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8. Considerations for the Design of an Onboard Air Traffic Situation Display*

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INTRODUCTION AND SYSTEM DESCRIPTION

Major changes in the air traffic control (ATC) environment will occur during the coming decade as the result of increased automation, improvements to the beacon and radar surveillance systems and upgrading of the runways and taxiways at the major airports. The introduction of computers and improved displays into the 20 enroute air traffic control centers and the implementation of the automated radar terminal system (ARTS) at the major airports, coupled with a steady increase in data link communications will contribute to the more effective utilization of airspace. This automation will substantially aid the controllers by improving the processing of the surveillance and flight data, by providing electronic identity and altitude labels on the display scopes and by assisting in the sequencing and flow control process. In addition, area navigation and the curved path microwave landing system will make it possible to feed more traffic into those airports which are upgraded with parallel runways and high-speed turnoffs.

To most effectively capitalize on this advanced capability and fully utilize the limited facilities at an airport, it will be increasingly important to more tightly couple the controller and the pilot. The flow of information to pilots should include a means of understanding the intentions of the controller in addition to the specific real-time commands. Various types of data links have been proposed for this function, ranging in capability from a simple readout display for replacing the voice channel, to an advanced system which would automatically transfer instructions from the ground computer directly into the aircraft flight director. With this latter mode of operation, the controller and the pilot would monitor all operations and intervene when appropriate.

The underlying concept in these systems is to provide an effective command-response relationship between the controller and his supporting computer and the pilot and his avionics. This concept is a logical extension of the current practice of vectoring aircraft and is deeply embedded in the historical development of air traffic control. The extensive use of vectoring is viewed as an essential yet undesirable change from the clearance-response relationship which still exists throughout the majority of a flight, during which pilots are cleared to execute a flight plan and do so with little communication with the ground system.

Advances in technology have now made it reasonable to question if the command-response relationship between controllers and pilots in congested terminal areas is either necessary or in fact beneficial. Computers are now capable of generating flight routes from runway to runway which are conflict-free of other controlled aircraft. It is also feasible to present to pilots a display of all pertinent air traffic, controlled and uncontrolled. The combination of these new capabilities with an appropriate data link now permits a safe return to the clearance-response relationship

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* This describes a portion of the work on traffic situation displays being performed jointly by the Lincoln Laboratory, Electronic Systems Laboratory, Flight Transportation Laboratory, and Man-Vehicle Laboratory at MIT.

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throughout a flight, while retaining or enhancing the increased capability provided by the other new equipment being developed.

About 18 months ago, it became apparent to the ATC group at Lincoln Laboratory that as a result of recent advances in airborne computers, digital data links, and computer-driven CRT display technology, it was technically feasible to provide a system in the aircraft that would enable the pilot to have access to the NAS/ARTS data base. The ARTS data base will, at a future date, include flight routes in **4–D** in addition to the traffic data. Furthermore, since the pilot would be only interested in the segment of NAS/ARTS data on his flight route, it seemed that it could probably be assimilated by a busy aircrew.

The basic concept of remoting information to the cockpit is not new. It was explored in TELERAN **(1966)**, RATCA **(1963)**, and televised radar **(1966).** However, the important difference between these early systems and the system now proposed is that currently available technology permits only data of interest to each particular aircraft to be automatically selected and presented. In addition, the traffic data will be more adequately processed by the ground computer and target altitude information will be available.

Our studies indicate that a high-quality replica of a selected segment of a controller's scope could be relayed over a narrow-band digital data link and that this data could be integrated with aircraft heading and navigation information to provide the pilot with a display which would be useful in congested air space. The ability to employ small airborne computers enormously increases the display flexibility and this factor coupled with the improved quality of the NAS/ARTS computer-processed data should enhance the operational utility of the system. The display might include alphanumeric symbols, air route maps, and controller instructions.

Since the terminal area problem is most severe from the traffic management standpoint, we have investigated the task of remoting ARTS data into the cockpit. There are many variations of the basic concept which are technically feasible, but the scheme which appears most practical is the class of system (fig. **1)** which broadcasts all of the pertinent information on a common channel.

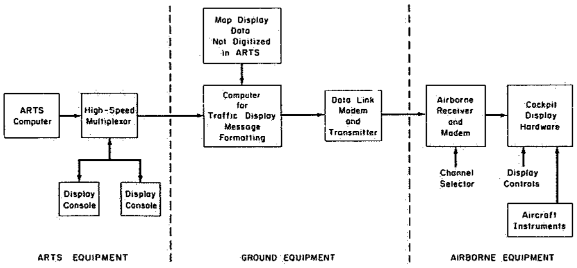

FIGURE 1.—Traffic display system block diagram.

Using available technology, traffic information in a **64** by **64** mile sector of air space would be digitized and transmitted once every few seconds over a narrow-band VHF channel. The digital data stream would contain the identity, geographical coordinates, altitude, ground speed, and heading of each aircraft. The airborne computer would select the identity code of its own aircraft from the common stream and would thereby obtain its position coordinates and altitude as observed by the ARTS ground facility. The pilot could select the range and altitude band which he wished to have displayed and only those targets in the selected categories and navigation reference fixed would appear on the display.

This type of data link has a number of attractive features. It provides to the pilot information on all aircraft which are under ground surveillance either by beacon or radar and it presents the information to him in the same frame of reference as is being observed by the ground controller. The pilot can quickly confirm if his air-derived flight information agrees with the ARTS data. The controller can quickly and precisely send instructions to one or a limited number of aircraft in a form which is both quantitatively and readily interpretable. This could be accomplished through the use of a light pen or keyboard to issue commands or to show graphically vectors indicating the flight route to be followed. This information would be available simultaneously to all aircraft in the system. The controller monitoring the information could rapidly sense if the aircraft was obeying commands. Similarly the aircraft could observe his performance with respect to the ground navigation fixes and his nearby neighbors.

THE IMPACT OF THE TSD ON THE ATC SYSTEM

Traffic Situation Display (TSD) and the present ATC system.—The provision of better information in the cockpit can be used in many ways. It is not necessary to associate either centralized or distributed management concepts with the existence of the traffic situation display on board the aircraft. The congruency of the information available to the pilot and his ATC controller allows the pilot to understand the traffic situation and the commands that a controller is issuing to him and to other aircraft. The pilot can assist the controller by anticipating his commands, and reacting more quickly, or at a proper rate to achieve the ATC controller's intentions. He can also make small or minor corrections to maintain a desired traffic situation such as following another aircraft in trail at a given distance. Thus without any change in present ATC procedures, it is likely that the traffic would flow easier and that the ATC controller's workload would be reduced.

Reduction of *ATC* separation standards.—The most important benefits that a TSD can bring lie in achieving a reduction in the present IFR separation standards. By tightening the control over aircraft separations through including the pilot as a monitor and active control agent, it would seem to be possible to demonstrate reduced standards at higher levels of safety than the present system offers.

The basic aircraft separation of three miles is partially based on time delays between controller observance of a situation and the initiation of target response. With the pilot in the loop observing the separation, this time delay is much reduced through avoiding communications delays on a busy radio channel. When the separation is small, but the gap is widening the pilot can be assured of safety, and will be confident of allowing a much smaller separation to occur.

Examples of traffic situations where improved information offered by the TSD are

(1) Airborne separations in the departure area between successive takeoff aircraft, or between a missed approach and a preceding departure. Here both the relative position and present altitude of the preceding target can be seen by the following aircraft which can ensure that the separation is positive and increasing.

(2) Air to ground separations between an aircraft on approach and aircraft landing or taking off on the runway. If beacon information is available for surface targets, the pilot will be able to monitor runway occupancy and progress towards clearing the runway, and to call his own missed approach if necessary. The present **2** mile requirement for a takeoff in front of an approach could be greatly reduced, and would depend upon the departure standards established in **(1)** above.

(3) Separation standards for approaches on parallel runways could be reduced because of pilot monitoring of the joining procedures at different altitudes and the ability of the pilots to coordinate their longitudinal position relative to approach aircraft on the other runway. In the event of a blunder, a pilot would see aircraft from the parallel approach wandering into his approach zone and could initiate corrective action much earlier.

Change of ATC procedures.—There are a number of procedures which one can envisage for an ATC system which has targets with TSD capabilities. Aircraft could be commanded to follow another aircraft in trail at a given distance simplifying control commands for a string of aircraft, although this raises the question of string stability. An IFR spacing pattern similar to the VFR square landing pattern can be established where pilots are responsible for their final spacing on landing for a sequence established by the ground controller. Successive aircraft on standard, instrument departures could be commanded to maintain "1000 ft below" separation during climbout until lateral radar separation is established by the controller. Similar instruction could be issued for arrival aircraft where the following aircraft on descent track "1000 ft above" the preceding aircraft.

At crossing points, aircraft with a TSD could be issued altitude clearances conditioned upon passage of other traffic, e.g., "clearance below *X* thousand feet after observing passage of target *Y* at crossing point. Report starting descent." Thus a controller could set up in advance a control action to be initiated by the pilot after the traffic situation has resolved itself.

Introduction of guidance commands.—ATC instructions for guidance of targets which are generated on the ground by a controller or computer can be displayed to the pilot on the TSD. There are various concepts and situations where one can envisage such usage in the terminal area.

The desired position for a target to achieve a landing slot can be displayed as a "bucket" along arrival routings and onto final approach. Speed commands and speed changes could be issued such as to achieve metering into the terminal area and rough final spacings.

Alternatively, the "time to turn" command could be counted down on the TSD to avoid a radio transmission by the ground. The inbound vector and desired speed would also be displayed. Elimination of this transmission delay would improve the accuracy of the "time to turn" process.

The scheduling of "buckets" for the runway system would allow setting up staggered spacings for parallel runway operations, and would open up the possibility of operating coordinated landings on crossing runway systems. This would allow substantial increases in IFR operating capacities at certain airports, and certain wind conditions.

From the above, it is clear that a potential exists for a number of new and beneficial applications which would be possible if a substantial portion of the air traffic were to be equipped with a TSD. There is a need for simulation of these concepts, and a detailed analysis of possible new procedures to establish the value in proceeding further with this line of ATC development.

THE IMPACT OF THE TSD IN THE COCKPIT

Normal operations.—At present, pilots construct a mental image of the traffic environment from information received through radio communications, visual scanning for other traffic, knowledge of standard procedures and previous experience. A pictorial situation display provides this traffic information to the pilot at a glance. The uncertainty and ambiguity associated with mentally synthesizing a time varying traffic situation is largely eliminated. A TSD provides a continuous display of information with predictable quality. Unlike the information received from present sources, data from a TSD are available whenever a pilot needs it. Both pilot and controller responses can be based on information received through a common data base.

The information transfer process between controller and pilot is more efficient. Controller instructions can be simplified and abbreviated without sacrificing message content. Messages of advisory nature may often be eliminated (such as transmitting spacing advisories to traffic following in trail or giving reasons for speed changes, etc.). With a TSD pilots will be able to see more clearly the reason for clearances which are being issued to their own aircraft and other aircraft, and a means will be provided to independently cross-check the validity of a clearance. Because of advanced cues provided by a TSD, a crew can plan ahead and make better decisions. Flap schedules, pressurization regulation, and other items related to aircraft management can be more appropriately timed. Response to controller requests can be reduced because pilots are continuously aware of the ATC situation. In general, reactions are quicker and more precise. The proper rates of control can be applied to achieve the controller's intention.

Emergency situations.—When unusual circumstances arise the pilots will receive cues from a traffic display much sooner than can now be expected. Because of this advanced notice, the pilots can be awaiting an amended clearance, and preparations to execute that clearance can be initiated much sooner. In emergency situations which involve an aircraft in the near vicinity deviating from its expected course, the TSD becomes a critical source of information for evaluating the threat, considering alternative courses of action and executing an evasive maneuver. If, and when, an amended ATC clearance is given, the pilots will be able to immediately see the reason for its issuance. The TSD will give the pilot confidence that the command is appropriate, and it will convey a measure of the urgency of the situation.

A TSD will provide assurance when the ATC system is functioning properly. Positive and continuous indication will be given when adequate separations exist. When certain types of ATC failures occur, a TSD can offer an added margin of safety or even an avenue of escape. (Failures such as loss of a ground communication channel during radar vectors.) The time delays associated with detecting, evaluating, and reacting to a threat can be greatly reduced when a common source of information is available to both the controller and pilot. In the coming years, this will be even more important because efforts to increase the capacity of the ATC system are resulting in new procedures which greatly reduce the longitudinal and lateral separations between aircraft (such as conducting simultaneous approaches to closely spaced parallel runways).

Collision avoidance.—TSD will be a valuable aid in helping to avoid mid-air collisions or near mid-air collisions within the terminal area. As it is currently structured, the display would operate as a proximity warning indicator or pilot warning indicator (PWI). (We make the distinction here between PWI systems and collision avoidance systems (CAS). A CAS provides a command to the pilot (e.g., fly up, fly down) to avoid collision, while a PWI system only informs the pilot of nearby traffic.) In the PWI system, it is the function of the pilot or other crew members to detect that a hazardous situation exists, assess the degree of threat posed by the other aircraft, and then take appropriate action to avoid collision.

The primary trade-off in using this traffic situation display as a PWI device comes from the desire to have, on the one hand, a very large field of view so that aircraft with high closing velocities can be seen in time to make small corrections to avoid a near miss, and on the other, a small field of view is desirable for the stationkeeping and following tasks in the terminal area. In fact, it has been suggested by some people that perhaps two displays will be required to accommodate these two functions.

Display format and symbology should be designed with the PWI function in mind so that the probability of detecting a threat is high and so that a rapid assessment of the situation can be made which leads to the correct evasive maneuvers if required.

Crew workload allocation.—A preliminary assessment of the TSD is that the workload of the pilot in traffic following tasks will remain comparable to that which currently exists. However, when one considers the additional functions which the display might perform including merging with other traffic, area navigation, and collision avoidance, it is clear that even greater demands will be made on the pilot if he is to perform all of these tasks and fly the aircraft as well.

Can we reduce this additional load imposed upon the pilot by having other crew members perform some of these functions? For example, it might be possible for the flight engineer to watch the display and use it as a PWI device. The first officer might use it to report to the pilot on the progress of making good courses and times to various waypoints in an area navigation scheme, and he might also be responsible for inserting and modifying waypoints.

It is well within the realm of possibility that the TSD will eventually be placed in the center of the instrument panel where the HSI is currently located. In this case, the pilot will then be using the display as one of his primary guidance and navigation displays, and it no longer will be relegated to the role of a secondary information display.

DISPLAY FORMAT, SYMBOLOGY, AND PRESENTATION

This section is a review of what may be called presentation variables or display parameters for the design of a TSD using data uplinked from an ARTS-I11 system. We shall describe the important elements of the display and the considerations peculiar to this application for a horizontal situation display.

Background reference and display *orientation.*—The background reference element can take form in various levels of complexity. Between the extremes of no background reference and a facsimile of a Jeppesen chart lie a nondescript grid and a simple map with only standard air routes and navigation fixes. Several considerations which will influence the selection of the reference to be provided are the desirability of some area navigation capability and the fact that Jeppesen charts will be available in the cockpit to provide any detailed information which is desired. A reasonable compromise would be some form of map containing key navigation facilities but less information than is available on standard charts and approach plates.

Whatever the form or content of the map, certain other decisions regarding its orientation and motion must be made. For translation, the first level of decision is whether the map will move so own aircraft is always in the same position of the display, or the map will be fixed and the symbol of own aircraft will move across it. Very simple estimates of the greatest number of miles per inch that it is reasonable to put on the display and the number of miles travelled in terminal area operation quickly indicate the difficulty with a fixed map for our applications. In the case of own aircraft symbol remaining fixed near the center of the display, there still remains a number of variations for the presentation.

The map can be oriented so that UP on the display corresponds to north, the aircraft's heading, or the direction defined by the ground track. Numerous reports have shown that confusion arises when travelling south on a north-up display. Visual acquisition of landmarks and other aircraft should be easiest using heading-up display information and most difficult with the north-up display.

The position of own aircraft, which is needed for centering the map on the display, will come from uplinked ground radar data in the system described here. Since the radar update occurs every 4 sec, the map translation would most easily be accomplished every 4 sec. Prediction computations done onboard would be required to project a continuously translating map. This problem is independent of the display orientation, but similar options are available for the track-up display. (The heading-up display might be continuously oriented from an external heading reference.)

Other *traffic*.—Probably the most important feature of the overall concept is the presentation of selected traffic information. Simple operations on the new data which is available every 4 sec can provide the relative position of other traffic. The past few positions of those aircraft can be displayed as history tracers to aid the pilot. Tracking and prediction of relative motion is another option, but this appears to be a costly option from the implementation point of view. However, it would allow the traffic to move continuously on the display and could be used to generate predicted paths of flight.

If the map translation is discontinuous, there will probably not be any question about how the traffic moves since they will jump together. However, if the map has continuous translation, a choice exists for displaying continuous traffic or unpredicted traffic (having discontinuous motion) between updates. Their coordinates may be frozen so they stay fixed relative to the translating map, or they can stay at a fixed range from own aircraft's symbol on the display. Either case can result in extremes of misrepresentation.

Data rates higher than once every 4 sec may be available in the future. These rates would reduce the significance of any differences which are found to exist between the acceptability of traffic symbols moving continuously through prediction and those jumping at the basic update rate.

Alpha-Numeric data tags.—The proposed data link provides identification, altitude, and tracking estimates of ground speed for selected transponder-equipped aircraft. The type of alphanumeric information useful to the pilot depends on the task he is performing. One possibility is to have the data tag move with the symbol of the other aircraft. The effects on display legibility and interpretation of the characters moving across the display face, possibly in jumps, will depend upon the beam width and persistence properties of the particular scope. An alternative method is to present the alpha-numerics in tabular form. This may improve legibility and reduce clutter, but will introduce difficulty in associating an aircraft with its data tag.

Display scales.—There are three variables which have a direct relationship upon one another: the display scale (in miles/inch), the field of view of the display (in miles), and the scope size (in inches). Specifying any two determines the third. Since each phase of an approach has a characteristic range of viewing interest (field of view) and a set of tolerances for performing maneuvers, a variety of scales (miles per inch) will be required. Each viewing scale must display enough range to provide basic collision avoidance capability as well as presenting all of the picture needed to plan and execute the current maneuver. The precision possible in an aircraft-following task will depend on the display gain, the number of inches on the display corresponding to the desired separation. The value of the scale setting must be easily and unambiguously identifiable.

Scope size.—If, as stated in the previous paragraph, the phase of the flight specifies a desired field of view, then the scale of the display can be adjusted so that this desired view fills whatever size of a display is available. This means that there will be more miles per inch on a smaller display, and the alpha-numerics which will have to remain a legible size, will occupy a larger percentage of the display area. The results of this imposed change in scale and added clutter on task performance will have to be examined to determine the limitations of a small scope which may be required in certain aircraft.

Command information.—For more advanced systems, the ground might provide commanded position information for each aircraft, or onboard systems might generate commands for the aircraft based on arrival times and/or spacing with other aircraft. The symbology and scales for such command information will require studies to ensure compatability with the other data presented and to avoid excessive clutter of the display.

THE SIMULATION FACILITY

Graphics computer.—The cockpit simulation facility assembled at M.I.T. to evaluate the potential applications of airborne displays has as its central elements an Adage AGT–30 computer (fig. 2) and a prototype SST cockpit shell donated by Boeing (fig. 3). The AGT–30 computer (fig. 2) is only moderately fast having a **16** K core memory with a 2 microsecond memory cycle time, but it does feature a unique peripheral hybrid array that can rototate, translate, and scale 3D vectors at rates ranging from *5* to 40 microseconds per vector depending on the vector length. This fast hardware operator permits the display of very complex 3D line images at flicker-free rates. Moreover, as each line is being drawn, the central processor may continue on with other calculations while awaiting an interrupt signifying the completion of the draw. As a consequence, the computer in real-time solves the equations of motion of the simulated aircraft, maintains three independent displays (two in the cockpit and one at the operator's console), monitors and responds to discrete and continuous inputs by the pilot, provides selected analog outputs to an x-y plotter and six strip chart recorder channels, and processes experimental data on-line so that selected statistical summaries are available at the end of each run.

Cockpit.—With respect to the cockpit, the objective was to provide a full-workload environment for a transport pilot approaching a major terminal so that a realistic evaluation of various display options could be obtained. Analog pick-offs were installed for the pilot inputs for aileron, elevator, rudder, throttle, speed brake, flaps, heading set, and course set. Up to 60 discrete

FIGURE 2.—Adage AGT–30 graphics computer.

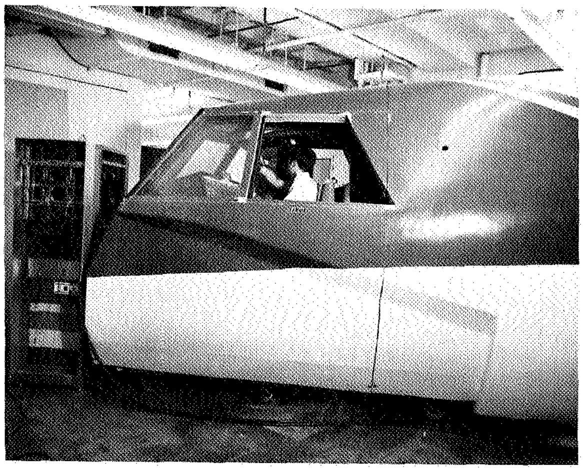

FIGURE 3.—Boeing prototype SST cockpit shell.

pickoffs indicated landing gear setting, stabilizer trim action, VHF COMM/NAV frequency settings, VOR/ADF selection, and display control inputs. Computer-generated discrete outputs were provided for marker beacon lights and intensity control.

Figure 4 shows the interior of the cockpit simulator during operation. Two cockpit displays were 16-inch Digital Equipment Corporation Type 30A CRT units modified so that they could be driven by the continuous voltages from the Adage hybrid array and vector generator. One display presents a set of basic flight instruments (altimeter, vertical speed, airspeed, radio magnetic indicator, attitude indicator, and horizontal situation indicator) whose dynamic response corresponds to the simulated flight conditions. The second unit positioned between the two pilot stations is used to present the various ATC display options being investigated such as an aircraft-centered navigation map, other aircraft in the vicinity, alpha-numeric information, etc. The third display at the computer console is a standard Adage unit which is used to monitor experiments or is used by the ATC ground controller when one is required. A set of built-in function switches, a light pen, and two foot pedals supply additional control inputs by which the experiments may be directed. In addition to the dynamic instruments and numerous dummy switches and knobs representing checklist items, photographic reproductions of the remaining cockpit panel instruments were mounted at the captain, first officer, and flight engineer stations. The present configuration corresponds to a Boeing 707–123B transport.

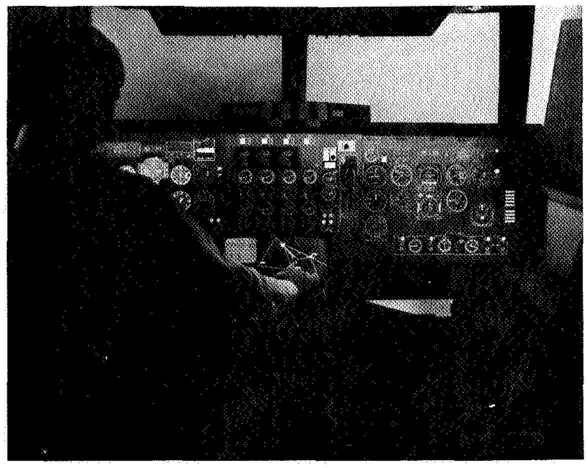

FIGURE 4.—Interior view of simulator.

Interface equipment.—The logic interface between the cockpit and the computer was largely constructed from commercial DEC building blocks. Nexus encapsulated operational amplifiers were used as buffers between the cockpit pickoffs and the multiplexer channels feeding the analog-to-digital encoder in the AGT–30. Some dynamics, such as the time lag between actuating the throttles and the buildup of thrust (EPR reading), were simulated by active RC circuits at the interface.

DESCRIPTION OF THE EXPERIMENTAL PLAN

The previous sections outlined some of the features which require consideration when designing a TSD. A set of symbols and reasonable fields of view were selected to reduce the number of variables confronting us when planning the experiments which are being performed to evaluate the various display options. Another set of experiments (ref. 1) is being done to investigate the TSD in the ATC system.

The display option experiments are being divided into two phases.

Phase 1 Experiments

The first phase of testing addresses the following factors: (1) display format for alpha-numerics, (2) scope utility for different sizes and shapes, and (3) effects of continuous and jumping traffic on the extraction of information from the display.

To elaborate briefly on these factors:

(1) With various alpha-numeric data (identification, altitude, and ground speed) selectively available, consideration must be taken to present this data in a way which makes it easy to associate the data with its respective aircraft. Two forms of data presentation have been considered. One is a traditional moving tag which stays along side of the actual aircraft symbol. This tag remains horizontal in the heading-up orientation. The other form is a stationary tabu-

lar presentation with a single character affixed to the aircraft symbol to establish the tie between an aircraft and its data.

(2) These formats were tried out on a rectangular scope (13.3 cmX18.4 cm) and on a scope **18.4** cm square.

(3) Here we are concerned with the effect of jumping or continuously moving symbols on the ability to extract information from the display.

Figures 5 and **6** show two examples of the display used during this phase of testing.

Phase **1** ***test plan.—***

Situation: With the subject sitting in a normal pilot position, a variety of display options will be presented. There will be no primary or even secondary flying task, but rather the subject is instructed to give his full attention to the traffic display.

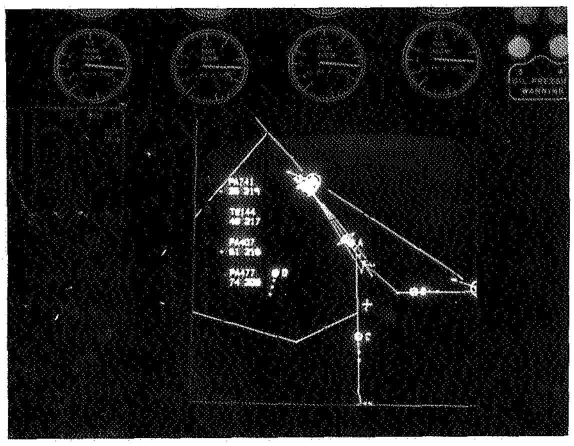

FIGURE 5.—Alpha-numeric **data in vertical table. Own aircraft at cross; other aircraft with tracers. Display size is 7-1/4 in. by 7-1/4** in.

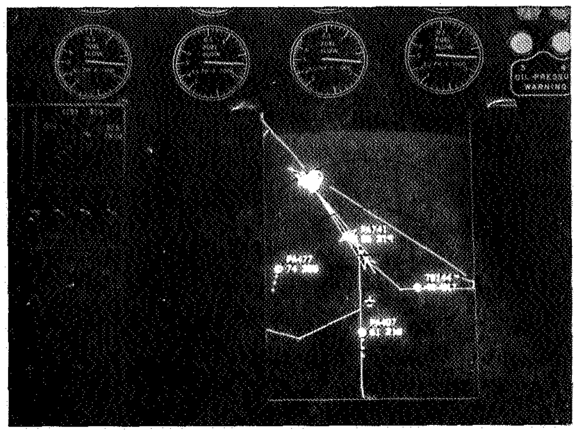

FIGURE 6.—Alpha-numeric **data in moving tag. Display size is 5-1/4 in. by 7-1/4 in. Note symbols for outer-marker and airport.**

Task: With no traffic on the display, the subject is verbally given the flight identification for one **of** the test aircraft (e.g., TWA 426). This aircraft as well as one to four others then pop up on the display and the subject hits a response button as soon as he has identified the relative position, the altitude, and the ground speed of the selected aircraft.

Measures: The computer records the response time, and the accuracy of the subject's observations is recorded externally.

Phase **2** Experiments

The second phase of testing requires piloting a simulated jet transport class aircraft through a variety of maneuvers within a simulated traffic situation. The flight is composed of a series of maneuvers which might be expected when following another aircraft into a terminal area; included among these are (1) acquisition of an assigned spacing directly behind the other aircraft, **(2)** following through a turn, and **(3)** maintaining spacing through a deceleration.

With these flight conditions and requirements, the following display options are to be investigated:

(1) Ground reference frame (GRF) and traffic translation
  (a) Continuous GRF translation with continuous traffic translation
  (b) Continuous GRF translation with traffic frozen in the GRF between 4-sec updates.
  (c) Both GRF and traffic frozen in translation between 4-sec updates
(2) Display orientation
  (a) North-up
  (b) Heading up with continuous update
(3) Background reference
  (a) With a background map showing nominal traffic routes
  (b) With no background reference
(4) Scope size
  (a) Large—providing 12.0 cm of forward viewing distance on the scope

(b) Small—providing 9.9 cm of forward viewing distance.

Figures 7 and 8 show two examples of display options used during the second phase of testing.

This list of feature options gives 24 different conditions. The experimental design employs four test subjects. Each subject is tested in two sessions. Half of them have a heading up display for the first session and north up for the second session. The others encounter the displays in the opposite order. One subject in each of the two orientation groupings has no background reference for his first session and does have this reference in his second session. The reverse is true for the other two subjects. Within each session, half view the three translational options first on a large scope, then on a small scope. The order of presenting translation cases is also randomized among the subjects.

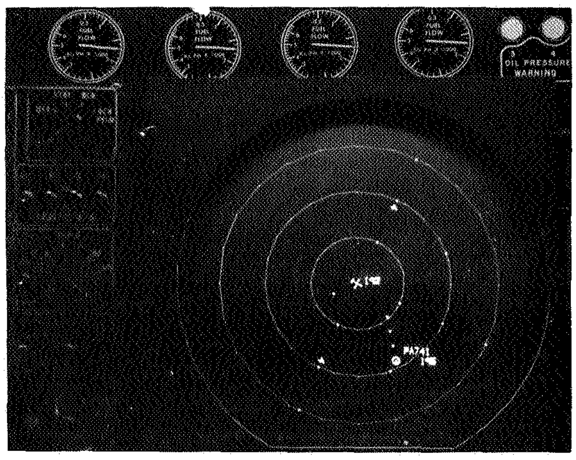

FIGURE 7.—North-up display without map. PA 741 shown with tracers and ground speed tag. Scale is 2 miles per range ring.

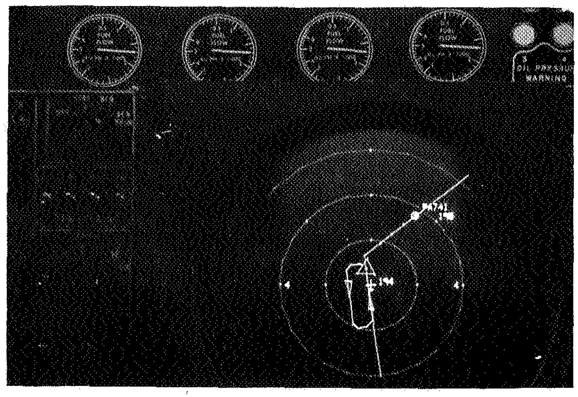

FIGURE 8.—Heading up display with map;
2 miles per range ring.

The subjects were experienced pilots: a current instrument instructor; Navy reservist; 707 flight engineer; and a first officer on Electras. Each subject had at least three hours of familiarization training on the simulation, about half of the time was devoted to practice with the actual test situation which the subject would first encounter in the testing. At the beginning of each test session the subjects were given two more practice runs before starting data runs. When the scope size was changed midway through the session a 15-minute break was taken, and an abbreviated practice run was made before recommencing data cases. The translational options could be changed at any time without stopping the flight, and they were all interspersed throughout the practice cases.

EXPERIMENTAL RESULTS

This section contains a brief review of the experimental results. See reference 2 for a more complete description.

Observations of the data from phase 1 tests show the search time does not increase greatly as one goes from a case having two aircraft on the screen to a case with three, but the time rises more abruptly as one goes to four or five aircraft being present. The increase is not as sharp when going from three to four aircraft in the tabular presentation as for the moving tag case. The tabular data experiments require a search for the specific aircraft identification and then a search for the associated aircraft. This double search tends to increase the response times by 30 to 50 percent over the times required for collecting data from moving tags. Of the two styles of tabular data, the side presentation appears more favorable.

In the flight tests of phase 2, data on range, lateral error, course deviation, side task performance, and the head monitor were recorded. Plots of the ground track were also generated on a map. The pilots were found to be able to perform the flight task with virtually the same high level of precision on all the display options. With no map present, the turn at ACTON tended to be a little late or a little early, but in all cases the error was immediately recognized and the turn was appropriately extended or cut short to bring the aircraft in line with the traffic. The measures used to compare the displays were ones indicating workload rather than absolute performance, since the performance was so steady. Viewing time for the traffic display, as extracted from head monitor data, and side task scores were used.

Preliminary results from this data show a reduced workload for the heading up display, but all other features show less clear preferences.

Three measures of workload were selected for intense analysis to find differences between the display options. Viewing time for the traffic display was entered in two forms: **(1)** Dwell time—average time the subject's head orientation remained in the selected position, hopefully corresponding to viewing the TSD, and *(2)* Total time spend in the prescribed orientation as a percentage of the time over which the record is taken. The third measure was the time average value of the magnitude of the side task deviation.

Analysis of variance and subsequent student's t-tests were applied to each of these measures for each of the four intervals over which data were collected.

A five dimensional array of data—(3 measures over 4 intervals) × (4 subjects) × (2 display orientations) × *(2* display sizes) × (3 translation styles)—was set upon an IBM **360–67** by use of the time-share program APL. APL possesses capabilities for easy restructuring of and operating on multidimensional arrays, providing immediate results, and thus allowing various forms of analysis to be applied conveniently. Considering a single workload measure on a particular data interval, the experimental design reduces to a 3-way classification, with four replications (subjects) per cell.

The same four subjects performed all the tests, so the within cell (among subjects) variance estimate is the appropriate factor for testing the significance of all other variances by an F-test. Before the analysis was cerried out, the scores for each subject for each measure on each section of the flight were reduced to zero mean. This was done because we are interested in preferences and variations in preferences as indicated by the data, rather than variations in the level of the scores for the different subjects. The variations between the operating levels of the four subjects were generally greater than the variations of any single subject, so an effect to first minimize these differences in operating levels was in order.

The results of such an analysis are presented in table **1.** For each major feature which showed significant variance between its indices, individual t-tests were examined for each subject on the particular measure and data interval. For the student's t-test, the data were treated by calculating the differences between the scores of those cases differing only by the feature being examined.

Interval **3** of the data begins with the third section of the flight and interval 4 of the data takes over after 2 min of flight section three, by which time the deceleration transients have supposedly died out.

Statistically significant findings at the **10** percent level were

(1) Of the **12** data sets (three measures on four data intervals) eight showed a significant variance between orientations. All but one of these eight data sets lead to t-tests which showed significantly better scores for heading-up cases. The one other data set exhibited a north-up preference at a significant level.

(2) The display size did not show a eignificant effect.

(3) The translation options require close examination. Section **3** of the flight (data intervals **3** and 4) is a case in which the necessary control actions are fairly well established, so the display provides a check that the pilot's action had the expected effect. For these intervals of the data, the differences showing significance favor both other options over the case of continuous map translation with traffic jumping every 4 sec. For this unfavored case it can be noted that the pilot must watch until he sees the traffic jump to be sure of the correct measure of the spacing. Conclusions for sections **1** and *2* are tenuous, though the pilot questionnaires fill in the guidelines which the data are weak in providing. The data for side task performance show the case of both continuous traffic and map to be significantly better than the case of both jumping.

TABLE 1.—*Analysis of Variance Table* for *Phase 2 Experiments*

	Or.	Sz.	Tran.	Or.-sz.	Or.-tran.	Sz.-tran.	Or.-sz.-tran.	Data interval
Dwell time	"9.766	1.191	^{c}11.531	^{b}4.153	08.713	0.028	0.277	1
	"3.012	0.328	^{c}4.358	1.625	^{a}2.736	0.503	0.706	3
	0.027	0.011	0.710	1.385	0.848	0.753	0.984	3
	c10.943	0.004	82.558	0.976	1.146	0.371	0.488	4
Attention, %	0.177	0.410	2.304	0.827	0.904	1.156	1.207	1
	0.821	0.124	82.786	0.270	0.985	1.763	1.932	2
	"3.478	0.709	1.176	3.289	2.186	0.462	1.037	3
	^{c}7.423	^{a}3.519	^{b}5.514	^{a}7.045	0.856	0.427	0.724	4
Side task	2.832	0.843	0.389	2.226	0.181	0.008	0.066	1
	3.954	0.998	0.630	2.362	0.021	0.844	1.076	2
	^{b}6.598	^{b}4.243	^{a}2.718	"8.900	0.241	0.908	1.971	3
	^{b}5.208	0.158	0.525	0.641	1.911	1.676	2.152	4

Notes:

(1) Data structure: Orientation (Or.) by size (Sz.) by translation (Tran.) with entries from each of four subjects composing each cell. Each subject's scores have been reduced to zero mean within each cell.

(2) F-test figures for principle features and interactions are shown, with significance indicated by ^{a} = 0.10 level, ^{b} = 0.05 level, ^{c} = 0.01 level.

However, the other two measures show the reverse preference at a lower level of significance. Other investigations (ref. **1**) have found the after image of jumping traffic to be useful in judging relative motion for more complex tasks.

(4) The interactions which are indicated are not too ambiguous because generally two of the primary features have already shown significant variation. Perusal of the original data reveals that the cases which fail to provide two variables of significant variation require the qualification that the heading-up orientation is favored most when appearing in a large display. Note that this interaction is only significant in three of the **12** data sets, and a heading-up smallinteraction is favored once.

Summary of Experimental Findings

Phase I.—Unless a terribly cluttered map is to be presented on the display (which would lead to unresolvable conflicts of data tags with map elements) it appears very desirable to implement moving tag alphanumerics. *If* tabular data are used, however, a slight preference exists for the table appearing in a single column at the side of the display, rather than in rows at the bottom.

Phase 2.—For the flight tasks employed in these tests, which were a combination of navigation through a familiar flight pattern and following predictable traffic in this pattern, a heading oriented display generally leads to lower workload scores and better pilot acceptance than a north oriented display. Neither performance nor workload measures appear to be influenced significantly by the display sizes tested. Pilot opinion was not critical of the smaller scope, while the larger one was naturally favored. For the translation options, either the case of continuous map and traffic or that of jumping map and traffic appear acceptable, with the pilot preference going to the fully continuous case. The continuous map with jumping traffic is undesirable from the standpoints of both workload and pilot opinion.

REFERENCES

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