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An Airborne Traffic Situation Display System

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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ABSTRACT

An airborne traffic situation display system which could be used as an adjunct to the evolving National Airspace System/Automatic Radar Control Terminal System (NAS/ARTS) is described. In the proposed system, a contemporary realization of an old concept, the NAS/ARTS data are broadcast. A small digital computer in an aircraft then selects from the message stream the data on its own aircraft, nearby aircraft, and a local map. These data, plus aircraft heading data from a directional gyro, are used to generate a situation display that can be aircraft-centered and heading-oriented.

Accepted for the Air Force
Joseph R. Waterman, Lt. Col., USAF
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I. INTRODUCTION

Three interrelated problems associated with the evolving air traffic control (ATC) system are controller workload, terminal area capacity, and safety. An airborne traffic situation display system is proposed as an aid in alleviating some of these problems by providing pilots with more information on their environment and by improving the coupling between the pilot and the ground-based controller-computer elements of the ATC system. The proposed add-on feature to the system presently planned by the FAA would provide pilots with a display of nearby traffic and pertinent map information such as air routes, restricted area boundaries, position of navigational aids and, in a fully evolved system, hazardous weather. Figure 1 shows a typical display picture in the terminal area. The display in an aircraft would be on a CRT with the image usually centered on that aircraft and oriented with the aircraft heading up; other display options could be provided. The situation display equipment could be integrated with other airborne equipment performing functions such as ATC data link, area navigation, collision avoidance, and pilot warning indication.

Current FAA plans for upgrading the ATC system include the introduction of a data link for ATC commands and the automation of additional functions presently performed by controllers. The former will deprive pilots of the traffic information they presently derive from the party-line voice communication link. The latter will require that accurate, reliable surveillance data be available in the ground computers. The proposed airborne traffic situation display system broadcasts these surveillance data to aircraft in a format that allows equipment in an aircraft to select and display pertinent traffic data in the cockpit.

As improvements to the surveillance and control components of the centralized ATC system evolve, airborne navigation and control equipment will also improve so that coupled, four-dimensional area navigation is practical. Ultimately all these improvements may make it possible for the roles of both

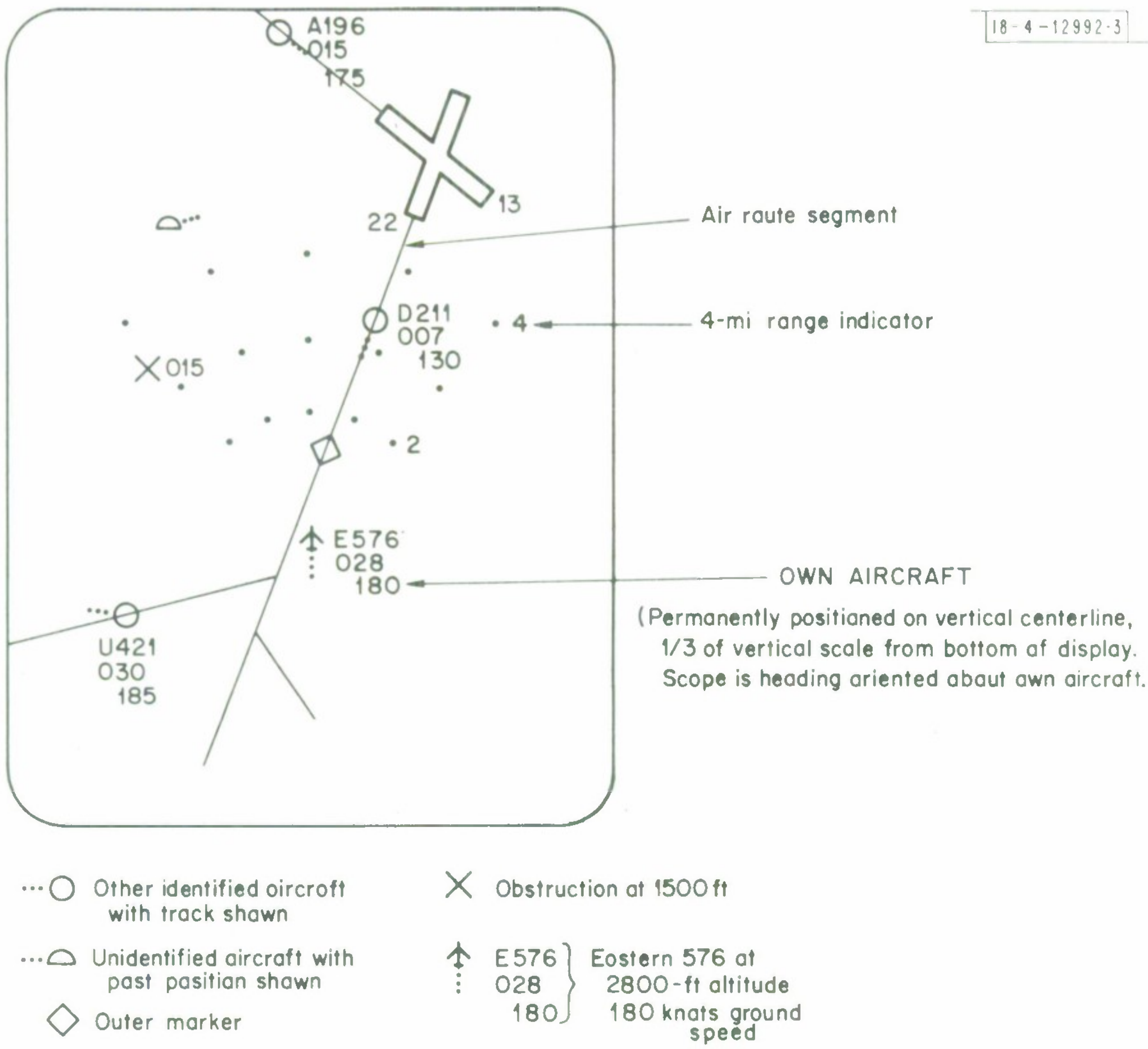

Fig. 1. Typical cockpit presentation (area on scope = 9 miles by 12 miles).

pilots and controllers to be changed to those of monitors who revert back to their present roles in the ATC process only in the event of an equipment malfunction, human error, or for training purposes. For this mode of operation to function safely in the event of an equipment malfunction or human error, the pilots and controllers will need to be supplied continually with information on the current situation. The proposed situation display system would accomplish this objective in the cockpit. Also, it would continually provide flight crews with assurance that the ATC system was functioning properly since they could observe the relative positions and courses of nearby traffic as well as the congruency between air derived position data and ground-based surveillance data on their aircraft. This feature would be extremely useful in transition and terminal airspace during visual meteorological conditions (VMC) where pilots have difficulty in accurately estimating the relative altitude and velocity of climbing and descending traffic. Alphanumeric tags displayed alongside traffic aircraft on the situation display would contain altitude and ground-speed data.

The impact of pilot assurance upon controller workload is difficult to estimate. Since the system would provide automatically much of the traffic information which currently is transmitted over voice circuits, it is reasonable to predict a steady reduction of this voice traffic as experience is gained with the system. Since each voice communication is an interruption of the controller's concentration upon the over-all air situation, the impact upon his workload may be far greater than is immediately obvious.

Another example of the potential utility of the proposed concept is in connection with navigation in a restricted airspace by general aviation and other types of aircraft. The traffic situation display would provide both controllers and pilots with common current maps which would not be cluttered with routes applicable to other weather and runway conditions or other altitudes. The map information would be presented such that pilots could easily determine and possibly control their position in relation to restricted airspace, thereby decreasing controller workload and improving safety. This feature could be increasingly important in the future if V/STOL aircraft operating between remote airports and congested hubs cause additional restrictions to be placed on the airspace.

The potential impact of the proposed situation display upon terminal area capacity is difficult to predict. If the traffic information is not used by the pilot or auto-pilot to fly the plane with respect to other traffic, capacity improvements will result only if the system enhances pilot assurance to the point where spacings can be reduced and full advantage can be taken of improvements to other ATC system components. On the other hand, if procedures are changed to allow the traffic information to be used in the cockpit, then it may be possible to fine tune the system performance. This mode of operation is appealing because it could provide in all weather conditions some of the flexibility which prevails today in terminal areas in VMC but is lost in instrument meteorological conditions (IMC). For example, pilots could assist controllers in more accurately establishing and maintaining prescribed spacings between aircraft, which would result in a reduction of dispersion over the threshold. Also, as more experience is gained with the system, the cockpit data could be used for additional functions such as passing in both the terminal and en route areas.

II. BACKGROUND

The concept of an airborne traffic situation display is definitely not new or original – it has simply come of age. Schemes that involve transmitting ground-derived radar data to aircraft were discussed in Volume 8 of the M.I.T. Radiation Laboratory Series and have been investigated by at least three* different groups at various times during the past 25 years. In recent years, schemes in which aircraft transmit air-derived data to other aircraft and the ground have also been proposed. The scheme described in this report involves uplinking data from the ground; it has been selected because it is compatible with the evolving NAS/ARTS system and also with the wide range of user equipment which the ATC system must service. Aircraft need only surveillance system equipment, e.g., a transponder, to be included in the uplinked data base.

* Among these are TELERAN-RCA (1946), RATCA-USAF (1963), and TELEVISED RADAR-FAA (1966).

The airborne traffic situation display concept is being resurrected at this time because technology has progressed to the point where it is now technically and economically feasible to implement it as an add-on feature to the evolving NAS/ARTS air traffic control system. The proposed system can take advantage of the availability of: (1) clean computer-processed data on the ground, (2) altitude information from Mode C beacons, (3) advanced digital data link techniques, and (4) airborne digital processing and display equipment capable of sorting the uplinked data and generating a display of pertinent information which can be read in all ambient light conditions.

The NAS/ARTS computer-display system which is now being introduced into service is the source of data in the proposed system. As the capability of this system grows during the coming decade, accurate and reliable data on traffic in most of the airspace will be available to controllers and will reside in digital form in the computers. These data can be formatted on the ground and broadcast over a relatively low-rate data link to the aircraft. As additional surveillance systems are introduced into the system, e.g., satellites and airport surface detection equipment, their data can be integrated into the system without requiring any modifications to the airborne situation display components.

The impact of the proposed system upon the over-all ATC system would obviously be a function of the number of aircraft equipped with the display equipment and the procedures developed by the pilots and controllers to take advantage of the information in the cockpit. With no procedural changes, the display can serve as a "security blanket" to the pilot of the equipped aircraft. At the other extreme, some proponents of highly decentralized or cockpit managed ATC systems envision extensive procedural changes with responsibility for most of the management shifting to the cockpit. We believe that the procedural changes associated with the proposed system would be between these two extremes, would involve smooth evolutionary transitions as experience is gained with the system, and would result in improvements to controller workload, terminal area traffic capacity, and safety.

Because of the many interesting attributes of the proposed system, Lincoln Laboratory established in May 1970 a project to investigate the concept

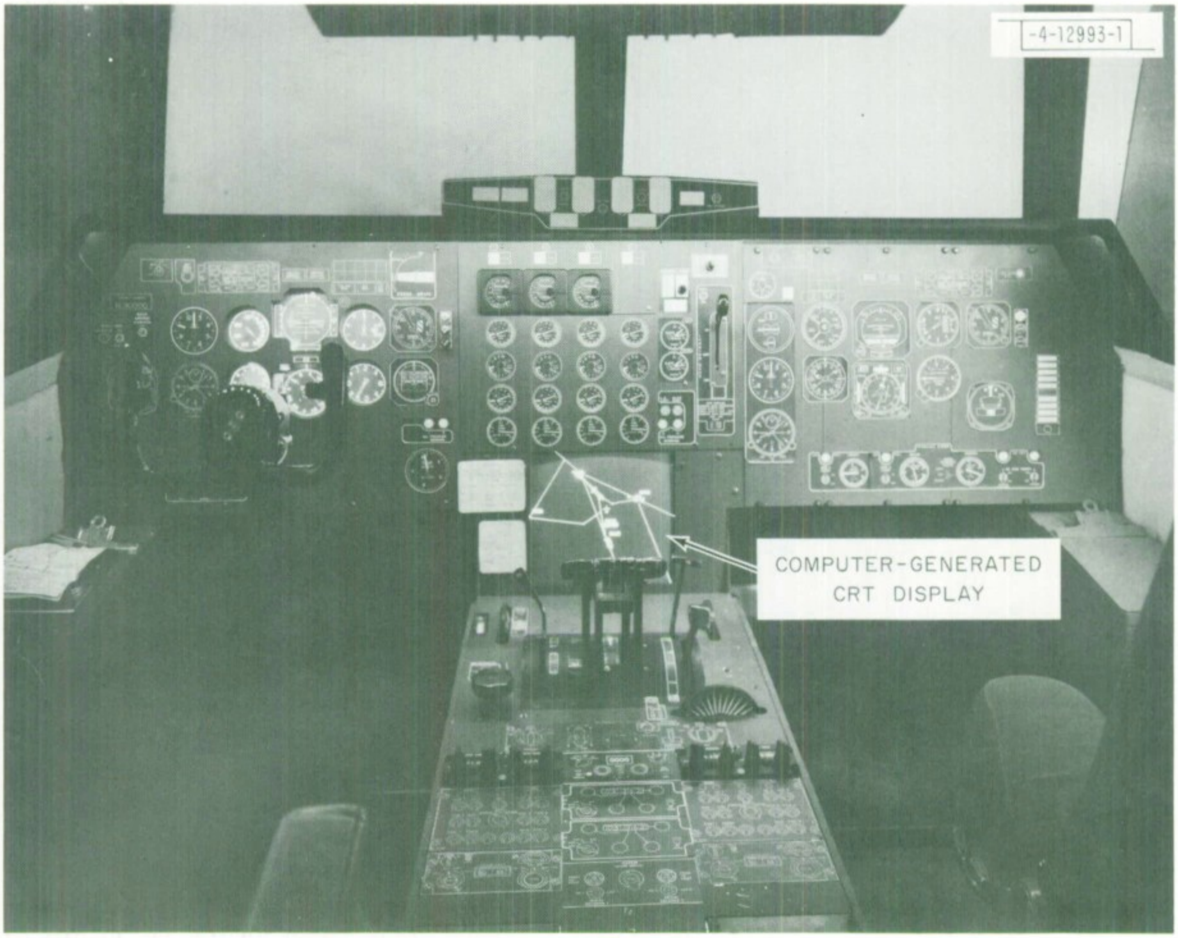

Fig.2. Simulated air traffic situation display in flight simulator.

further. A system definition study has been completed, and some of the results are reported in Sec.III. The preliminary design of an experimental system is now under way. Lincoln Laboratory is collaborating with the Flight Transportation Laboratory, the Electronic Systems Laboratory, and the Man-Vehicle Laboratory on the M.I.T. campus on operational research studies, display parameter definition, and the human factors aspects of the system. The latter three laboratories developed a computer-driven cockpit display simulator which permits a pilot to fly a 707-type aircraft within a typical terminal area. Figure 2 is a photograph of the interior of the cockpit.*

Interesting simulation experiments† performed by Thomas Imrich and Robert Anderson have demonstrated the wide range of control options which the proposed system allows in the terminal area. In their theses, they investigated the feasibility of pilots using the display to fly the simulated 707 with respect to other simulated aircraft or ground computer controlled guidance "bubbles." Both concepts imply procedural changes with the former corresponding to "electronic VFR" and the latter a scheme designed to facilitate cooperative monitoring and control by both the pilot and controller in a highly automated system. Pilot acceptance of the additional information and a more active role in the spacing control task was excellent, pilot performance with respect to delivering aircraft over the outer marker implied improvements in terminal area capacity over today's system, and controller communications workload was reduced. These results correlate closely with those obtained in the TELERAN experiments.

III. SYSTEM DESCRIPTION

A block diagram of the proposed traffic situation display system is shown in Fig. 3. It contains three equipment groups: (1) the ARTS III components with which the proposed system will interface, (2) the ground-based equipment that will serve all aircraft, providing common information via a data link, and

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* The cockpit was provided by Boeing Aircraft Company.

† Experimental data and report references were not available when this report was written.

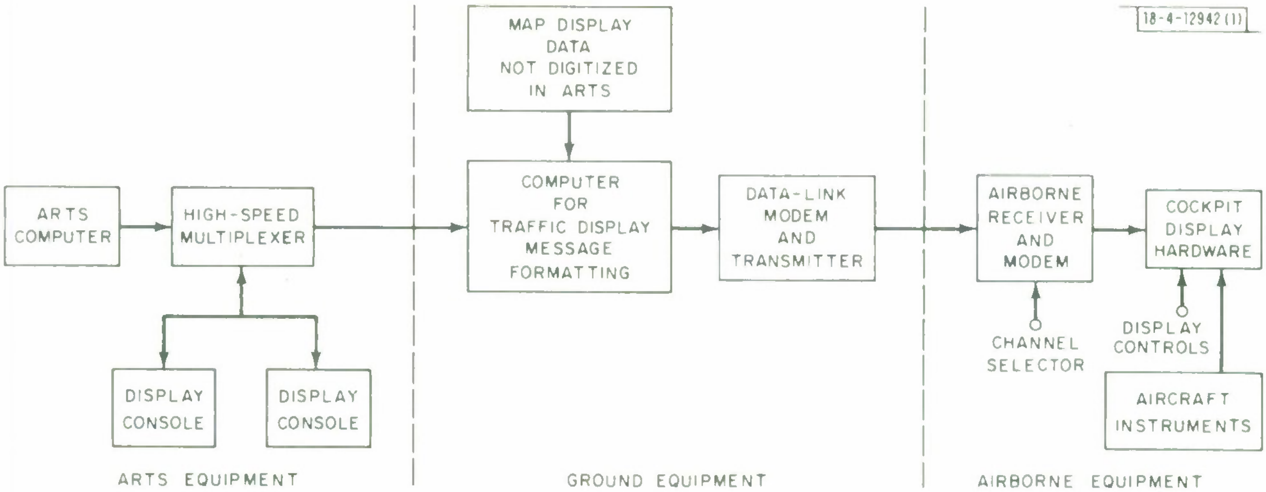

Fig.3. Block diagram of traffic display system.

(3) the airborne equipment in each aircraft, including data link receiver, computer, and display facilities. Although an ARTS computer is shown in Fig.3 as the source of traffic data, NAS and airport surface surveillance data could also be uplinked to the same airborne equipment. A small message processing computer would provide a common message format.

In Fig.3, the ARTS III equipment has been simplified to include only elements relevant to the proposed system, i.e., the computer containing the digital data base, and the I/O processor which sends the data to both the controller displays and the proposed system. The controller displays also receive video data from the radar(s); this information is not uplinked because it is not in digital form. In enhanced versions of ARTS III, all radar data will be digitized and available for uplinking.

A. Message Processing Computer

This computer is the ground-based component which interfaces the ARTS III system and the traffic display data link. Its function is to format digital data into a stream of messages suitable for transmission over the data link. The source of traffic data is the digital display data base of the ARTS III system. In initial versions of ARTS, these data will contain only information derived from beacon-equipped aircraft. Later versions of ARTS will process primary radar data from multiple radars, will digitally display airway fixes, airways, control area boundaries, and weather contours, and will generate and display suggested sequencing and spacing commands for the controllers. The map data source shown in Fig.3 allows some of these advanced features, as well as others such as three-dimensional standard approach and departure routes, to be included in an experimental version of the proposed traffic display system.

The controller displays in ARTS are refreshed by digital data transmitted over I/O processor channels, 24 to 30 times each second. A much slower update rate, such as once every 4 seconds (the present radar data rate in the terminal area), is all that is required for the message processing computer of the proposed system. Equipment on the airplane will re-establish an acceptable update rate after the data are received. An experimental evaluation of the proposed concept can be conducted without changing either the ARTS III software or hardware. The experimental system would access the ARTS III digital display data by means of parallel connections made to one or more of the I/O channels driving the controller displays. In a final version of the system, an I/O channel would be dedicated to the message processing computer interface, and software would be introduced into the ARTS system to service this channel. Such a modification would place an additional demand on the order of 1 percent on the ARTS equipment. The advantage of this approach over that proposed for an experimental system is that it minimizes the time delay associated with the traffic information reaching the cockpit. Also, it removes the time skew problem associated with a single frame of information presented on a controller's display.

B. Data Link

The data link consists of a transmitter and receiver as well as the modems required to interface with the ground and airborne computers. Studies indicate that the data required to service more than 100 aircraft in a terminal environment could be handled at an 8K bit/second transmission rate, providing a complete traffic picture every 4 seconds. This data rate can be accommodated in a 25-kHz VHF channel.

The messages transmitted over the data link will be of two types – one describing aircraft traffic, and the other, map information (including weather contours when available) and alphanumeric text such as barometer setting. The messages will be grouped so that a complete traffic picture will be uplinked at a rate on the order of once every 4 seconds; the map renewal rate may be less, depending upon the total amount of map information to be uplinked. Equipment on the aircraft will maintain the stored map information derived from the data link.

The information contained in the aircraft traffic message associated with a particular aircraft will be the X, Y coordinates of the aircraft and some combination of the following: altitude; alphanumeric identification (ID); ground speed derived from computer tracking data; transponder identification and/or emergency indications; and possibly, in the future, additional information such as alphanumeric sequencing and spacing commands. The extent of the information on a particular aircraft will depend on whether it is transponder equipped and on whether it is being tracked by ARTS.

Each map message describes an item such as a point object (VORTAC outer marker, etc.), a line object (runway, airway, restricted area, boundary, weather contour, standard approach and departure routes, ILS glide slope, etc.), or text (barometer setting, runway conditions, etc.). Uplinking map information insures that all aircraft and controllers have a common, current map and that the map is not cluttered with irrelevant data such as runways or approach and departure routes not in use at that time.

C. Airborne Equipment

The equipment on board the aircraft consists of the data link receiver and modem, a small digital processor, and display hardware. A directional gyro on the aircraft supplies heading data to this equipment.

When the airborne equipment is initially turned on, the processor is ignorant* of the position of the aircraft but does know its ID. Position is

*If the computer is shared by other functions in the aircraft or has access to other sensor data, the aircraft position may be known. The traffic display system is designed as an independent source of navigational and traffic information, and therefore is not dependent on such information.

determined by searching the first available message frame for the traffic message associated with the aircraft. This message is easily detected by examining the ID codes. Once the processor knows the position of the aircraft, it can select from subsequent message frames the pertinent traffic and map information. Traffic messages are examined to see which aircraft are within a specified volume surrounding the aircraft. The messages associated with these aircraft are stored within the computer. Map data are also stored in the computer if they refer to the geographic area surrounding the aircraft. The computer and display equipment then use these data to generate and update a display in the cockpit.

D. Airborne Display Hardware

A number of options exist for the choice of on-board equipment which reflect greater or lesser capability and cost. An experimental system is outlined in Fig.4. The principal subsystems are a small digital processor, an interface and control unit, a line and symbol generator, hardware to rotate the displayed picture, and the indicator including the CRT and its associated driving and power circuitry. Display modes are selected by the pilot via a display control panel.

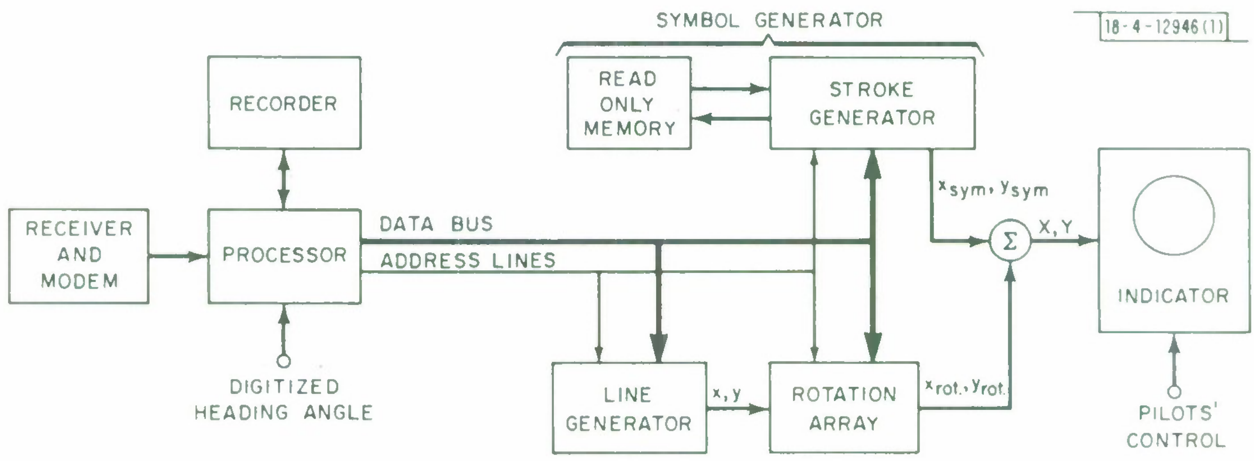

Fig.4. Cockpit display hardware: experimental system.

The processor selects from the incoming stream of uplinked data only those pieces of traffic and map information which are relevant to that aircraft and ignores the rest. With the relevant data it constructs a display file which is read out to the line and symbol generators at the display refresh rate. The line generator is used to draw such items as airways, runways, weather contours and outlines of restricted areas. The symbol generator is used for drawing both alphanumerics and special characters representing, for example, VOR's and obstructions. The output of the line generator drives an array of multiplying D/A converters. If the pilot chooses an aircraft-centered, heading-oriented presentation, the array performs the required angle transformation. Digital heading data are supplied to the array from on-board instruments and are routed to the array via the processor.

This experimental system would have sufficient computing and storage capacity to permit various options to be evaluated and system parameters to be optimized under actual flying conditions. Recording equipment would be connected to the processor to allow monitoring of system operation.

An airline version of the display equipment would be similar to the experimental system but without its additional computing and storage capacity or recorder capability. The operational features included will depend on the experience gained during flight and simulation tests of the experimental system. The processor and indicator need not be dedicated to the traffic display but could be integrated into the aircraft's processor and display complement.

A general aviation version of the display equipment could be so designed that the cost would be within the price range acceptable to general aviation operators. It would use the same uplinked data as the airliner version; however, only limited map information would be shown and the display scale would be fixed. The display would be aircraft-centered and heading-oriented; heading would be derived from the aircraft directional gyro. Each target would be displayed as a 3-digit number representing the target's altitude; the position of the number would indicate the target location. The processor for this system would be a very small special-purpose serial computer with a serial memory.

IV. CONCLUSION

An airborne traffic situation display system is described which will provide pilots with significantly more information on their environment than they now have during IMC, and which will be a useful supplement to vision during VMC. The source of the data for this system is the NAS/ARTS system presently being deployed. Transmission of these data to aircraft requires little additional investment in ground equipment.

Relatively simple airborne equipment for the proposed system can be built at a price acceptable to some general aviation users; higher-cost, more versatile equipments would be used by commercial airliners. Both types use the same uplinked data base. As improvements to the ground equipment provide controllers with a better picture of the air and airport surface environment, these improvements can be made available to the cockpit without requiring a change in the airborne equipment.

The ultimate impact of the proposed system on the evolution of the ATC system is difficult to forecast and should be evaluated through simulation and by field trials in a NAS/ARTS environment. Preliminary simulation studies of the system indicate that it may provide a means for improving safety, controller workload, and terminal area capacity.

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13. ABSTRACT

An airborne traffic situation display system which could be used as an adjunct to the evolving National Airspace System/Automatic Radar Control Terminal System (NAS/ARTS) is described. In the proposed system, a contemporary realization of an old concept, the NAS/ARTS data are broadcast. A small digital computer in an aircraft then selects from the message stream the data on its own aircraft, nearby aircraft, and a local map. These data, plus aircraft heading data from a directional gyro, are used to generate a situation display that can be aircraft-centered and heading-oriented.

14. KEY WORDS

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situation displays	human factors