WADC TECHNICAL REPORT 59-236

# A SUMMARY OF RESEARCH METHODS, OPERATOR CHARACTERISTICS, AND SYSTEM DESIGN SPECIFICATIONS BASED ON THE STUDY OF A SIMULATED RADAR AIR TRAFFIC CONTROL SYSTEM

*J. S. Kidd*

*Laboratory of Aviation Psychology*

*The Ohio State University*
*and*
*The OSU Research Foundation*

*JULY 1959*

Contract No. AF 33(616)-3612
Project No. 7184
Task No. 71583

AERO MEDICAL LABORATORY
WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

1,300 — February 1960 — 23-624

# FOREWORD

This article summarizes and attempts to integrate the system-simulation portion of a program of research on human engineering aspects of air traffic control conducted in the Laboratory of Aviation Psychology and the Department of Electrical Engineering of The Ohio State University. The object of this research has been to establish psychological principles applicable to the design and operational use of air traffic control facilities and other complex man-machine systems.

The present report was prepared for the Engineering Psychology Branch, Aero Medical Laboratory, Directorate of Laboratories, Wright Air Development Center, under Contract No. AF 33(616)-3612, Project 7184, Task 71583, with Dr. James C. McGuire acting as Task Scientist. This work was initiated under Contract No. AF 33(616)-43 with Dr. Ralph W. Queal, Jr., acting as Project Scientist and Dr. Paul M. Fitts as Principal Investigator.

Assigning authorship to the present report is a difficult matter. The nominal author is best considered as a compiler of the work of a rather large group whose ideas and energy have made the program possible. First, Dr. Paul M. Fitts, as Director of the Laboratory and as Principal Investigator, had the imagination and foresight to set the program in motion. He was continually active in every phase of the research from planning studies to writing reports. The essential character of the program's product is due in large measure to his guidance. This tradition is currently being carried forward by Dr. George E. Briggs.

Drs. Ralph W. Queal, Jr., and James C. McGuire played essential parts in the program, providing continuous intellectual and moral support. Many of the ideas employed in the program of research were theirs.

Very special acknowledgment is due Dr. Lowell Schipper, who was instrumental in creating the methodological and operational foundations for the program as well as contributing a large share of the studies utilized in this paper. The present author was very fortunate to be able to come into the on-going program which was already in high gear as a consequence of Dr. Schipper's efforts.

Dr. Conrad L. Kraft has been directly or indirectly involved in every system study accomplished. This was in addition to his key function of supervision of the technical support phase of the total program.

Several others have made substantial contributions to the program. Dr. John Versace as investigator and collaborator, Drs. Maynard W. Shelly and Alfred F. Smode and Messrs. Robert Kinkade, James Hooper, and Gabriel Jeantheau have authored or co-authored reports in the series.

To all these, and many others also, the present author owes a debt of gratitude.

# ABSTRACT

This report summarizes fourteen laboratory studies of human engineering aspects of radar air traffic control systems. It includes a review of methodological developments and empirical findings. Human operator characteristics consistently observed in the task setting employed are presented, along with recommendations for system design and system management based on the experimental findings. Comments regarding the future potential of this type of research in dealing with significant human factor problems are also included.

## PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Walter F. Grether
WALTER F. GRETHER
Director of Operations
Aero Medical Laboratory

# TABLE OF CONTENTS

# A SUMMARY OF RESEARCH METHODS, OPERATOR CHARACTERISTICS, AND SYSTEM DESIGN SPECIFICATIONS BASED ON THE STUDY OF A SIMULATED RADAR AIR TRAFFIC CONTROL SYSTEM

## INTRODUCTION

Our contemporary civilization is typified by a steady and rapid increase in the degree of automation and mechanization of industrial and military operations. Such a trend has created new problems as some of the older ones have been solved. In an oversimplified version, one of the most basic problems is the optimum relationship between man and his machines.

One avenue of approach to this broad problem area is through engineering psychology as a research specialty. The present report is based on a program of research which represents one form which the engineering psychology approach can take. Specifically, the research can be described as being concerned with relatively complex man-machine system operations, and the studies were carried out through the use of a set of techniques generally designated as dynamic system simulation.

While each of the separate experiments that provide the empirical content of this report have been published individually, there are several justifications for attempting a summary document at this time. The most pertinent factor is the matter of integration. It is possible, after five years of data collection and fourteen major studies, to abstract principles which are both methodological and substantive in nature and which have been either of consistent or cumulative significance throughout the program. These general factors may, it is hoped, provide an empirical foundation for anticipating future prospects of the systems research specialty, both in terms of the research activity itself and in terms of engineering and management applications of the substantive findings.

Historically, the idea of designing a job to fit the worker is not new. It was emphasized by Munsterberg in his early books on industrial psychology (18), and stressed by Raymond Dodge in his report on military psychology to the National Academy of Science following World War I (2). The idea did not win wide acceptance, however, until World War II. Since that conflict, the field of engineering psychology has grown very rapidly.

From the beginning, work in engineering psychology was centered on such questions as (a) how men read instruments, (b) how they make movements, and (c) how instruments and controls can be designed to improve human performance. While such work continues to have an undiminished significance, recently interest has been increasing rapidly to much larger and more complex problems: the study of man's performance in systems.

The "system concept" has already been tested in application in several important ways. The close relationship between the design of machines and systems,

---

Manuscript released by the author 29 June 1959 for publication as a WADC Technical Report.

on the one hand, and the development of effective personnel subsystems, the establishment of training programs, and the maintenance of human skills, on the other hand, is now recognized and acted upon in industry and in the military. Also it has become apparent that there are basic analogies between the dynamics of interaction of men with other men and of men with machine components, not only from the viewpoint of productivity, but also with respect to motivation and job satisfaction. The systems concept thus tends to include all pertinent aspects of information exchange between system elements, and system research involves many nonmechanistic variables.

While much useful systems research has been conducted in field settings, the material reported here has been gained primarily in connection with efforts to simulate man-machine systems under laboratory conditions and to study human performance in systems in this controlled environment. While there is a very real conflict between realism and control in system research, the key proposition of this report is that long-range future success in solving specific problems will rest in no small part on carefully controlled laboratory experimentation and on the development of inductively derived theory that will permit predictions of human performance in a system context.

For the purposes of this report, a system is defined as an assemblage of elements engaged in a common task (or employed for some common purpose), these elements being related to each other in such a way that the degree of success achieved by the assemblage is primarily a function of their interactions. Thus, a system is characterized not so much by its component elements as by how these elements are linked together. The term "system" has been used in other ways. These alternate descriptions should not be confused with the present definition. For example, the term "system" has long been used to specify groups of interrelated physical and biological elements which have no "task" or "purpose" as such. The planetary system is perhaps the best-known example of a large physical system; the respiratory and circulatory systems of the body are familiar examples of biological systems. The kind of system of concern here, however, is a goal-oriented, man-machine system, and communicative interactions and feedback dynamics are emphasized. The justification for controlled investigation of such systems rests on the importance of determining, by actual experimentation, the nature of the interactions between men and machines in a dynamic situation.

At one time the basic methodology in the experimental laboratory involved the study of one variable at a time. This type of methodology has given way to multiple-variable experiments and to the use of multiple correlation, analysis of variance, factor analysis, and other statistical procedures developed specifically to permit analysis of multidimensional experimental data. Thus, today, many kinds of interactions are being studied. As indicated above, the kinds of interactions of special interest to the engineering psychologist are man-machine interactions.

## METHODOLOGY EMPLOYED IN A RESEARCH PROGRAM ON HUMAN ENGINEERING ASPECTS OF AIR TRAFFIC CONTROL

Interest in the human factor aspect of air traffic control system problems was greatly intensified by government-sponsored studies made in Berlin and other American air bases in Germany during the Berlin Airlift in 1949. More inclusive studies in air traffic control began in 1950 when the National Research Council

Committee on Aviation Psychology sponsored a planning and field study of human engineering problems in air traffic control with funds from the Air Navigation Development Board. This year-long study, in which many psychologists participated, eventuated in a report (3) which provided the basis for a planned program of laboratory experimentation.

In 1952, under sponsorship of the Air Force's Aero Medical Laboratory, such a program was initiated at the OSU Laboratory of Aviation Psychology. During the first year, construction of an air traffic control simulator was begun. Personnel of the Ohio State University Department of Electrical Engineering assumed major responsibility for the design of the special-purpose analog computer equipment which was used to provide realistic simulation of an air traffic control system (6, 7). Figure 1 shows the control room where the operation of a radar approach control center is simulated.

Four plan-position indicator (PPI) displays provide the central information sources to the radar controller. The radar control room is illuminated by the Broad Band Blue Lighting System developed by Dr. Conrad L. Kraft of this Laboratory (15, 16). Radar operators in this control room are in voice communication with target generator operators who portray the role of pilots and who make the requested changes in speed, heading, and altitude of the simulated aircraft in the

Fig. 1. Simulated radar air traffic control center showing radar scopes and operator positions.

system. The room containing the major simulator components is shown in Fig. 2. Approximately 15 target generator operators are required in a full-scale system experiment employing all 30 target units; under most conditions a single pilot can "fly" two airplanes (i.e., operate two consoles in the pilots' room) at the same time if need be.

The pilot's console was designed to minimize nonprogrammed error. Thus, instead of using a joystick to bank a simulated airplane when he desires to make a turn, the target generator operator adjusts a dial to the desired new heading, selects the desired direction and the rate of turn, and activates a "Start Turn" switch. The aircraft then turns at the desired rate and rolls out precisely on the new heading.

From time to time additional components have been added to the simulator. As an illustration, recently each pilot's console was provided with a cathode ray tube (CRT) display which shows the ground position of his particular airplane. Published reports refer to the latter as an"airborne position information"(API) display.

The program of system research has been planned around two broad objectives: (a) to establish general principles relating to human engineering aspects of air traffic control systems, and (b) to provide a contribution to the development of a general theory of the capacities and limitations of individuals and of small groups of people in performing the kinds of decision-making functions required by complex man-machine systems such as air traffic control.

It is now appropriate to review some of the methodological concepts that have guided the development of the research program, to describe critical aspects of this methodology, including such things as the criteria which we used to evaluate performance, and to say something about the efficiency of this methodology. The term "methodology" is used here in a broad sense—to indicate the way we went about seeking answers to selected problems.*

Laboratory organization.—The first aspect of this broader methodology involves the gross organization of the laboratory and its program. From the beginning, the conduct of systems research was conceived as a multifacet activity. Large-scale dynamic simulation was recognized as the key facet, but it seemed potentially inefficient to limit research to the level made available by the electronic ATC simulator. Therefore, a program of supporting technical and fundamental research was initiated and carried out concomitantly with the simulator studies. In actual operation, a very effective reciprocity has been worked out between the "technical studies" and the "system studies." For example, problems have been generated by the research accomplished in the simulator context which could be attacked with less cost and frequently with more precise control in the more abstract and less complex setting provided by the technical studies approach.

---

* Some of the methodological problems involved in this type of research have been reviewed in a previous report (4). The matter of how criteria were developed is covered in detail therein and is thus not given special emphasis again here.

Fig. 2. Arrangement of target generators, associated analog computer equipment, and "pilot" positions.

In other instances, the technical studies could provide the means to pre-evaluate experimental variables in anticipation of their inclusion in a simulator study.

Simulation.—The second major aspect of methodology is a consideration of the philosophy of simulation. This particular area is typified by the state of tension between the "real" and the "ideal" task environments. By and large, the tendency has been to resolve this tension in favor of the "ideal" wherever it has been possible to do so. Thus, the task environment has been "cleaned-up" in the sense that, for example, voice communications have been rendered relatively noise-free, radar sweep line and clutter have been eliminated, and optimum ambient conditions with respect to lighting, temperature, and work space layout have been maintained insofar as possible. There are two essential justifications for the idealization process: first, because of the inevitable delay between conception and implementation of research material, one must anticipate the advances in engineering technology in order to attain maximum compatibility at the time the research results are actually applied; second, the most effective definition of a dimension is usually based on the specification of its boundary conditions. The upper limit of system performance has been an unknown quantity and it was its specification that was consistently attempted. Moreover, the use of optimum conditions to establish the most general characteristics of the system does not preclude the controlled degradation of system characteristics at an appropriate stage in the research program in an attempt to get answers to more detailed questions. Furthermore, even with optimization of many salient features of the task, a high level of realism can be achieved. Part of this realism derives from what might be called the "sound effects" of the situation. Those who take the role of pilots, for example, are intensively coached in the special language and inflections of real-life pilots. Also, the dynamic character of the task is such as to catch the imagination of the participants to the point that they are completely integrated parts of the successful operation of the system.* The most important factor in providing the required realism, however, comes in the nature of the responses required of the operator. If the decisions to be made by the operator in the simulated task setting require discriminations comparable to those found in the real situation, if they involve similar requirements for prediction of future consequences, and if they call out the same value considerations, then adequate realism is present.

Finally, there is a factor in simulation that is set neither at an ideal level nor at a truly realistic level. That factor is input load and its level is normally set near the estimated upper capacity limit of the system. As a consequence, the high stress imposed on the system results in maximum system sensitivity to the effects of the experimental variables. It is a truism that "any old system" can handle minimum input loads; it is only when the pressure is on that the better system configuration has a chance to reveal its superiority. (The high stress factor, it should be noted, is a more or less exclusive prerogative of simulator research since the higher error frequencies which ordinarily result would be intolerable in most field settings.)

---

* It should be noted that participants who have worked the real-life counterpart of the system being simulated can be relied upon to display much the same level of concern, and to rely on habits formed in the real system even when working in the simulated environment. Thus, such participants bring a sizable proportion of the attained realism with them as part of their experience.

Statistical design.—A third major feature of the methodology has been the consistent utilization of multivariate statistical designs. This approach has allowed for the most efficient use of research time and funds and, at the same time, has sustained the emphasis on interactive processes that is fundamental to the system concept. Certain peculiarities common to systems research have led to the rather consistent usage of the latin-square variation of the factorial design which involves internal statistical control of interindividual sources of variability.* The limited population of suitably trained experimental participants (subjects) and the minimal emphasis on learning and skill acquisition variables makes the latin-square design both feasible and desirable for systems research. (In terms of statistical power, the designs employed have consistently allowed the rejection of the null hypothesis when differences in performance in the range between 5% and 10% have been observed. This level of differentiation is quite compatible with the engineering realities associated with the system being studied.)

Task setting.—A fourth major consideration of methodology has been the selection and implementation of task parameters. The present program has relied consistently on the so-called pattern-feeder portion of the radar approach control system as a model for the establishment of task characteristics. This was done for several reasons. First, from a practical point of view, the pattern-feeder operation can be a major bottleneck in the air traffic approach sequence. Second, this function appears as most typical in that it resembles other portions of the system more than they do each other. Finally, it was relatively easy to instrument for simulation purposes. Some essential features of the task are (a) as few as one man or as many as four men at a time could be assigned the pattern-feeder function; (b) aircraft typically enter pattern-feeder jurisdiction while in cruising status and are passed on to subsequent jurisdiction only after position, heading, speed, and altitude have all been adjusted; and (c) the approach course may be as much as 50+ mi.

A more detailed description of the task, quoted verbatim from a recent experiment (12), gives the picture most adequately:

> The control environment.—Two pattern-feeder controllers constituted the control team whose performance determined system effectiveness. The two operators shared the pattern-feeder function equally between them, using a modified sector control procedure. Two additional men were always present in the simulated radar control center. The first of these took the nominal role of a pickup controller and acted as an intermediary between the enroute and the terminal system. His task was to follow a predetermined plan of action, consisting solely in the passing of "buck slips" to the pattern-feeder controllers at prearranged times. He also acted as a general monitor for the conduct of the experiment, checking

---

* The latin-square variation has definite limitations due to the inability to isolate sequential effects and their interactions. This is unfortunate where the research emphasis is on problems of training and skill acquisition. However, most of the work done in the program reported here was concentrated on high-level performance as influenced by task and environmental factors. Thus, the inability to assess sequential effects was not considered critical.

"pilot" performance and other activities. Thus, this man had no differential effect on the performance of the system under the various conditions studied.

The second additional man took the role of a GCA controller. He accepted properly set-up aircraft at the GCA gate, i.e., he accepted the output of the pattern-feeder controllers if it were satisfactory. He also exercised an important umpire function: he decided whether go-arounds were necessary on the basis of a pattern-feeder failure to achieve objectively specified ranges of speed, heading, and separation of aircraft at the GCA gate, and immediately ordered such go-arounds if necessary. These objective standards were well-known to the controllers.

Control task.—The task of the two-man pattern-feeder controller team was to direct aircraft entering the system at a range of 50 mi. and at varying altitudes into one or the other of the GCA gates using minimum flight times and minimum fuel consumption, while maintaining the aircraft separations prescribed by safety rules.

Each problem consisted of 28 aircraft, 24 landing and 4 departing. The aircraft entered the system at an average rate of one every 35 sec. or, in terms of rate per controller, one every 70 sec. per pattern-feeder controller (i.e., per 180° sector). The total number of aircraft in each problem was divided equally between the two controllers, each controller being responsible for 12 landings and 2 departures.

Each problem included 14 jet interceptors, 8 jet bombers, and 8 jet cargo aircraft. These types were also balanced between the two controllers. The assumed operational characteristics of the three aircraft types represent hypothetical future aircraft (hypothetical aircraft were used in order to avoid the problem of security classification). While these characteristics are hypothetical, they fall within the range which it has been estimated that future air traffic control systems may accept.

The division of the pattern-feeder task between the two operators was accomplished by the use of a modified sector control arrangement. Assignment of control responsibility was determined by the sector of entry. The total control area was divided in half on the east-west diameter from 270° to 090°. All aircraft entering (or desiring to leave through) the north half were assigned to one controller, and all aircraft entering (or desiring to leave through) the south half were assigned to the other controller.

The control area included two landing fields which were separated by 15 mi. and equidistant from the center of the control zone. The active runways of these two fields were parallel and the final heading for landing in all cases was 270°. One-half of the aircraft entering each controller's area were destined for one of the two runways. Once responsibility for a given aircraft was assigned, however, no turnover to the other controller was permitted, even though a crossing of sector boundaries was involved. This particular aspect of the task situation required a high level of coordination between the

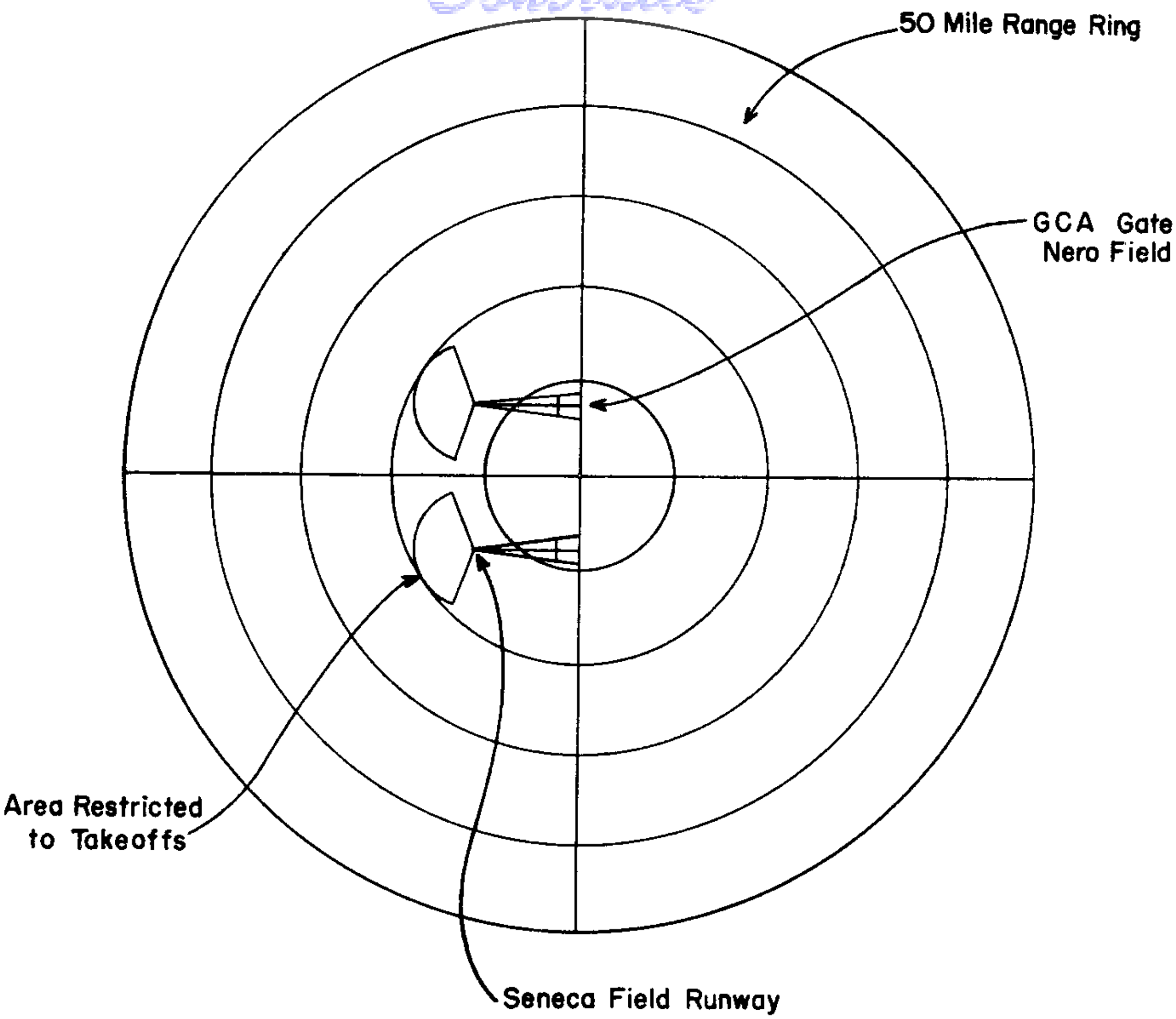

Fig. 3. Scaled drawing of the PPI overlay.

two members of the pattern-feeder control team. Thus, the final sequence of traffic established just prior to GCA turnover was a joint effort of both team members.

Figure 3 is a detailed diagram of the control area, as seen on the PPI displays, illustrating the sector divisions and the arrangement of the two airfields.

The landing aircraft entered the control zone at their prescribed cruising speeds and altitudes, and with headings that would take them within ±5° of their ultimate destination.

GCA requirements were that each aircraft be on a heading within ±10° of 270° and at 2,500 ft. The required pattern speeds for the three types of aircraft were: fighters, 250 kt.; bombers, 250 kt.; and cargo, 200 kt. GCA would not accept aircraft if minimum separation of 30 sec. could not be maintained for the duration of the glide path (e.g., for 60-sec. flight time in the case of a leading cargo aircraft and an overtaking bomber or interceptor).

While maintaining the over-all features of the task constant, variations have occurred from experiment to experiment regarding such factors as input load or rate of entry, runway configuration, types of aircraft flown, etc. in order to stress specific features of the operation. However, it should be noted as a general principle that the justification for changing the value of such parameters from study to study must be explicit and not unfounded or whimsical. The continuity of the program should be kept intact by maintaining a relatively high degree of comparability from study to study when it is at all feasible to do so. Such continuity may provide the basis for important deductions. Even though such deductions have limited scientific status, they can form a sound basis for subsequent investigations.

Concepts.—The next major feature of methodology concerns the definition and organization of the inputs and outputs of research: experimental variables and system criteria. It has been helpful, we have found, to establish general descriptive categories for both classes of variables and to describe studies and their outcomes in these terms. Three basic labels have been used to describe the population of experimental variables normally employed in the program: (a) traffic factors, (b) display-instrumentation factors, and (c) organizational-procedural factors. Traffic factors include such individual items as traffic input rate, aircraft heterogeneity, input flow organization, and control zone and landing field configuration. Display factors include such items as the form and mode of information inputs to the system (e.g., voice communication vs. visual display), information distribution, and information degradation. Organizational factors include such items as control team size, function distribution in the system, and special control procedures. As is apparent, these categories serve mainly to provide internal cohesiveness rather than conceptual rigor.

The sources of specific, testable variables within these categories have been diverse. Many of the hypotheses studied thus far have come from operational and engineering personnel who were faced with identifiable problems or who were inspired to conceive of possible techniques for system improvement in the course of their intimate contact with the operational system. A second source has been the process of research itself. Research has often been noted to be a self-regenerative activity. During the conduct of one study which is designed to answer a specific problem, one frequently notes other problematic characteristics of the system, and so on. A third, and currently minor source of hypotheses, has been the general schema of experimental psychology. Hopefully, as system research gains momentum, theory will become sufficiently well developed and appropriately structured so as to provide a more effective source of research hypotheses.

In terms of criteria development, a more difficult situation obtains than is true of experimental variables. First, it sometimes is not possible to obtain or determine any ultimate standards for system performance. This is especially true where there is any kind of conflict or trade-off between subcriteria. Such is certainly the case in air traffic control system research where safety and efficiency may not be entirely mutually compatible outcomes. The philosophical overtones involved in the safety criteria make for some disavowals of reality in the sense that absolute safety is set as the ultimate goal in operational air traffic control and, unfortunately, one can never realize the absolute. However, since simulation techniques can be used to test ideas that would result in high risk in real life, a working compromise can be achieved at the research level. A useful expedient is to treat safety and efficiency as independent, noninteractive entities, and to attempt to measure and evaluate both components of output as precisely as possible. Precision, in this case, derives from utilizing several sources and several dimensions of measurement. First, when possible, it is desirable to have a battery of indicants rather than a single measure of each output entity. Thus, it has been our custom to measure efficiency in terms of over-all flight time, per cent delay, fuel consumed in flight, and frequency of missed approaches. Safety has been variously assigned as frequency of separation errors at different stages of the approach and maintenance of specified intervals between landings and departures. Second, there is much to be said for making observations at several different levels of output; that is, it is advisable to measure the output of individual components, subassemblies, and the total system. In the program reported here, the content and frequency of voice communications have been the most useful of the subcriteria. Other such indices have included the "unit instruction" frequency (treating two or more aircraft as a single unit), delay in responding to emergencies or major disturbances in the system, and opinion (job satisfaction) inventories. In many cases, evaluation of the subcriteria has led to conclusions having a material consequence for over-all as well as subsystem design and system management.

## EMPIRICAL RESULTS

A total of 14 major system experiments have been completed at this writing (8, 9, 10, 11, 12, 13, 14, 20, 21, 22, 23, 24, 25). Four more are currently in some stage short of final editorial revision. In general, the trend has been toward increasing scope and complexity. The 14 completed studies have been summarized in most of their essential characteristics in Table 1. While it is not feasible to recapitulate the contents of the table in the text, several over-all characteristics are worthy of note. In the 14 studies listed, for example, a total of 17,269 aircraft flights were simulated. It takes little imagination to estimate the immense costs that would have been involved had these studies been done in the field rather than in the laboratory. A second factor, quite important in the interpretation given to the total array of findings, concerns the characteristics of the people who participated as controllers; in Studies II through VIII, highly skilled professional controllers from the Directorate of Flight and All Weather Testing, Wright Air Development Center, were active participants, while in Studies I, IX, X, XI, XII, XIII, and XIV, college students were trained in the laboratory to serve as controllers. The advantages for realism of simulation inherent in the use of professionals have been touched upon in the preceding section. The contravening value obtained from the utilization of laboratory-trained operators is the ability of the experimenter to use a substantially increased sample of personnel.

A third major over-all consideration involves the derivation and interpretation of incidental observations. First, it can be noted that, once obtained, Table

Summary of Major Air Traffic

| TITLE | AUTHORS | VARIABLES | Control Team Size | Input Load | Number of A/C Types |
|---|---|---|---|---|---|
| I<br>Human Engineering Aspects of Radar Air Traffic Control: Performance in Sequencing Aircraft for Landings as a Function of Control Time Availability | Schipper, L.M.<br>Versace, J. | Time available for controller action to avoid incipient collisions (5 levels between 4 min. and 8 min.) | 1 | 4 aircraft per problem | 1 |
| II & III<br>Human Engineering Aspects of Radar Air Traffic Control: Experimental Evaluations of Two Improved Identification Systems under High Density Traffic Conditions | Schipper, L.M.<br>Versace, J.<br>Kraft, C.L.<br>McGuire, J.C. | "Clock code" vs. "light pencil" methods of target identification | 1 | Variable | 4 |
| IV<br>Human Engineering Aspects of Radar Air Traffic Control: A Comparison of Sector and In-Line Control Procedures | Schipper, L.M.<br>Versace, J.<br>Kraft, C.L.<br>McGuire, J.C. | Method of division of control function<br>Composition of control team<br>Input load | 2 | Variable | 2 |
| V<br>The Effect of Emergencies and Communication Availability with Differing Entry Rates | Versace, J. | Interphone vs. face-to-face communications<br>Class of emergency (major vs. minor)<br>Input load | 2 | Variable | 2 |

1
Control System Studies

| PARAMETERS | | | | RESULTS | INCIDENTAL OBSERVATIONS | CONCLUSIONS AND RECOMMENDATIONS |
|---|---|---|---|---|---|---|
| | Total Number of Flights | Control Zone Configuration | Others of Particular Interest | | | |
| | 640 | 20-mi. radius | Final common path designated | No significant effect on performance | Substantial learning effects | Four minutes are sufficient for conflict avoidance under load conditions observed |
| | 1600 | 90° sector; 50-mi. radius | Return-to-base from combat mission simulated | No significant effect on performance | Level of input load may be set too low | Choice of target identification method may be made on basis of engineering feasibility |
| | 832 | 90° sector; 50-mi. radius | All targets coded with "clock-code" identity | No significant main effects observed | Subjects x conditions interaction is significant | Operational convenience may be used as criterion for use of either sector or in-line control set-up |
| | 1152 | 90° sector; 50-mi. radius | Standard conditions | Face-to-face communication may be a minor distraction<br>Emergency procedures are quickly routinized and lead to little performance degradation<br>Performance degradation is gradual function of increasing system load | Identity coding allows the utilization of highly flexible routing procedures to the betterment of system performance | Some functions such as emergency procedures and inter-controller communication procedures should be standardized while other functions such as routing during the approach should be kept flexible |

Table 1

| TITLE | AUTHORS | VARIABLES | Control Team Size | Input Load | Number of A/C Types |
|---|---|---|---|---|---|
| VI<br>The Use of Displays Showing Identity versus No-Identity | Schipper, L.M.<br>Kraft, C.L.<br>Smode, A.F.<br>Fitts, P.M. | Clock-code identification system vs. no identification system<br>Input load | 1 | Vari- | 2 |
| VII<br>Terminal System Effectiveness as a Function of the Method Used by Controllers to Obtain Altitude Information | Schipper, L.M.<br>Kidd, J.S.<br>Shelly, M.W.<br>Smode, A.F. | Voice Interrogation vs. continuous visual display of altitude information<br>Input load | 1 | Variable | 2 |
| VIII<br>The Effect of Enroute Flow Control on Terminal System Performance | Kidd, J.S.<br>Shelly, M.W.<br>Jeantheau, G.<br>Fitts, P.M. | Entry regularization in time (5 conditions), space (2 conditions), and sequence (2 conditions) | 2 | Entry interval 35 sec. | 3 |

(Cont'd)

| PARAMETERS | | | RESULTS | INCIDENTAL OBSERVATIONS | CONCLUSIONS AND RECOMMENDATIONS |
|---|---|---|---|---|---|
| Total Number of Flights | Control Zone Configuration | Others of Particular Interest | | | |
| 1280 | 90° sector; 50-mi. radius | Controller allowed option to "hold" aircraft outside terminal zone | ID system significantly superior to no ID<br>Marked interaction effect between ID variable and input load variable; presence of ID much more effective under high-load conditions | Requests for altitude information found to constitute 15% of controller communication | Omnipresent target ID leads to increased system efficiency and simplified control procedures |
| 1280 | 90° sector; 50-mi. radius | Standard conditions | Performance was relatively unaffected by mode of altitude presentation<br>Controller talk time was reduced by 8% through the use of visual display of altitude | Supervisors and monitors in the simulated control center found the visual display to be of help in their particular tasks | Information inputs via the usual visual mode should be integrated so as to require minimal accommodation shifts and time sharing of attention |
| 2880 | 360° sector; 50-mi. | Two landing fields in terminal area | No significant effects on performance were attributable to the different experimental conditions | An indication that controllers employ "unit instructions" (tend to create temporary groups of aircraft) under stress conditions was obtained<br>Frequency of control instructions increases as proximity to GCA turnover increases | Operators tend to use effectively a strategy of gradual reduction in entropy (or successive approximation) rather than one which requires relatively long-range planning and prediction |

Table 1

| TITLE | AUTHORS | VARIABLES | Control Team Size | Input Load | Number of A/C Types | |
|---|---|---|---|---|---|---|
| IX<br>Air Traffic Control System Effectiveness as a Function of the Division of Responsibility between Pilots and Ground Controllers | Kidd, J.S.<br>Kinkade, R.G. | Level of use of airborne position information equipment<br>Heterogeneity of aircraft type | 1 | aircraft under control at all times | Variable | |
| X<br>A Comparison of Two Methods of Controller Training in a Simulated Air Traffic Control Task | Kidd, J.S. | Programmed level of input load during "system" training phase of an extended training operation | 1 | Variable | 1 | |
| XI<br>Load Balancing and Procedural Flexibility in a Two-Man Radar Approach Control Team | Kidd, J.S.<br>Hooper, J.J. | Method of control assignment (entry sector, destination, rotation)<br>Procedure for exchange of control assignment (allowed, allowed in specific area, disallowed) | 2 | Entry interval 45 sec. | 2 | |
| XII<br>The Joint Effectiveness of Airborne Position Information Equipment and Target Identification on a Simulated Air Traffic Control System | Kinkade, R.G.<br>Kidd, J.S. | Method of use of API-type equipment under several background configurations (ID vs. no ID), Ground Reference Points present, Fixed Approach Paths present | 2 and 1 | Entry interval 30 sec. | 2 | |

(Cont'd)

| PARAMETERS | | | RESULTS | INCIDENTAL OBSERVATIONS | CONCLUSIONS AND RECOMMENDATIONS |
|---|---|---|---|---|---|
| Total Number of Flights | Control Zone Configuration | Others of Particular Interest | | | |
| 1450 | 360° sector; 50-mi. radius | GCA equipment failure introduced once during every problem | Redistribution of work load through use of API equipment led to significant increase in system performance<br>Relative delay per aircraft was less with mixed types | Side effects due to emergencies at lowest levels of controller participation were slight | Allowing the controller to assume more of a monitoring role is beneficial to the system |
| 320 | 180° sector; 50-mi. radius | Standard conditions | Higher input loads during training resulted in superior performance at program termination | Adequate performance levels attained by all trainees in under 20 hours of total training time | High activity during training advisable where safety factor does not intervene |
| 1944 | 180° sector; 50-mi. radius | Two landing fields in terminal area | Destination method was superior<br>Free exchange option preferred | Coordination and integration between team members constitutes additional load on the system | Task demands should be balanced over various phases of the total task when feasible |
| 1412 | 180° sector; 50-mi. radius | Ground reference points and fixed approach paths were in some problems present in the terminal zone | API equipment can be used to derive target ID<br>The use of both facilities (API and ID) simultaneously yields maximum system adaptability | Arbitrary restrictions on the approach path configuration available to the controller are inefficient | When information-processing facilities are optimal, maximum procedural flexibility is desirable |

Table 1

| TITLE | AUTHORS | VARIABLES | Control Team Size | Input Load | Number of A/C Types |
|---|---|---|---|---|---|
| XIII<br>A Comparison of One-, Two-, and Three-Man Radar Approach Control Teams under Various Conditions of Input Load | Kidd, J.S. | Control team size<br>Input load (90-, 60-, and 30-sec. entry intervals. | Variable | Variable | 2 |
| XIV<br>The Effect on Performance of Different Proportions of Monitored Elements in a Control System | Kinkade, R.G.<br>Kidd, J.S. | Proportion of aircraft having API-type equipment (0, 33, 67, 100%) | 1 | Eight aircraft under control at all times | 2 |

observations of this kind were employed at later stages as the basis for new studies in which the problems they raised became central issues. Second, it should be emphasized that it was the high degree of task complexity that provided much of the opportunity to make such observations meaningful.

## TENTATIVE GENERALIZATIONS REGARDING HUMAN OPERATOR CHARACTERISTICS

It is possible, after reviewing all 14 studies in the series, to abstract several common characteristics pertaining to the interaction of men and machines which seem to be of fundamental psychological import. This is not to say that a novel theory or newly discovered behavioral mechanisms are forthcoming. On the

(Cont'd)

| | PARAMETERS | | | RESULTS | INCIDENTAL OBSERVATIONS | CONCLUSIONS AND RECOMMENDATIONS |
|---|---|---|---|---|---|---|
| | Total Number of Flights | Control Zone Configuration | Others of Particular Interest | | | |
| | 1944 | 180° sector; 50-mi. radius | Single landing field with dual runway employed; departure clearance requirements simulated | System efficiency decreases as input load is increased<br>Given constant load, only slight superiority observed with larger teams<br>Performance decrement occurs when input load is increased in proportion to team size | No reliable prediction of team performance could be derived from the individual performances of the team members | Integration and coordination between team members is a source of task load. Such demands on operators should be minimized |
| | 535 | 180° sector; 50-mi. radius | Standard conditions | Regular progressive increase in performance was observed as the proportion of API-equipped aircraft was increased | None | Mixing monitored and actively controlled elements in a system is not noticeably deleterious to system performance |

contrary, the characteristics of the human operator having significance for system performance are directly derivable from well-established, fundamental psychological constructs. The end sought here, then, is one of selective emphasis and conceptual structuring such that both applications and subsequent research can be pursued in the most integrated and effective way.

Three topic titles can be used to summarize the system characteristics that influence operator performance: (a) distribution of responsibility, (b) input organization, and (c) procedural flexibility.

Distribution of functions.—The problem of distribution of responsibility among men, and among men and machines, turns out to have several subdimensions. When such a distribution leads to a net reduction in input load to any given operator, that operator's performance can be expected to improve. Thus, in those studies wherein monitoring vs. active control was a factor, it was found that the monitoring role was commensurate with improved output. The first study of the effect of the employment of API equipment (11) constitutes a case in point. Here, a redistribution of function between pilots and the ground controller was possible. The pilot was able to set his own course through the terminal approach phase and could, under certain circumstances, make his own decisions regarding let-down and speed adjustments. The ground controller, even in the most extreme case of function redistribution, still retained responsibility for conflict avoidance since only the ground controller could observe the relative position of all aircraft in the system. Moreover, the ground controller had the responsibility to detect and correct "system errors" (e.g., inefficient approach path due to equipment misalignment) when they occurred. Thus, the controller assumed, essentially, an over-all monitoring function, while the details of approach path configuration were dealt with by the individual pilots. In both "normal" and emergency situations which were simulated, system performance was superior when the task elements were shared as compared to the case where the ground controller was directly involved in every decision-making detail of flight path definition, as in a completely manual operation. It should be emphasized that the total load to the system was not modified over the various conditions of the test. No loss of vigilance on the part of the ground controller occurred through lack of system activity. The key factor leading to increased system effectiveness was a reapportionment of load along operationally functional lines. That is, the responsibility for each separate function was allocated so that no conflict of roles developed and no additional coordination demands were imposed on the system.

A further affirmation of the importance of the functional aspect of task redistribution is provided by the data from the thirteenth study in the series (9) which was concerned with the size of the pattern-feeder approach control team. Single operators, working alone, were compared with teams of two and three operators working together on the same job. The comparisons were made under a number of input load conditions. In this instance, the improvement in system performance as a consequence of adding team members (thus reducing the work load per operator) was disappointingly slight. Under conditions where input load was increased proportionate to increases in team size, a net loss in performance occurred. It was concluded from these observations that task redistribution was not effective under the conditions described because the reduction in operational demands on the operators was contravened by an increase in coordination demands plus a loss in role specificity such that any operator at any one time might be subject to confusion regarding where his personal responsibility ceased and his co-worker's responsibility began.

The two reports cited above constitute only a portion of the evidence which allows the conclusion that reapportionment of function leads to an economical increase in system effectiveness only when operator or component functional integrity can be maintained with the consequent minimization of coordination requirements and confusion arising from overlapping responsibilities.

Aspects of this problem which require and are receiving further investigation include such factors as the power or authority structuring in the team organization, the quantitative description of activity components or distinct operations, and the extension of the monitoring concept to include the entire range of input and output events.

Input organization.—The information input situation in a task setting such as radar air traffic control is typified by high potential volume and diversity of sources. These attributes require that some intervention in the form of preprocessing and organizing operations exist between the operator and the flood of input data. The problem at issue is: How should such intervention be done so as to best meet the operational needs and perceptual capabilities of the operator? The system features which comprise the manipulatable elements of the problem are such factors as display configuration, input mode or channel, and code form or symbology. The operator response mechanisms of import include such factors as recognition thresholds, discrimination thresholds, receptor adjustments, sensory capacity, sensory interactions, etc.

The functional approach adopted in meeting the problem of input organization was based on the following guide lines which were developed as the problem progressed: (a) the availability of different categories of information should be correlated with their respective usefulness for system operations; (b) essential discriminations should be facilitated by the accentuation of discrimination cues; (c) interference effects from such sources as input simultaneity should be minimized; and (d) requirements for rapid receptor adaptation should be avoided.

An application of the requirement specified under (b) above is exemplified by the investigations of alternative methods of target identification completed during the program of research (22, 23). In these two studies, facilities were introduced whereby it was possible for the controller to avail himself of several sophisticated techniques for either continuous or "on demand" target identification. The results of these investigations gave quantitative support to the expectation that such an aid to discrimination would materially benefit system performance.

The study of a prototype visual display of altitude information (21) provides an example of an attempt to reconcile the requirement for high availability with an avoidance of interference effects. Interestingly enough, the prototype altitude display which was independent of the primary PPI display was not successful because (we believe) of the rapid receptor adjustment required in the use of both displays (PPI and altitude) in unison. Thus, an attempt to solve one incongruity of display criteria exposed still another.

The problem of input organization is thus one in which the best solution is often the best compromise between disparate criteria. Work is continuing in this area, particularly with regard to the form of the display proper, mechanization of information-processing functions, and the form of electronic output (e.g., analog vs. digital).*

Procedural flexibility.—The third topic area, procedural flexibility, may be defined as the range of optional means available to the operator for attaining some system goal. The problem again revolves mainly around the interaction of

---

* The extremely vital role of the technical support research, especially for input organization problems, cannot be overemphasized. The complexity of the problem requires that many detailed fundamental aspects be undertaken with the most precise control of conditions.

equipment characteristics with human propensities and limitations. For example, a system component designed ostensibly to relieve the operator of some routine subtask may effectively limit the number of alternative tactics in dealing with certain situations. Moreover, when considering procedures it is also apparent that we begin to cross over from an exclusive concern with system design and enter the realm of system management. This is a consequence of the fact that procedural limits may be created directly by management directive. Even so, the basic parameters are comparable and the question remains: What procedures and what level of procedural flexibility will be most compatible with operator abilities and limitations?

One of the most pronounced limitations affecting procedures is the general human inability to make very accurate predictions of future events when system dynamics include nonlinear elements. While this observation has its original derivation from motor skill investigations not included in the present program (e.g., "quickening" studies [1]), it helps to explain many findings in the present series. For example, it was observed early in our program that the controllers tended to follow an iterative method of decision-making in the air traffic control task; that is, rather than make a small number of large corrections, they would make a large number of relatively small corrections of heading, altitude, and airspeed, often postponing commitment to one course or another until the last available moment. In this fashion, they were able to compensate for their inability to deal with nonlinear extrapolations by reducing system dynamics to a large set of approximately linear components. Given this tendency to respond on a moment-by-moment basis which can eventuate in an almost infinite variety of dynamic arrangements of system elements, procedural rigidity in terms of a limit on the range of options available to the operator acts as a barrier to efficiency.

It is recognized, however, that there is at least one advantage inherent in procedural rigidity or specificity that should not be overlooked. In instances of sudden stress, such as would be brought about by emergencies, a reduction in the number of available controller options is compatible with a reduction in confusion and the natural human tendency to decline in adaptability under high stress conditions (19). Thus, we are again faced with the consequences of antagonistic response tendencies on the part of the human operator. On the one hand, he performs most effectively if he can manipulate the system elements on a moment-to-moment basis, freed of arbitrary restraints. On the other hand, he may be unstrung by a lack of specificity when high stress conditions prevail. The approach currently being taken to clarify the issues involved is to examine in detail such matters as differential influence of equipment-imposed vs. directive-imposed procedural limitations, machine facilitation of the operator's capacity to anticipate future events, and the development of methods for shifting tactics when conditions change from "normal" to "emergency".

In general summary, we have seen that distribution of responsibility is effective when the reapportionment of effort and decision-making is carried out along operationally functional lines and when it leads to a net reduction in input load to the operator. Input organization is seen to mean centralization and integration of inputs up to the limit of mutual interference. Procedural flexibility is seen as advantageous through its compatibility with the iterative problem-solving process employed by human operators. More significant in the long run perhaps is the fact that the three problem areas chosen for exposition are, themselves, closely interrelated, first on an operational level and second on the level of a basic psychological mechanism. On the operational level, it is apparent that distribution of function can affect procedures, that procedures can influence display requirements, and, in fact, each one of these factors can be in either a cause or effect relationship with every other factor. The old truism that you affect the whole system by modifying a single component is reaffirmed here. However, it appears possible now that the range and extent of these effects can be predictable and thus controllable,once some of the basic interactions are exposed by research and analysis.

In regard to the kind of system of concern here, it is also possible that a single underlying behavioral principle can tie together even the rather broad generalizations proposed so far. This most crucial single factor appears to be that human short-term memory (temporary storage) is relatively susceptible to interference. It can be demonstrated that this one factor plays a part in all the above-mentioned human factor considerations. Thus, with regard to distribution of responsibility, it is the short-term memory capacity that is burdened when input sources are multiplied without a commensurate reduction in net input load. Input organization likewise stresses the loss of memory content that occurs when an operator switches his attention from one display to another. Insofar as procedural flexibility is concerned, the lack of extrapolative capacity seems to be but one facet of the memory problem in that extrapolation requires the simultaneous synthesis of a number of discrete items of information; any momentary loss leads to a wrong prediction.

In summary, it may be hypothesized that many, if not all, variables which are found to influence human decision-making performance in the man-machine context will also be found to create differential demands on the short-term information storage function of the operator.

## PRACTICAL APPLICATIONS

The solution of a host of practical problems has been and continues to be the prime purpose of the research program as presented here. Keeping in mind the very real limitations of experimentation in so complicated an area as air traffic control operations, it is nevertheless possible to suggest some system design characteristics and management policies that appear at this time to have reasonable promise of material benefit to system performance.

Our studies and observations have led to the following general recommendations:

Traffic load.—In an essentially manual radar-type system with the inclusion of reliable, continuous target identification and interference-free communications, one normally skillful operator can easily control an eight-aircraft load with near-minimum flight delay and rather complete safety. No restraints need be imposed regarding aircraft performance homogeneity or initial sequential organization. This load should be functionally homogeneous, however, in that all aircraft should be in the same phase of flight (i.e., departing a terminal, approaching a terminal, or enroute). Mixtures across these categories are possible under lighter loads (five or less aircraft under control simultaneously), but avoidance of this situation is suggested.

The eight-aircraft load leads to different landing (or processing) rates depending on such parameters as average airspeed and route or control area dimensions. Given very high-speed military aircraft and a control phase of 50 mi. as an example, processing rates are in excess of one aircraft per minute per controller.

Loads in excess of 10 aircraft under simultaneous control begin to exceed normal operator capacity and lead to a sharp increase in flight delay and very marginal safety accomplishment. A positive feedback or snowball effect obtains and progressive decay of performance is observed.

The above suggestions apply in situations of IFR conditions and where the ground controller has standard cognizance over all major flight parameters such as course, altitude, and airspeed. By the use of various equipment facilities and operational procedures, the function of the controller can be modified in such a way that the number of aircraft being processed can be increased without appreciable performance or safety decrement. In these instances, the controller is allowed to share some portion of the task load imposed by each aircraft either with another person or with a machine aid. An example of this redefinition of controller function is the case where the controller can share responsibility for approach path definition with the pilot through the use of some form of airborne position information equipment (see above).

Procedures.—Considerable caution must be exercised in setting up the procedures for sharing the task load. For instance, as indicated above, adding equivalent operators in an arbitrary fashion to the control team does very little to increase effectiveness. When task components are distributed, it must be in such a way so as to maximize the functional autonomy or independence of the participants; otherwise, coordination requirements will use up most of the gains in task load reduction. This is especially true in terminal operations where sequencing of aircraft is so important. An activity such as sequencing where timing and predictive justment come very much into play is best handled by a single individual.

Another caution grows out of a consideration of procedures. This regards the possibility of overrigidifying system operations as a consequence of mechanization or automatization of functions. The human component in the system provides the resilience required in the face of changing task demands and environmental conditions. In order to be a contributor to system performance, the operator must be given the opportunity to utilize this capacity. This simply means that care must be taken in the introduction of new equipment such that it does not limit the range of controller decision making and choice of tactics, but rather is designed to facilitate his activities in this line.

It is important to emphasize here that we are not suggesting that automation of complex systems is undesirable. Obviously, there is a real need for automatic data-processing and storage facilities in air traffic control, and certain routine decision-making functions may be effectively provided by automatic means. However, we do maintain that such automation must proceed only when it is clearly demonstrated that such a facility would materially enhance the human operations in the task. We maintain that human decision-making functions must continue to hold a central place in the air traffic control system for without the human, flexibility of system responsiveness can be severely impaired.

The reason for this latter consequence is obvious when one considers that the number and kinds of alternative courses of action available in a fully automatic system are preprogrammed. Thus the flexibility of action under diverse task and environmental conditions is no greater than that originally built into the automatic components, and this, obviously, is limited. To approach the degree of human responsiveness to changing demands, an automated decision-making device would be prohibitively large and costly. It follows, then, that whereas the human operator may introduce undesirable lags into the system and while he may, on occasion, commit errors, a cure-all for these ills (all-out automation) may very well only expose the system to a far more serious disease (procedural rigidity), especially under emergency operations.

Displays.—The final concern in system design involves the form, quality, and content of the information inputs to the controller. First, a distinction is required between what should be continuous and what should be available only on demand. Continuous position information, reliably presented, appears to be the main and critical element in air traffic control. When this is supplemented by reliable target identification (continuous, if possible) and ready availability of altitude, speed, and heading data, the essential framework for effective operations is present. Status, route, and ambient conditions information are somewhat low on the priority scale in terms of frequency of use. However, when they are required for decision making, the need is vital. Thus, the latter information should be present "on demand."

One of the major problems of information presentation concerns integration vs. interference. It is apparent, for example, that dispersal of display elements is not in the best interest of effective control. Unitary, as opposed to multiple, presentation should be the rule. However, limits are imposed by the chance that in trying to get everything on a single display, crowding and interference will take place. There is probably nothing more disconcerting to the working operator than to have one set of critical inputs obscured by another equally critical set. The solution to this dilemma seems to be to allow the operator substantial control over display characteristics. For example, he might be allowed to erase, temporarily, one set of normally continuous information while reading out the set which has been obscured. Thus, integration can be achieved without the interference penalty.

## FUTURE TRENDS

The program reviewed here represents only tentative first steps toward answers to vital problems. New techniques of methodology are already proving themselves as greater numbers of investigators turn their efforts toward man-machine systems. Such things as the more extensive and rational use of operational games for system simulation, and techniques for the continuous evaluation of systems having nominally discrete outputs (i.e., the product may be a single act, such as launching a missile, or a discrete set, such as landing a series of aircraft, as opposed to vehicular guidance systems where outputs are in a continuous form) are now on the horizon.

Much is now being accomplished by way of integration across the lines of disciplinary specialization. The ends of system management will be well served by the increasing joint efforts of system research and analysis specialists with those who are concerned with personnel selection and training. A recent article by Melton (17) describes in detail the considerable potential benefits. Some of the benefits are already apparent in the work of the System Development Corporation of the air defense system as described by Goodwin (5).

The systems research specialty also seems to be an especially good meeting ground for the experimental psychology and social psychology specialties. The matter of cross-validation between field and laboratory can be implemented by such cooperation, since the social psychologist can bring to bear well-established techniques for dealing with the ambiguities of the less controlled field phenomena. The role to be played by those social psychologists who are especially concerned with interaction and communication between members of small groups has already been touched upon.

Industrial and electronics engineering, as well as operations research, have provided the firm backbone of research into man-machine systems from the start.

It is possible now to anticipate the character of the specific problems that will be pursued in the near future. One example taken from the air traffic control system concerns vigilance and monitoring activities. Load can conceivably be set too low as well as too high, and system performance may suffer from a lack of operator alertness or involvement in the system. Along these same lines, the effect of load variability must be explored. Furthermore, we know far too little about the components of load. Perhaps we need a concept like the "bit" from information theory in order to do task analyses of more than limited usefulness. Obviously, there is much to be done just with regard to this one facet of man-machine system operations.

On a more general level, one can anticipate an increasing emphasis on organized theory. This is in part a function of improving methodology and in part a function of the increasing interest and acceptance of the research specialty in academic circles.

Along with consideration of the scientific future, concern should be given to the future in terms of applications. The advent of radically new kinds of systems such as manned space vehicles is an obvious but highly challenging opportunity for future development. Less obvious perhaps are the opportunities available in such mundane areas as product-control systems. In the long run, these latter may be the more important areas of man-machine system research and applications. Certainly insofar as military applications are concerned, logistics and other support activities will continue to represent the dominant outlay of funds and manpower.

Finally, the potential values to the individual should not be ignored. If research such as has been outlined here can help facilitate the effectiveness of the individual by making his job as nearly appropriate to his needs, abilities, and personal safety and comfort as possible, then no further justification is required.

# REFERENCES

1. Birmingham, H. P., and Taylor, F. V. A Human Engineering Approach to the Design of Man-Operated Continuous Control Systems. NRL Report 4333. Naval Research Laboratory, Washington, D. C., April 1954.

2. Dodge, R. "Mental Engineering during the War." American Review of Reviews. Vol. 59. 1919. pp. 504-508.

3. Fitts, P. M. (Ed.) Human Engineering for an Effective Air Navigation and Traffic Control System. Committee on Aviation Psychology, National Research Council, 1951.

4. Fitts, P. M., Schipper, L. M., Kidd, J. S., Shelly, M. W., and Kraft, C. L. "Some Concepts and Methods for the Conduct of System Research in a Laboratory Setting." In G. Finch and F. Cameron (Ed.), Air Force Human Engineering, Personnel, and Training Research. NAS-NRC Publication 516. National Academy of Sciences, National Research Council, Washington, D. C., 1958.

5. Goodwin, W. R. "The System Development Corporation and System Training." American Psychologist. Vol. 12. August 1957. pp. 524-528.

6. Hixson, W. C., Harter, G. A., and Warren, C. E. A Radar Simulator for Use in Air Traffic Control Studies. WADC Technical Report 53-418. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-43 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, January 1954.

7. Hixson, W. C., Harter, G. A., Warren, C. E., and Cowan, J. D., Jr. An Electronic Radar Target Simulator for Air Traffic Control Studies. WADC Technical Report 54-569. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-43 between the Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1954.

8. Kidd, J. S. A Comparison of Two Methods of Controller Training in a Simulated Air Traffic Control Task: A Study in Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 58-449. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, January 1959.

9. Kidd, J. S. A Comparison of One-, Two-, and Three-Man Control Units under Various Conditions of Traffic Input Load. WADC Technical Report 59-104. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between the Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, June 1959.

10. Kidd, J. S., and Hooper, J. J. Division of Responsibility between Two Controllers and Load Balancing Flexibility in a Radar Approach Control Team: A Study of Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 58-473. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, February 1959.

11. Kidd, J. S., and Kinkade, R. G. Air Traffic Control System Effectiveness as a Function of the Division of Responsibility between Pilots and Ground Controllers: A Study in Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 58-113. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, June 1958.

12. Kidd, J. S., Shelly, M. W., Jeantheau, G., and Fitts, P. M. The Effect of Enroute Flow Control on Terminal System Performance: A Study in Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 57-663. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1957.

13. Kinkade, R. G., and Kidd, J. S. The Effect of Procedural Variations in the Use of Target Identification and Airborne Position Information Equipment on the Performance of a Simulated Radar Approach Control System. WADC Technical Report 58-624. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, March 1959.

14. Kinkade, R. G., and Kidd, J. S. The Effect of Different Proportions of Monitored Elements on Operator Performance in a Simulated Radar Air Traffic Control System. WADC Technical Report 59-169. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, June 1959.

15. Kraft, C. L. A Broad Band Blue Lighting System for Radar Approach Control Centers: Evaluation and Refinements Based on Three Years of Operational Use. WADC Technical Report 56-71. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, August 1956.

16. Kraft, C. L., and Fitts, P. M., with the assistance of A. R. Perong. A Broad-Band Blue Lighting System for Radar Air Traffic Control Centers. WADC Technical Report 53-416. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-43 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, January 1954.

17. Melton, A. W. "Military Psychology in the United States of America." American Psychologist. Vol. 12. December 1957. pp. 740-746.

18. Munsterberg, H. Psychology and Industrial Efficiency. Houghton-Mifflin Company, New York, N. Y., 1913.

19. Patrick, J. R. "Studies in Rational Behavior and Emotional Excitement. II. The Effect of Emotional Excitement on Rational Behavior in Human Subjects." Journal of Comparative Psychology. Vol. 18. 1934. pp. 153-195.

20. Schipper, L. M., and Versace, J. Human Engineering Aspects of Radar Air Traffic Control: I. Performance in Sequencing Aircraft for Landing as a Function of Control Time Availability. WADC Technical Report 56-67. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-43 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, February 1956.

21. Schipper, L. M., Kidd, J. S., Shelly, M. W., and Smode, A. F. Terminal System Effectiveness as a Function of the Method Used by Controllers to Obtain Altitude Information: A Study in Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 57-278. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, June 1957.

22. Schipper, L. M., Kraft, C. L., Smode, A. F., and Fitts, P. M. The Use of Displays Showing Identity vs. No Identity: A Study in Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 57-21. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, February 1957.

23. Schipper, L. M., Versace, J., Kraft, C. L., and McGuire, J. C. Human Engineering Aspects of Radar Air Traffic Control: II and III. Experimental Evaluations of Two Improved Identification Systems under High Density Traffic Conditions. WADC Technical Report 56-68. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-43 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, July 1956.

24. Schipper, L. M., Versace, J., Kraft, C. L., and McGuire, J. C. Human Engineering Aspects of Radar Air Traffic Control: IV. In-Line vs. Sector Control with High Density Traffic. WADC Technical Report 56-69. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, September 1956.

25. Versace, J. Human Engineering Aspects of Radar Air Traffic Control: V. The Effect of Emergencies and Communications Availability with Differing Entry Rates. WADC Technical Report 56-70. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1956.