NATIONAL BUREAU OF STANDARDS REPORT

6985

PROJECT SERAPE

Simulator Equipment Requirements for Accelerating Procedural Evolution

by

A. A. Ernst

To

Federal Aviation Agency

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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INTRODUCTION

Project SERAPE was a Program Planning Study. The purposes of the program that was evolved are summarized by the title and are expanded upon in the following text. These are the complementing objectives of improving the procedures for controlling air traffic by means of laboratory experiments and of defining the equipment required for the system simulations that are employed in such experiments. The immediate objective of the study was to plan a program of productive laboratory experiments. However, the more basic purposes of the study were educational: to inform the National Bureau of Standards about air traffic control and to inform the Federal Aviation Agency about the simulation approach to systems analysis that is under development at NBS.

Project SERAPE was originally prepared for oral presentation with the visual aids of 17 flip charts which are somewhat self-explanatory. These charts are the basis of this report, and each one is presented with descriptive commentary in the succeeding paragraphs. At this point it is important to note that project SERAPE is not the detailed design of either a control concept or a specific experiment; rather, it is the framework within which a broad family of specific experiments can be designed and carried out. It develops the guidelines of an experimental program in terms of methods and means as well as objectives. It introduces the requirements for simulation equipment by presenting material for a family of experiments that might be performed within the general capabilities of the NBS facility. It outlines the methods for utilizing available equipment and identifies the principal features of the program required for the digital computer. It also indicates necessary and desirable additions to existing equipment. Project SERAPE does not include the detailed design of individual experiments. Both the detailed design and the conduct of system experiments require the active participation of the system designer; such activities were beyond the scope of the planning study.

The fundamental purpose of Project SERAPE, as has been observed, was the communication of information. It was done to illustrate how certain analytical methods might be applied to the solution of a significant class of problems in air traffic control by means of a particular kind of systems simulator. The need for illustration arises from the fact that there are many methods of experimental analyses, many classes of problems, and many kinds of system simulators; and each kind, class, or method is difficult to describe out of context with its alternatives. On the premise that "recourse to example" would alleviate the need for compiling an anthology of alternatives, which would be difficult and time-consuming, Project SERAPE utilizes an example to describe the kind of systems simulator, to characterize the class of problems, and to outline the analytical method.

However, Project SERAPE did not convey these ideas as well as had been hoped. Experience indicated the need for demonstration. For purposes of demonstration, Project SERAPE has been partially implemented at NBS; this has included the preparation of the digital computer program and the augmentation or modification of equipment as needed. This combination of equipment and computer program is known as Air Traffic Control Number Two (ATC-2) and was described in NBS Report 6819. The best aid to communication proved to be the process of implementation with the active participation of members of the FAA staff. Project SERAPE now stands as a versatile "vehicle" for laboratory experiments in the control of air traffic. While the operation of the portions implemented has been demonstrated a number of times, no specific experiments have yet been designed in detail to take use of this vehicle.

A measure of orientation was obtained by prefacing Project SERAPE (the paper study) with two charts which serve to introduce the example. The first chart presents some rather fundamental observations about "systems of operations", a class that includes air traffic control systems. These observations help to circumscribe and give direction to the analytical methods to be employed. The second chart describes the kind of functions that can be served and the purposes that can be addressed. The kind of simulation can be characterized as lying toward the opposite end of the spectrum from the kind most used by operations research groups. Emphasis is placed upon the use of deterministic models rather than probabilistic ones; human decisions and reactions are "real" rather than "assumed"; partitioning is according to similar feedback loops in parallel rather than the "single-thread" concatenation of different kinds of loops. In addition to investigations of performance level (or quality), this approach permits experiments in system capacity by "deterministic parts" and avoids the simplifying assumptions required for representing the "probabilistic whole".

The remainder of this report consists of a discussion of the 17 aforementioned charts. At this point it might be appropriate to point out that a "SERAPE" is an intricately woven Mexican blanket that is commonly worn as an outer garment over other clothing. The choice of the word is descriptive of both the wide applicability and the complexity of the project to be discussed.

CHART I

SYSTEMS OF OPERATIONS

CHARACTERISTICS

SYSTEMS ARE MADE BY MAN TO SERVE MAN'S NEEDS —
AND MAN SHOULD BE THE MASTER RATHER THAN THE SLAVE.

WHILE USED BY MAN, SEMIAUTOMATIC SYSTEMS ALSO INCLUDE MEN AS ELEMENTS —
AND ONE MAN MAY BE BOTH USER AND ELEMENT.

DEFINITION

AN OPERATIONS SYSTEM CONSISTS OF PROCEDURES FOR USING TOOLS FOR A PURPOSE.
OPERATING PROCEDURES ARE FUNCTIONS OF BOTH THE PURPOSE AND THE TOOLS AVAILABLE.

DEVELOPMENT

SUCH SYSTEMS ARE EVOLVED THROUGH USE RATHER THAN PREDESIGNED;
AN INTERLOCKING REFINEMENT OF PURPOSE, TOOLS, AND PROCEDURES.

PROBLEMS OF DESIGN

CAN OPTIMUM PROCEDURES BE PRE-ESTABLISHED EITHER EFFECTIVELY OR SAFELY?

CAN TOOLS BE SPECIFIED INDEPENDENTLY FROM OPTIMIZING PROCEDURES?

CAN PURPOSES BE DEFINED WITHOUT KNOWING MAN-MACHINE PERFORMANCE?

APPLICATION OF SYSTEMS SIMULATOR

ACCELERATING THE COMMON EVOLUTION OF PROCEDURES, EQUIPMENT REQUIREMENTS, PURPOSES.

CHART 1. SYSTEMS OF OPERATIONS

It is commonly required to improve the performance of operating systems with respect to both the quality of operations and the capacity of the system. Technology can be successfully applied to these purposes through mechanizing many of the functions within a given system. However, misapplications of technology can result when the perspective of the engineer is not in harmony with that of the user of the system. Misdirection of emphasis commonly results from inadequate knowledge of, on the one hand, real problems of operation and, on the other, the relative suitability of available techniques. The purpose of Chart 1 is to identify a few points where agreement between the engineer and the user is needed for an effective attack upon specific system problems.

Several factors favor the concept of evolutionary rather than revolutionaly improvement. The maintenance of day-to-day operations requires a gradual incorporation of improvements. A policy of progressive mechanization appears to be dictated by the very size and complexity of the present system of air traffic control. Gross automations tend to be inflexible while, in the interest of operational efficiency, the system organization should remain continuously adaptable to evolving purposes and constraints. Finally, simply to allow improvements to keep pace with the growth in requirements, it seems necessary to provide for the iterative advancement of tools and the procedures for using them.

If mechanization is to be progressive, methods are needed for assigning precedence to the functions to be so mechanized. If guidance is lacking, functions are likely to be chosen for mechanization according to criteria of "convenience" and "challenge" rather than according to criteria of "need" and "feasibility". In the light of recent history, it seems worth noting a few "do's" and "don'ts". Don't bother to mechanize functions which are already waiting to be designed out of the system. Do mechanize routine functions that are clearly definable. Don't attempt to mechanize human intelligence in the immediate future. Do emphasize the convenience of the user over that of the equipment designer. Do minimize communication redundancy with respect to man's perception and action and thus with respect to transmission bandwidth. However, do first thoroughly understand the function to be mechanized together with its relationships to associated system functions. In short, it seems necessary to reaffirm the philosophy that the black box is placed in the system in order to serve the requirements of men whose job is to operate the system rather than to operate the black box. In fact, the black box which anthropomorphically requires the man to acquire new knowledge and new skills does not promote improved performance. The purpose of the black box is to enable the man to concentrate upon basic system functions whose performance requires exercise of human experience and intelligence.

CHART 2

DETERMINISTIC SIMULATION IN REAL TIME

CAN ACCURATELY REPRESENT THE SYSTEM ENVIRONMENT – e.g., WORLD PLUS AIRCRAFT.

ALLOWS CONTROLLED EXPERIMENTATION WITH NONLINEAR AND INTELLIGENT INDETERMINATE ELEMENTS – e.g., MEN.

FORCES DETAILED DEFINITIONS OF SYSTEM PROBLEMS.

ASSURES PROBLEM IDENTITY FOR COMPARING ALTERNATIVE SOLUTIONS.

FACILITATES THE TESTING OF HYPOTHESES AND THE DEVELOPMENT OF:

- PROCEDURAL REQUIREMENTS
- EQUIPMENT SPECIFICATIONS
- INFORMATION FILING SYSTEMS
- INFORMATION HANDLING AND DISPLAY TECHNIQUES

ENABLES EDUCATIONAL DEMONSTRATIONS.

CHART 2. DETERMINISTIC SIMULATION IN REAL-TIME

A simulator is a means for performing experiments in the laboratory rather than in the field. Experiments serve to both augment and confirm the results of mathematical analyses as well as to be used wherever the latter are inappropriate. The laboratory frequently offers experimental advantages with respect to control and measurement, and it may also offer economic advantages.

The physical experiment requires deterministic simulation as contrasted to probabilistic simulation which serves the broad needs of operational analysis. Thus, deterministic simulation is especially adapted to evaluating proposed solutions to specific system problems. While measures of the adequacy of inventions are the primary purpose, the establishment of deficiencies serves the important purpose of clarifying the problem for which solutions are being sought.

Simulation in real time enables the investigation of procedures for employing black boxes. It is thus particularly adapted to evaluating the steps in a progressive mechanization of the functions of a man-machine system of operations.

Chart 2 identifies some of the more important functions that can be served and purposes that can be addressed through deterministic simulation in real time.

CHART 3

PROBLEM AREAS IN AIR TRAFFIC CONTROL

AIRPORT CAPACITY — AS THE LIMITING FACTOR.

THE DESIGN OF RUNWAY AND APPROACH FACILITIES.

AIRWAYS STRUCTURE — FOR LOWEST COLLISION PROBABILITY.

SPEED RATIO ACCOMMODATION IN RANDOM VS. ORGANIZED FLYING.

INFORMATION HANDLING — SEMI-AUTOMATIC.

DATA ACQUISITION, CORRELATION, HANDOVER
REQUIREMENTS

FILING SYSTEM MAINTENANCE AND USE.
MEMORY ORGANIZATION

DISPLAYS FOR DATA ASSOCIATION AND CRITERIA RECOGNITION.
SELECTIVE PRESENTATION

COMPUTATIONAL AIDS TO CONTROLLER.
MONITOR, EXTRAPOLATION & ETA REVISION

CHART 3. PROBLEM AREAS IN AIR TRAFFIC CONTROL

The evaluation of possible solutions to specific problems has been submitted as a major purpose of deterministic simulation in real-time, particularly when such solutions involve new procedures as well as new equipments. In order to serve this purpose, it is almost axiomatic that the simulator facility must be capable of either containing or activating any of the inventions to be evaluated. The designer of a simulation facility obviously cannot anticipate all inventions in all detail. He must, therefore, content himself with providing some general capability for examining a limited class of inventions that are functionally related. One approach to establishing requirements for a simulation facility is to begin with a broad classification of existing problems rather than of future inventions.

Accordingly, Chart 3 introduces three broad problem areas as a starting point for converging upon the characteristics of functionally related classes of problems. It is not intended to carry this process out to the detailed delineation of a specific problem in air traffic control. Since we are more concerned with functional similarities than with detailed differences, it is preferred to characterize sets of related problems. Requirements for simulation equipment are then gotten at by the following steps:

(1) Formulate a somewhat generalized functional statement of a group of problems that are functionally related.

(2) Postulate a number of elementary hardware solutions which help to further identify problems that have characteristics in common;

(3) Thereby identify functional capabilities that are prerequisite to conducting such evaluations.

Our attention is focused upon problems of information handling for a number of reasons. First, it is an area of rapid technical advancement which promises many problem solutions that will need to be evaluated. Second, there are many man-machine interactions which will require experimental evaluation. Next, progressive mechanization of information handling functions will enlarge the need for evolving new procedures in the laboratory. Finally, problems of information handling are closely related to the capabilities of NBS.

CHART 4

INFORMATION HANDLING EXPERIMENTS

OBJECTIVE — DETERMINE REQUIRED QUALITY OF DATA ACQUISITION AND CONSOLIDATION WHICH ARE SIMULATED AT VARIOUS LEVELS OF QUALITY.

CRITERIA — DEFINED IN TERMS OF REQUIREMENTS FOR CONTROL USE ONLY.

GEOMETRY — D.C.A. COMPLEX TO RANGES OF 25, 50, OR 100 N.M. AT USER'S OPTION.

DISPLAYS — SPECIALIZED ACCORDING TO RELEVANCE & IMPORTANCE OF DATA.

TRAFFIC — RANDOM DISTRIBUTION; THE AVERAGE RATE BEING CONTROLLED.

SPECIFIC JOB — **ARRIVAL MANAGEMENT** — INCLUDING COORDINATION WITH BOTH ENROUTE AND DEPARTURE CONTROL.

SPECIFIC CRITERIA — TO FORM ARRIVING GROUPS HAVING MINIMUM INTERNAL INTERVALS & MAXIMUM INTERVALS BETWEEN GROUPS FOR DEPARTURES.

METHOD — EVOLVING IMPROVED PROCEDURES THAT REQUIRE NEW MEANS FOR ACQUIRING, HANDLING & PRESENTING INFORMATION.

CHART 4. INFORMATION HANDLING EXPERIMENTS

This chart indicates the broad scope of the problems of information handling and the correspondingly wide variety of factors to be considered, even in a limited family of experiments. It is suggested that the manual exercise of restricted control responsibilities can significantly affect such remote problems as data acquisition through establishing the kind and quality of information required in the system. An important set of restricted responsibilities is defined as arrival management, including coordination with both enroute and departure control, but excluding the usual collateral responsibilities such as "report confirmation", data correlation, bookkeeping, and information transfer.

A family of experiments requires a number of ingredients in addition to alternative definitions of the "specific job". Among these are (a) the measures of goodness of performance against "specific criteria", (b) a representation of the real world in terms of both "geometry" and "traffic", (c) a simulation of the system for acquiring and handling information, (d) an assortment of methods and means for presenting information as well as accepting the outputs of the controller, and (e) a variety of procedures for employing the different tools that will be made available to the controller. A variety of options is available for each of these ingredients, and the number of combinations could become great. In order to keep matters in hand it will be necessary to limit the number of ingredients to be varied and to arbitrarily fix the others in some reasonably realistic way.

It is the substance of this study that, insofar as operations are dependent upon information handling, they are intimately related to both the methods for presenting information and the procedures for using the related tools of display and communication. This portion of operations contains problems which are stimulating the invention of a variety of new devices for the display and communication of information. Changes in operating procedures will be required in order to exploit some of the new features that will be offered. Thus it is believed that evaluating new devices will necessarily entail the evolution of appropriate operating procedures.

The foregoing rationale is the basis for relating "procedural evolution" to the requirements for simulator equipment. Some general requirements are implicit in the next five charts which further relate and define the arbitrarily fixed ingredients; namely, the geometry, traffic simulation, and the specific job, together with its performance criteria. The last of these five charts (Chart 9) suggests both a method and a means for applying the decisions of the controller to the operation of the system. The remaining eight charts suggest methods and means for selecting and presenting information needed by a traffic controller. The requirements upon the simulator thus become more explicit in that it must be capable of activating such "inventions" in a manner that will permit their evaluation.

CHART 5

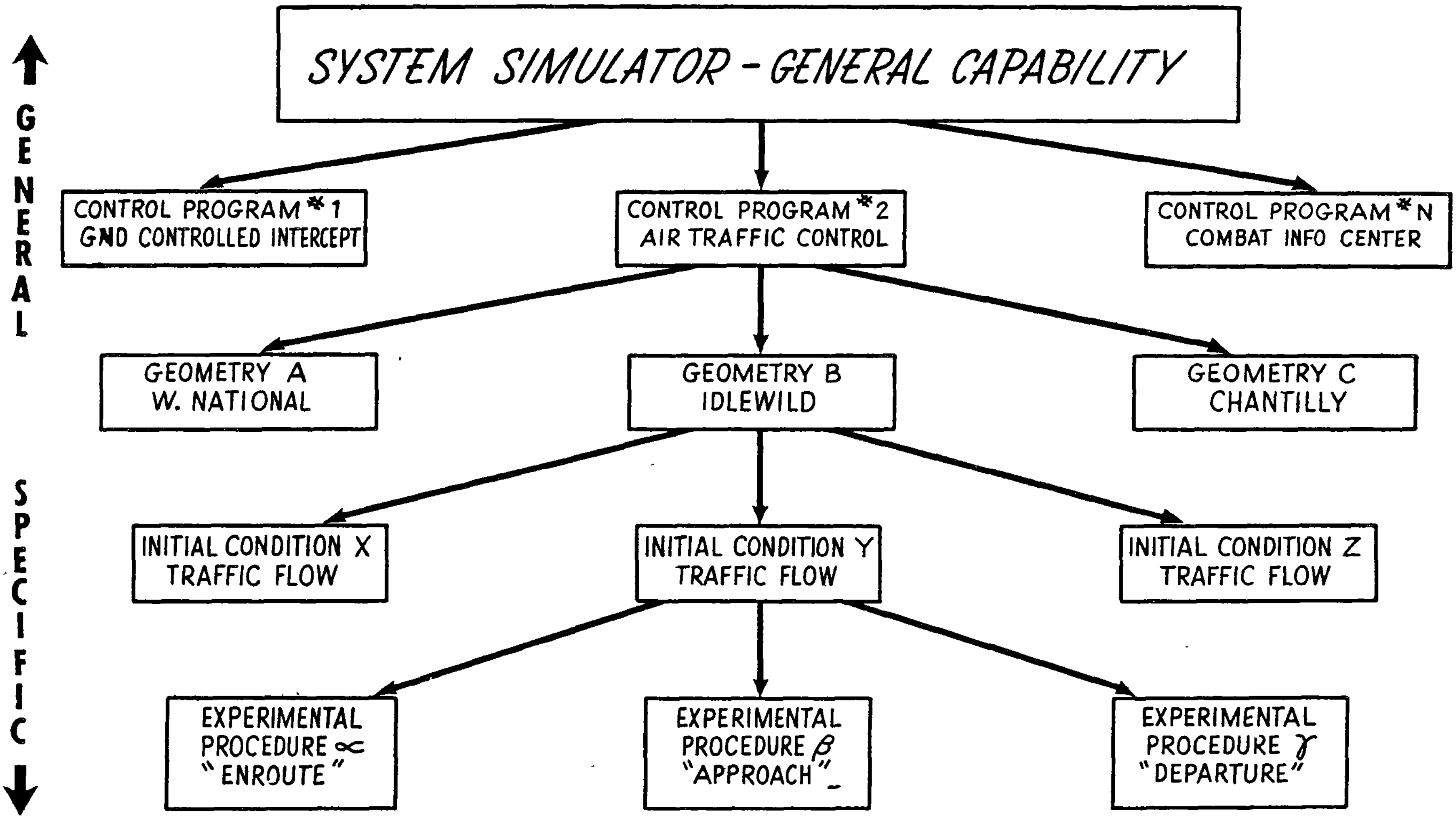
GENERAL
SPECIFIC
SYSTEM SIMULATOR - GENERAL CAPABILITY
CONTROL PROGRAM * 1
GND CONTROLLED INTERCEPT
CONTROL PROGRAM * 2
AIR TRAFFIC CONTROL
CONTROL PROGRAM * N
COMBAT INFO CENTER
GEOMETRY A
W. NATIONAL
GEOMETRY B
IDLEWILD
GEOMETRY C
CHANTILLY
INITIAL CONDITION X
TRAFFIC FLOW
INITIAL CONDITION Y
TRAFFIC FLOW
INITIAL CONDITION Z
TRAFFIC FLOW
EXPERIMENTAL
PROCEDURE ∝
"ENROUTE"
EXPERIMENTAL
PROCEDURE β
"APPROACH"
EXPERIMENTAL
PROCEDURE γ
"DEPARTURE"

CHART 5. SYSTEM SIMULATOR - GENERAL CAPABILITY

There is a rather basic conflict between the desire that a laboratory simulator have general capability and the requirement that it either contain or be capable of activating specific inventions. The discussion of Chart 4 indicated that a degree of generality could be achieved for a class of functionally related problems, that the area of information handling is such a class, and that it offers a considerable breadth of application. However, **even** limited generality cannot be directly reconciled with inventions that are highly specific. Yet it is possible to moderate this conflict through viewing each "specific" as a cross-product of a number of elements which may be independently defined. The possible number of cross-products can then be minimized and delineated by defining the elements so as to bear a hierarchical or layered relationship. Chart 5 illustrates this approach to relating the "general" to the "specific".

It is first endeavored to devise a system simulator having general capabilities. Generality is then assumed until a particular application proves otherwise, whereupon the facility is made "more general" as necessary. The first level of specificity is defined as a "control program" which represents a particular kind of operation such as GCI, ATC, or CIC. It is endeavored to design the control program so that it will accommodate any arbitrarily chosen theatre of operation, such as the geometries of the navigation aids surrounding either Washington National, Idlewild, or Chantilly airports. It is desired to define the geometry, in turn, so as to accommodate any reasonable configuration of traffic that might be dictated by experimental purposes. Finally, the traffic configuration should be represented in sufficient detail so that it will accommodate a variety of experimental control procedures which may be devised for either enroute, approach, or departure control. The effectiveness of the layering approach can be improved through providing sufficient flexibility at each level to accommodate changes and refinements in the next lower level.

The hardware inventions, which are now shown, may be built into the simulator, but they will more often be "specific tools" whose utility is to be evaluated by the experiment. This chart tends to overlay the black boxes of the system, and the inter-relationships will be expanded upon in subsequent charts. In particular, the relationship between operating procedures and tools will receive attention through presenting examples of a number of hypothetical inventions in the display and control area.

CHART 6

GEOMETRY-COMMERCIAL TERMINAL COMPLEX

TRAFFIC TERMINALS — *WASHINGTON, FRIENDSHIP, CHANTILLY.*

RESTRICTED ZONES AND MAJOR MILITARY AIRFIELDS

FEEDER FIXES — *12 MOST USED.*

AIRWAYS — *12 MOST HEAVILY TRAVELED.*

SECONDARY FIXES — *12 TERMINATING PRINCIPLE AIRWAYS.*

NAVAIDS — *PROGRAMMING FOR LF, DF, & OMNE-DME.*

DOMAIN — *500 NAUTICAL MILES SQUARE.*

WORKING RANGE — *50 N.M., NOMINAL; 25 N.M. OR 100 N.M., OPTIONAL.*

DETAILS — *MOST COMPLETE IN VICINITY OF DCA-ALSO MAIN HOMING POINTS FURTHER OUT* (EVEN THO NOT SHOWN ON "ARRIVAL TOTEBOARD")

CHART 6. GEOMETRY - COMMERCIAL TERMINAL COMPLEX

Air traffic moves with respect to fixed geographical locations within a given domain. Each location can be described by three coordinates measured from an appropriate point of reference. It is convenient to use a cartesian system having a reference such that all coordinates are positive. The "flat earth" approximation is adequate for nominal domains because the error is usually less than the system resolution which is inversely related to the size of the domain. It is straight-forward to tabulate any desired group of geographical fixes in a "look-up" table that is appropriately indexed for both navigation and display purposes.

It may be desired to describe the geometry in terms of lines as well as points. Items such as airways, sector boundaries, and restricted zones are examples of applications for which lines are more suited than points. For purposes of display, lines may be generated either by programming, by "video-mapping", or by simple overlay. The latter is the cheapest, but is not subject to manipulation and magnification.

This chart itemizes a number of factors which should be considered with respect to either activating displays or creating traffic configurations. In Chart 5 it was noted that, with a little foresight, the "table-of-geometry" can be made practically independent of all other elements of the simulation.

CHART 7

TRAFFIC SIMULATION

INITIAL CONDITIONS

TERMINATIONS MAY BE AT EITHER ONE, TWO, OR THREE AIRPORTS.
EITHER PART OR ALL OF FORTY FLIGHTS MAY BE TERMINATING.
TENTATIVE APPROACH ROUTES PRE-ASSIGNED TO TERMINATING FLIGHTS.
RANDOM ARRIVALS AT DIFFERENT AVERAGE RATES.
TERMINAL CAPACITY EXCEEDED IN OPTIONAL MANNERS AND DEGREES.
NEW FLIGHTS TO REPLACE THOSE LANDING OR LEAVING SECTOR.

TRACK GENERATION

HORIZONTAL AND VERTICAL MOVEMENT AT SEVEN TYPICAL RATES.
EACH FLIGHT PRE-PROGRAMMED THROUGH SUCCESSIVE CLEARANCE POINTS.
FLIGHTS NOT PREVIOUSLY ACQUIRED BY APPROACH CONTROL WILL AUTOMATICALLY STACK.

COMPUTATION AIDS

TIME-TO-GO RECOMPUTED AT EACH FIX; REVISED AT EACH CHANGE OF CLEARANCE.
TIME-TO-GO UPDATED AS DESIRED FOR GRAPHICAL PRESENTATION.
E.T.A. COMPUTED FOR TOTE BOARD DISPLAY ONLY; UPDATED FOUR TIMES PER MINUTE.

NEW CLEARANCES

ASSUMPTION OF CONTROL ENTERED DIRECTLY INTO INFO. HANDLING SYSTEM.
LANDING & TAKE-OFF CLEARANCES RELAYED TO DEPARTURE CONTROL.
APPROACH CLEARANCES CONFIRMED OR CHANGED VIA RADIO TO "PILOT".
PILOTS "MANEUVER" BY CHANGING PROGRAM CONSTANTS THRU A/C CONTROL BOXES.

CHART 7. TRAFFIC SIMULATION

In order to evaluate new devices and new procedures for controlling air traffic, it is necessary to have a sample of traffic over which control can be exercised. When experimental evaluations are to be performed in the laboratory, it becomes necessary to generate a suitable traffic configuration by means of simulation. The simulator representation of any given traffic configuration is performed in accordance with a pre-plan or "scenario" that consists of two parts: (a) the movement of aircraft according to both flight plans and instructions from controllers, and (b) the communications that are carried on between each pilot and the ground system. In studies of conventional radar control, the execution of such scenarios is accomplished by a number of "pilots", each operating a radar-track generator and communicating by wire with the ground controller(s). It is presently possible to program a digital computer to automatically execute the mechanical portion of the scenario. Such automation is particularly adapted to activating "synthetic" plan-position-indicators such as are comtemplated for the future, as contrasted to the azimuth sweep presentation of the primary radar indicator. The automated mechanical scenario also offers significant experimental and economic advantages over the manual technique as discussed in an associated report entitled "Aircraft Track Generation."

This chart itemizes a number of factors that should be taken into account when preparing the program for a digital computer. The chart also indicates computational aids that are being planned for future control systems and which might be incorporated in the simulation. Finally, the chart indicates functional capabilities that are needed to enable controllers to issue new clearances and instructions to the aircraft in the simulated system. The necessary complement of functions is effectively illustrated by a discussion of the provision of means for "exercising control" and is the subject of Chart 9.

Two important limitations of the mechanized scenario should be noted in order to prevent misapplication. First, it is still necessary to prepare the communications portion of this scenario for manual execution whether communication is to be entirely by voice radio or partly by data link. However, it may still be sufficient to employ but one "pilot" for all of the aircraft under the cognizance of a single controller. Second, it is not feasible to use a digital computer for the detailed representation of aircraft dynamics which would be necessary for experiments with blind approach and landing systems wherein the dynamic response of the aircraft and pilot become critical. It is preferred to employ conventional flight trainers for such "single-thread" experiments.

CHART 8

SPECIFIC JOB–ARRIVAL MANAGEMENT

APPROACH CONTROL RESPONSIBILITY

MEMBER OF MULTIPLE AIRPORT TEAM OF TWO OR MORE.
DIVIDED ACCORDING TO AIRPORT, SECTOR, OR OTHER GROUND RULE.
IN CHARGE OF LOCAL MISSED APPROACH AND P.A.R. *OPERATION.*

TASK OF ETA PHASING

INCREASE ADJUSTABILITY BY TAKING CONTROL AT EARLIEST CONVENIENCE.
FORM ARRIVING GROUPS, HAVING MINIMUM INTERVALS WITHIN EACH GROUP AND MAXIMUM INTERVALS BETWEEN GROUPS.

ADJUSTMENT MEANS

ASSIGN AND/OR REVISE CLEARANCES FOR – CHANGES IN SPEED, ALTITUDE, AND HEADING; RATES OF DESCENT & CLIMB; PROCEDURES FOR TURN & APPROACH.

EN ROUTE COORDINATION

INITIATES TRANSFERS BY ASSUMPTION OF CONTROL RESPONSIBILITY.

DEPARTURE COORDINATION

KEEPS DEPARTURE CONTROL INFORMED ON PERIODS RESERVED FOR DEPARTURES.

CRITERIA

PRECISE TIMING ($\Delta Ta = K + X - 0$)*; FUEL CONSUMPTION; PRIORITY CHANGES.*

CHART 8. SPECIFIC JOB - ARRIVAL MANAGEMENT

The more difficult air traffic control problems relate to controlling the approach of aircraft to busy terminals. The operation that contends with these problems is here named "Arrival Management" which implies more latitude in both scope and kind of responsibilities than is presently denoted by the term "Approach Control". The relative difficulty of approach problems is evident in the ascending gradient of performance required by the mechanics of the operation. As one approaches a busy airport, aircraft density increases, maneuvers must be more precise, information correlation and aircraft sequencing become more exacting, and reports must be progressively more frequent, more precise, and more timely. The already difficult operating problems are becoming more difficult due to the advance in aircraft performance characteristics as well as in the amount of traffic to be handled, which combine to require a continuing evolution of the broad job of arrival management.

The responsibility for approach control may have to be shared among two or more controllers simply as a result of the magnitude of the job, e.g., the amount of traffic and the range at which single-thread control must be initiated in order to achieve the desired quality of sequencing. Problems of operation are made more difficult by the requirements of cooperation among members of the approach team, particularly if a complex of two or more terminals is considered. Evolving team organization and modifying responsibilities to meet changing conditions is one purpose of simulation.

The task of sequencing or phasing the estimated times of arrival (ETA) is an essential part of arrival management that must be modified so as to improve the quality of performance under IFR conditions. For purposes of experimental design, it is necessary to define the task and the means available for its execution in such a manner that the performance criteria are subject to straightforward quantitative measurement. Here it becomes important to discriminate between "Analysis" and "Training", the former being employed to determine whether a concept merits the undertaking of the latter. The problem, then, is to design experiments that will test new concepts and new devices without requiring the expenditures of large amounts of time for the development of new skills by a group of experimental subjects. Thus, these statements of task, means, and criteria are somewhat arbitrary and oversimplified for the purpose of minimizing the need for acquiring new skills. It is attractive to undertake gross performance measurements such as the average landing rate achieved by the experimental controller when confronted with a realistic sample of saturating traffic. However, such a measure is necessarily sensitive to the evolution of new procedures for using new tools. While this may well be the ultimate objective, it is a lengthy process relative to others which may require only simple learning. It is preferred to begin with a winnowing of ideas by means of simplified experiments that yield definitive and readily compared measures.

The chart indicates a variety of options which might be tried in various combinations and subsequently augmented as the complexity of the problem is increased. It also indicates the collateral obligation of coordinating with other controllers who have responsibilities different from Arrival Management.

CHART 9

AIRCRAFT CONTROL BOX

ITEM	OPTIONS	HARDWARE	BITS
CONTROLLED AIRCRAFT	FLIGHT NUMBERS	STORAGE + DECODERS + DISPLAYS	10
SPEED CHANGE	ENTER	TOGGLE + IND.	1
INCREMENTS	± 10, 20, 40 KNOTS	5P6T	5
ALTITUDE CHANGE	ENTER	TOGGLE + IND.	1
CLEARANCE	$0 \rightarrow 315^{00}$ FT.	3P8T (4K) + 3P8T (.5K)	6
RATE	NORM, 500, 1000, 1500	2P4T	2
HEADING CHANGE	ENTER	TOGGLE + IND.	1
SELECT MANEUVER	1 OF 6	3P6T	3
TURN	NORM, EMERG.	1P1T	1
1 MIN. HOLD 2 MIN. HOLD	R/L	1P1T	1
NEW FIX	1 of 64	3P8T + 3P8T	6
PROCEED	FLIGHT PLAN	———	—
VECTOR	ANY ± 1.4°	SHAFT ENCODER + STORE	7
STROBE	———	BUTTON	—
INITIATE	READ IN	BUTTON/INTERLOCK	1
RESET	CLEAR FLIGHT No.	BUTTON	—
		TOTAL	45

NOTE: FLIGHT No. STORE AUTO LOADED AND SELF-INTERLOCKED

CHART 9. AIRCRAFT CONTROL BOX

The experimental requirement for the ability to exercise "Real-time" control over simulated traffic was introduced by Chart 7. In particular, the over-ride of automated track generation requires functional capabilities that are here illustrated by a discussion of a set of means for effecting such over-ride. However, before describing the means for control, it is desired to explain briefly the method chosen for automatic track generation.

The method employed for automatic generation of aircraft tracks makes use of a digital computer program that consists of four essential elements: (1) a table of geometry which contains the locations of pertinent navigation aids, (2) a table of aircraft characteristics which contains profile mechanics, (3) a table of flight plans which describe the traffic configuration for the "Mechanical Scenario", and (4) a library of computational subroutines which generate aircraft tracks through reference to the three tables. The library contains a subroutine for each flight operation or maneuver such as DF homing and others that are accomplished by the application of appropriate translation and acceleration factors. The selection of subroutines applicable to a given flight at a particular time is governed by reference to the table of flight plans. Translation is continuous in three dimensions until the initiation of some change or maneuver is indicated. It is thus convenient to exercise control through modification of the flight plans. Since each maneuver, once initiated, is automatically carried to completion, the duties of the "experimental pilot" are quite intermittent and can readily be time-shared. This circumstance serves to further minimize the need for both operators and equipment for executing the mechanical portion of the scenario.

This chart describes the console devised at NBS for exercising experimental control over simulated traffic. The console offers a variety of means for changing either speed, altitude, or heading. Since control is to be applicable to any aircraft in the traffic sample on a time-shared basis, the first requirement is the ability to designate the flight number of the aircraft to be controlled. The second requirement is the ability to designate one or more compatible maneuvers in accordance with either new clearances or instructions from the controller. Next, initiation of the new maneuver(s) requires means for modifying or over-riding the preprogram of the computer. Finally, it is necessary to prepare to receive the next communication from the ground controller.

The aircraft control box is primarily intended for the use of operators who serve as pilots and who are in wire communication with the experimental controller. If the control functions are to be time-shared among different flights as intended, the operator will have to pretend that he is whichever pilot who is in communication with the experimental controller, regardless of who is initiating the communication. Alternatively, it may be desired to simulate an operation which makes use of a semi-automatic data link. In this case, the aircraft control box would be physically moved to the "control room" and made directly available to the experimental controller as a "message composer". In such an event, it would be desirable to augment the control options with an assortment of stereotyped words and phrases that are routinely employed in ground-air communication.

CHART 10

DISPLAYS - CLASSIFIED BY TYPE OF INFORMATION

NAME

DESIGNATOR

FLIGHT NUMBER - THE ONE AIRCRAFT BEING DEALT WITH — FLIGHT NUMBER

PLACE

CRT *1 - CONSOLIDATED PLAN POSITION INDICATION (CPPI) — PLAN POSITION

{SCREENABLE ACCORDING TO NAME, ALTITUDE, OR OTHER ATTRIBUTES} — {KEYSET, ALTITUDE LAYER}

CRT *2 - TIME-TO-GO BAR GRAPHS — TIME-ROUTE

TIME — SIMULATED TIME-OF-DAY; ≅ REAL

ATTRIBUTES

STATUS BOARD - GENERAL DATA; THE ONE A/C OF IMMEDIATE CONCERN - CATEGORY KESET

TOTE BOARD - UNIQUE DATA; UP TO FIVE MOST IMPORTANT A/C — AUTO-MAN. CALL-OUT

UNIQUE VARIABLES - PRECISE ALTITUDE & VECTOR; THE ONE A/C — ANY SINGLE CALL-OUT

COORDINATION

NUMBERS - DEPARTURES WAITING AND TOTAL PENDING (20 MIN.) - AUTO. - (FROM D.C.)

CHART 10. DISPLAYS - CLASSIFIED BY TYPE OF INFORMATION

The remaining charts relate to the presentation of information to operators of an air traffic control system. Emphasis is placed upon methods rather than means, and upon function rather than form. All operating decisions, whether made by controllers, file operators, or computers, are necessarily based upon information; consequently, display or presentation of this information constitutes a bottleneck that has a direct effect upon both the effectiveness and the efficiency of operations. It is believed that the ready availability of pertinent information is far more important than the technique of its display. However, strict adherence to this point of view leads to a lengthy search for basic principles which, if found, are difficult to apply. It is more productive to attack the problem from the standpoint of specific requirements for hardware, provided that emphasis is placed upon the requirements for information rather than the techniques of display.

It was suggested in Chart 4 that displays should be specialized according to the relevance and the importance of information with respect to the exercise of particular sets of responsibilities, such as those of approach control as contrasted to those of entering flight plans. The specialization of displays must be undertaken methodically because it is conceptually complex, but it will certainly offer both economic and operational advantages. The decision-making capability of any one man is impaired both by the lack of important information and by the presence of information that is important to somebody else. Studies of human behavior indicate that man's assimilation of information is characterized by a limited rate (narrow bandwidth), but that his interest oscillates between the general and the specific. Thus, the information needs of a controller change progressively and repeatedly, from a minimum of information about a large number of aircraft toward a maximum of detail about a very few aircraft and this suggests that relevance is dynamic. The constraint of narrow bandwidth applies not only to the individual but also to the economics of hardware; it is quite impracticable, or worse, to attempt to transmit and present all information about all things at the maximum rates that might be desired. This points to the economic need for a set of specialized displays, each tailored to most efficiently present a particular kind of information. The conclusion is that, with care, such a set of specialized displays can be made compatible with the user's needs for information. The problems are largely the methodological ones of information organization, selection and presentation, and of inter-display correlation.

One of the first tasks is to classify information according to types that are self-consistent with respect to requirements for display equipment and human assimilation. This chart presents the preliminary results of an effort to establish such a classification. It identifies three basic classes, together with some important leftovers which are placed in the miscellaneous category for the present. One obviously significant class is the "name" (flight number) that uniquely designates a specific aircraft and sets it apart from all others. The name also designates a system "pigeon-hole" where all information about that particular aircraft may be assembled and kept up to date for ready reference. A second class is the "place" (or location) of an individual aircraft both in time and in space. This second type of information is adapted to graphical presentation and assimilation, but it is normally measured, transmitted, and stored in numerical form. Characteristically the demands for storage and bandwidth seem profligate to the resolution of measurement, because each number represents but one point in a continuum. The handling of continua as a class presents difficulties that are in marked contrast to the problems of handling alphanumeric information, as will be seen. A third class consists of "attributes" or factual descriptors which may be applied to any particular aircraft. They are usually characterized by the complicating requirements both of alphanumeric presentation and of symbolic interpretation in the assimilation process. On the other hand, descriptors are highly compressible, thus easing the requirements for storage and communication bandwidth.

The factual descriptors tend to contain the depth of detail that is required with respect to but a few aircraft at once, and human reference to these is generally less wholesale and more selective than is reference to continua such as plan-position. Selective reference is also characteristic of certain numerical quantities such as precise altitude, heading, and ground speed, which are generally needed for only one aircraft at a time. Considerable advantage may be taken of selective reference and the normal sequence of selection in the design of both equipment and procedures. Information may be graded from "primary" through "second order" to "miscellaneous", according to both the selectiveness and the frequency of reference. Thus, some important items of information might be classified as miscellaneous because very little bandwidth is required for infrequent selection, transmission, presentation and assimilation. Examples are found in the information required for "coordination" with other members of the operating team, which includes such items as time-of-day and tabulations of the departure backlog.

Chart 10 also indicates some preliminary thoughts on meeting the problem of general interest versus specific interest. For example, when a controller is in communication with a particular flight, he will have use for factual information presented on a single-aircraft "status board". If an operation requires that a controller's attention be time-shared among two or more flights, he would have use for concurrent and somewhat more detailed factual information presented on a flight-strip "tote board". This suggests that, in order for a set of displays to complement each other, the degree of detail should be inversely related to the number of aircraft shown. However, this concept raises problems of convenience and effectiveness in the screening, selection, and cross-correlation of displayed data by semi-automatic means. Possible solutions will receive more specific attention in subsequent charts.

CHART II

DISPLAYS-CRT #1-CPPI

CONSOLIDATED PLAN POSITION INDICATION (CPPI)

X,Y; CENTERED AT D.C.A., - OR AT ANY OTHER POINT WHENEVER DESIRED.
RANGE; NOMINAL 50 N.M. (100 N.M. DIA.); OPTIONAL 25 OR 100 N.M.

BRIGHT-UPS

SPECIFIC A/C INTERROGATED - OR IN COMMUNICATION
CLASS OF A/Cs SPECIFIED BY EITHER CATEGORIES OR ALTITUDE LAYERS
EMERGENCY

CONFIRMATION HOOK

RECEIPT OF CHANGE (CORRECTION, DATA ADDITION, OR INSTRUCTION) BY ANOTHER PART OF SYSTEM OR AN A/C.

ALTITUDE BAR GRAPH

HOOK ON ₵ OVERLAY -

VECTOR INDICATOR

HOOK ON ρ-θ OVERLAY

(Altitude bar graph and vector indicator:) INTERROGATED A/C ONLY (TEMPORARY EXPEDIENT)

CHART 11. DISPLAYS - CRT NO. 1 - CPPI

Since the control of air traffic is an operation in both space and time, it is necessary to have a picture of what transpires, the degree of clarity depending upon the requirements of the individual controller. Mental visualization is employed, but maintaining a mental image that is complete and accurate in four dimensions is difficult at best and is generally inadequate. Graphic aids to visualization, such as the plan-position-indication of the search radar, have proved most helpful if not essential under many circumstances. However, the conventional PPI display leaves much to be desired from the standpoints of both application and human engineering. This chart is concerned primarily with the dimensional deficiencies and the correlation problems, the latter seeming to increase with any attempts to correct the former.

In establishing the four dimensional picture, it appears that the most desired elements are a ground projection in two dimensions, the altitude and some time dimension such as the "time-away" from any arbitrarily chosen point or other aircraft. A four dimensional picture is difficult to visualize and more difficult to construct. It is good practice to consider first the two most important dimensions and to refer to the others as needed, whether in mental effort or in equipment design. The ground projection may be considered most important for two reasons: (1) the traffic domain is very thin compared to its breadth, and (2) action is normally most rapid in the horizontal plane. Thus, the two dimensional radar display is an excellent beginning except for the fact that the slant-range dimension can severely distort the ground projection right where distortion is least tolerable -- in the vicinity of the airport. This deficiency will be corrected upon the installation of the three dimensional radars which will also provide the presently lacking dimension of altitude but at the expense of a certain amount of data-processing. This chart assumes cartesian coordinates because they are more effectively handled by the present state of the art than are polar coordinates. This chart also assumes a new data-processing function, namely, the consolidation of information from two sources whose data differ as to sampling rate and accuracy. As contrasted to air defense, air traffic control needs to have long-range information that is combined with "close-in" data having higher sampling rates, higher accuracy, and the best of low-altitude coverage.

Data processing makes possible consolidated plan-position-indication that is continuous, i.e., not flickering either randomly or in azimuth sequence. It also becomes convenient to enable the controller to manipulate the display with respect to both centering and magnification according to variations of his information requirement. The suggested use of a complementary set of contrasting display techniques compounds the task of display correlation. However, the advent of data processing converts the general correlation problem from one of "how to do it" to one of "what should be mechanized".

This chart suggests intensity modulation as a convenient and effective means of correlating plan-position-information with other displays, whether they are alphanumeric or graphic and whether the correlation is unique or by class. However, multiple cross-correlation among different kinds of displays appears to require the use of symbolism. While there are many effective techniques for presenting symbols, recourse to symbolism should be minimized because available techniques are still very inefficient with respect to information bandwidth and thereby with respect to both performance capacity and dollars.

There is a requirement for correlation between the displays and the rest of the system as well as among displays. Controllers should be provided with indication of actions taken both by other individuals and by equipment in the semi-automatic system.

In addition to target position, the primary CPPI can be used to present such desired information as vectors, bar graphs, and local geometry; but such augmentation should not be carried to the point of cluttering the display. In augmenting the CPPI display, we not only risk confusing the user, but we also encounter some state-of-the-art limitations. Display cycling time, even of CRT's, is not so fast as might be desired. Overlays are cheap and effective, but not subject to manipulation. Video mapping is manipulatable, but requires intensity suppression, is quite costly, and is not compatible with the random rastor display generation which is attractive because of its low bandwidth requirements.

CHART 12

DISPLAYS - CRT #2 TIME-TO-GO

BAR GRAPHS OVERLAY

VERTICAL —— TIME-TO-GO

SCALE EXPANDED FOR EARLIEST 15 MINUTES.

HORIZONTAL — APPROACH ROUTE AND DESTINATION

7 BARS EQUIVALENT TO STATUS BOARD SUB CATEGORIES.

BRIGHT UPS

SAME AS CRT #1 - EXCEPT DEPARTURES AND FLYOVERS WILL BE BLANKED OUT AFTER NEAREST SECONDARY FIX.

CONFIRM HOOK

SAME AS CRT #1.

CHART 12. DISPLAYS - CRT NO. 2 - TIME-TO-GO

It is here proposed that a secondary CRT be employed as a means for graphic presentation of the time dimension. The suggested configuration would display "time-to-destination" in columns according to "approach route". Such a display would be of value for approach sequencing, since it indicates future conflicts that might develop as a consequence of both overtaking and merging. It is also suggested that the time scale be made nonlinear so as to correspond to the tightening of separation standards as the terminal area is approached. Comments on the provisions for interdisplay correlation are the same as those made for CRT No. 1.

It should be noted that the suggested display configuration has at least one significant shortcoming which derives from an inherent difficulty in computing the estimated times of arrival. In order to extend utility, it is necessary to begin computing ETA's substantially in advance of arrival. But the time required for the terminal maneuver cannot be accurately allowed for since its configuration cannot be anticipated in detail. One solution to this problem would be to provide means for the controller to inject his estimates of the times to be required for the terminal maneuvers.

A display configuration of possibly greater merit would plot altitude (vertical) against time-away (horizontal). Such a configuration would afford simplified monitoring of altitude separation which is particularly important in the terminal area. The notion of "time-away" rather than "time-to-destination" would logically accommodate departures as well as arrivals. Furthermore, it would be convenient to make the reference points selectable at the option of the controller, i.e., any desired airways intersection or fix in lieu of either the destination or the holding point. However, with respect to the destination itself, this display configuration remains deficient with regard to time requirements for variable terminal maneuvers. Moreover, effective means would be required to enable correlation with monitoring of horizontal separation on the ground projection display.

The foregoing display configurations have application as aids to manual conflict recognition and resolution. The basic information is the same as that required for the automatic recognition of conflicts, but the criteria may be as flexible and as complex as the skill and experience of the controller permit. Further, it is submitted that manual monitoring of such displays might be simpler than manual perception and interpretation of the outputs of automatic devices for conflict recognition.

CHART 13

DISPLAYS – MISCELLANEOUS

Display		CODE
NE 6 7	**FLIGHT NUMBER** – *OF SPECIFIC AIRCRAFT BEING EXAMINED OR COMMUNICATED WITH AFTER SELECTION BY ANY OF MEANS PROVIDED*	10 BITS (4+3+3)
12 2 3 ¼	**TIME-OF-DAY** – *GENERATED OUTSIDE COMPUTER; STARTING TIME PRE-ESTABLISHED; RATE APPROXIMATELY REAL*	13 BITS (4+3+4+2)
3 9	**DEPARTURES WAITING & TOTAL PENDING (20 Min.)** *EACH LANDING SLOT ACHIEVED PERMITS SUBTRACTION OF 1 FROM BOTH DIGITS – IF ANY WAITING* *COMPUTER ADDS 1 TO EITHER OR BOTH DIGITS AT SIMULATED FREQUENCY*	7 BITS (3+4)

CHART 13. DISPLAYS - MISCELLANEOUS

Among the alphanumeric displays to be described, three are quite simple and are grouped here for the preliminary discussion of symbolic presentation. It should be noted that the term "miscellaneous" applies to the displays and not to the information content, flight number or "name" having been previously identified as one of the primary classes of information. The boxes at the left of the chart are a diagrammatic representation of the type of indicator that employs in-line projection. These are used at NBS primarily because they can be driven by transistor circuits and are therefore subject to extremely rapid electronic switching. This capability is of considerable importance where it is desired to avoid delays in random switching of large numbers of indicators. The right-hand column indicates the order of the number of bits required for activating numerical displays. The center column indicates the purpose of each display and also the means of activation.

The "Flight Number" indicator shown has a special purpose that distinguishes it from others that are associated with the automated flight strips. For reasons of economy of data transmission, there have been provided only enough digits for representing commercial traffic. The presentation of numbers for military and private flights would require additional indicators and a correspondingly longer code. The means provided for selection will be discussed in Chart 17.

The "Time-of-Day" indication is in Greenwich Central Time to a resolution of 1/4 minute. There are provisions for manually setting the clock to any starting time called for by the "scenario" of an experiment. The clock is directly driven by a "Simulator Synchronizing and Control Unit" and is automatically stopped whenever it becomes necessary to "freeze" an experimental run, restarting when the run is continued.

An indication of the departure backlog is suggested as a means for facilitating coordination between approach and departure control. In real operations, the indicator would be a remote monitor of a tally indicator that is operated by the departure controller. In simulation, the backlog indicator is operated automatically.

A converse indication of slots available for take-off could be provided but is not suggested because the opportunities for departure cannot be anticipated as well as the requirements thereof. It is here assumed that the present procedures for releasing departures are adequate.

CHART 14

DISPLAYS — STATUSBOARD CATEGORIES & SUBCATEGORIES

A/C TYPE - 3 BITS

7 - 707; DC-8
6 - VISCOUNT; ELECTRA
5 - DC-7; S. CONS.
4 - DC-6; CONS.
3 - CONV; MARTIN
2 - DC-4; ST. CRUISER
1 - DC-3
0 - — ? —

CONTROL - 2 BITS

3 - ARRIVAL (BRIGHT ON CPPI)
2 - DEPARTURE
1 - ENROUTE (DIM ON CPPI)
0 - —— ? ——

IDENTITY - 2 BITS

3 - SCHEDULED
2 - ITINERANT
1 - MILITARY
0 - — ? —

APPROACH ROUTE - 3 BITS

7 - A - S - C
6 - B - S - C
5 - A - N - C
4 - A - S - N
3 - A - N - N
2 - B - S - N
1 - A - S - F
0 — ? —

NEXT FIX - 2 BITS

3 - LAST EN ROUTE FIX
2 - FEEDER FIX
1 - OUTER MARKER
0 - —— ? ——

PRIORITY - 2 BITS

3 - EMERGENCY (VERY BRIGHT ON CPPI)
2 - HIGH
1 - LOW
0 - — ? —

CHART 14. DISPLAYS - STATUS BOARD CATEGORIES AND SUBCATEGORIES

In order to gain both operational and economic advantages, it has been proposed that factual descriptors should usually be presented separately from the graphic display of continua; furthermore, that the display of descriptive information should employ a number of different techniques each chosen according both to the depth of the users' interest and to the kind of information content. For example, the status board is intended to display terms that can be used either to generally describe an individual flight or to define a limited class of flights. General descriptors such as "aircraft type" can be codified for efficient handling, but these would not include details of unique interest such as ETA's that require expanded representation. Chart 14 illustrates the former kind of information and a method of organization as well as an appropriate means of display. It is intended to contrast this kind of information with that which on the one hand is suited for graphic display on cathode-ray tubes and on the other hand is suited for alphanumeric display by means of automated flight strips.

The chart presents an abridged dictionary of terms divided into six categories. These particular choices of names for the categories and terms for the subcategories are probably not the most appropriate for any specific control task, but the choices can be altered (according to certain rules) so as to best accommodate the needs of any particular user. The rules that have been devised for organization and choice of terms for a consistent set are discussed in detail in a separate report entitled "Information Selection for Controlling Air Traffic", so the following comments will be relatively brief.

This status board display presents a six-term description that is applicable either to any specific flight or to a class of flights. To this end, categories are chosen such that all are applicable to every flight and the terms within each category are chosen so as to be comprehensive; for example, the identity of any specific flight must be either "scheduled", "itinerant", "military", or "unknown". In order to maximize the efficiency of the dictionary, redundancy is avoided through choosing categories that are independent of each other. The chart also indicates, after each category title, the number of bits required for encoding the terms in that category; in the present example, a 32-word dictionary that is divided into 6 categories will require only 14 bits for presenting 6 terms of information about any aircraft. By contrast, a relatively tremendous number of bits would be required for the generalized alphanumeric transmission and presentation of symbols (6 binary bits being needed for each symbol of the 6-term description); moreover, any changes in the choice of individual terms would probably require a revision of the code length.

Further advantages of the message code over the alphanumeric code relate to the utility of the information display and its ease of manipulation. It is desirable to present all terms of the dictionary simultaneously and continuously in order (1) to indicate what a flight is not as well as what it is, and (2) to indicate the options available for purposes both of information filing and of information selection as will be discussed with regard to Chart 17. It is intended that the "positive" information be emphasized by means of indicator lights adjacent to the applicable terms. The utility of suppressed "negative" information can be illustrated by reference to the category entitled CONTROL which indicates a means of correlation with the graphic CRT displays. An approach controller is primarily responsible for "arrivals", but he is also concerned with departures that may interfere with his operation and with forewarning of enroute flights that are about to become his responsibility. Thus, it seems advisable that the graphic displays indicate the position of all flights in the area, but that those flights for which he has assumed approach responsibility be emphasized by some such means as making them much brighter than the others.

One purpose of Chart 14 is to indicate that, while the relative economic advantages of different display concepts can be demonstrated by simple arithmetic, the measures of relative utility are matters of human judgment and acceptance which generally require experimental confirmation.

The utility of an abridged dictionary depends largely upon the selection of effective terms. While the rules of choice may be quite simple, the actual devising of a useful dictionary is surprisingly difficult. It may be noted, for example, that the category A/C Type fails to be comprehensive, because it does not tabulate all possible types of aircraft. The process is quite similar to that of choosing subject headings for a filing system in that usage always suggests a set of choices that would have been better. This chart presents the second set of four abridged dictionaries that have been devised for air traffic control, the other three of which are discussed in the report, "Information Selection for Controlling Air Traffic". The ATC-2 program incorporated and tested the third set of terms. The fourth set of terms, which has not yet been tried experimentally, is believed to be a substantial improvement over the earlier attempts.

It should be noted that some features of the status board are combined with some features of the tote board in both the Aircraft Control Box and the "message composer" of a data link which would be designed to afford the selection of a few terms from a limited dictionary of commonly used words, phrases, and numbers. Such devices would lack the generality of a typewriter, but would be both much more convenient and much more economical within their intended scope of application. The displays associated with those devices are intended as aids to the control of and communication with individual aircraft; hence, they are designed to present individual details on a time-shared basis. The status board and tote board combine to fill a corresponding need for the controller to be provided automatically with associated information already within the system.

CHART 15

TOTE BOARD-APPROACH CONTROL-D.C. AREA

	FLIGHT NUMBER			A/C TYPE	ETA				F.F. DES.	SEC. FIX	AIR-WAY	CLEARANCE ALTITUDE			6 MORE-?
(5)															
(4)															
(3)															
(2)	CA	4	4	VIS	12	2	3	¼	SPR DCA	ARC	42	1	1	5	
(1)	NE	6	7	202	12	2	0	½	DON DCA	HNT	(20)	0	7	0	

COMBINED AUTO-MANUAL LOAD + AUTO ADVANCE AND REVISION

CHART 15. TOTE BOARD - APPROACH CONTROL - D.C. AREA

An electronic tote board is proposed for the semi-automatic display of "flight-strip" information on several flights at once. The information to be presented would be tailored both to the needs of a particular control responsibility such as approach and to a particular navigation geometry such as that surrounding the District of Columbia. The tote board is intended to functionally augment the status board by supplying information not adapted to the more efficient message-code display. It is suggested that the information content should be unique to individual flights, and that each flight-strip should repeat the flight number and certain other descriptors that are displayed elsewhere on a single-aircraft basis.

The functions of the tote board are addressed to all purposes that are presently served by flight strips with the notable exception of keeping records of flight progress. This latter function can be very well performed by new electromagnetic techniques for data storage, but at the cost of introducing and solving a corollary problem. This is the one of providing the operator with means for immediate and selective reference to information that is not stored in visible form. It has been recently demonstrated that the problem of semi-automatic reference can be adequately solved provided there is appropriate organization of both the filing and the display systems. The factors involved in the latter problem are discussed in the separate report on information selection. Examples of important functions other than keeping records of flight progress are given in the next chart. For the moment, it is sufficient to note that these functions relate to (1) the monitoring of operations for several different purposes, (2) the rapid time-sharing of attention among several flights of immediate interest, and (3) miscellaneous functions such as display correlation, team coordination, and the transfer of cognizance(hand-over). This chart indicates the type of information that is appropriate for tote board display, but it does not attempt to enumerate the entire complement of items which might be required by an approach controller. The column of numerals at the left is intended both as an aid to display correlation and as an indication of precedence such as landing sequence. The same numerals would also be automatically painted on the faces of the CRT's adjacent to the corresponding aircraft blip. Any single numeral would be automatically illuminated to indicate some special circumstance such as the flight in communication or the ETA being revised.

Efficiency relates to both utilization and hardware economics. The convenience of utilization (utility) will be discussed with respect to the purposes listed in the next chart. With regard to hardware economics, the efficiency is approximately that of the miscellaneous displays of Chart 13. The efficiency cannot be so high as that of a message code (status board) display, but it need not be nearly so low as that of alpha-numeric (typewriter or charactron) displays. The in-line projection technique of display is suggested for reasons which are similar to those given in the discussion of Chart 13, but which are more graphically illustrated with respect to flight strip information. For example, each navigation point (or fix) is normally designated by three alphanumeric characters whose general display would require three indicators and an operating code of 18 binary digits. But control sectors and zones are not general and contain a very limited number of fixes, and the responsible controller learns to treat the abbreviation of each as a single unit of information. The concept is appropriately applied to the design of hardware, whereupon any of 32 fixes can be designated by a five-bit code rather than the 18 bits required for alphanumeric designation. The same rationale applies to the designation of airways, aircraft types, and air carriers, and also to the final numeral of the clearance altitude and the ETA which are designatable by only one bit and two bits, respectively, rather than the nominal four-bit decimal code. The potential economy is particularly noteworthy in designating the combination of feeder fix and destination for a multiple terminal complex which rarely contains more than eight such combinations. Thus, the selective designation of one of these eight would require only three bits as contrasted to the 36 bits which would be required for straight alphanumeric representation. In the aggregate, the potential savings in transmission, storage, and decoding are such as to merit serious consideration. A speed-up in both display and assimilation rates is a by-product of designing the equipment to behave in a manner compatible with human behavior, i. e., specialized with respect to both job and locale.

CHART 16

TOTE BOARD OPERATION

FIVE STRIPS — ANY COMBINATION OF THE FOLLOWING:

CONFIRMATION OF DATA ENTRIES INCLUDING CHANGES

ACCEPTANCE OF FLIGHT PLANS

THE NEXT THREE AIRCRAFT TO LAND—AUTO ADVANCE & REVISION

AUTO MONITOR OF CONFLICTS, OMISSIONS, REPORT FAILURES, etc.

AUGMENTATION OF STATUSBOARD FOR UNIQUE INQUIRIES

CORRELATION OF FIX REPORTS, RADAR DATA, etc.

CHART 16. TOTE BOARD OPERATION

The operational purposes of a semi-automatic tote board dictate the functional capabilities that are required. However, functional capabilities are limited by feasibility with regard to both economy and utility. The utility of a rack of flight strips is something less than optimum for a number of reasons, one being that it contains a built-in problem of "table look-up" that can become as annoying as a telephone directory when the controller is under stress. In order to maximize utility, the controller should be confronted only with information pertinent to control as contrasted to bookkeeping. When semi-automatic processing makes it possible for "helpers" to up-date and maintain the record, the controller's "rack" of semi-automatic flight strips needs to present only control information that has been pre-abstracted from the exhaustive record. With regard to economy of hardware, the logistics problem may be worse than the initial cost; and both mitigate against the display of information that is not only unnecessary but also unwanted. Thus, a suggested approach is to mechanize only a relatively few flight strips per display console initially. A good number to start with is the maximum number of flights that concern a controller at any one time since electronic switching will enable the repertoire to accommodate shifting interests. This chart recommends five automated flight-strips for experimentally determining whether more are needed, due either to switching difficulties or to an increase in the controller's capacity. The chart suggests six different applications which might represent the jobs for six separate consoles at a busy terminal, or which may be combined into one job at the average airport.

Almost any operation requires capabilities for entering new data into the record and for modifying or correcting old data, whether the record is on paper or in magnetic cores. Visual confirmation of posting accuracy is required in either case, but the contents of an electronic store must be fed back through an electronic display.

Once entered into ground support system, flight plans are frequently transferred from one place or individual to another. Either the acceptance or assumption of responsibility is subject to local circumstances and must be objectively completed before the source is relieved of its obligations. Such transfers obviously require the display of flight strip information, particularly when high-speed data links are employed. Moreover, concurrent display at both the transmitter and receiver is required unless acceptance is pre-assured through use of a "courier" or middle-man.

An approach controller must be able to share his attention among all flights in the approach pattern including those both entering and leaving. His "rack" must therefore accommodate several flight strips at once; and since it is mechanized, it also can and should incorporate means for semi-automatic sequencing of the flight strips.

Monitoring consists of comparing the real situation with the desired situation and, as needed, making decisions and taking appropriate action. Monitoring, in general, requires a multiplicity of flight strips. For example, whether conflict recognition is automatic or manual, the strips of the flights involved should be assembled immediately as an aid to the controller in deciding upon the action to be taken in order to resolve the conflict manual monitoring being required even for automatic resolution. Similarly, automatic flight strips might be used to show the failure of flights to enter the area on schedule.

It has been indicated that the status board, while extremely efficient for certain kinds of information, leaves much detail to be presented by other means. It has been recommended that one automatic flight strip be reserved for augmenting the status board in making unique inquiries of the system file and in communicating with individual aircraft.

It has been observed that the flight number is, in effect, the name of the system pigeon-hole where all related information should be filed and kept up to date for ready reference. However, the filing has to be done objectively and, to a large extent, manually. When an operator receives a voice-radio report from a flight, he must refer to the correct pigeon-hole (or flight-strip) in order to enter the appropriate information. When the pigeon-hole is an electronic store, he needs a visual display to assure proper correlation of the information. Similarly, when a radar track is initially acquired, human intervention is required in steering the radar data to the proper pigeon-hole. This is accomplished by correlating the radar data with position information previously acquired by radio link. If the hardware has been properly designed, the single correlation act sets up a switch configuration which automatically steers the ensuing flow of radar track data to the proper bin. The correlation operation is not repeated until the flight comes within range of a radar capable of giving more accurate, more frequent, and possibly more complete positional information.

CHART 17

CONTROLS FOR DISPLAYS

NAME - FLIGHT NUMBER DESIGNATOR SWITCHES.

PLACE - LIGHT PENCIL - TIME COINCIDENCE ON BOTH CRT'S.
JOY STICK-HOOK - X-Y COINCIDENCE ON CRT *1.
TIME-TO-GO-ROUTE COINCIDENCE ON CRT *2.
MAGNIFICATION - AREA SELECTION - CHANGES CRT *1 ONLY.

ATTRIBUTES - KEY SET - CLASS WHICH IS ANY COMBINATION OF SUBCATEGORIES ON STATUSBOARD.
ALTITUDE & ZONE - SELECTS LAYER FOR EXCLUSIVE BRIGHT UP OR DISPLAY (CAN ELIMINATE ALL OTHER A/C).

FLIGHT STRIP - SELECTS TOTE BOARD SLOT FOR ENTRY OR REMOVAL. CORRELATED WITH STATUSBOARD OR COMMUNICATION.

ACTION - KEY & BUTTONS FOR INTERROGATE, - CHANGE, TRANSMIT, Etc.

CHART 17. CONTROLS FOR DISPLAYS

The previous charts have suggested the desirability of an assortment of displays, some capable of dealing with but few flights at one time. It was also indicated that the resulting problems of intercorrelating displays could be conveniently handled by means of automatic data processing. In addition, problems of information selection are encountered when the capacity of certain displays is deliberately limited, and the necessary selection processes can only be partially mechanized at best. The reason is that the display of information was limited in an endeavor to achieve a best match with the interests of the operator, and these interests are variable, sometimes changing quite rapidly. Thus, any selection mechanism, however automatic and responsive, must somehow be informed of the changes of user interest. It follows that the operator must be provided with control over the displays, and that these controls should be individually adapted to the different control jobs rather than to the data processor, i.e., not a typewriter.

Controls are only needed for the selection of what has been described as "primary" information, which is here defined as that information which is the subject of initial questions in a controller's line of inquiry. Appropriate subjects have been defined as those which speak to questions such as "where is he?", "who is there?", and "where are they?" and they include the flight number, the location, and certain primary attributes. Primary information is considered to include airways, since one might well be concerned with which flights are on a given airway at a particular time. An example of second order information is precise heading, it being very unlikely that one would ask "where are all aircraft making good a ground course of 314° magnetic?". The chart enumerates a number of control functions which are thought to be appropriate, and in some cases, it suggests a device such as a light pencil or a joystick.

It presently appears that the selection of flight strip information for display on the limited tote board can be made largely automatic. Means would be desired for manually designating the sequence of approach and landing, but even manual call-out probably can be made incidental to primary inquiries such as "who is that?".

While a few of the controls accomplish only passive selection, the majority may also serve to initiate some action in the system, some being specifically for that purpose. Examples of the latter might include selecting communication channels and changing information in the filing system. It is mandatory that incidental manipulation of such controls have no effect upon the operation of the system. Thus, collateral controls such as buttons and keys are frequently required to enable the controller to indicate that "action" is to be taken or initiated.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This report is essentially an assemblage of numerous rationales and conclusions that tend to be interdependent. Many of these conclusions relate to simulation as was the primary purpose; but, as a natural by-product, many others relate to the design of operating systems. In summarizing, it is appropriate to indicate some of the broader conclusions that may already be drawn from both SERAPE, the paper study, and ATC-2, its partial implementation.

Both the need for simulation experiments and the evolutionary nature of the air traffic control system were taken as premises for the study. The need for laboratory simulation was discussed in both the introduction and in connection with Chart 2; while the rationale for progressive mechanization was presented in connection with Chart 1.

An early observation was that deterministic simulation which deals with real relationships rather than postulates serves the important purpose of promoting understanding and communication among equipment designers, computer programmers, and operations specialists. The reason is that real-time simulation experiments are intended to test and evaluate devices whose design speaks to the need of the controller and whose activation is provided by the programmer.

An important conclusion is that the data processing requirements for laboratory simulation are not basicly different from the requirements for data processing in the real system. The information handling problem was introduced by Charts 3 and 4. Chart 5 indicated how the simulator facility could be made capable of either containing or activating system inventions. The remaining charts suggested a variety of such inventions, and these were used in developing particular requirements not only for equipment activation but also for computer programming. These requirements are seen to be applicable to the system as well as the simulator.

A corollary conclusion is that both the simulation facility and the system data processor should incorporate means for rapid "stream processing". This function is particularly important in the acquisition and filing of data, the correlation of reports, communication between processing centers, the activation of displays, and controller coordination. All of these operations entail relatively high rates of information flow, and, in the foreseeable future, all will require some degree of human intervention. Particularly high flow rates are required even for marginal adequacy in the selection and presentation of information. Chart 14 suggested an application for iterative scanning of large files of flight information in but a fraction of a second. For this application, it was not difficult to build a stream processing device capable of screening English words at rates above 1 million/second. It is here desired to repeat earlier recommendations* that the data processor, whether used for simulation or for operations, be specially equipped with efficient means for handling the high flow rates associated with the input, the output, and the distribution of information.

This report has indicated that the problem of adaptive display places a major burden upon the facilities for manipulating and processing data. It has been argued that neither adequate utility nor reasonable efficiency is likely to be achieved by the "brute force" approach which results from over-simplification of the display problem. This report has suggested the desirability of diversifying and specializing displays, and of deliberately limiting the capacity for displaying certain kinds of information in the interest of both utility and economy. It has been recognized that such an approach will generate new problems both of inter-display correlation and of information selection. However, it is believed that difficulties due to complication of the display concept can be made trivial by comparison with the gains from a corresponding reduction in information flow through both controller and equipment.

Project SERAPE has suggested a complementary set of specialized displays for the primary purpose of illustrating a variety of requirements for their activation and, in particular, how such requirements might be minimized. The ATC-2 program was used for only a preliminary evaluation of these suggestions. But the concept of a set of complementary displays that are conveniently manipulated and adapted seems sufficiently attractive to merit further refinement and a more thorough evaluation with respect to particular sets of operating requirements.

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ELECTRICITY. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

METROLOGY. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

HEAT. Temperature Physics. Heat Measurements. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research Equation of State. Statistical Physics Molecular Spectroscopy.

RADIATION PHYSICS. X-Ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

CHEMISTRY. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

MECHANICS. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Combustion Controls.

ORGANIC AND FIBROUS MATERIALS. Rubber. Textiles Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

METALLURGY. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

MINERAL PRODUCTS Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

BUILDING RESEARCH. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials Codes and Safety Standards. Heat Transfer. Inorganic Building Materials

APPLIED MATHEMATICS. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

DATA PROCESSING SYSTEMS. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering

ATOMIC PHYSICS Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics.

INSTRUMENTATION. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

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BOULDER, COLO.

CRYOGENIC ENGINEERING. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

IONOSPHERE RESEARCH AND PROPAGATION. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

RADIO PROPAGATION ENGINEERING. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis Propagation-Terrain Effects Radio-Meteorology. Lower Atmosphere Physics.

RADIO STANDARDS. High frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards

RADIO SYSTEMS. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

UPPER ATMOSPHERE AND SPACE PHYSICS. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.