AM 65-31

DEVELOPMENT AND EVALUATION OF A RADAR AIR TRAFFIC CONTROL RESEARCH TASK

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Released by

P. V. SIEGEL, M.D.
FEDERAL AIR SURGEON

December 1965

FEDERAL AVIATION AGENCY

Office of Aviation Medicine

ACKNOWLEDGMENTS

The development of the task system and associated audio-visual materials required the support and interest of a number of people whose contributions the authors wish to acknowledge.

Within CARI, Harlie W. Huffman contributed significantly to our early design thinking in the area of electronics. Eugene H. Barker was instrumental in developing the still-photography technique for filming the animated radar targets.

From the FAA Academy, John H. Lanius and William J. Berkley were particularly helpful in our planning. We were also fortunate and grateful to obtain the full-time services of Bernard Fonza and Duard Leslie for several months. These two men demonstrated considerable insight and originality in developing the scripts for all the 1-hr task programs, in filming the animated radar targets, in developing the airways map and flight-strip materials, and in tape-recording the voice communications. Perry Bolyard provided administrative support in behalf of our need for volunteer subjects for the experiments.

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I. Introduction.

This report describes a synthetic radar air traffic control task for laboratory, human-factors research and the results from initial pilot experimentation. The conditions under which air traffic controllers work, involving workload, time pressure, and responsibilities for lives and property, demand a better understanding of factors that could degrade performance. Need for the research tool as described herein arises from specific conditions that have appeared at times to compromise efficient operator performance and that would not feasibly be evaluated outside the laboratory. Initially, for example, there was a question of the secondary effects of commonly used drugs on controller proficiency. Like most people, controllers resort to over-the-counter and prescription medicaments in their desire to alleviate symptoms or to combat an ailment. Many drugs, however, especially the ataractics and antihistaminics, have a depressant side action and consequently possess the potential for disrupting skilled behavioral responses. In another area of concern, Psychology Laboratory research has uncovered a suggestion of differences among air traffic control (ATC) facilities where behavioral data were related to shift- and task-rotation schedules. Hence, it seems reasonable to pursue a program of definitive study relating work task schedules to operator efficiency.

When attention was first drawn to the need for human-factors research on ATC operator-performance variables, the Air Traffic Service made available certain radar-simulator equipment. Such simulators, traditionally used in training, require one or more human programmers to operate controls that determine the appearance and movement of targets on a CRT display. Initial observation of the equipment made apparent a critical objection to its acceptance for research use. To compare a given subject's performance from one day to another and to arrive at any conclusions regarding the variables under study requires assurance that the data reflect the subject's, and not the experimenter's, proficiency. It was determined that programmer's control settings could vary not only within a given day, but also from day to day, in terms of both accuracy and latency; i.e., when a dial was set. Hence, the reliability of the simulator as a research tool was seen to be limited by the system that programs it; i.e., the human. A further objection was that the simulator's mechanical function failed to provide consistent agreement between control settings and target location and movement on a day-to-day basis.

The alternative was to eliminate the human programmer. An automated system could function with high reliability by feeding programmed signals into a radar display and recording subject responses to the target patterns. By connecting several displays in parallel, concurrent testing of subjects in groups could be realized. Thus, on a given day, an experimenter could test several subjects on different levels of an independent variable while having knowledge of environmental and task control. Such capability affords the experimenter greater freedom of experimental design. The approach further requires only a single technician to monitor system performance and change task programs.

With acceptance of the above rationale, engineering design and development of the system described below was undertaken with the collaboration of the Installation and Materiel Depot of the FAA Aeronautical Center. The requirements originally set forth called for a system that would ensure repeated presentation of realistic target patterns and of other synchronized visual and auditory stimuli and that would provide suitable instrumentation for measuring and processing subjects' motor and verbal responses. The system was to enable the experimenter to evaluate a number of human functions, to include *vigilance* in the detection of critical targets, *monitoring* of the course and altitude of enroute traffic, *reaction time* both to centrally located and to peripherally located visual warning signals, and *identification* of potential conflictions.

II. The Radar ATC Task System.

A. *Task Description.* The experimental situation developed utilizes six task consoles located in separate rooms, plus a programming and data-processing complex (Figure 1) located in a separate control room. The subject's console, shown in Figure 2, is designed to simulate certain current and future developmental aspects of a controller's task in a semiautomatic enroute ATC center. Slanted at 70°, the radar display shows airways, checkpoints, intersections, and aircraft targets within the subject's control sector. An airways map immediately below the display is available for reference. Up to six radar targets are presented at one time by 35-mm filmstrips, made up from an animated display.

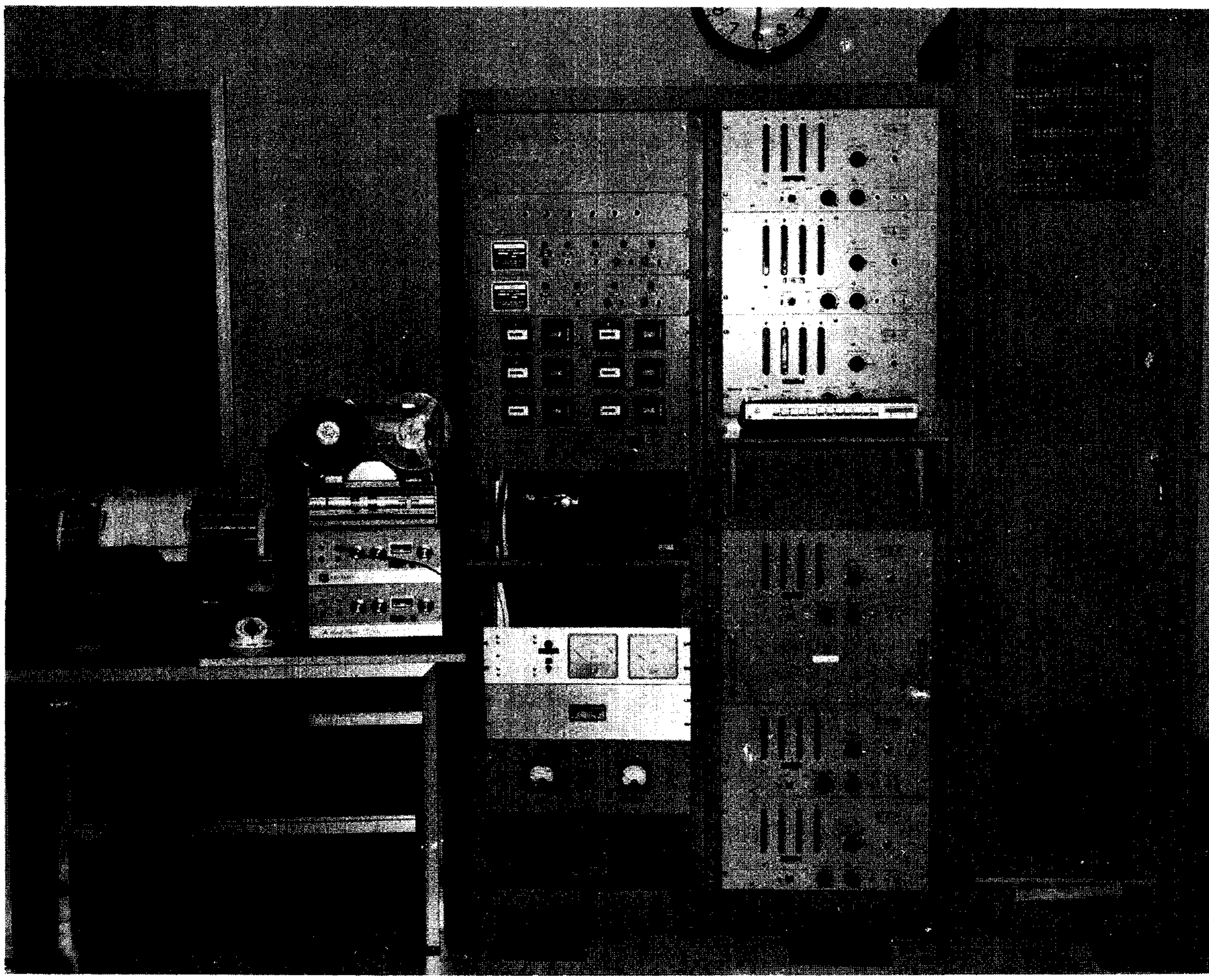

FIGURE 1. Programming and data-processing complex.

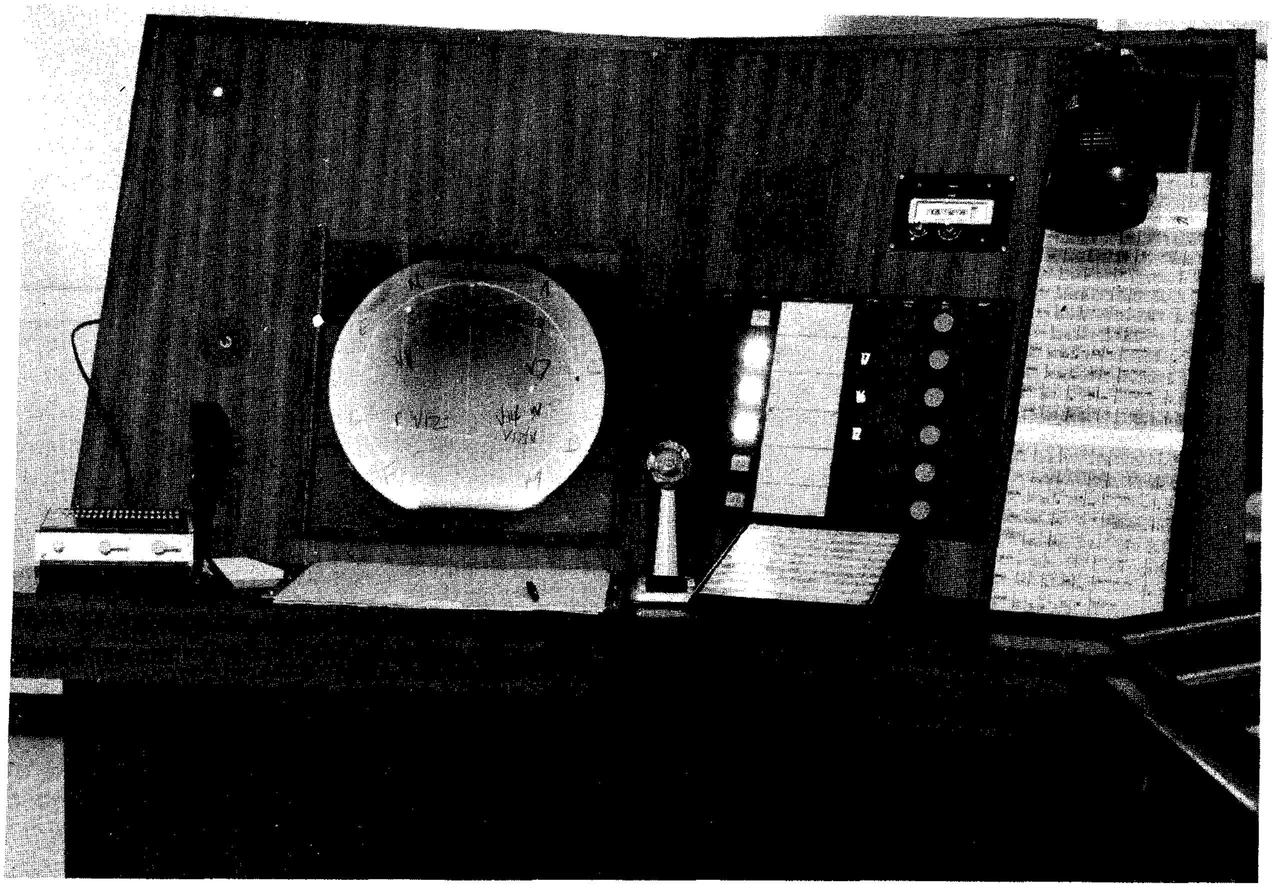

Figure 2. Radar ATC task console.

The animation technique involved still photography, using a Robot 18MB filmstrip camera, of small metal chips set on a flat-black, 19-in.-diameter circle of cardboard, with airways being represented by strips of 1/16-in.-wide, red chart tape. Processing of the Plus X film used was in modified DK 50–1:1. The metal chips were appropriately painted with bands of white, black, and shades of gray to simulate trails from which airspeed and direction of travel could be inferred. A magnetic backing to the chips permitted accurate positioning to the cardboard mounted upon thin sheet metal. For each photograph, targets were advanced individually by hand using plastic index strips calibrated for airspeeds ranging from 300 to 600 knots. The range represented by the control sector was established as 100 mi.

Filmstrips are rear-projected from a distance of 27 in. onto Polacoat lenscreen using a DuKane Model 576–47B projector equipped with a Buhl Microwide 612–380 lens. Filmstrip advance is programmed to occur every 10 sec and is accomplished rapidly by Geneva mechanism. The radar visual display appears within a 11-3/4-in.-diameter circle.

Traditional flightstrips give flight plan and altitude information. Aircraft carry fictional identifications (e.g., HR=Horizon, DX=Dixie) to eliminate familiar associations. Flightstrips for "active" aircraft are placed in a small rack in front of the operator, while those not current are stored to the right in a bay slanted at 60°.

The auxiliary display panel located to the right of the radar screen contains indicators that are to be associated with up to six aircraft targets. A green flashing light in the first column announces the "entry" of a new aircraft. Pressing the indicator stops the flashing light and, in turn, illuminates an adjacent, numbered "beacon-code" indicator. This is followed, shortly, by the activation of a digital readout indicating the flight altitude (in thousand feet) of the aircraft. Programmed altitudes vary from 11,000 to 22,000 ft. If the displayed altitude should change during the problem to a value different from flight plan, the subject is required to depress a blue "altitude check" button next to the indicator. Another subtask requires pressing of a related, yellow "route-check" button if an aircraft's track changes to an incorrect heading after clearing an intersection. In both of these later subtasks, detections made within 30 sec are signalled by illumination of the indicator. Deviations are all programmed for self-correction within 30 sec. The last column contains a red "handoff" button to be depressed within 10 sec of a target's appearance over a handoff point. Pressing the button at the correct time illuminates it, and within 30 sec the panel row is cleared for entry of the next aircraft. Failure to respond to either an entry or handoff within 10 sec is signalled by a buzzer. A white plastic strip, next to the beacon-code column, provides the subject with a space to make grease-pencil notations as needed.

To the left of the radar screen is a light gun to be used to "interrogate" bogey aircraft that appear, unannounced, off an airway. To test the operator's attention to peripheral events, a red "fail-safe" warning light (located at the top of the console), normally "on," is periodically programmed to begin flashing for 30 sec. It is to be reset by movement of a lever switch immediately below. The distance from the light to the exact center of the projected radar display is 22 in.

Tape-recorded voice communications from "pilots" announce over a speaker the aircraft entries and position reports. A digital clock is available on the console for reference. Subjects are asked to acknowledge all transmissions and repeat estimates, using a desk-stand microphone.

A rack to the subject's right is used for "deadwood." In addition to the lighting produced by the projector, a 40-w lamp mounted at the top right of the console provides illumination of the flight strips. Intensity of illumination in the test rooms is somewhat less than that found in ARTCC's but greater than that found in IFR rooms. Typical (average) brightness readings, taken with a Spectra brightness spot meter, were as follows: airway reference map on desk, 0.40 ft-l; strips at desk level, 2.32 ft-l; strips in vertical rack, 3.62 ft-l (range 0.41 bottom to 11.50 top); white plastic strip, 0.58 ft-l; clock, 4.42 ft-l; altitude readouts, 2.40 ft-l; illuminated beacon code, 169.1 ft-l; radar targets, 3.85 ft-l (range 1.30 to 6.68); and intersection markings, 0.86 ft-l. Orange filters are used over the lamp and radar screen.

B. *Programming and Scoring.* Task programming is accomplished through relay circuitry selected by codes punched in paper tape that is pulsed every 10 sec to advance through a tape reader (Figure 3). The tape code also controls the advance of the filmstrip projector. Whenever a critical event (e.g., altitude deviation) is programmed to occur at a console, a reference signal activates electronic counters. A subject's correct response stops the counter, which, after all counters are stopped or after 30 sec, is scanned and reset by a coupler. The stored values, now in binary-coded-decimal format, are then released to a Friden Flexowriter (Figure 1), which types the time of the event occurrence within the test hour, a coded event identification, and all subject response times in hundredths of a second. The Flexowriter also punches all data on paper tape for reference. Figure 4 is a flow diagram illustrating the essential programming events.

A bank of counters and timers (Figure 3) cumulates the frequency and duration of subject communications in response to recorded pilot "reports" played from the tape recorder shown.

C. *Problem Characteristics.* Seven, hour-long, punched-tape problems were prepared from detailed scripts. On the average, each problem requires the subject to handle 30 aircraft, thereby entailing 30 responses each to entries and handoffs (the latter were not timed). Target load never exceeds six active aircraft (not counting bogey targets) and is never less than one aircraft at any one time. Time of entry and direction of flight are distributed irregularly, with an attempt being made to avoid a concentration of targets in any one area of the display. The altitude and route check, warning light, and bogey subtasks were each programmed to occur once within every 10-min block of time, with the time of their occurrence within each block being distributed irregularly.

Table 1 presents summaries of basic operator workloads, in terms of event rate, which characterize each of the seven problems used in our studies. These workloads are imposed by the flight plans and nature of the control sector (i.e., number of airways and intersections and their configuration) associated with each problem. Each of the seven subtables shown in Table 1 sum-

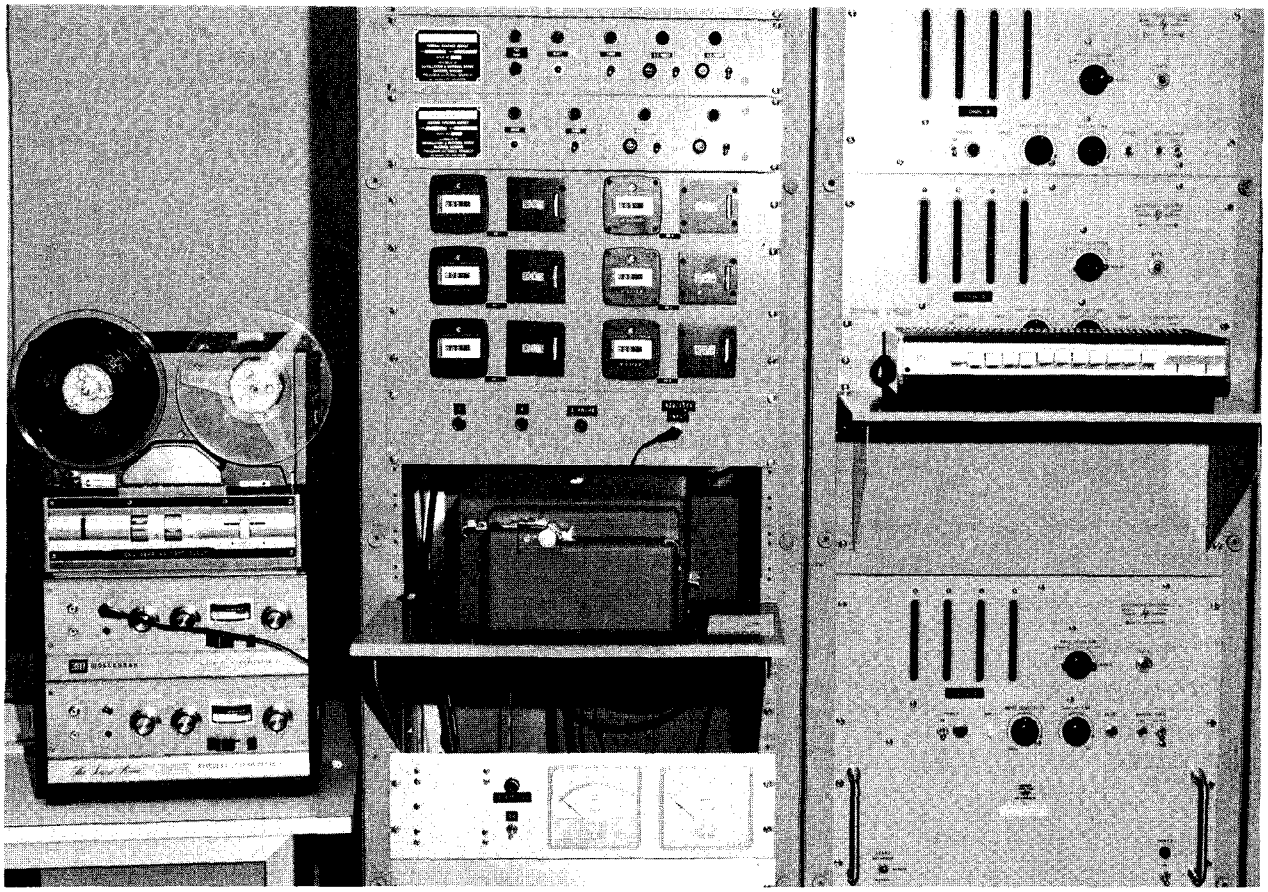

FIGURE 3. Audio and tape-reader inputs.

marizes the event rate load for one ATC problem; the subtables do not reflect increases in workload imposed by programmed deviations from flight plans. The column at the left of each set of subtables lists the events making up each problem: (1) *Entries* refers to the number of new aircraft scheduled to appear on the radar screen. Starred-entry frequencies during the first 10 min of the problem indicate that the frequency includes aircraft already on the radar screen when the problem began; this never exceeds two aircraft. (2) *Intersection crossings* indicates the number of times aircraft pass through intersections without changing airways; the operator must monitor intersections to detect unauthorized route changes and to ensure that aircraft are following their flight plan in terms of time and direction. (3) *Airway changes* refers to scheduled or planned airway changes. The ATC operator must watch intersections to ensure that scheduled airway changes take place. (4) *Voice transmissions* refers to the number of voice transmissions the ATC operator must acknowledge. (5) *Handoffs* refers to the number of aircraft whose responsibility the ATC operator must transfer as they leave his area of control. The entries in the main body of each subtable are the number of events of a given class occurring during each successive 10-min subperiod of the problem. The total number of events per 10-min subperiod (within-column) can be taken as an indicator of amount of operator task loading. Summarized at the bottom of each subtable are the characteristics of the airway sector the operator must monitor during the problem in terms of the number of airways and airway intersections.

For those desiring additional insight into the development of a problem, Appendix A contains a complete script for a single problem with complete associated flightstrip, voice-transmission, and airway data.

Appendix B contains details on the electrical-engineering design and operation characteristics of the system.

Table 1. Summary of ATC operator basic work load.

Problem 1

Events	10-min subperiods 1	2	3	4	5	6	Total events
Entries	6	5	4	5	4	4	28
Intersection crossings	7	7	6	7	9	8	44
Airway changes	2	0	3	1	0	2	8
Voice transmissions	15	11	14	12	14	14	80
Handoffs	2	4	7	2	5	5	25
	No. airways: 6 No. intersections: 5						

Problem 2

Events	10-min subperiods 1	2	3	4	5	6	Total events
Entries	7*	5	5	5	4	5	31
Intersection crossings	7	5	8	7	5	6	38
Airway changes	1	3	1	1	4	1	11
Voice transmissions	13	13	14	13	14	12	79
Handoffs	2	4	6	6	3	5	26
	No. airways: 6 No. intersections: 4						

Problem 3

Events	1	2	3	4	5	6	Total events
Entries	7*	7	4	6	4	5	33
Intersection crossings	9	8	10	6	11	8	52
Airway changes	2	4	4	3	4	3	20
Voice transmissions	16	19	17	17	18	16	103
Handoffs	3	6	6	4	6	6	31
	No. airways: 7 No. intersections: 7						

Problem 4

Events	1	2	3	4	5	6	Total events
Entries	8*	5	6	3	5	6	33
Intersection crossings	8	12	7	8	9	8	52
Airway changes	1	0	3	1	1	1	7
Voice transmissions	15	17	17	12	13	16	90
Handoffs	4	5	5	5	5	3	27
	No. airways: 6 No. intersections: 6						

Problem 5

Events	10-min subperiods 1	2	3	4	5	6	Total events
Entries	8*	4	6	4	4	6	32
Intersection crossings	8	9	6	7	9	6	45
Airway changes	1	1	3	2	1	2	10
Voice transmissions	15	14	14	14	15	14	86
Handoffs	2	5	5	6	5	4	27
	No. airways: 6 No. intersections: 5						

Problem 6

Events	10-min subperiods 1	2	3	4	5	6	Total events
Entries	8*	4	4	6	3	6	31
Intersection crossings	6	8	9	7	7	10	47
Airway changes	1	0	1	1	1	0	4
Voice transmissions	14	10	14	14	13	15	80
Handoffs	2	6	4	5	3	5	25
	No. airways: 5 No. intersections: 5						

Problem 7

Events	1	2	3	4	5	6	Total events
Entries	8*	4	5	4	6	4	31
Intersection crossings	5	6	6	6	7	4	34
Airway changes	2	1	1	1	1	2	9
Voice transmissions	12	11	11	12	14	10	70
Handoffs	2	6	4	4	5	5	26
	No. airways: 5 No. intersections: 4						

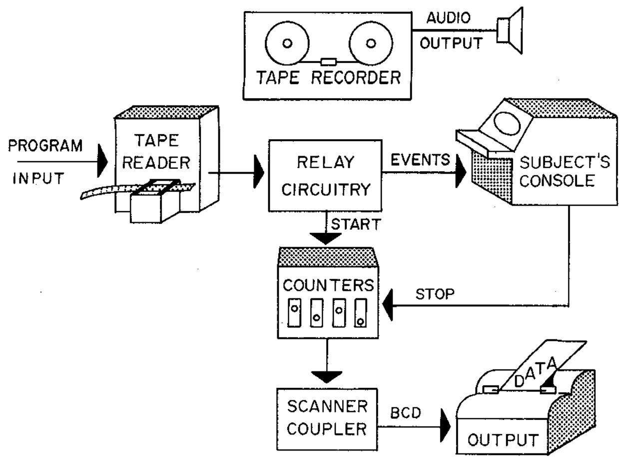

FIGURE 4. System flow diagram.

III. Experiment I.

The purpose of the initial study was twofold: (a) to measure and compare the amount of learning by different types of subjects over 9 hr of practice; (b) to check equipment and experimental procedures under prolonged operational conditions.

A. *Method.* Six instructors from the FAA Academy volunteered to serve as subjects with the knowledge they would be paid an hourly overtime rate for their participation. The three tested the first week were experienced flight-service personnel, familiar with ATC phraseology and flightstrips, but having no radar-control experience. The three tested the second week were terminal ATC controllers with radar experience, but having no work history in enroute (center) control. Five of the subjects clustered in age around 30 yr, while the sixth, an FSS instructor, was in his 50's.

The FSS group was tested the first week on Tuesday, Thursday, and Friday evenings; the terminal group was tested on Monday, Tuesday, and Wednesday evenings of the following week. Subjects reported to the laboratory at 6 p.m. On the first evening for each group, an initial hour was devoted to task indoctrination and demonstration by the experimenter using a practice problem. Prior to the start of each problem, subjects were given time to arrange their flightstrips, study their control-sector airways map, and mark the radar screen as desired. Three 1-hr problems were run each evening separated by 15-min "breaks." Six different problems were involved in the testing, with those from Day 1 being repeated on Day 3. During the breaks, the experimenter informed each subject individually of signals missed in the problem just completed.

B. *Results.* Figures 5 and 6 show the plots for the two test groups of the response times averaged over each hour for each of the five scored subtasks. The separate curves all show a general decline with time, reflecting task learning, and indicate the relative difficulty of the subtasks. The flashing entry light is certainly the most perceptible stimulus event and provokes a quick response. Increased response times appear to follow in the order (a) warning light, (b) bogey, (c) route check, and (d) altitude check. It had been predicted that route check would produce the highest response times due to the amount of attention and forethought needed to anticipate a deviation; however, subjects presumably were able with training to learn to monitor traffic effectively at the time when deviations could be expected. On the other hand, subjects apparently devoted less attention to scanning of the auxiliary panel where altitude deviations were to be detected.

Irregularities apparent in the two figures are felt to be a function of (1) changes in orientation toward the task as subjects concentrate on one subtask this hour (at the expense of others), a second

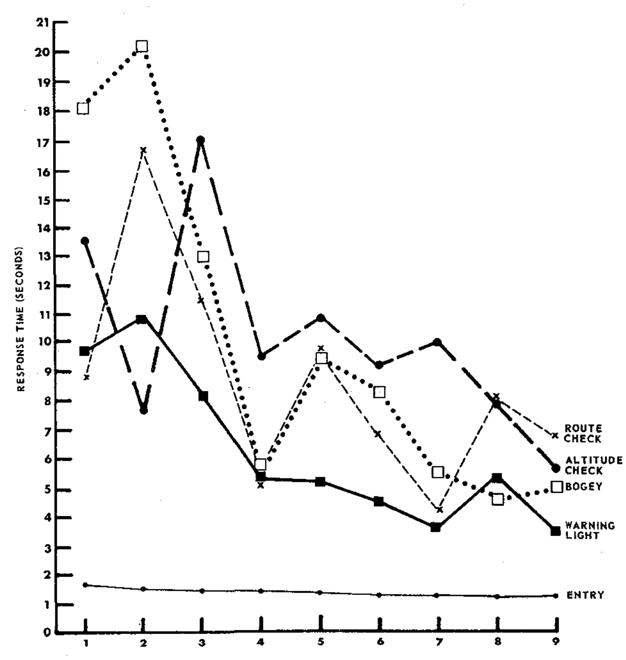

FIGURE 5. Radar ATC task learning by terminal instructors.

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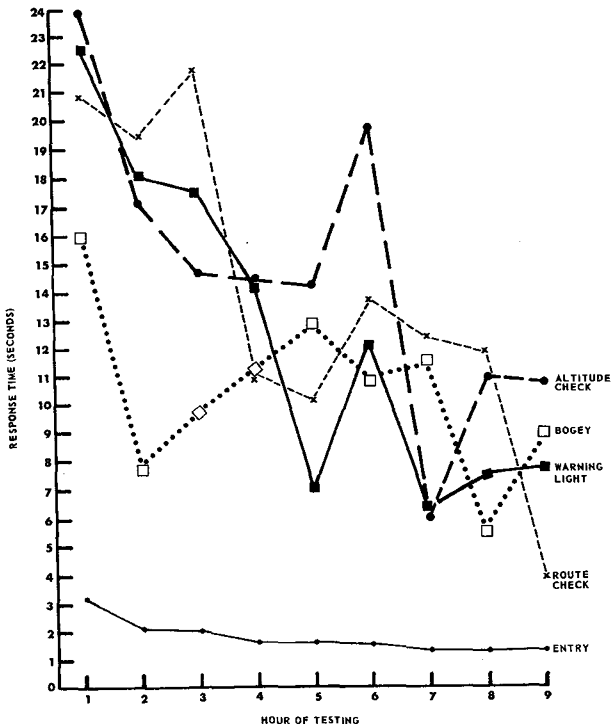

FIGURE 6. Radar ATC task learning by FSS instructors.

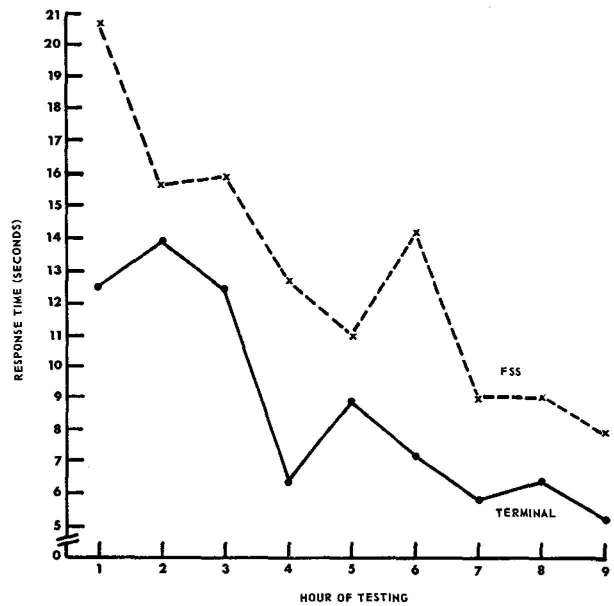

FIGURE 7. Test-group comparisons: Average of four monitoring subtasks (altitude and route check, bogey, warning light).

subtask the next hour, etc., (2) tiredness produced by a full day's work of teaching in their own laboratory, and (3) the small number of subjects represented by each point. Note that a few missed signals, each involving 30 sec of error, could have a marked effect on the mean values* plotted.

By Day 3 (Hours 7, 8, 9) subjects are apparently reaching the point of subtask integration and overall task mastery. Perhaps this state would have been more evident at an earlier point in time if testing could have been conducted under more ideal conditions (i.e., daytime) with training distributed over several days. Achievement of a stable level of performance by Day 3 is also suggested by the curves of Figure 7, which compare the response time means of the four monitoring subtasks other than entries for the two test groups. This figure also clearly reveals a higher level of performance by the terminal group as contrasted with the FSS group. Such a result, if attributed to the different experience backgrounds of the two groups, would appear to validate the design of the experimental task as one involving radar ATC task elements, or, put another way, as one requiring human functions or abilities similar to those needed by radar ATC personnel.

The superiority of the terminal subjects appears to prevail for all subtasks as seen in Figures 8 to 12. This is surprisingly true even in the case of the simplest response, that to entries. One point that perhaps requires explaining is the initial, poor response to bogey targets evidenced by the terminal subjects in Figure 12. From posttest debriefing, this was related to an initial tendency on their part to ignore all traffic except that under ATC jurisdiction, a tendency characteristic of their real-life controller's task.

The final chart, Figure 13, shows the duration and frequency of voice communications plotted

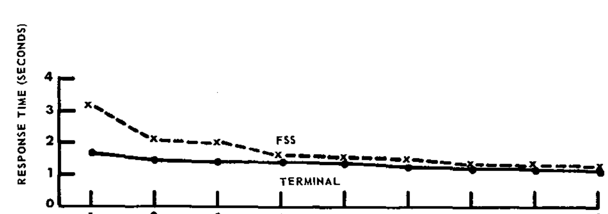

FIGURE 8. Test-group comparisons: Entries (radar ATC task).

*Because of extreme scores, the median statistic would be a more appropriate reflection of behavior during the first few hours of testing; however, the mean was considered to be the better overall index of task proficiency for the 9-hr period.

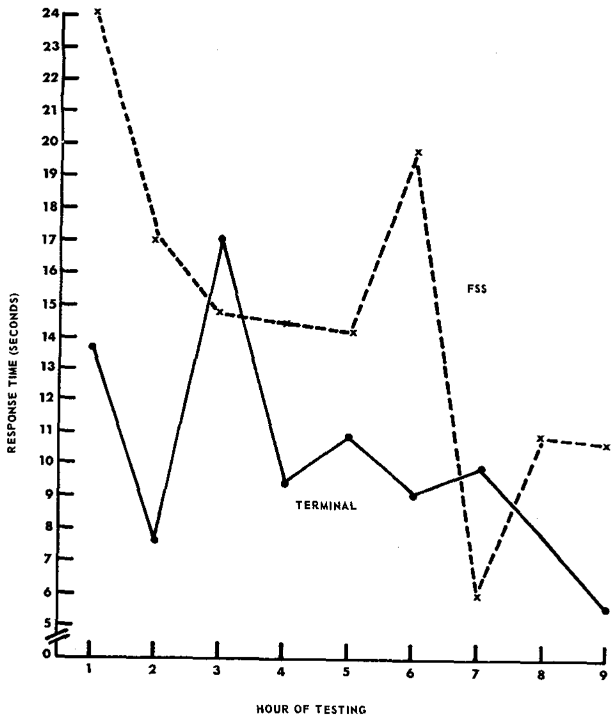

FIGURE 9. Test-group comparisons: Altitude checks (radar ATC task).

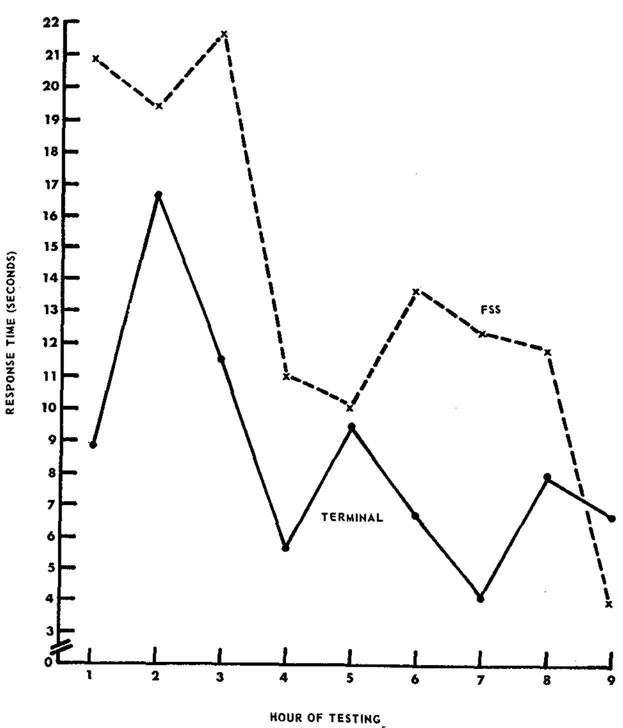

FIGURE 10. Test-group comparisons: Route checks (radar ATC task).

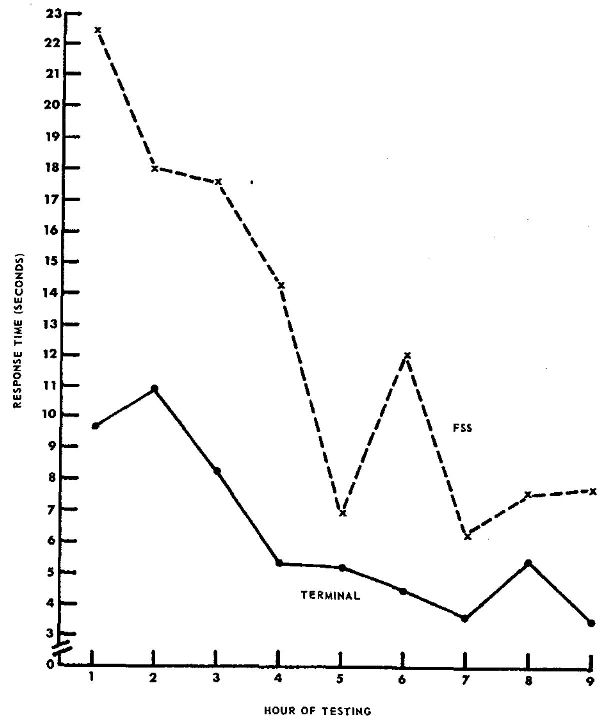

FIGURE 11. Test-group comparisons: Warning light (radar ATC task).

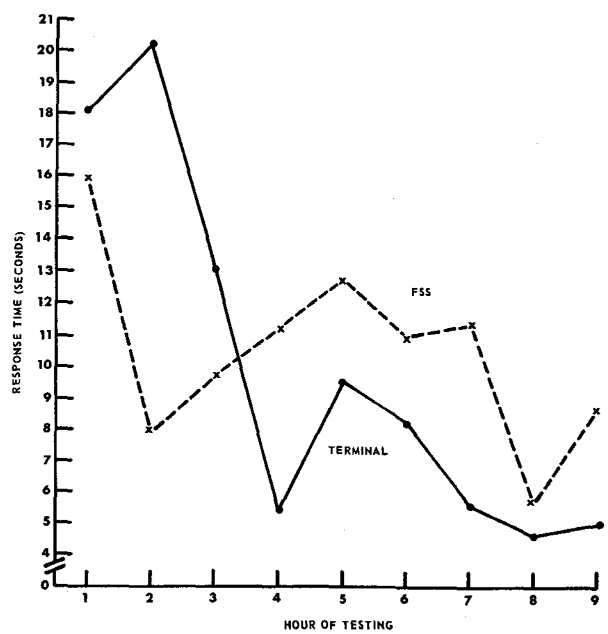

FIGURE 12. Test-group comparisons: Bogey targets (radar ATC task).

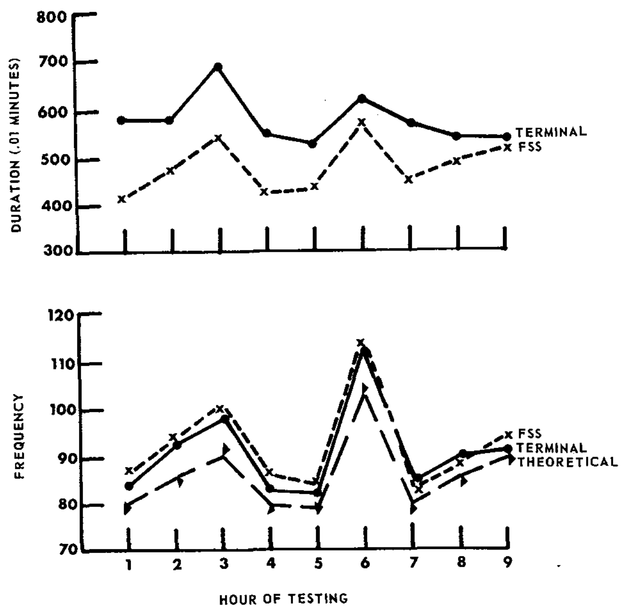

FIGURE 13. Voice-transmission data: Group comparisons (radar ATC task).

for each hour. The frequency plots give the mean number of times the subjects of the two groups pressed the microphone talk button. The theoretical curve is based on a single response to each incoming pilot report. Apparently subjects in some instances press the bar more than once to complete a transmission. This could be taken as an index of lapsed attention. If so, the FSS subjects are generally more "guilty" in this regard. Although responding more frequently, the FSS subjects apparently talk less when they do initiate a call than do the terminal subjects; this is apparent from the plots for the duration data at the top of the figure. Put another way, the rates of duration to frequency suggests that terminal subjects were able to get more into their messages. This could reflect a greater ability to time-share the activities involved in their task.

The problems used in testing during Hours 1, 2, and 3 were identical to those used, respectively, in Hours 7, 8, and 9. The curves of Figure 13 reflect this fact and, in part, provide some support for the repeatability or test-retest reliability of the task. At least there is some evidence that the subjects were responding to instructions. Looking back at Figures 5 through 12, one can also appreciate the performance improvement on these identical problems that occurs between Day and Day 3.

IV. Experiment II.

As noted above, the performance curves permit doubt as to whether a stable baseline of performance had been achieved in the latter 3 hr of testing. Questions naturally follow as to whether (a) performance would stabilize earlier as a function of practice being less concentrated in time, and (b) additional practice would confirm such stability, perhaps at a lower level. There also was an interest in determining how enroute ATC controlers would perform at the task. These considerations formed the basis for the second study.

A. *Method.* Three instructors from the FAA Academy volunteered as subjects and were paid an overly overtime rate. All were experienced in enroute ATC work. Their ages were 38, 44, and 45.

Indoctrination and the first hour of testing were on a Friday. Two-hour sessions, from 5 to 7 p.m. immediately following the work day, were then conducted the next week on Monday, Wednesday, and Friday, and a second week on Tuesday, Wednesday, and Thursday, thereby providing a total of 13 experimental hours. The 2-hr sessions, it should be noted, were a compromise from desires to have scheduled daily, single-hour, "distributed-practice" test sessions. Task procedure was as described before, with 15-min intervals between problems. Seven problems were used in testing, with those from Hours 1 to 6 being repeated for Hours 8 to 13.

B. *Results.* Figure 14 shows the plot of the response times averaged over each hour for each of the five scored subtasks, together with the plot of the response-time means of the four monitoring subtasks other than entries. The latter curve would suggest that a stable baseline of performance is reached by these subjects at Hour 8. Generally, it appears that, compared to the FSS and terminal subjects, the enroute group (1) takes longer to reach baseline, (2) tends to perform somewhere midway between the two groups through Hour 7, but (3) thereafter is superior in performance to both. The greater struggle evidenced by the enroute group in reaching baseline was unanticipated. One conjecture is that habit interference during early stages of practice precluded an efficient integration of subtasks. In any event, it would seem that this study failed to shed any light on the value of less concentrated practice. Otherwise, the relative difficulty of the sub-

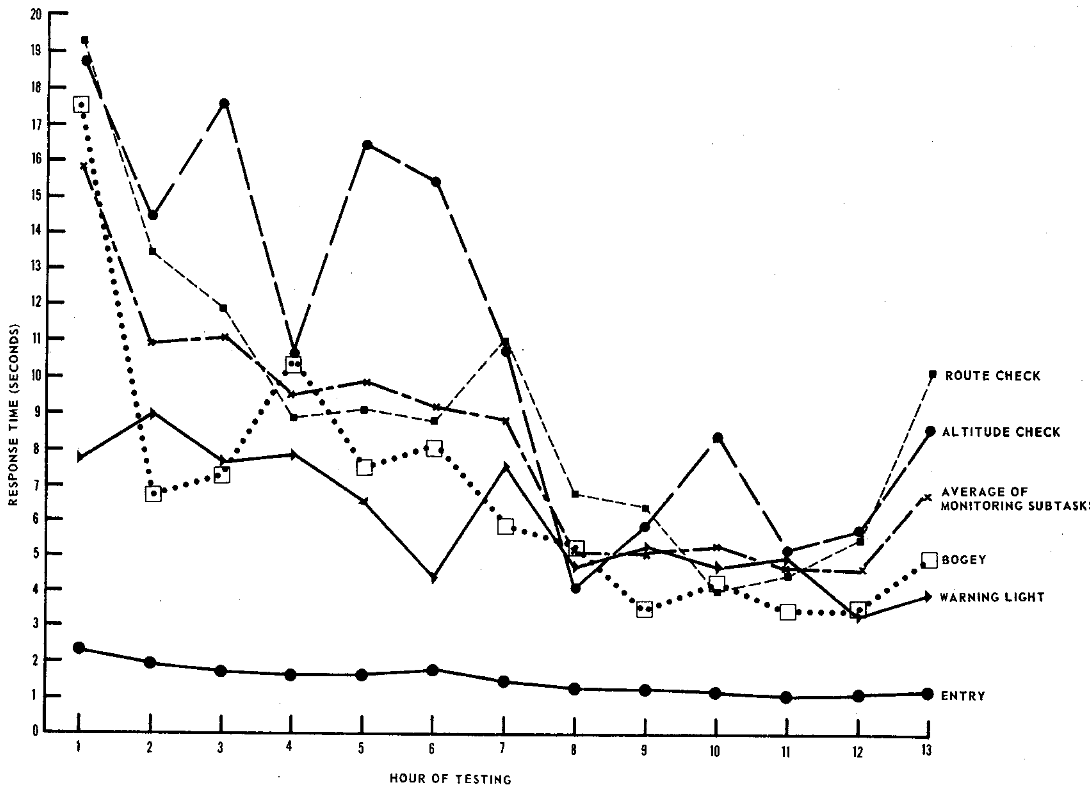

FIGURE 14. ATC task learning by enroute instructors.

tasks, as indicated by the separate curves of Figure 14, appears comparable to the earlier results. The voice-transmission data, Figure 15, reveal that duration and frequency of voice transmissions for the enroute group are lower in contrast to the FSS and terminal subjects. This could be a reflection of succinct, yet more complete, communications.

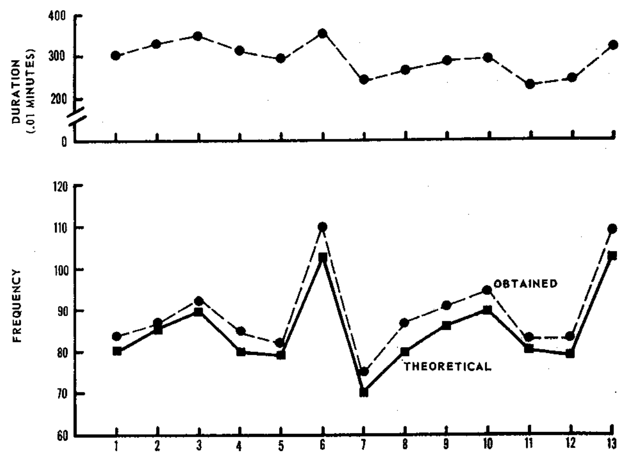

FIGURE 15. Voice-transmission data: Enroute instructors radar ATC task.

V. Discussion.

From the results of initial testing and subject critiques, the task and its programs seem fully suited to the purposes for which they were designed. Because of the number of skills the task requires and because of the relative ease with which a number of subjects can be tested, the task should warrant consideration in any exploratory test programs related to improved controller selection, screening, or proficiency appraisal. There was no attempt in this initial study to look at the relationship between age and performance, but a study of age-related functions should provide some further understanding of the growing body of evidence that air traffic control is a "young man's game."

One feature of the experimental task that should be of interest to training personnel is that, from the outset of testing, the subject is forced to begin learning a large number of task functions, or subtasks, in an attempt to stay ahead. The concept of whole-task learning here, of course, is quite different from the initial, part-task learning traditionally given to prospective controllers. The irregularities apparent in the separate subtask curves presented above, although no doubt in part a function of the small number of measures represented at each point, can be taken as evidence for the struggle for whole-task learning that involves subtask integration. Initially success at monitoring one subtask may mean that another subtask is being monitored poorly. Failure to respond to entries or handoffs provokes a buzzer that can motivate the subjects in future problems to try to reduce the number of missed signals. Generally, initial performance appears disorganized with the subject switching his concentration from one subtask to another as he becomes aware of his errors. Later, with experience at the task, he refines his approach, develops search patterns, and organizes his activities.

In accord with the above logic, a simpler, less-expensive version of the task could be considered for facility testing, with a minimum amount of attention required by training personnel. For example, a filmstrip projector is manufactured with a record-player attachment that employs prerecorded, inaudible tones to advance the film. Animated filmstrips and phonograph records containing hypothetical, synchronized pilot communications could be produced in quantity for distribution to and circulation among facilities. There, such materials could be used in automated training of groups of controllers who would be required to detect conflictions, practice proper use of strip-marking or phraseologies, identify erroneous position reports, etc.

To extend our own test-program capability, we have recently made use of an optical, photographic technique. The equipment produces new filmstrips from the masters at any desired angle of rotation. With three rotations, for example, we effectively have four programs with identical target workloads, differing only in terms of the appearance of airways and of the direction of target movement. Tape-recorded audio communications and flightstrip notations, except for location identifiers, do not have to be revised. Such a capability now permits day-to-day comparison of performance under comparable environmental and task conditions, while controlling for possible memory effects.

Initial experience with the task system dictated two desirable changes. The first was replacement of the console-mounted projectors with television monitors. This alleviates two problems: (a) noise from the projector relay that could serve as a cue to the subject of the change in display; (b) the considerable time and effort required to change filmstrips at all six consoles between hourly tests. Filmstrips are projected directly into a television camera for distribution to the monitors. The second change involved eliminating the use of the traditional flightstrip holder and going to a new card format that can be inserted into spring-clip fasteners on the plastic strip area located in the auxiliary display panel (see Figure 2). We have found that the flightstrips used initially required a good deal of "busy-work" (e.g., handling and marking) that appeared to detract from the operator's efficiency, thereby precluding a purer understanding of his critical task behaviors.

To date, interests of systems engineers and operations personnel have suggested several other uses for the system in studies related to controller proficiency, including research on target characteristics such as size and sharpness, workload as a function of number of targets and speed (e.g., supersonic transport) of targets, control techniques and sector arrangement, and display design. In particular, we feel that experience with the system will contribute to human-engineering knowledge in the particular area of work stations, insofar as it involves such questions as how does one design displays to attract attention, what pattern of efficient search can be recommended, and what is the optimum layout of displays.

APPENDIX A*

SAMPLE ATC PROBLEM

This section describes the script and associated material that form the basis for the ATC task research problem. Included are: (1) a representative ATC event script (Table A1) listing in time sequence (a) all events to which the ATC subject must *attend*, (b) those events to which he must *respond*, and (c) those events that are *timed* and *scored;* (2) a listing (Table A2) of all flight-strip data by entry order and flight number; (3) a listing (Table A3) of all voice transmissions from aircraft that the ATC subject receives; (4) an airway diagram (Figure A1) for the problem; and (5) representative flight strips (Figure A2) that have been used with the problem.

Table A1 is arranged in three columns: *Time*, *Event Record*, and *Voice Transmissions*. The *time* column shows that each problem begins at 0000 min and ends at the end of 5950 min. It also shows that events are updated every 10 sec. In the *Event Record* column opposite each 10-sec segment are listed the events occurring therein. Events preceded by an (X) indicate an event to which

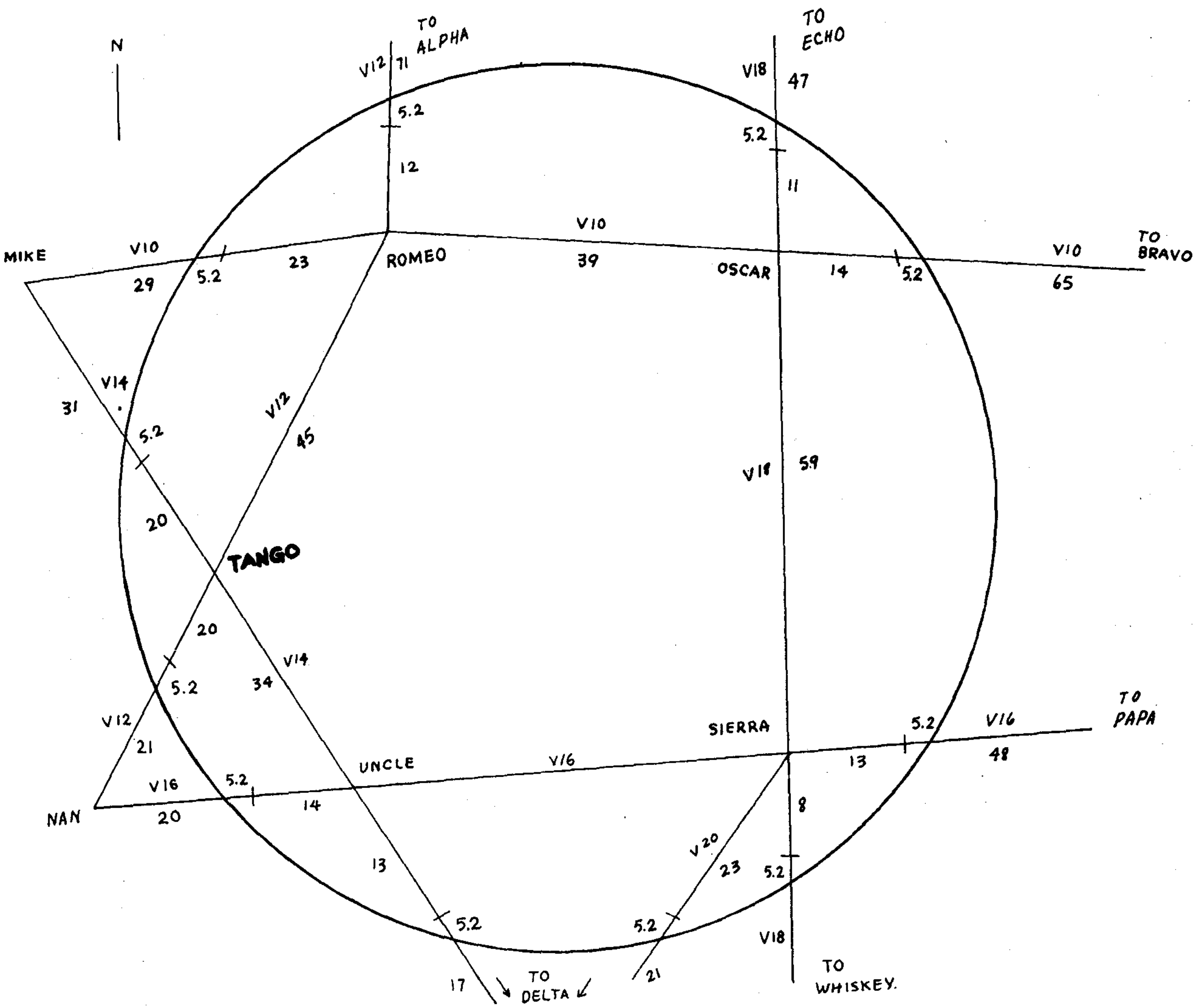

FIGURE A1. Airway configuration.

*Prepared by Gilbert L. Neal.

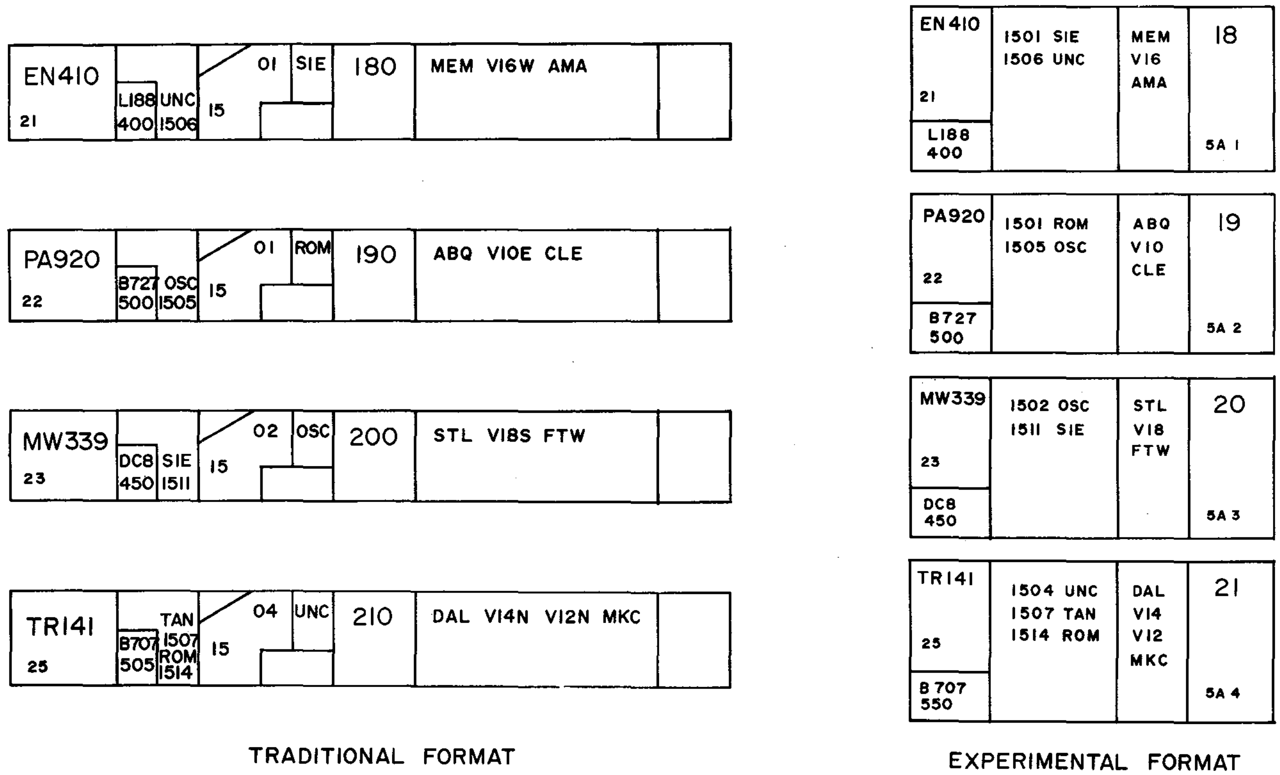

FIGURE A2. Flightstrip formats.

the ATC subject must make a prescribed overt response, such as pressing a button to acknowledge the entry of a new aircraft on the radar screen. *Underlined* "X-ed" events are timed and scored. All events must be observed and evaluated since each subject must decide whether a response is required. The abbreviation "EL" means that an entry light flashes; the number with it refers to the location of the entry light. The abbreviation "FS" and a number refer to flightstrips listed in Table A2, where full flight-plan information on an aircraft is given. The *Voice Transmission* column of Table A1 lists the code for each transmission (VT) scheduled to be presented to the subject; complete content of all voice transmissions is given in Table A3.

It should be noted that airline designations in Table A2 are fictitious; i.e., EN . . . Enco; DX . . . Dixie; MW . . . Midwestern; TR . . . Transcontinent; MX . . . Mexico; BR . . . Branner; HR . . . Horizon; SE . . . Southeastern; and PA . . . Pacific. "A", "V", and "N" stand for Airforce, Navy, and nonairline VFR flights, respectively.

TABLE A1. Event script: Sample ATC problem.

Time	*Event record*	*Voice transmission*
	Air Traffic Status at 0000:	
	EN 410, V16, ovr Sierra, 18,000 (FS #1)	
	PA 920, V10 ovr Romeo, 19,000 (FS #2)	
0000	Start Problem	
10	(X) *EL #3*	VT #1
20		
30	Enter MW339, V18, 20,000 (FS #3)	VT #2
40		
50		VT #3
0100	(X) *Bogey on*	
10		
20		
30		
40	Bogey off	
	(X) *EL #5*	
50		
0200	Enter TR141, V14, 21,000 (FS #4)	
10		
20	(X) *EL #4*	VT #[illegible]
30		
40	Enter BR950, V12, 17,000 (FS #5)	
	MW339 ovr Oscar	
50		

Time	*Event record*	*Voice transmission*
0300		VT #5
10	(X) *MW339 Altitude error (+2,000 ft)*	VT #6
20		
30		
40		
50		
0400	TR141 ovr Uncle	
	MW339 at correct altitude	
10	(X) *Fail-safe warning*	
20		VT #7
30	BR950 ovr Tango	
40		VT #8
50		
0500		VT #9
10		
20		
30	EN410 ovr Victor	
40	(X) *EL #6*	
50		VT #10
0600	Enter MX166, V18, 16,000 (FS #6)	
10		
20	(X) Handoff PA920	VT #11
30		
40		
50		
0700		
10		
20		
30	(X) Handoff EN410	
40		
50	TR141 ovr Tango	
0800	(X) TR141 *Fails to turn*	
10	MX166 ovr Oscar	VT #12
20		
30	TR141 corrects course	
40		
50		
0900	BR950 ovr Romeo	
10	(X) *EL #2*	
20		VT #14
30	Enter DX375, V14, 12,000 (FS #7)	
40		
50	(X) *EL #1*	VT #15
1000		
10	Enter HR882, V20–V18, 17,000 (FS #8)	
	Handoff BR950	
20		
30		VT #16
40	MW339 ovr Sierra	
50		
1100		VT #17
10	(X) *EL #4*	
20		
30	Enter SE191, V16, 15,000 (FS #9)	
40	(X) Handoff MW339	
50		VT #18
1200		
10		
20		
30		

Time	*Event record*	*Voice transmission*
40		
50	(X) *Bogey on*	
1300		
10		
20	DX375 ovr Tango	
30	Bogey off	VT #19
	HR882 ovr Sierra	
40	TR141 ovr Romeo	
50	(X) *TR141 incorrect turn*	VT #20
1400		
10		VT #21
20	TR141 corrects course	
30		VT #22
40		
50		
1500	(X) *EL #3*	
10		
20	Enter A11038, V12, 16,000 (FS #10)	
30		VT #23
40		
50	(X) Handoff TR141	
1600		
10	MX166 ovr Sierra	
20		
30	(X) *Fail-safe warning*	VT #24
40		
50		
1700	(X) Handoff MX166	
10		
20		
30		
40	(X) *EL #5*	
	A11038 ovr Romeo	
50	SE191 ovr Sierra	VT #25
1800	Enter EN211, V10, 18,000 (FS #11)	
10	DX375 ovr Uncle	
20	(X) *EL #6*	VT #26
30		
40	Enter TR412, V20–V18, 19,000	VT #27
50		VT #28
1900	(X) *HR882 Wrong altitude (+1,000)*	
10		VT #29
20	(X) Handoff SE191	
30		
40		
50	HR882 at correct altitude	
2000	(X) Handoff DX375	
10	EN211 ovr Oscar	
20		VT #30
30		
40	(X) *EL #4*	
50	HR882 ovr Oscar	
2100	Enter HR113, V10–V12, 14,000 (FS #13)	
10		VT #31
20		
30		
40	TR412 ovr Sierra	
50	(X) *TR412 wrong turn*	
2200		VT #33

Time	Event record	Voice transmission
10		
20	(X) Handoff HR883, TR412 course corrected	
30		
40		
50	(X) *TR412 at wrong altitude (−1,000)*	
2300		
10		
20	HR113 ovr Oscar	VT #34
30	(X) *Bogey on*	
40	TR412 at correct altitude	
50		
2400		VT #35
10	Bogey off	
20	(X) *EL #2*	
30	EN210 ovr Romeo	
40	Enter MW314, V14–V12, 20,000 (FS #14)	
50		VT #36
2500	(X) *Fail-safe flashes*	
10		VT #37
20		
30	(X) Handoff A11038	
40		
50	(X) *EL #1*	
2600		
10	Enter V61588, V16, 13,000 (FS #15)	
20		
30	(X) *EL #3*	VT #38
40		
50	BR416, V20–V16, 15,000 (FS #16)	
2700	(X) Handoff EN211	
10		
20		VT #39
30		
40	HR113 ovr Romeo	
50		
2800	(X) *EL #5*	VT #40
10		
20	Enter N81778, V14, 19 (FS #17)	
30		
40		VT #41
50	Handoff HR113	
2900	MW314 ovr Tango	
	V61588 ovr Uncle	
10		
20	TR412 ovr Oscar	VT #42
30		
40	(X) *EL #4*	VT #43
50		
3000	Enter PA118, V12–V10, 16,000 (FS #18)	VT #44
10		
20		VT #45
30	N81778 ovr Uncle	
40	(X) Handoff TR412	
50		VT #46
3100		
10		
20	(X) Handoff MW314	

Time	Event record	Voice transmission
30		
40		
50	(X) *N81778 at wrong altitude (+1,000)*	
3200	PA118 ovr Romeo	
10		
20	BR416 ovr Sierra	VT #47
30	(X) *BR416 wrong turn*	
40		VT #48
50	N81778 at correct altitude	
3300	BR416 corrects course	
10	(X) *EL #6*	
20		
30	Enter EN819, V18, 21,000 (FS #19)	
40	V61588 ovr Sierra	
50	(X) *EL #2*	VT #49
3400		
10	Enter A12004, V16, 17,000 (FS #20)	VT #50
20		
30	(X) Handoff PA118	
40	N81778 ovr Tango	
50		
3500		VT #52
10	EN819 ovr Sierra	
	(X) Handoff V61588	
20		
30		VT #53
40	(X) *EL #4*	
50		
3500	Enter SE121, V12–V14, 18,000 (FS #21)	
10		
20	(X) Handoff BR416	VT #54
30		
40	A12004 ovr Uncle	
50	(X) Handoff N81778	VT #55
3700		
10		
20		
30		
40		
50	(X) *Bogey on*	
	SE121 over Romeo	
3800		
10		VT #56
20		
30	Bogey off	
40	(X) *EL #1*	
50		
3900	Enter HR222, V10, 20,000 (FS #22)	
10		
20	(X) *Fail-safe flashes*	VT #57
30		
40		
50		
4000	(X) *EL #3*	
10		
20	Enter TR623, V14, 21,000 (#23)	
30		
40	(X) *EL #5*	VT #58
50		

Time	Event record	Voice transmission
4100	Enter N32441, V12, 12,000 (FS #24)	
10	A12004 ovr Sierra	VT #59
20	HR222 ovr Oscar	VT #60
30		
40		VT #61
50		
4200	EN819 ovr Oscar	
10		VT #62
20		
30	TR623 ovr Uncle	
40	SE121 ovr Tango	VT #63
50	(X) Handoff A12004	
4300		VT #64
10		
20	(X) Handoff EN819	
30		
40	N32441 ovr Romeo	
50		
4400		VT #65
10	(X) *Bogey on*	
20		
30		
40		
50	Bogey off	
	(X) *EL #2*	
4500		
10	Enter BR425, V10, 18,000	
20		
30	(X) *EL #6*	*VT #66*
40		
50	Enter DX826, V20–V18, 21,000 (FS #26)	
4600		
10	(X) *N32441 at wrong altitude (+1,000)*	VT #67
20	TR623 ovr Tango	
30	HR222 ovr Romeo	VT #68
40	SE121 ovr Uncle	
4700	(X) *SE121 wrong turn*	
10	N32441 at correct altitude	VT #70
20		
30	SE121 corrects course	
40	BR425 ovr Oscar	
50		
4800	(X) *Fail-safe flashes*	VT #71
10		
20		
30	(X) Handoff TR623	
40		
50		
4900	(X) Handoff SE121	
10		VT #72
20		
30		
40	(X) Handoff HR222	
50		
5000		VT #73
10		
20	(X) *EL #3*	
30		
40	Enter MW630, V18, 17,000 (FS #27)	
50		
5100	(X) *Fail-safe flashes*	VT #74
10		
20		
30		
40		
50	(X) Handoff N32441	
5200		
10		
20	(X) *El #4*	
30		
40	Enter MX128, V16, 19,000 (FS #28)	
50		
5300	BR425 ovr Romeo	VT #75
	(X) *EL #1*	
10		VT #76
20	Enter A92900, V16, 20,000 (FS #29)	
30		
49	(X) *EL #5*	VT #77
50		
5400	Enter EN327, V18, 17,000 (FS #29)	
10		VT #78
20	(X) *A92900 wrong altitude (+2,000)*	
30		
40		
50	MX128 ovr Uncle	VT #79
5500	MW630 ovr Tango	
10	(X) *MW630 wrong turn*	
20	A92900 at correct altitude	VT #80
30	(X) Handoff DX826	VT #81
40	MW630 corrects course	
50	EN327 ovr Sierra	
5600		
10	(X) Handoff BR425	VT #82
20		
30		
40		
50	(X) *Bogey on*	
5700	A92900 ovr Sierra	
10		VT #83
20		
30	Bogey off	
	(X) *EL #6*	
40		
50	Enter SE131, V10, 15,000 (FS #31)	
5800		VT #84
10		
20		
30	(X) Handoff MW630	
40		
50		
5900		
10		
20	(X) *EL #2*	
30	MX128 ovr Sierra	
40	Enter N43201, V12, 19,000 (FS #32)	VT #85
50		
	STOP PROBLEM	

TABLE A2. Flightstrip data: Sample ATC problem.

1 EN410; 21; L188; 400; 1501 SIE, 1506 UNC; MEM V16, AMA; 18
2 PA920; 22; B727, 500; 1501 ROM, 1505 OSC; ABQ V10 CLE; 19
3 MW339; 23; DC8; 450; 1502 OSC, 1511 SIE; STL V18 FTW; 20
4 TR141; 25; B707; 550; 1504 UNC, 1507 TAN, 1514 ROM; DAL V14 V12 MKC; 21
5 BR950; 24; B707; 600; 1505 TAN, 1510 ROM; AMA V12 MKC; 17
6 MX166; 26; DC8; 450; 1508 USC, 1516 SIE; STL V18 DAL; 16
7 DX375; 22; L188; 400; 1513 TAN, 1519 UNC; ABQ V14 DAL; 12
8 HR882; 21; B727; 500; 1513 SIE, 1520 OSC; DAL V20 V18 CHI; 17
9 SE191; 24; B707; 550; 1514 UNC, 1519 SIE; ABQ V16 ATL; 15
10 A11038; 23; B52; 450; 1517 ROM, 1525 TAN; MKC V12 AMA; 16
11 EN211; 25; B707; 550; 1520 OSC, 1525 ROM; CLE V10 ABQ; 18
12 TR412; 26; CV88; 550; 1523 SIE, 1530 OSC; DAL V20 V18 CHI; 19
13 HR113; 24; L188; 400; 1523 OSC, 1529 ROM; ABQ V10 V12 STL; 14
14 MW314; 22; DC7; 350; 1528 TAN; CHI V14 V12 DAL; 20
15 V61588; 21; TV; 450; 1529 UNC, 1533 SIE; AMA V16 ATL; 13
16 BR416; 23; CRVL; 450; 1532 SIE; AMA V20 V16 STL; 15
17 N81779; 25; B707; 500; 1530 UNC, 1535 TAN; DAL V14 MKC; 19
18 PA118; 24; DC8; 500; 1530 ROM; STL V12, V10 AMA; 16
19 EN819; 26; CV88; 500; 1535; SIE, 1543 OSC; FTW V18 STL; 21
20 A12004; 22; B47; 450; 1536 UNC, 1540 SIE, AMA V16 MEM; 17
21 SE121; 24; B707; 550; 1537 ROM, 1542 TAN, 1546 UNC; CHI V12 V14 DAL; 18
22 HR222; 21; DC8; 450; 1541 OSC, 1547 ROM; LAX V10 PIT; 20
23 TR623; 23; B727; 500; 1543 UNC, 1546 TAN; SAT V14 CHI; 21
24 N32441; 25; L188; 400; 1544 ROM, 1550 TAN; CHI V12 AMA; 12
25 BR425; 22; DC8; 450; 1549 OSC, 1554 ROM; PIT V10 SFO; 18
26 DX826; 26; B707; 550; 1550 SIE, 1555 OSC; DAL V20 V18 STL; 21
27 MW630; 25; L188; 400; 1555 SIE, 1604 OSC; DAL V18 STL; 17
28 MX128; 24; B727; 500; 1554 UNC, 1600 SIE; SFO V16 CLE; 19
29 A92900; 21; P2V; 300; 1557 SIE, 1605 UNC; ATL V16 ABQ; 20
30 EN327; 23; DC7; 350; 1555 TAN; CLE V14 V12 DAL; 14
31 SE131; 26; CV88; 500; 1600 ROM, 1605 OSC; ABQ V10 ATL; 15
32 N43201; 22; CRVL; 500; 1603 TAN, 1609 ROM; AMA V12 MKC; 19

NOTE: Flightstrip-data order is as follows: flight number; beacon code; type aircraft; airspeed; checkpoint; flight origin, airway(s), and destination; and altitude.

TABLE A3. Aircraft voice transmissions: Sample ATC problem.

VT code	*Time*	*Voice transmission*
		Message prefix: "Oklahoma City Center this is . . ."
VT1	0010	Enco Four ten over Sierra at zero zero, one eight thousand estimate Uncle at zero five, over.
VT2	0030	Pacific nine twenty, was over Romeo on the hour at one nine thousand, estimating Oscar at zero five, over.
VT3	0050	Midwestern three thirty nine, now on your frequency.
VT4	0220	Transcontinent one forth one, listening your frequency, over.
VT5	0300	Branner nine fifty, listening your frequency, over.
VT6	0310	Midwestern three thirty nine was over Oscar at zero three, two zero thousand, estimating Sierra at one one, over.
VT7	0420	Transcontinent one forty one was over Uncle at zero four, twenty one thousand, estimate Tango at zero eight, over.
VT8	0440	Branner nine fifty was over Tango at zero four, one seven thousand, estimate Romeo at one zero.
VT9	0500	Pacific nine twenty was over Oscar at zero five, one nine thousand, estimate Bravo at one five, over.
VT10	0550	Enco four ten was over Uncle at zero five, one eight thousand, estimate Nan at one two, over
VT11	0610	Mexico one sixty six, now listening your frequency, over.
VT12	0810	Transcontinent one forty one was over Tango at zero eight twenty one thousand, estimating Romeo at one five, over.

VT code	*Time*	*Voice transmission*
VT13	0830	Mexico one sixty six was over Oscar at zero eight, one six thousand, estimate Sierra at one six over.
VT14	0920	Branner nine fifty passed Romeo at zero nine, one seven thousand, estimate Alpha at one eight, over.
VT15	0950	Dixie three seventy five now on your frequency, over.
VT16	1030	Horizon eight eighty two, now on your frequency, over.
VT17	1100	Midwestern three thirty nine passed over Sierra at one one, two zero thousand, estimate Whiskey at two zero.
VT18	1150	Southeastern one ninety one, listening your frequency, over.
VT19	1330	Dixie three seventy five was over Tango at one three, one two thousand, estimate Uncle at one nine, over.
VT20	1350	Horizon eight eighty two was over Sierra at one three, one seven thousand, estimate Oscar at two one, over.
VT21	1410	Transcontinent one forty one was over Romeo at one four, two one thousand, estimating Alpha at two four, over.
VT22	1430	Southeast one ninety one was over Uncle at one four, one five thousand, estimate Sierra at one seven, over.
VT23	1530	Air Force one one zero three eight, now listening your frequency, over.
VT24	1630	Mexico one sixty six passed Sierra at one sic, one six thousand, estimate Whiskey at two five.
VT25	1800	Air Force one one zero three eight, was over Romeo at one eight, one six thousand, estimate Tango at two five, over.
VT26	1820	Southeastern one ninety one, was over Sierra at one eight, one five thousand, estimate Papa at two five, over.
VT27	1840	Enco two eleven now on your frequency, over.
VT28	1850	Dixie three seventy five was over Uncle at one eight, one two thousand, estimate Delta at two four, over.
VT29	1910	Transcontinent four twelve listening your frequency, over.
VT30	2020	Enco two eleven was over Oscar at two zero, one eight thousand, estimate Romeo at two four, over.
VT31	2130	Horizon eight eighty two was over Oscar at two one, one seven thousand, estimating Echo at two nine, over.
VT32	2130	Horizon one thirteen listening your frequency, over.
VT33	2200	Transcontinent four twelve passed Sierra at two two, one nine thousand, estimate Oscar at two two, over.
VT34	2320	Horizon one thirteen, was over Oscar two three, at one four thousand, estimate Romeo at two eight, over.
VT35	2400	Air Force one one zero three eight, was over Tango at two four, one six thousand, estimate Nan at three one, over.
VT36	2450	Enco two eleven, was over Romeo at two four, one eight thousand, estimate Mike at three one, over.
VT37	2510	Midwestern three fourteen, now on your frequency, over.
VT38	2630	Navy six one five eight eight, listening your frequency, over.
VT39	2720	Branner four sixteen, now on your frequency, over.
VT40	2800	Horizon one thirteen was over Romeo at two eight, one four thousand, estimating Alpha at three seven, over.
VT41	2840	Nan eight one seven seven eight, listening your frequency, over.
VT42	2920	Midwestern three fourteen, was over Tango at two nine, twenty thousand, estimate Nan at three seven, over.
VT43	2940	Navy six one five eight eight, was over Uncle at two nine, one three thousand, estimate Sierra at three four, over.
VT44	3000	Transcontinent four twelve was over Oscar at two nine, one nine thousand, estimate Echo at three six, over.
VT45	3020	Pacific one eighteen, now listening your frequency, over.
VT46	3050	Nan eight one seven seven eight was over Uncle at three zero, one nine thousand, estimate Tango at three four.
VT47	3220	Pacific one eighteen was over Romeo at three two, one six thousand, estimate Mike at four zero, over.
VT48	3240	Branner four sixteen, was over Sierra at three two, one five thousand, estimating Papa at four one, over.
VT49	3350	Enco eight nineteen, now on your frequency, over.
VT50	3410	Navy six one five eight eight, was over Sierra at three four, one three thousand, estimate Papa at four three, over.
VT51	3430	Air Force one two zero zero four, now on your frequency, over.
VT52	3500	Nan eight one seven seven eight was over Tango at three four, one nine thousand, estimate Mike at four one, over.
VT53	3530	Enco eight nineteen was over Sierra at three five, two one thousand, estimate Oscar at four two.
VT54	----	Southeastern one twenty one, listening your frequency, over.
VT55	3650	Air Force one two zero zero four, was over Uncle at three six, one seven thousand, estimate Sierra at four one, over.
VT56	3810	Southeastern one twenty one, was over Romeo at three eight, eighteen thousand, estimate Tango at four two, over.

VT code	Time	Voice transmission
VT57	3920	Horizon two twenty two, now on your frequency, over.
VT58	4040	Transcontinent six twenty three, on your frequency, over.
VT59	4110	Nan three two four four one, now on your frequency, over.
VT60	4120	Air Force one two zero zero four was over Sierra at four one, one seven thousand, estimate Papa at four eight, over.
VT61	4140	Horizon two twenty two, was over Oscar at four one, twenty thousand, estimate Romeo at four seven, over.
VT62	4210	Enco eight nineteen, was over Oscar at four two, twenty one thousand, estimate Echo at five zero, over.
VT63	4240	Transcontinent six twenty three passed over Uncle at four two, twenty one thousand, estimate Tango four six, over.
VT64	4300	Southeastern one twenty one was over Tango at four three, one eight thousand, estimate Uncle at four seven, over.
VT65	4400	Nan three two four four one was over Romeo at four four, one two thousand, estimating over Tango at five zero, over.
VT66	4530	Branner four twenty five, listening your frequency, over.
VT67	4610	Dixie eight twenty six, on your frequency, over.
VT68	4630	Transcontinent six twenty three, was over Tango at four six, twenty one thousand, estimate Mike at five three, over.
VT69	4650	Horizon two twenty two, was over Romeo at four six, twenty thousand, estimating Mike at five four.
VT70	4710	Southeastern one twenty one, was over Uncle at four seven, one eight thousand, estimate Delta at five one, over.
VT71	4800	Branner four twenty five, was over Oscar at four eight, one eight thousand, estimating Romeo at five four, over.
VT72	4910	Dixie eight twenty six, was over Sierra at four nine, twenty one thousand, estimate Oscar at five four, over.
VT73	5000	Nan three two four four one, was over Tango at five zero, twelve thousand, estimating over Nan at five seven.
VT74	5100	Enco three twenty seven, listening your frequency, over.
VT75	5300	Mexico one twenty eight, now on your frequency, over.
VT76	5310	Branner four twenty five was over Romeo at five three, one eight thousand, estimate Mike at five seven, over.
VT77	5340	Air Force nine two nine zero zero, now on your frequency, over.
VT78	5410	Midwestern six thirty, now on your frequency, over.
VT79	5450	Dixie eight twenty six, was over Oscar at five four, twenty one thousand, estimating Echo at zero one, over.
VT80	5510	Mexico one twenty eight was over Uncle at five five, nineteen thousand, estimate Sierra at zero zero, over.
VT81	5530	Enco three twenty seven, was over Tango at five five, one four thousand, estimate Nan at zero three, over.
VT82	5610	Midwestern six thirty, was over Sierra at five six, one seven thousand, estimate Oscar at zero four, over.
VT83	5710	Air Force nine two nine zero zero was over Sierra at five seven, twenty thousand, estimating Uncle at zero five, over.
VT84	5800	Southeastern one thirty one, now on your frequency, over.
VT85	5940	Mexico one twenty eight, was over Sierra at five nine, twenty one thousand, estimating Papa at zero seven, over.
VT86	5955	Nan four three two zero one now on your frequency, over.

APPENDIX B*

ELECTRICAL-ENGINEERING DESIGN

This appendix is a technical explanation of the ATC task-system design and operation using a block diagram, charts, and photographs. The information presented is intended for technical personnel with a background in electronics who desire an overall understanding of the complete system. No specific details of the electrical circuitry or construction of the system are given. Refer to the report text for an explanation of the purpose of the ATC system and how it is used.

All references to system circuitry pertain to the block diagram shown in Figure B1.

Programmer and Controls. Operation of the ATC task is initiated by starting the Pulse Generator shown in Figure 3, text (fourth panel above tape reader). The Pulse Generator contains switches, indicator lamps, and an A. W. Haydon Company, P/N WI 3601, timer. The timer has two switches that operate once every 10 sec. One timer switch produces the 10-sec system master pulse, which is 40 msec long, and the other switch is for reset control of the timer.

The output from the Pulse Generator goes to the Tape Reader Start-Stop control. This control is a latching relay arrangement, whereby the 40-msec pulse from the Pulse Generator latches a relay for start control of the tape reader.

The start control output from the Tape Reader Start-Stop Control operates the tape-reader magnetic clutch, causing the Tape Reader to read the punched paper tape. The tape reader continues to read until a stop code is encountered, initiating a stop pulse that is applied to the Tape-Reader Start-Stop Control and causing the "start" relay to unlatch. The tape reader is an eight-level Friden Model 2, shown in Figure 3, text, that operates at 600 RPM (one reading per 100 msec). The tape for the reader is punched (coded) on the Friden Flexowriter Model SPD, Figure 1, text, which is also part of the data-acquisition complex. The ATC task system requires 37 different code combinations to accomplish all events. Seven of the eight tape levels are used for coding programmed operations, and the eighth level is used to initiate the stop pulse from the Tape Reader to the Tape Reader Start-Stop Control. Operating the Flexowriter carriage return is the only way to register a hole in the eighth level.

Seven outputs and a command pulse from the Tape Reader are connected to the Transfer Tree. The seven outputs control the Transfer-Tree relays, which route the command pulse to one of the 36 outputs. The Transfer Tree is wired to correspond to an arbitrarily assigned code. The sequence of operation is such that the input-to-output path through the Transfer Tree is completed before the command pulse is applied; the pulse is removed before the path is interrupted. Application of the command pulse is controlled by a switch operated by a cam fixed to the tape-reader drive shaft. Thirty-three outputs from the Transfer Tree go to the Matrix, and one each goes to the Bogey-Target Control, Warning Light Control, and Projector Advance Control. Operation of these three controls will be covered in a later section.

The Matrix that follows the Transfer Tree consists of 6 rows and 27 columns of relays such that any row output can be connected to any column output to form a complete electrical path. The 33 inputs to the Matrix result in 162 (6×27) possible outputs. The 6 rows are associated with 6 horizontal rows at the console display panel, and the 27 columns are associated with the following system operations: 1 for entry, 12 for altitude, 12 for altitude error, 1 for route check, and 1 for hand-off. To initiate an event at the console through the Matrix, a row is first selected and the information stored by the Matrix, using relay circuitry; then the column is selected. After the column is selected, a pulse approximately 100 msec long is routed to the Event Control associated with the selected row and column, and then the Matrix resets to normal. An output from the Matrix also goes to Task Identification Coder and Counter Start-Stop Control whenever entry, altitude check, or route check are programmed. Action of these outputs will be discussed below.

The 162 outputs from the Matrix connect to the Event Controls, which consist of five identical circuits (Row #2 Control through Row #6 Control) and Row #1 Control, which is similar to the

*Prepared by Clifton E. Hunter.

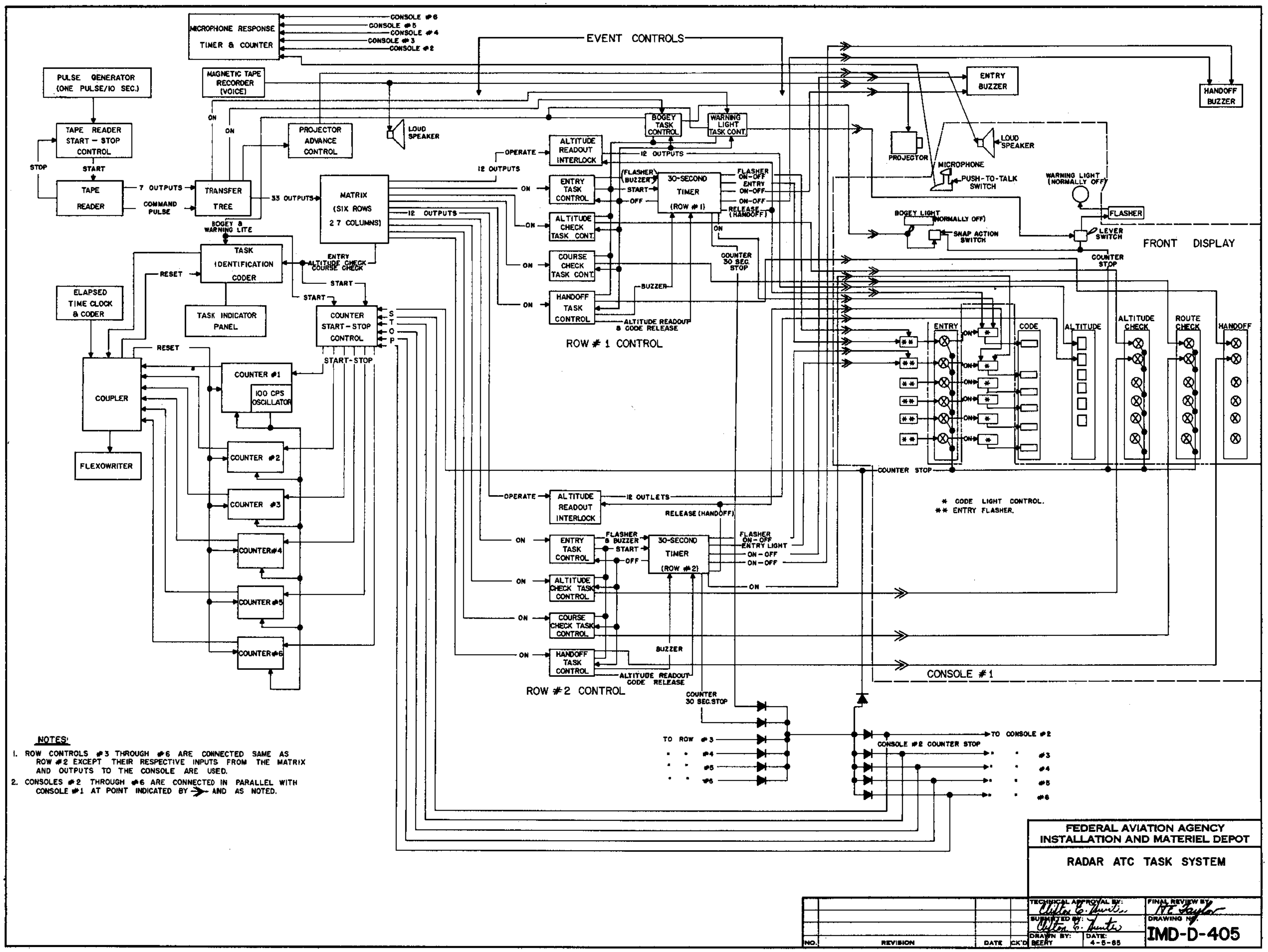

FIGURE B1. System block diagram.

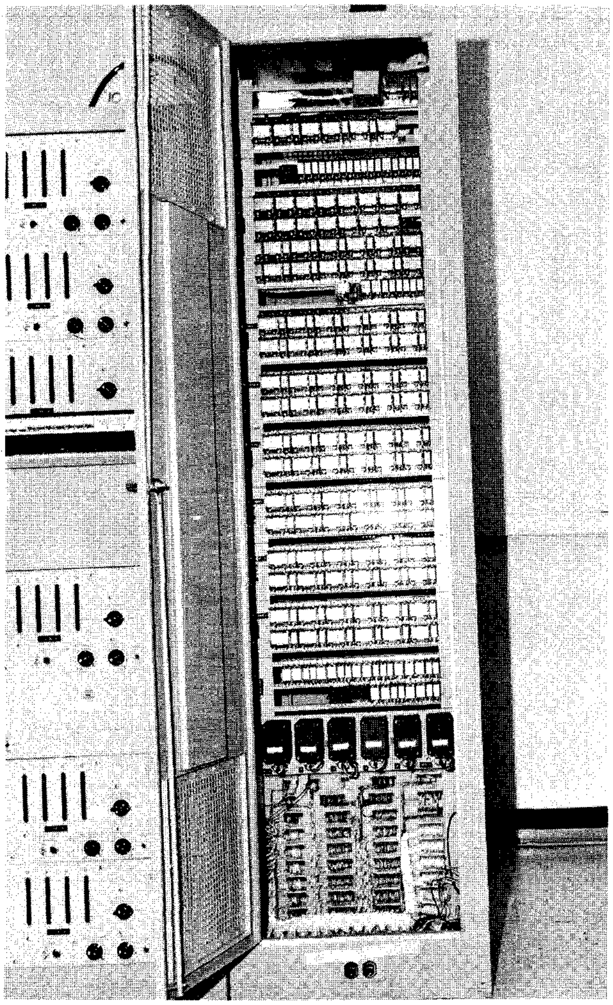

FIGURE B2. Transfer tree.

others except that it controls the bogey-target and warning-light events. These latter events do not have multiple occurrences at the console display, so they share some of the control function that Row #1 Control provides in order to reduce the number of electrical components. All programmed task events are maintained for approximately 30 sec at each console, and certain functions are maintained until other events are completed. Subfunctions associated with some programmed events occur at intervals within a 30-sec period. Timing of the 30-sec periods for event control and subfunctions is accomplished by six 30-sec timers (one for each console display panel row) shown mounted in the lower part of the equipment rack in Figure B2. The timers are A. W. Haydon Company, P/N WI 3604, with seven switches that operate at a predetermined time in accordance with the 30-sec timer-sequence diagram, Figure B3. More details of the event-control circuit are given in the section to follow.

Series of Events. The explanation of a series of events that can be programmed and their action, following the block diagram, will be covered to give an overall understanding of the ATC task system. The series of events refer to Console #1 and Event Controls, Row #1 Control; however, the explanation to follow applies to all consoles (as may be connected to the programmer) and to the other row controls except in the case of the bogey-target and warning-light events.

All programmed system action is started after the tape reader reads the preprogrammed paper tape. Output from the Tape Reader goes to the Transfer Tree as described above, and the Transfer Tree outputs go to the Matrix, Projector-Advance Control, Bogey-Target Control, or Warning-Light Control. The outputs from the Transfer Tree are the "decoded" inputs at the Tape Reader, and from here the output creates specific system actions.

Each time (normally every 10 sec) the Tape Reader reads a group of codes the projector is programmed to advance the filmstrip one frame. Output from the Transfer Tree through the Projector Advance Control to the Projector causes the film to advance. The Projector requires a 250-msec pulse to advance the film. Since the output pulse at the Transfer Tree is 19 msec long, it must be lengthened at the Projector Advance Control prior to reaching the projector. The Projector Advance Control is composed of relays including a G. C. Wilson and Company, Model 591, 0.02- to 5-sec adjustable time delay to lengthen the 19-msec pulse to 250 msec or greater. The filmstrip projector used at the console is a DuKane Model 576–47B less base. In order to mount the projector on the console, the base was removed and parts housed therein (DC power supply, switches, and remote-control receptacle) were relocated in a separate housing.

Provided no other console event is in operation, the first logical task event to be programmed is "entry." The output from the Transfer Tree to start the entry task consists of two pulses to the Matrix for selection of the console row and the entry task. An output from the Matrix causes a relay in the Entry Task Control to latch up, a start pulse is furnished to the Counter Start-Stop Control (starting Counter #1), and an input is furnished to the Task-Identification Coder. This

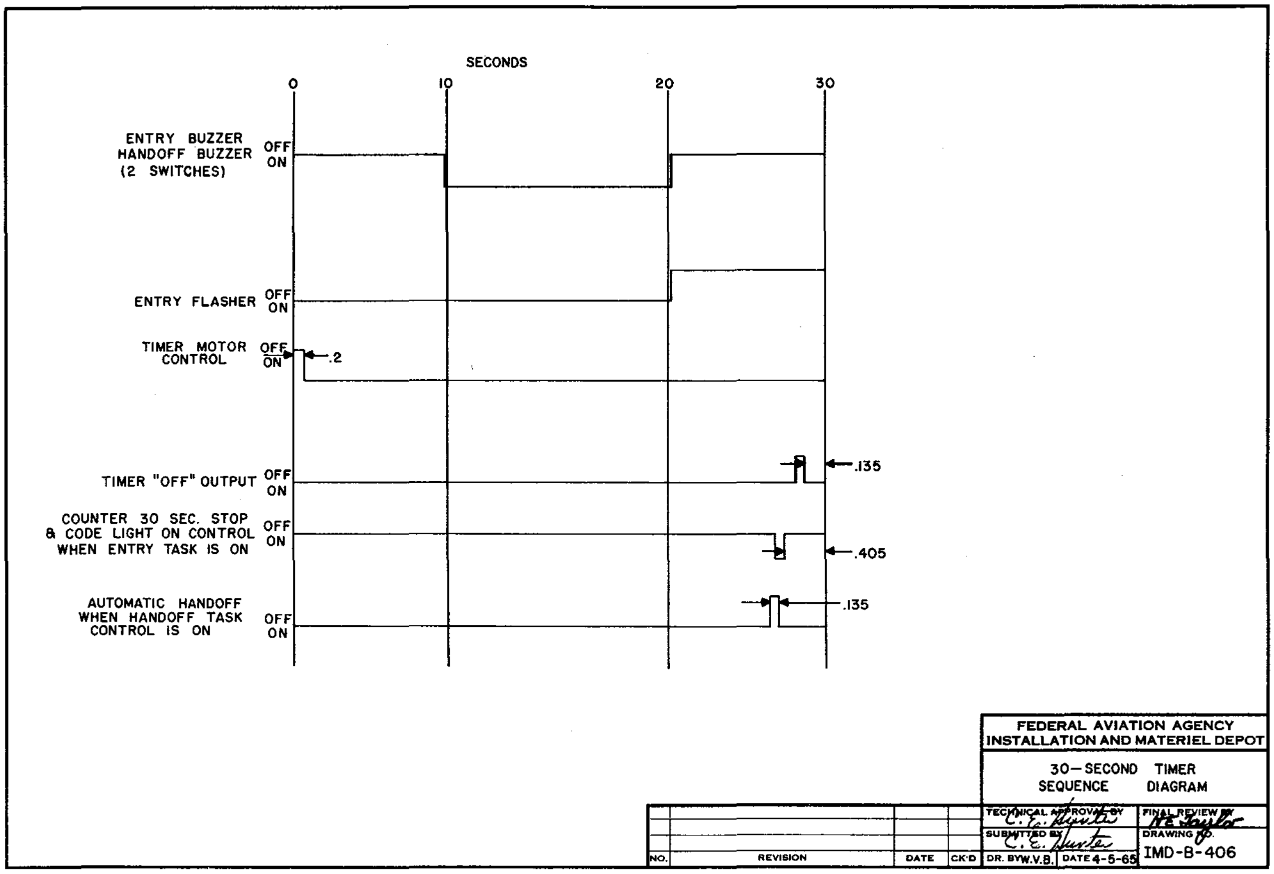

FIGURE B3. Timer-sequence diagram.

latter input is further coded so that identification information is furnished to the data-acquisition complex (discussed in the following section). An output from the Entry Task Control starts the 30-sec Timer, which was resting at zero time reference. Another output from the Entry Task Control applies voltage through the 30-sec Timer to the Entry Flasher located in Console #1, causing the Entry illuminated-type pushbutton light to flash on and off. Provided the Entry pushbutton switch is not operated, the light will continue to flash for 20 sec, then stop flashing and remain on; meanwhile, 10 sec after the entry light has commenced flashing, the Entry Buzzer will have begun sounding for 10 sec. The flasher and buzzer subfunctions are controlled by switches on the 30-sec Timer, as shown by the timing diagram, Figure 33. At approximately 29.5 sec in the 30-sec period, the 30-sec Timer operates the Code light on through the Code Light Control, unlatches the relay in the Entry Task Control, and pulses the Counter Start-Stop Control, stopping the counter for Console #1. Release of the relay in the Entry Task Control causes the Entry Light to go off, and the 30-sec Timer motor-control switch (Figure 20) takes control of the timer and stops it at zero time reference. A latching relay in the Code Light Control causes the Code light to remain on. Operating the Entry pushbutton during the 30-sec interval causes the Code light to come on and remain on due to the Code Light Control, causes Counter #1 to stop, causes the Entry Flasher and Entry Buzzer to be inactivated (whether operating or not), and finally causes the Entry light to remain on until the end of the 30-sec period.

An altitude associated with the entry is normally programmed next to appear on the face of the Row #1 digital readout. The digital readouts are Industrial Electronic Engineer Series No. 10,000, which display numbers 11 through 22. The output from the Transfer Tree that causes an altitude to be displayed at Console #1 consists of two pulses to the Matrix for selection of the console row and the altitude number. Output from the Matrix illuminates an Altitude light at Console #1 through the Altitude Readout Interlock. Now, Row #1 Code light and the programmed Altitude *light* are on.

When "altitude check" is programmed, the outputs from the Transfer Tree to the Matrix consist of pulses to select the row, as before, and a new or incorrect altitude number, as the case may be. There are two outputs from the Matrix to the Row #1 Control, a start pulse to the Counter Start-Stop Control and an input to the Task-Identification Coder. Action of the Counter Start-Stop Control and Task Identification Coder are the same as in the case of the entry task. One pulse input to the Row #1 Control goes to the Altitude-Check Task Control, latching a relay that starts the 30-sec Timer formerly resting at zero time reference. The same pulse activates the Altitude-Check illuminated-type pushbutton on the console display so that, if it is operated during the 30-sec period, that light will come on. At the same time that the Altitude-Check pushbutton is activated, the new "error" altitude appears at the Altitude readout due to the output from the Matrix to the Altitude Readout Interlock. The old displayed altitude is extinguished immediately before the new altitude appears by an electrically interlocked relay circuit in the Altitude Readout Interlock. If the Altitude-Check pushbutton is not operated, at approximately 29.5 sec of the 30-sec period, the 30-sec Timer causes Counter #1 to stop and unlatches the relay in the Altitude-Check Task Control, thereby resetting the 30-sec Timer to zero time reference. Operating the Altitude-Check pushbutton during the 30-sec period causes the Altitude-Check light to come on and Counter #1 to stop. The Altitude-Check light is extinguished at the end of the 30-sec period by the unlatching of the relay in the Altitude-Check Task Control.

The "error" altitude displayed by the Altitude readout remains the same until it is programmed to change back to the correct altitude. This is accomplished as it was following the entry task, except that the error altitude is extinguished before the correct altitude reappears.

Operation of the "route-check" task proceeds in a fashion similar to that of the altitude-check task. For operation of the bogey-target and warning-light tasks, the Matrix is not required since these tasks are displayed in only one location at the console display.

A programmed bogey-target task causes the output from the Transfer Tree to latch a relay in the Bogey Task Control that starts the 30-sec Timer, activates the bogey-target response circuit, and furnishes a start pulse to the Counter Start-Stop Control and an input to the Task-Identification Coder. Action of the Counter Start-Stop Control and Task-Identification Coder is the same as described above. With no response to the bogey target, the 30-sec Timer (after approximately 29.5 sec of the 30-sec period) stops Counter #1, unlatches the relay in the Bogey Task Control, and advances itself to zero time reference. A response to the bogey-target task (removing the Bogey Light shown in Figure 2, text, from the holder) operates a snap-action switch located in the holder, stopping Counter #1. A light in the barrel of the Bogey Light can be turned on by a trigger-operated switch at any time during the task period. The function of the light is to simulate an actual radar interrogator gun. The bogey-light gun is made from an automobile time-light housing manufactured by Rite Autotronics Corp.

When the "warning-light" task is programmed, the output from the Transfer Tree causes a relay to latch-up in the Warning-Light Task Control, which starts the 30-sec Timer, starts the Warning Light (which is normally on) to flashing, and furnishes a start pulse to Counter #1 and an input to the Task-Identification Coder as in the case of the bogey-target task. The Warning Light is located near the upper left-hand corner of the console shown in Figure 2, text. With no response to the Warning Light, the 30-sec Timer (after approximately 29.5 sec of the 30-sec period) stops Counter #1 and unlatches the warning-light task-control relay, thereby causing the Warning Light to stop flashing and remain on (normal condition) and the 30-sec Timer to reset to zero time reference. Operating the Lever Switch located below the Warning Light during the task period causes the Warning Light to stop flashing and remain on and stops Counter #1.

The last event to be programmed is "handoff," and at this time the Code light and an Altitude light are normally on. Programming handoff causes outputs from the Transfer Tree to the Matrix to select the console row and handoff event. Since response to this event is not timed, there is no input to the Counter Start-Stop Control or Task-Identification Coder. Outputs from the Handoff Task Control start the 30-sec Timer and activate the Handoff illuminated-type pushbutton switch circuit. If the Handoff pushbutton is not operated during the 30-sec period, the Handoff Buzzer will sound during the 10- to 20-sec period. Operating the Handoff pushbutton during the event period causes the buzzer to be disabled and the Handoff light to come on. After approximately 29.5 sec of the 30-sec handoff period, regardless of whether there has been a response or not to the event, the Altitude light and Code light are extinguished by a switch on the 30-sec Timer. Due to the condition of the Handoff Task-Control Circuit, the latched relay in the Handoff Buzzer will sound during the 10- to 20-sec Timer, causing the Handoff light to go out (if it is on), and the 30-sec Timer resets to zero time reference.

The event controls for Row #2 through Row #6 are identical to Row #1, except that the bogey-target and warning-light controls are not repeated. All six console displays are identical, and additional consoles are connected as noted on the block diagram.

The sequence of operations described above is for illustration only. Any timed task (entry, altitude check, route check, bogey target and warning light) can occur separately at any 40-sec interval. Thirty seconds are required for the task and 10 sec are allowed for the response-time data to be recorded by the data-acquisition complex. The full 10 sec are not required for data acquisition; however, events can be initiated at intervals of 10 sec only. The handoff event that is untimed can occur at any 10-sec interval if no other timed task is occurring on the same row. The bogey-target and warning-light events are considered to be on Row #1. The altitude and projector-advance function can occur at any 10-sec interval.

Data Acquisition. As mentioned, with each timed event an electronic counter is used to record the response time. There is one counter for each ATC console. Five of the counters are Hewlett-Packard Co., Model 521AR–H68, and one is Model 521AR–H67, the latter being identical to the others except that it contains a 100-cps oscillator and output connector. All counter inputs are connected to count the 100-cps signal. The Counter Start-Stop Control accepts a voltage pulse from either the Transfer Tree or Matrix, depending on the event, that starts all counters simultaneously. When an event response is made at any console display, a voltage is applied to the Counter Start-Stop Control that stops its associated counter. If a response is made at each console display prior to the end of the 30-sec period, all counters will be stopped, and the data-acquisition equipment records the response times. If, however, one or all counters are not stopped via a response, the counters are stopped at approximately 29.5 sec by the 30-sec Timer. The automatic stop is available from all 30-sec Timers and is isolated from the individual control circuits by diodes as shown in Figure B1.

The Flexowriter, Dymec Model DY–2540 coupler, and the six electronic counters comprise the data-acquisition equipment and were purchased as a system, prewired to work together. The recording format for the Flexowriter is two digits of time information (input furnished by us), one digit of identification information (input furnished by us), and four digits of response-time information from each of six counters. Four digits of response time provide a measure to the nearest 0.01 sec when counting the 100-cps signal. When the Coupler is in the automatic mode of operation, it samples all inputs after all counters have stopped counting, converts the inputs to the Flexowriter code, and causes the Flexowriter to print out and return the carriage. After the Flexowriter has printed out the information, all counters are reset to zero by the Coupler.

Each time one of the timed events is initiated via the Transfer Tree or Matrix, a voltage signal is fed to the Task Identification Coder. The coder contains a relay arrangement that produces and holds a coded task-identification output that the Coupler accepts. Task-identification codes supplied to the Flexowriter by the Coupler cause the Flexowriter to print the number 1 for entry, 2 for altitude check, 3 for route check, 4 for bogey target, and 5 for warning light. After the output from the Task-Identification Coder is scanned, the

Coupler furnishes a reset pulse to the coder, causing it to return to normal condition. The Task-Identification Panel shown above the program tape reader in Figure 3, text, contains three lamps labeled 1, 2, and 2′, which indicate to the program operator the task in operation. Reading of the lamps is as follows: 1 for number 1, 2 for number 2, 1+2 for number 3, 2+2′ for number 4, and 1+2+2′ for number 5.

The Elapsed-Time Clock Coder is used to produce two digits of time information for the data-acquisition complex. The coder contains power switches, reset switch, indicator lamps, a stepping switch, and an A. W. Haydon Co., P/N 203, Series 13600, timer. The timer has two switches that operate once every minute. One switch advances the stepping switch and the other switch is for reset control of the timer. Output from the coder is such that the Coupler accepts the information and furnishes it to the Flexowriter each time the coder output is sampled by the Coupler. Time range for the coder is 0 to 99 min in 1-min intervals.

The Microphone Operation Count and Timing Panel shown above the tape reader in Figure 3, text, registers the number of times the microphone push-to-talk switch located at the console display is operated and the total accumulated time the switch is operated. This portion of the ATC task system is not electrically connected (except for power supply) to any other part of the system. The microphones (one is shown in Figure 2, text) are Turner Model 254C, the counters are Veeder-Root Series 1506 reset magnet counters, and the running-time meters are Cramer Type 633S with 0 to 999.99-min ranges.

Accessory Components. The Magnetic Tape Recorder and speaker system used with the ATC system is not electrically connected to the main system. The tape recorder is a Wollensak Model T–1980 stereo and mono record/playback unit with 11 w per channel output. One channel is used to drive seven 4-in.-diameter speakers. One speaker is located at each console display and one at the top of the left-hand program rack as shown in Figure 1, text. Output impedance of the recorder is 8 ohms, and the speaker input impedance is 3.2 ohms. All speakers are connected in parallel. Although this results in a poor impedance match, the audio fidelity is better than the condition to be simulated. Output from the recorder is connected to the system at a jack located above the program tape reader as shown in Figure 3, text.

A Talk-a-Phone Model T–C–4912 intercommunication system with one master station located at the programmer equipment and one station located at each display console is used with the ATC task system. The communication system facilitates maintenance, is used for giving indoctrinations and instructions, and permits communication between the program operator and subjects in case there are system malfunctions.

Primary power for the ATC task system is 48 v DC and 120 v AC. All system DC voltages come from two 48-v power supplies located in the bottom part of the left-hand program rack shown in Figure 1, text. Meters are associated with each power supply for monitoring current and voltage. One power supply is FAA type FA–5252 rated at 5 amp and the other is a Sola type 281561 rated at 10 amp. One power supply is used to operate the tape-reader magnetic clutch, elapsed-time clock coder (because of the stepping switch) and the transfer tree; this prevents large or frequent voltage transients from affecting lamp circuits in the console display. All DC power for each console is supplied by the programmer. AC power at each console is obtained by individual connection to the commercial power source. The only items requiring AC power at the consoles are the projector, a digital clock, and a desk lamp. A panel of six toggle switches enables the operator to select any one of the six ATC consoles for operation.

ATC consoles are connected to the programmer with a 150-wire telephone-type cable. All six 150-wire cables terminate at the programmer in the rear bottom of the equipment rack shown in Figure B2. Any console can be connected or disconnected at these points (at the console also) without affecting the programmer or other consoles.

IBM wire-contact relays and diode semiconductors are used to accomplish most switching and control functions. The programmer contains 101, 4-pole, 16, 6-pole, and 70, 12-pole IBM relays and 17 diodes. Each console contains 32, 4-pole and 6, 6-pole IBM relays and 18 diodes. The programmer and six consoles contain a total of 415 IBM relays and 125 diodes. The wire contact relay is low in cost, has an operate and release time of less than 10 msec, and has high reliability. Current rating for the relay contacts is 35 ma for 200,000,000 operations without contact-arc suppression. At 2,000,000 operations, however, the current rating is 2 amp, which exceeds all but a few switching requirements for the ATC task system. The relays are plug-in mounting and each major circuit function block is contained on a standard-size 19-in.-wide specially constructed relay-mounting frame. All circuit function blocks interconnect at the junction panel located in the lower portion of the rack shown in Figure B2. The equipment rack on the right side (Figure 1, text) is a standard FAA communication-equipment rack, which is 81 in. high and has center panel mounting and double doors; the other two racks are standard FAA relay racks, which are 72 in. high.

All lights and switches located on the right side of all consoles, as shown in Figure 2, text, are manufactured by Micro-Switch except the digital readouts previously mentioned. All these lights and switches are installed on an aluminum plate that can be easily removed. Front panels and relay assemblies, as shown in Figure B4, are interchangeable among consoles.

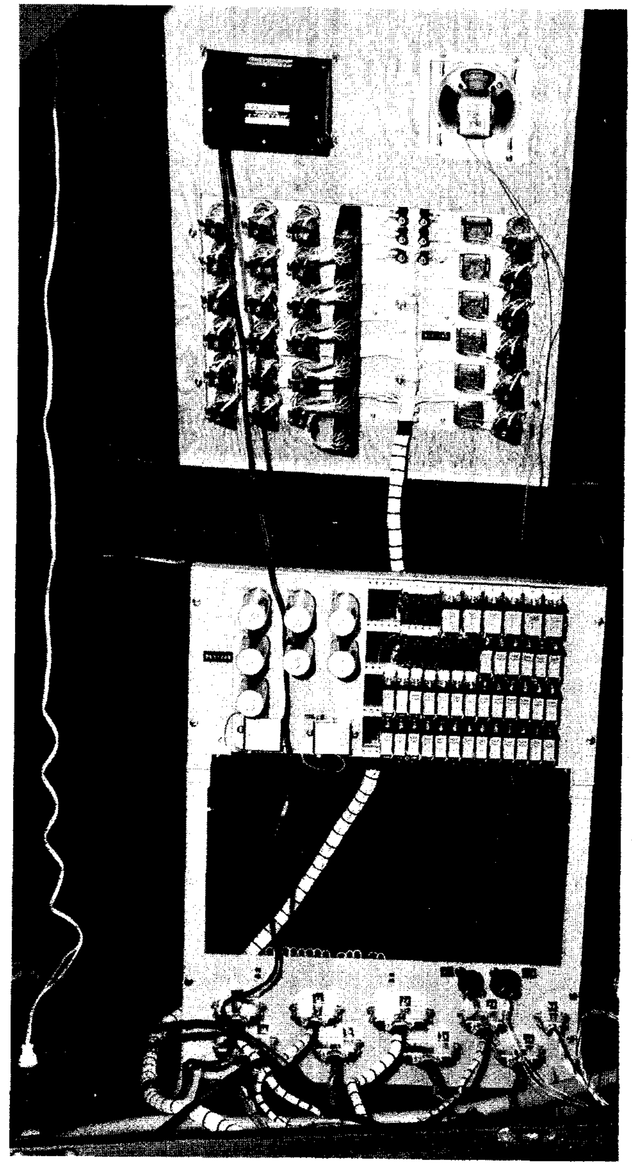

FIGURE B4. Console interior.

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