z.
13	Z	Next most significant 8 bits (16-23) of Z.
14	Z	Least significant 8 bits (24-31) of Z.

Character	Contents	Description
15	h	High order 8 bits (0-7) of h. h is a 16-bit integer and represents the barometric altitude of the aircraft. h is measured in feet and is scaled 2 to 1; therefore, h(max) $\simeq$64,000 ft.
16	h	Low order 8 bits (8-15) of h.
17	Va	High order 8 bits (0-7) of Va. Va is a 16-bit integer and represents the aircraft's ground speed. Va is measured in knots.
18	Va	Low order 8 bits (8-15) of Va.
19	Vi	High order 8 bits (0-7) of Vi. Vi is a 16-bit integer and represents the aircraft's indicated airspeed. Vi is measured in knots.
20	Vi	Low order 8 bits (8-15) of Vi.
21		Blank.
22		Blank.
23	Counter	High order bits (0-7) of a buffer counter value which is incremented on each transmission. The counter is a 16-bit integer quantity.
24	Counter	Low order bits (8-15) of the counter.
25	Transponder	Transponder status: bit 0: 1 if transponder is used in the simulation, : 0 otherwise. bit 1: 1 if the transponder is on, : 0 if the transponder is off. bit 2: 1 if the transponder is using altitude encoding, : 0 if the transponder is not using altitude encoding. bit 3: 1 if the squak button is on, : 0 if the squak button is off. The squak button remains on for 20 sec each time it is activated. bit 4-7: high order 4 bits of the 12-bit transponder code.

Character	Contents	Description
26	Transponder	Low order 8 bits of the 12-bit transponder code. The transponder code can be used for multiple aircraft identification.
27	Identifier	Identifies the ARC simulator from which this data originates. Represented by a one of eight code.
28	Voice Control	Least significant 6 bits form a one of six code to select the NAFEC intercom network for voice communications.
29	Freeze	Freeze mode: A status identification that the simulation has halted.
30	Synch	End of message synchronization character (EOM).

APPENDIX B

DATA BUFFER

NAFEC TRANSMIT - ARC RECEIVE

Character	Contents	Description
1	Synch	Synchronization character 1.
2	Synch	Synchronization character 2.
3	Rho	Most significant 8 bits (0-7) of Rho. Rho is a 32-bit floating point value and represents the ATC Radar Range. Rho is measured in feet.
4	Rho	Next most significant 8 bits (8-15) of Rho.
5	Rho	Next most significant 8 bits (16-23) of Rho.
6	Rho	Least significant 8 bits (24-31) of Rho.
7	Time	Most significant 8 bits (0-7) of the Problem Time value. Problem Time is a 32-bit number and is measured in seconds.
8	Time	Next most significant 8 bits (8-15) of Problem Time.
9	Time	Next most significant 8 bits (16-23) of Problem Time.
10	Time	Least significant 8 bits (24-31) of Problem Time.
11	Theta	High order 8 bits (0-7) of Theta. Theta ia a 16-bit integer and represents the ATC Azimuth Angle. Theta is measured in degrees.
12	Theta	Low order 8 bits (8-15) of Theta.
13		Blank.
14		Blank.
15	h	High order 8 bits (0-7) of h. h is a 16-bit integer and represents the barometric altitude of the aircraft. h is measured in feet and is scaled 2 to 1. h(max) $\simeq$64,000 ft.

Character	Contents	Description
16	h	Low order 8 bits (8-15) of h.
17		Blank.
18		Blank.
19		Blank.
20		Blank.
21		Blank.
22		Blank.
23	Counter	High order bits (0-7) of a buffer counter value which is incremented on each transmission. The counter is a 16-bit integer quantity.
24	Counter	Low order bits (8-15) of the counter.
25	Transponder	Transponder status: bit 0: 1 if the transponder is used in the simulation, : 0 otherwise. bit 1: 1 if the transponder is on, : 0 if the transponder is off. bit 2: 1 if the transponder is using altitude encoding, : 0 if the transponder is not using altitude encoding. bit 3: 1 if the squak button is on, : 0 if the squak button is off. The squak button remains on for 20 sec each time it is activated. bit 4-7: high order 4 bits of the 12-bit transponder code.
26	Transponder	Low order 8 bits of the 12-bit transponder code.
27	Identifier	Identifies which ARC simulator this data represents. Represented by a one of eight code.

Character	Contents	Description
28	Voice Control	Re-transmission of the current voice control value in the last six bits of this character. Represented by a one of six code.
29	Freeze	Freeze mode: A status indication that the simulation has halted.
30	Synch	End of message synchronization character (EOM).

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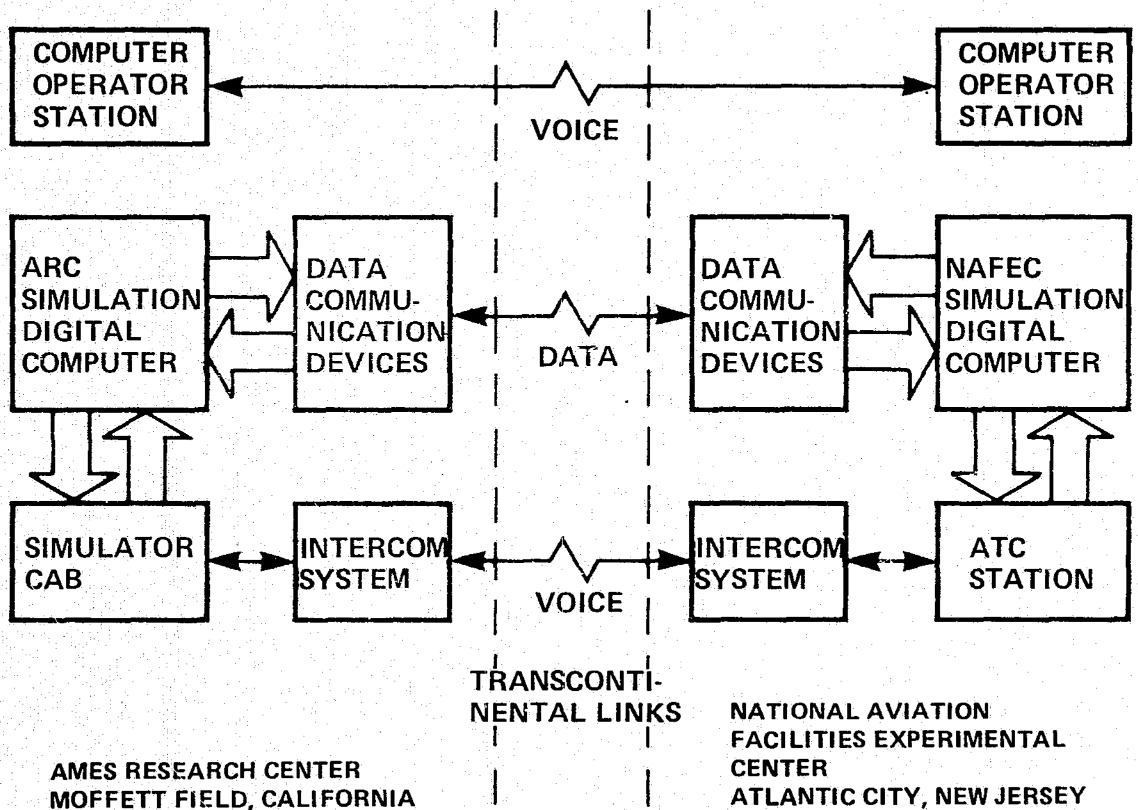

Figure 1.- Block diagram.

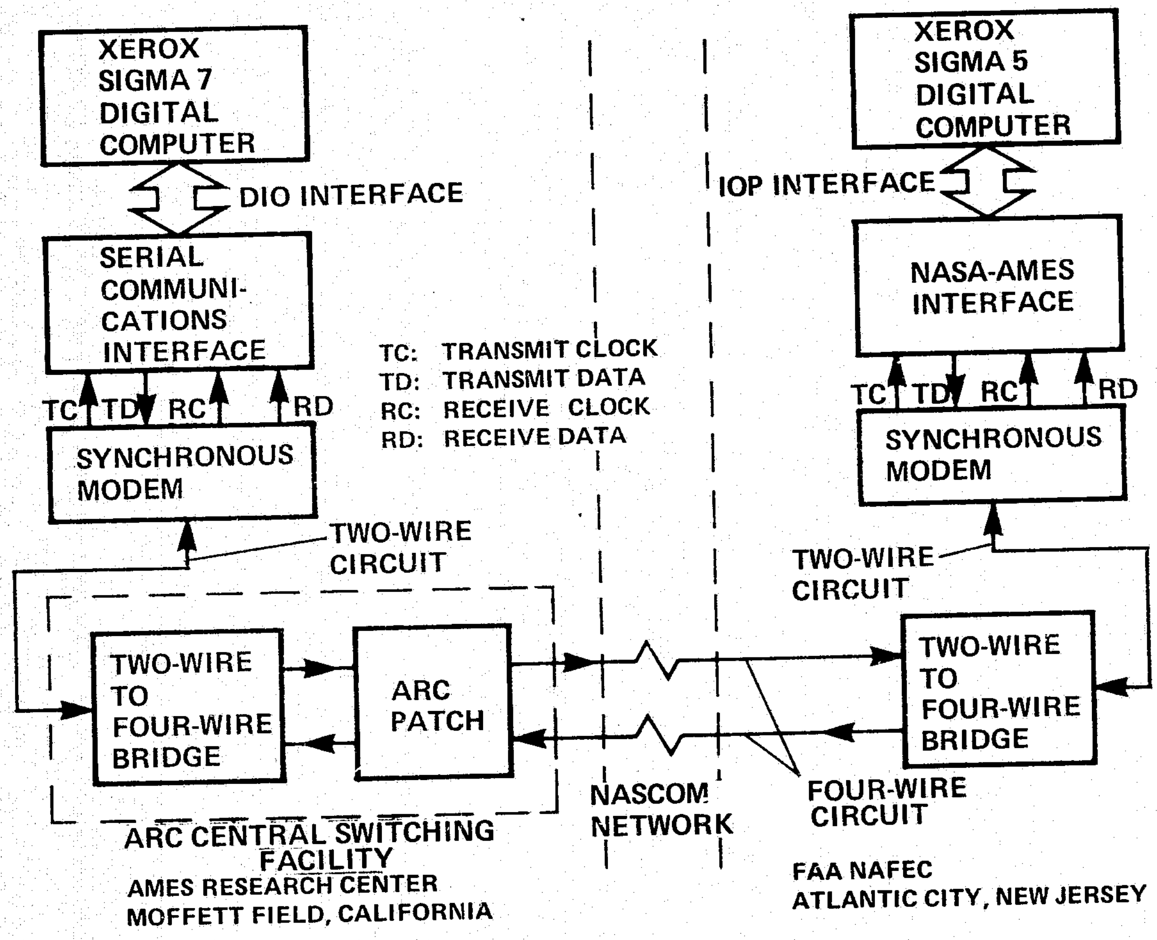

Figure 2.- Data link.

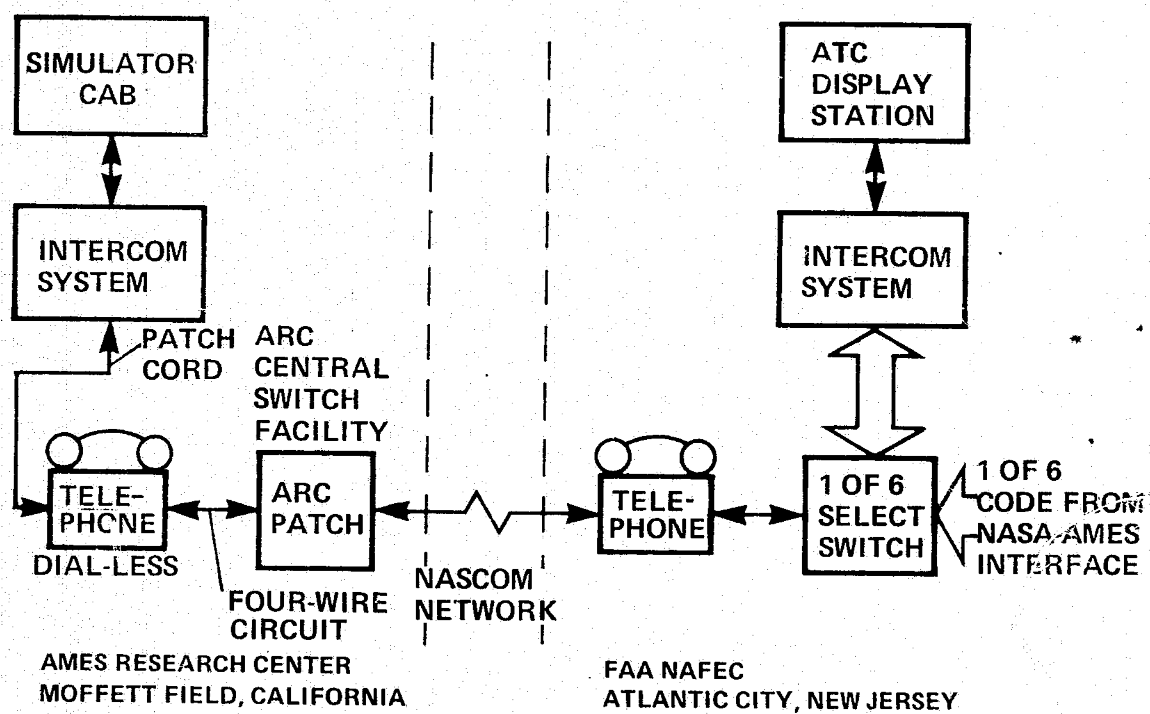

Figure 3.- Voice link.

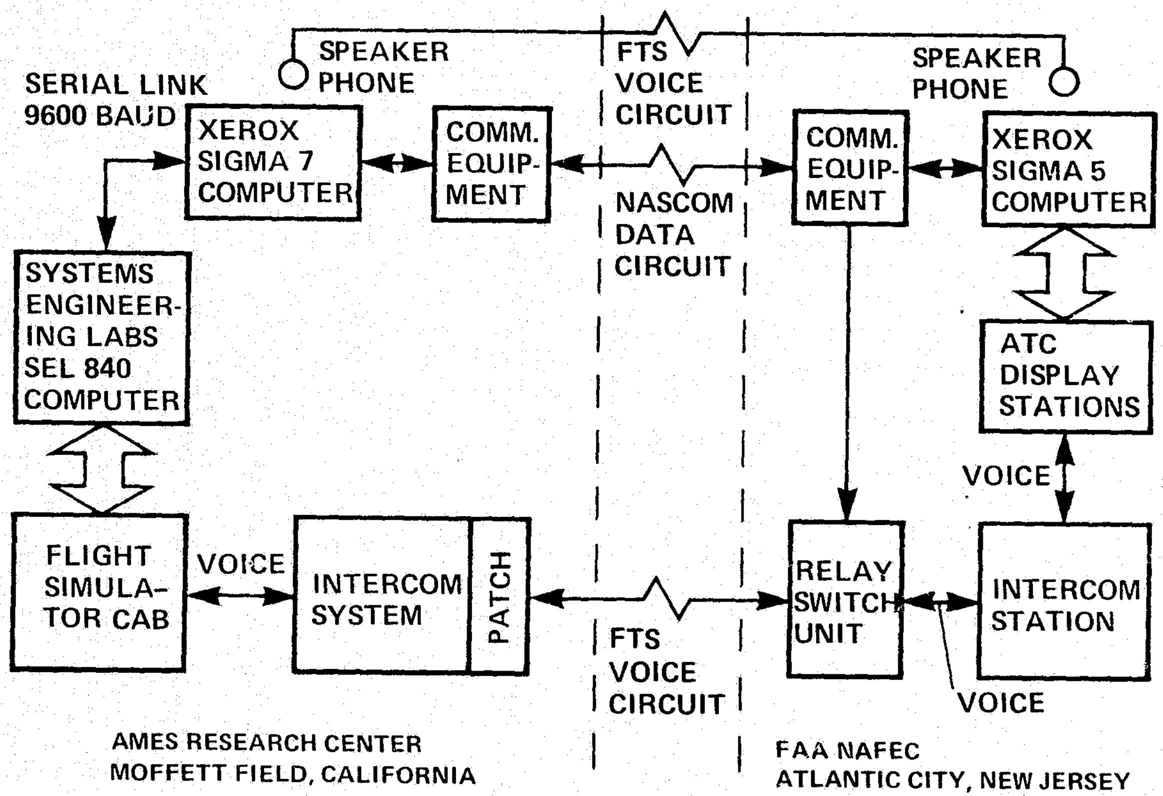

Figure 4.- Feasibility study configuration.