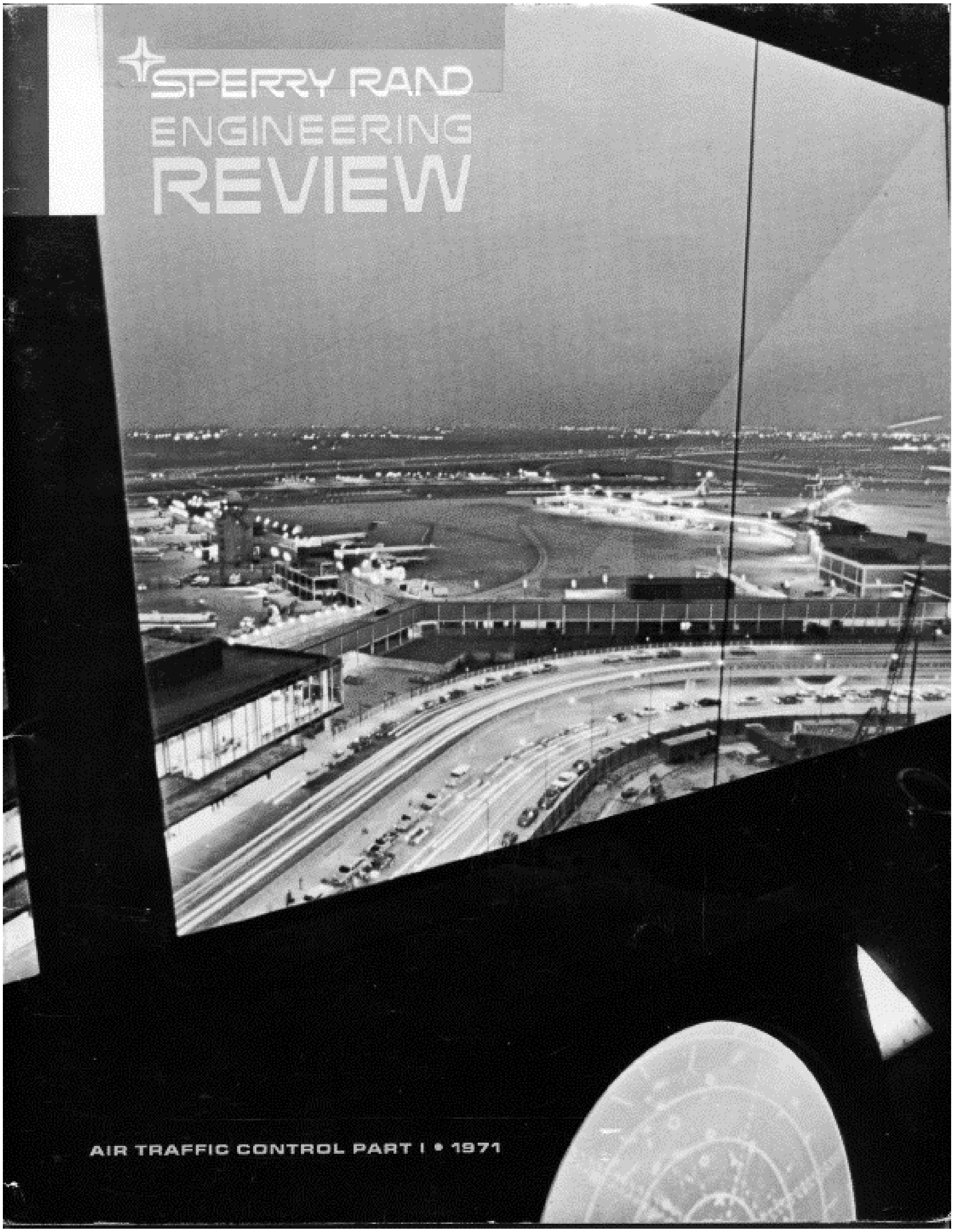
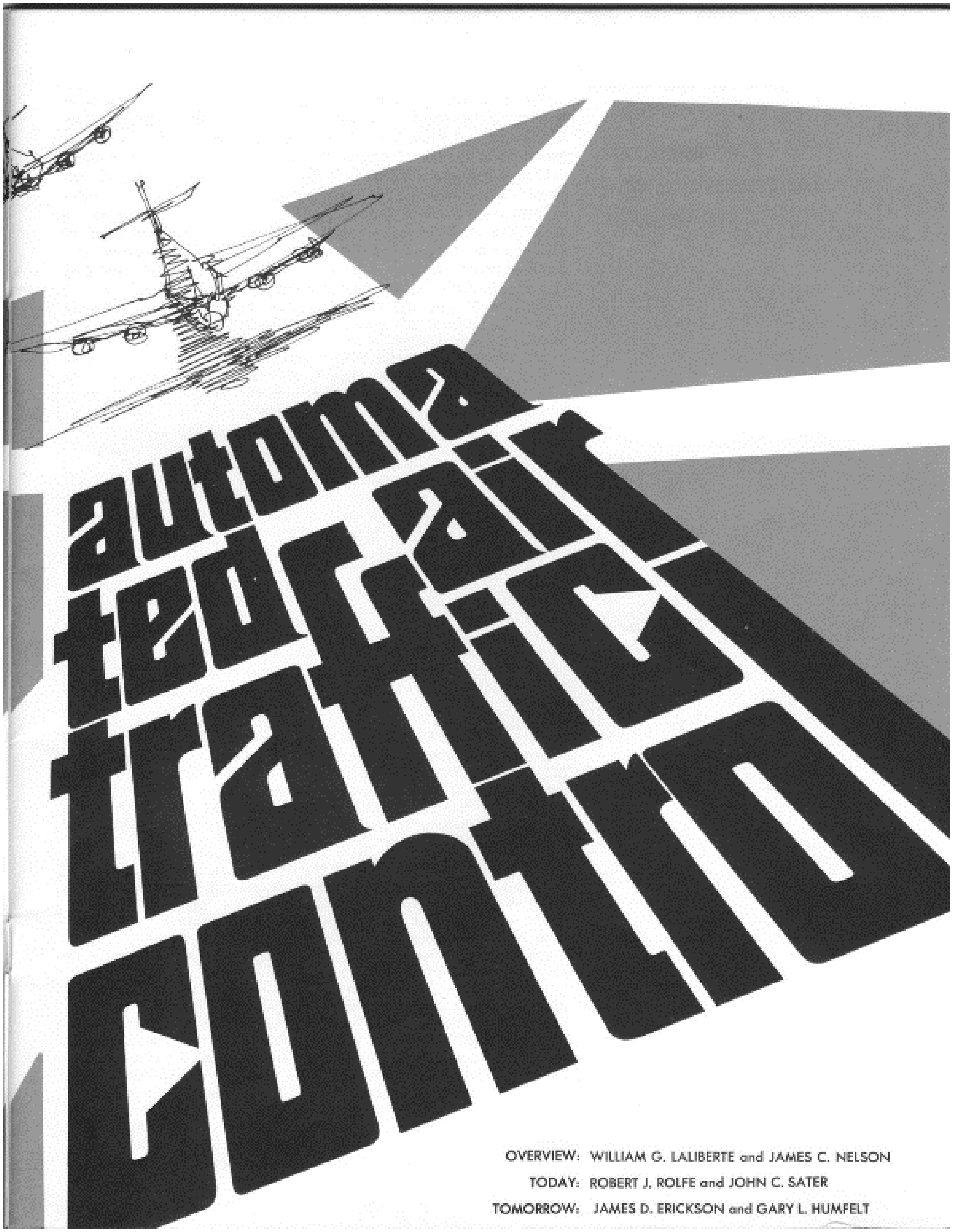


SPERRY RAND ENGINEERING REVIEW

AIR TRAFFIC CONTROL PART I • 1971



automated air traffic control

OVERVIEW: WILLIAM G. LALIBERTE and JAMES C. NELSON
TODAY: ROBERT J. ROLFE and JOHN C. SATER
TOMORROW: JAMES D. ERICKSON and GARY L. HUMFELT

Automated Air Traffic Control: OVERVIEW

One of the earliest legends of flying is the Greek myth of Daedalus and Icarus. Icarus, thrilled to discover he could fly, soared too close to the sun, and when his wing tips melted took an ill-fated plunge into the sea. To make a connection with present day flight, one would only need to replace Icarus with the millions of aircraft populating Earth's skies in 1971. Yet the problem is still basically the same: to keep from burning up and crashing into the sea, or the land—or all the other airborne vehicles. The latter condition, that of crashing into the growing multitude of aircraft, is a relatively new problem perplexing the air traffic controller, and is the subject of this and the following two companion papers.

For several years, the Federal Aviation Administration has devoted priority attention to the solution of the traffic controller's problems in high-density airport terminal areas. Since the mid-sixties, when the FAA first installed an automated radar terminal system (ARTS) at Atlanta (1964) and Kennedy (1968) airports, the traffic controller has been the main focus of attention. Even today, with the installation of the more advanced ARTS III either planned or underway in 62 major U. S. air terminals, the controller bears the ultimate responsibility for the safe delivery of passengers and crew from the moment they enter the aircraft until they step onto destination soil.

Developed by Sperry Rand's Univac Division for the FAA, ARTS III is a modularly expandable, radar-controlled, beacon-tracking system which satisfies the essential goal of air traffic system designers: it monitors—and has the potential capability of tracking—all aircraft flying within its radar range. In essence, ARTS "sees" all aircraft within a 55-mile radius of the terminal, and displays the tracks of all beacon-equipped aircraft. The information displayed for the controller includes identification, altitude, ground speed, etc. (see detailed article "Automated Air Traffic Control: Today").

As prime contractor for ARTS III, Univac is providing over-all systems management and coordination, hardware, operational and nonoperational computer programming, factory system tests, installation and checkout, initial maintenance and training services, and system documentation. By the middle of 1973, a total of 64 systems will have been installed in the U. S., including the basic 62 as well as one at the FAA Academy in Oklahoma City for training, and one at the National Aviation Facilities Experimental Center in Atlantic City for use by FAA engineers in developing still more advanced ARTS concepts and systems. By 1980, it is anticipated that 200 of the most advanced terminal automation systems will be in operation, thereby enabling the traffic controller to keep pace with the expected increase in global air traffic (see article "Automated Air Traffic Control: Tomorrow").

Air Traffic Control—from Signals to Symbols

Since the first pilots of the 20th century had only themselves to worry about in the untraveled sky, they had little need for sophisticated air traffic control systems. In fact, the modern traffic controller is a far cry from his earliest ancestor, the signalman, who in the decade before 1920 merely waved alternate green and red flags to give pilots clearance for take-off and landing.

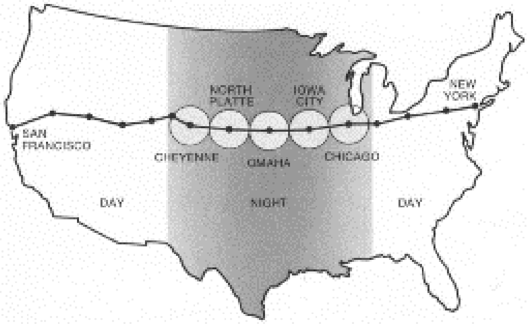
By 1930, the first audio tools appeared—voice radio, radio navigation, and instrument flight—complementing the visual aspect of air traffic control. Cleveland Municipal Airport became the first to install a radio-equipped control tower and before the 1930-40 decade ended, 35 more cities had radio-equipped airport traffic control. During this same period the first radio-navigation system, called the Four Course Range, began operating in the low frequency 200-400 kilohertz range.

With the development of radar during World War II, the air traffic controller had the advantage of visually displayed position information. This breakthrough enabled the controller to transmit separation information to the airborne pilots and thus keep aircraft at safe distances. As the

Route of U.S. Air Mail Service: 1924

Sperry searchlight beacons were needed for flying the mail across country. . . . As commercial aviation developed in the twenties and the need to perfect night flying increased, the market for Sperry beacons at airports and on air routes expanded. Sperry beacons guided the early mail pilots as they made dangerous flights along the "night airway." In 1924 five Sperry beacons and landing lights were used on the Chicago-Cheyenne leg of the first Chicago-to-coast airmail service; other routes were soon utilizing Sperry beacons.

From Elmer Sperry—Inventor and Engineer, by Thomas Parke Hughes, The Johns Hopkins Press.

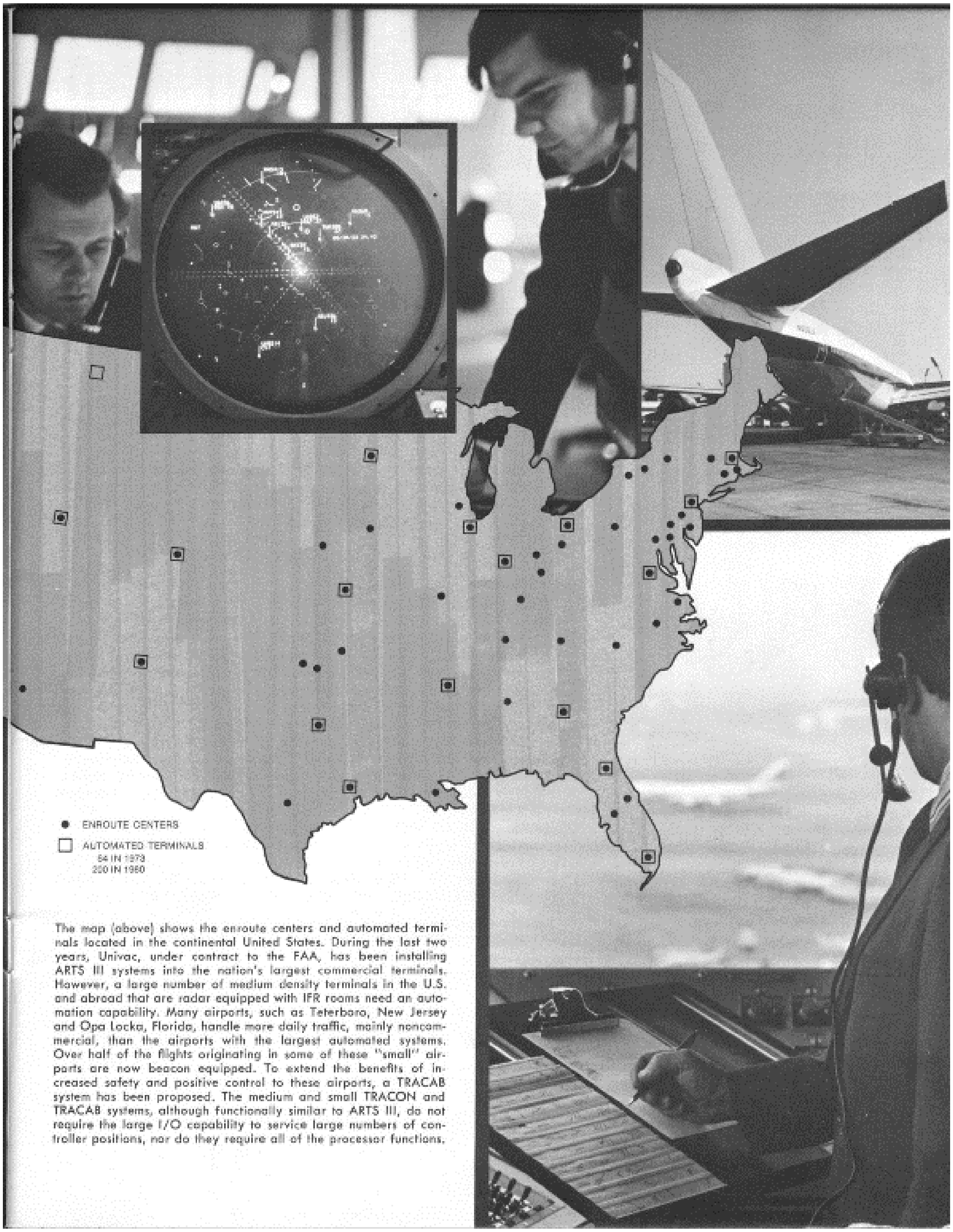


number of aircraft on the radar display increased, the problem of identifying specific aircraft became more complex. By the 1950's the density of traffic at major U. S. airports began to increase at a rate that made the controller's mental bookkeeping task next to impossible. To alleviate this burden, the Civil Aeronautics Administration introduced the computer to traffic control in 1957. From that year until the introduction of ARTS in 1964, the computer has been instrumental in allowing the controller to keep pace with rapidly growing flight statistics in the United States. Without the computer and its development into the sophisticated ARTS III of 1971, the high-density-airport traffic controller would be unable to manage the skies.

The Multi-Traffic Controller

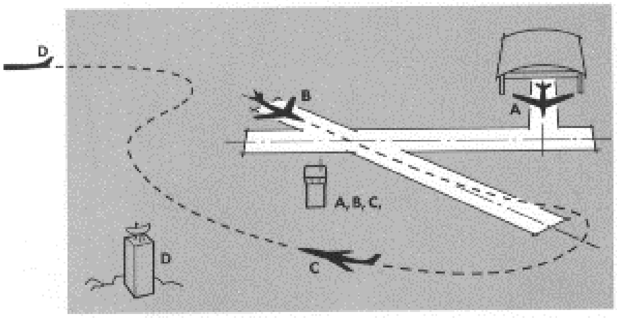
To do his job in the '20's the controller had only to wave a green or a red flag; in the '30's he operated a radio in the control tower; in the '40's he had to learn how to operate a radar set; and in the '50's he began using the computer. Now in the 1970's, with 20 enroute centers in operation across the country, 64 ARTS III installations scheduled by 1973, and automation planned for a total of 200 terminals by 1980, air traffic control is in need of more controllers to handle the expanding air population. In fact, at least four different kinds of controllers are required for any high-density airport terminal, three of whom are located in the air-


AL-DK



The map (above) shows the enroute centers and automated terminals located in the continental United States. During the last two years, Univac, under contract to the FAA, has been installing ARTS III systems into the nation's largest commercial terminals. However, a large number of medium density terminals in the U.S. and abroad that are radar equipped with IFR rooms need an automation capability. Many airports, such as Teterboro, New Jersey and Opa Locka, Florida, handle more daily traffic, mainly noncommercial, than the airports with the largest automated systems. Over half of the flights originating in some of these "small" airports are now beacon equipped. To extend the benefits of increased safety and positive control to these airports, a TRACAB system has been proposed. The medium and small TRACON and TRACAB systems, although functionally similar to ARTS III, do not require the large I/O capability to service large numbers of controller positions, nor do they require all of the processor functions.

port tower building, either the glass-enclosed area on top, or the instrument flight regulations (IFR) room, one or two stories below ground, and the fourth located in a nearby enroute control center. On the departure end of a flight, the sequence of responsibility over a beacon equipped plane is as follows:



A— *Ground Controller*—directs pilots taxiing in either direction between the aircraft parking area and the end of the runway.

B— *Local Controller*—gives pilots final clearance for take-off and landing.

C— *Departure-Arrival Controller*—guides aircraft away from or into the immediate airport vicinity at both ends of the flight. This responsibility is frequently shared by two people.

D— *Enroute Controller**—not located at the immediate airport terminal area, but assumes control of aircraft in the skies between departure and destination terminals.

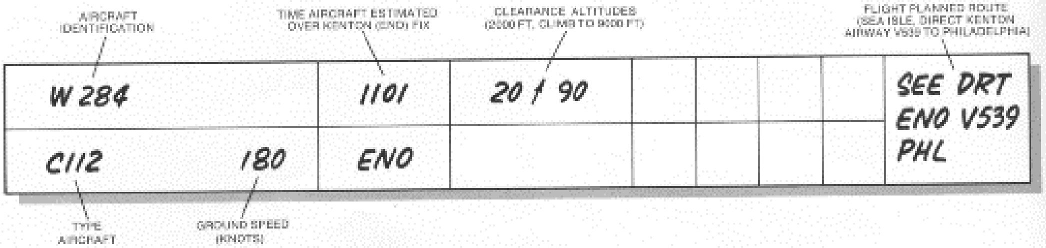
On arrival in the vicinity of the destination airport, the line of command is reversed: the enroute controller yields to the arrival-departure controller, who, in turn, passes control to the local controller, as the aircraft approaches the runway for landing instructions. As soon as the plane has touched down, the pilot shifts to the ground controller's radio frequency for directions toward his assigned parking area.

Pilot, Controller, and Computer

When a pilot negotiates a flight, for example, from Washington National Airport to Kennedy Airport in New York, the first item on his agenda is to file a flight plan with an FAA facility. He gives his name, type of aircraft, aircraft call number, planned flight route and altitude, alternate flight routes, etc. This flight plan information is then keypunched and fed into the computer. Approximately 30 minutes before the pilot taxis to the runway for take-off, the computer transmits the flight plan data to each traffic control facility concerned with the particular flight (in this case, Kennedy, Washington National, and the Leesburg, Virginia ARTCC), where it is printed out in the form of flight progress strips. As a result, even as the pilot releases his brakes, checks in by radio with the ground controller, and taxis to the runway, his traffic plans are being forwarded to each controller who will handle this flight.

In the ARTS III configuration, flight plan data is automatically communicated directly from one traffic control computer to another via interfacility data lines. Automatic input of data on impending arrivals and proposed departures relieves the air traffic controller of the need to enter this information manually into the system. In addition, ARTS III auto-

The flight progress strip is a small slip of paper on which the air traffic controller records aircraft identity, type of aircraft, flight route, altitude, and the various times the aircraft would pass over navigational fix points included on the flight plan.



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* Enroute controllers monitor aircraft from 20 air route traffic control centers (ARTCC's) strategically situated throughout the United States.

matically acquires, tracks, and displays information on aircraft assigned discrete beacon codes. It also provides the capability to pass control of an aircraft from controller to controller with minimum communication. (A blinking format on the controller's radar display alerts the controller that an aircraft is entering his area of responsibility.) FAA plans call for ARTS III to make a real-time check of the pilot's requested altitudes, routes, etc., against preferred routes and reservations already filed for other planes. If the computer detects a conflict, it will recommend the best alternative altitude and route available.

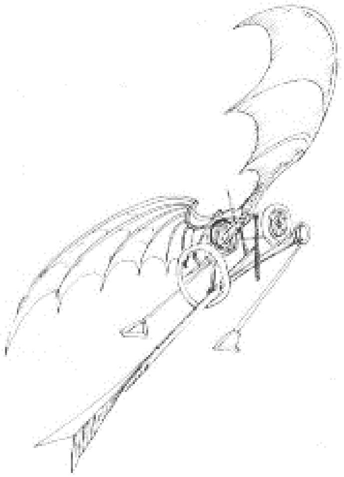
In the not too distant future it is also planned to have a computer system which will interconnect the various air traffic control facilities around the country. This computer system will be continuously updated with information concerning delays at the various air terminal areas. When delays in the New York terminal area become excessive, the computer in New York will apprise the ARTCC at Leesburg, Virginia (the enroute control center for the Washington National Airport and Dulles International Airport vicinities). Since time of departure from the Washington Airport will be delayed, the pilot will wait on the ground in Washington instead of burning expensive fuel in a holding pattern over Kennedy Airport. In the future, new airports, use of vertical take-off and landing aircraft, and automation systems such as ARTS III will decrease the number of times—and length of time—other aircraft will be delayed on the ground.

Equipment

Advanced airborne equipment can relieve flight crews of many duties, including landing an aircraft (see article "Automated Landing System"); and radar systems of the future will provide a greater range and more accurate identification of aircraft tracking from the ground (see article "Electronic Scanning Arrays for ATC"). But it is the capacity of these and other systems to work with each other that makes possible the much needed instantaneous and long range communication and control between all types of aircraft, controllers, and computers in the increasingly high density air traffic of the 1970's. This kind of capability is anticipated by 1980, at which time the modularly expandable ARTS concept will have reached fruition.

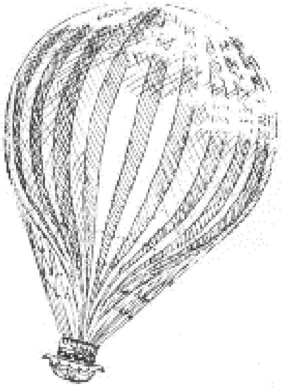
For the present, it is interesting to note that at two of the four busiest airports in America most of the aircraft received and dispatched fall into the general aviation category. These four airports are Chicago's O'Hare, Los Angeles International, Van Nuys (California), and Opa Locka (Florida). In terms of controllability, this means that a large percentage of the aircraft flying in and out of the four most congested U. S. air traffic terminal areas are not equipped with beacon radar transponder equipment, and therefore are incapable of total management by ARTS III at this time.

To accommodate nonbeacon aircraft in the air traffic control system, the controller must *hand carry* an aircraft through the airspace for which he is responsible. That is to say, the controller must follow the primary radar blips on his screen from radar sweep to radar sweep, relying upon a mental picture of aircraft identities, altitudes, and other flight plan information, without the benefit of the beacon radar transponder. Primary radar tracking capability, with alphanumerics, has been in existence since the early models of ARTS operating in Atlanta and New York. However, in these early radar tracking systems, it was often impossible to isolate real aircraft targets out of the total information received. Effects such as extraneous noise, bad weather, atmospheric anomalies, and other phenomena make it extremely difficult for a computer system to differentiate between actual targets and radar reflections. As a result, in setting up its ARTS III expandability program, Univac is developing a primary radar tracking system for the FAA. Like other modules being built, this system will be installed and evaluated in the Univac Wold-Chamberlain (Minneapolis-St. Paul) test facility prior to being added as a standard functional building block of the ARTS facilities. ■



Automated
Air Traffic Control:
TODAY

Since ARTS III is primarily a radar-controlled, beacon-tracking system, emphasis is placed on the radar's display capability to the air traffic controller. Both beacon and primary radar are used to derive position, or bearing and distance information, from the antenna orientation and the time delay between transmitted and received pulses of energy. A primary radar video return is the reflection of a pulse of energy bounced off the exposed surface of an aircraft (a blip on the radar screen). In the case of beacon tracking, the radar sends a pulse of energy from the ground to the aircraft. This pulse, in turn, triggers a transponder in the airborne system, causing a beacon (or coded) signal to be generated from air to ground, where it is processed by the computer to project identity, position, and altitude data onto the radar screen. This article provides a functional description of how the system operates, how the system relates to the aircraft it monitors and controls, and how the controllers relate to the system.



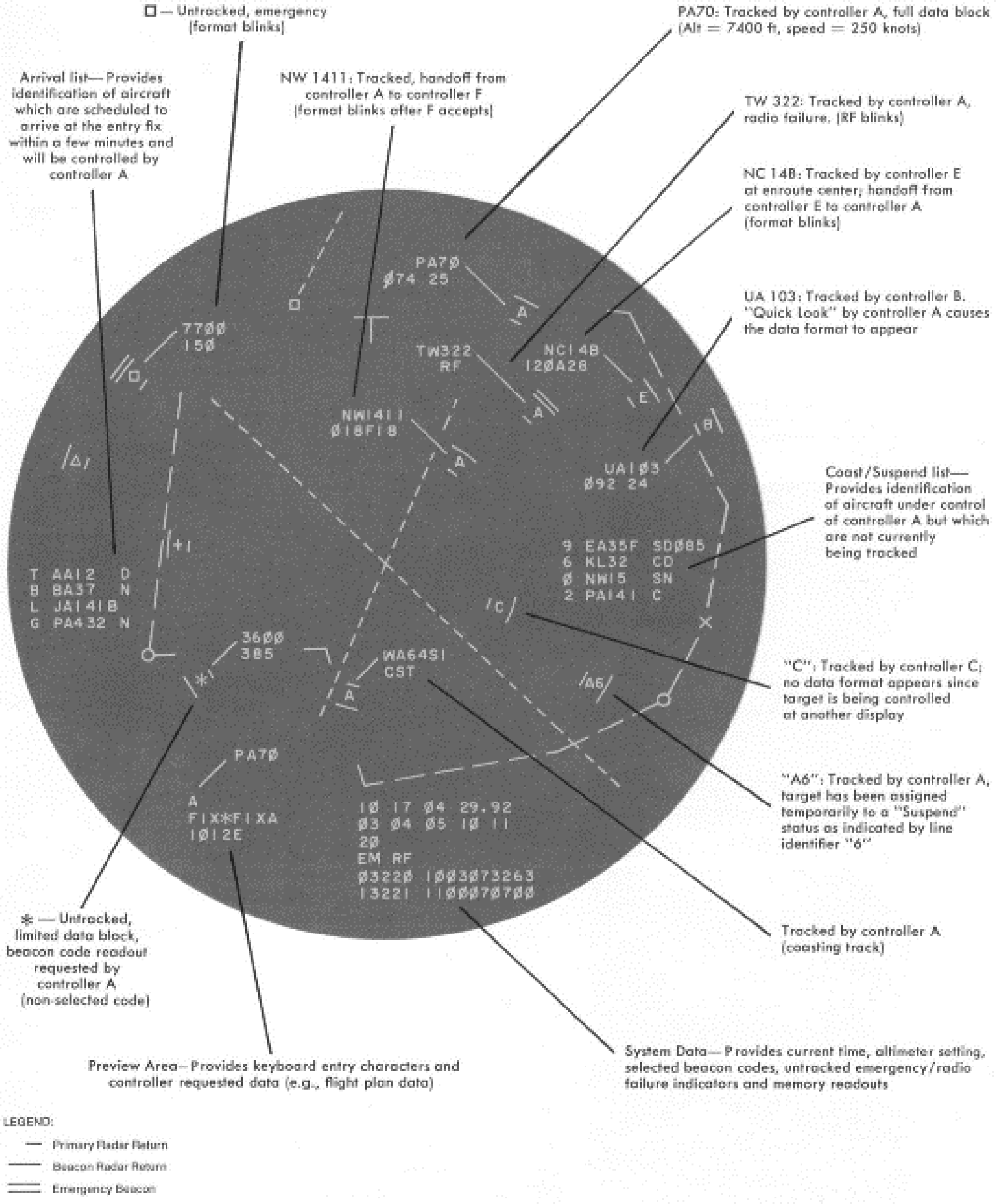
The Radar Screen—Man-Machine Interface

Flight data representing a dynamic picture of the air traffic situation is presented to the controller in several formats, depending on whether the aircraft are being actively tracked or merely monitored within the system. Tracked targets, which are limited to beacon-controlled aircraft, are presented on the cognizant controller's display at the target's reported position. The presentation consists of primary and beacon radar video and a full data block, which consists of the controller's identification symbol, a leader line and an alphanumeric tag indicating aircraft identification, altitude and ground speed (Fig. 1). If the controlled aircraft reports an emergency or a radio failure, the displayed full-data tag is the same except that an EM (emergency) or RF (radio failure) symbol, blinking to alert the controller, appears in place of ground speed. If the track fails to correlate with a beacon target, the symbol CST (coast) appears in the altitude position.

Unless deleted by the controller, untracked (uncontrolled) targets will appear on all displays (tracked targets appear only at the cognizant controller's positions). For each untracked target, the presentation consists of primary and beacon radar video, and either a single symbol or limited-data block. The single symbol format consists of a nonalpha target symbol, while the limited-data block involves the same set of nonalpha symbols plus a leader and an alphanumeric tag. The track symbol displayed for either format depends on whether or not the aircraft is responding with a beacon code selected for aircraft control in the terminal area, and whether or not the aircraft is responding with Mode C altitude data.

The format (single symbol or limited-data block) displayed depends on whether or not a nontracked aircraft has been selected by the controller via the data entry keyset and whether or not the nontracked aircraft is within an altitude band entered into the computer by the controller. Altitude will also be shown if the aircraft is within the altitude filter limits. Because such aircraft are not being tracked, speed is never displayed. Untracked aircraft reporting an emergency or radio failure are considered to have *selected* codes and their positions will be displayed as *selected* symbols. A blinking tag—*7700* (emergency) and *7600* (radio failure)—is also presented, together with altitude if it is reported.

These symbols and codes for tracked and untracked aircraft represent the primary informational relay of the dynamic traffic control situation to the departure and arrival air traffic controller(s). Additional information is also conveyed in tabular alphanumeric form, independently relocatable to any convenient place on the display. Two such lists, *arrival/departure* and *coast/suspend*, present data on controlled aircraft not being actively tracked. Arrivals and departures are usually assigned to separate controllers; thus, one will have arrival and coast/suspend lists and the other, departure and coast/suspend lists. Items on the arrival/departure lists



☐ — Untracked, emergency (format blinks)

PA70: Tracked by controller A, full data block (Alt = 7400 ft, speed = 250 knots)

Arrival list— Provides identification of aircraft which are scheduled to arrive at the entry fix within a few minutes and will be controlled by controller A

NW 1411: Tracked, handoff from controller A to controller F (format blinks after F accepts)

TW 322: Tracked by controller A, radio failure. (RF blinks)

NC 148: Tracked by controller E at enroute center; handoff from controller E to controller A (format blinks)

UA 103: Tracked by controller B. "Quick Look" by controller A causes the data format to appear

Coast/Suspend list— Provides identification of aircraft under control of controller A but which are not currently being tracked

"C": Tracked by controller C; no data format appears since target is being controlled at another display

"A6": Tracked by controller A, target has been assigned temporarily to a "Suspend" status as indicated by line identifier "6"

Tracked by controller A (coasting track)

* — Untracked, limited data block, beacon code readout requested by controller A (non-selected code)

Preview Area— Provides keyboard entry characters and controller requested data (e.g., flight plan data)

System Data— Provides current time, altimeter setting, selected beacon codes, untracked emergency/radio failure indicators and memory readouts

LEGEND:

— Primary Radar Return

—— Beacon Radar Return

═ Emergency Beacon

Fig. 1—A representation of the ARTS III video screen. Tracked targets, indicated with alphanumerics, may be offset to any 45-deg direction. Untracked targets are always offset to NE.

(Fig. 2a) are automatically added on the display as generated from flight plan inputs, a preset number of minutes before estimated time of arrival or proposed time of departure. Each time-ordered list, containing up to 26 lines and identified by alpha characters, displays aircraft identification and an alpha character indicating beacon utilization.

Active tracks which fail to correlate with a radar beacon target are, after several scans, automatically transferred to the coast/suspend list (Fig. 2b); controlled aircraft for which active tracking has been suspended (for instance, those temporarily assigned to a holding pattern) are also displayed here. This list contains a maximum of 32 lines, 10 of which are identified with a single-digit code. In addition to the line identifier, a letter indicating coast or suspend status and an alpha character representing beacon utilization are shown. For those suspended aircraft reporting a discrete code and Mode C altitude, the letter "D" and the corrected reported altitude will also be shown in the list. As with the arrival/departure lists, the coast/suspend list is displayed in time order. In both cases, once a line identifier has been assigned to a controlled flight, it remains with that flight until it is removed from the list. The controller also uses the line identifier to specify the flight when communicating with the computer.

In conjunction with the controller's use of a data entry keyboard, a preview area is provided on the display, giving the controller an opportunity to review or proofread written messages prior to actual computer

Fig. 2—Examples of the various types of tabular data. Each list, continuously and automatically updated by the computer, is displayed in time order sequence.

a	T AA12 D	American Airlines flight 12; discrete beacon code
	B NW70 N	Northwest Airlines flight 70; nondiscrete beacon code
	L UA141B	United Air Lines flight 141B; no assigned beacon code
	Z WA432 N	Western Airlines flight 432; nondiscrete beacon code
b	9 DA35S SD085	Delta Airlines flight 355; suspend status; discrete beacon code; corrected reported altitude 8500 ft
	7 EA30 CD	Eastern Air Lines flight 30; coast status; discrete beacon code
	0 PA15 SN	Pan American World Airways flight 15; suspend status; nondiscrete beacon code
	5 UA141B S	United Air Lines flight 141B; suspend status; no assigned beacon code
	3 WA86 C	Western Airlines flight 86; coast status; no assigned beacon code
c	NW70	Aircraft identification
	/	Requests program to assign a beacon code to aircraft
	A	Controller
	FIX*FIXA	Entry fix (arrival)
	1215E	Arrival time
d	10 17 04 29.92	Time of day; local barometer reading
	03 04 05 10 11	Selected beacon codes
	20	Selected beacon codes
	EM RF	Emergency and radio failure alert indicators
	03220 1003073263	Address of memory location and content of location
	13221 1100070700	Address of memory location and content of location

entry (Fig. 2c). After successful processing by the computer, the message is automatically deleted. If, however, an input error is discovered, a message so stating will appear in the preview area. This area is also utilized for reading messages from the computer (e.g., flight plan information).

The fourth tabular presentation is of system data (Fig. 2d). Time of day, area altimeter setting, keyboard-selected beacon codes, emergency and radio failure indicators, and readouts for keyboard-selected memory locations are displayed. Time is automatically updated, while altimeter setting must be periodically entered to allow for altitude conversion of Mode C data.

Thus, by contrast to earlier radar screens which presented only certain fixes, markers, and target video, the ARTS III screen displays a picture of the terminal area situation in sufficient, dynamic detail as to allow a significant easing of the controller's task. It should be noted that the informational formats and contents are not restricted to those described. Because of the flexibility and modularity of the ARTS III, considerable variation is possible, permitting tailoring of the display and the system to a particular site. How the system performs these functions and its adaptability are the subjects of the following sections.

System Description

ARTS III is an add-on system. Basically, three major subsystems (Fig. 3) are added to existing terminal area equipment: the data acquisition subsystem (DAS), the data processing subsystem (DPS), and the data entry and display subsystem (DEDS).

data acquisition subsystem

The ARTS III DAS, which will accept inputs from a variety of airport surveillance radars and beacon interrogators, consists of the azimuth, range and timing group; the beacon reply group; and the azimuth pulse generator. The azimuth, range and timing group generates all the basic timing pulses for use by the DAS; the beacon reply group detects and interprets the beacon video signals; the azimuth pulse generator, physically mounted to the radar antenna pedestal, converts radar-antenna position to digital position data. Each DAS also includes additional circuits, permitting the ARTS III system to operate independent of existing beacon video decoders.

Beacon equipment at each site acquires data from transponder-equipped aircraft that automatically report their beacon code, or beacon code and altitude, depending on the type of transponder aboard the aircraft. Transponders equipped for altitude reporting transmit data that is automatically encoded directly from a pressure-sensing altitude transducer in the aircraft. (The transmitted altitude data is measured in 100-foot increments with respect to a standard pressure of 29.92 inches of mercury.) The beacon replies are in the form of coded pulse trains unsuitable for direct processing by a computer. Therefore, beacon video information is transferred via wideband transmission media to the DAS, where the beacon reply group detects, isolates, and correlates the beacon replies with sweep position information. The DAS also digitizes the analog information and sends it to the DPS. The information includes range and azimuth of the beacon report, as well as the beacon code and altitude, when this information is received in ungarbled form. The DAS also provides partially decoded beacon video directly to the DEDS via an analog channel for use in a back-up mode.

In the basic ARTS III, the analog primary radar video is not used by the DAS, but instead is sent directly to the DEDS, along with timing signals for presentation on the displays. The primary radar system thus yields redundant coverage for beacon-equipped aircraft and also provides position information on aircraft that do not have transponders. The DAS does not provide a target detection function (sweep-to-sweep correlation of replies). This function is performed by software within the data processor.

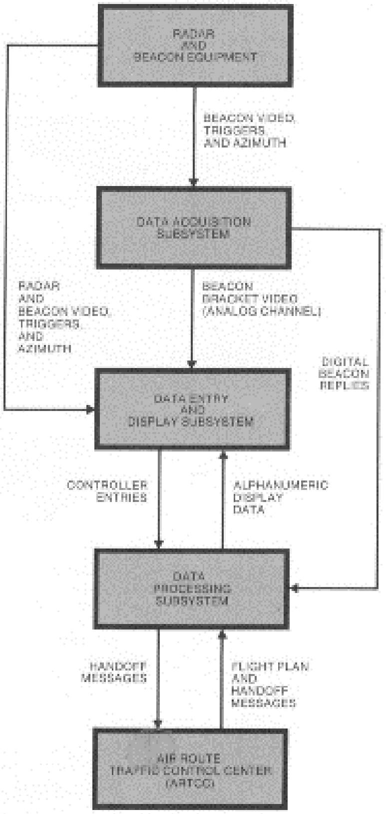


Fig. 3—The IOP carries the burden of over-all communications. Major tasks are monitored by an executive subprogram that assigns processing on an as-needed priority based on external demands.

data processing subsystem

The DPS consists of the data processor and its peripheral equipment, as well as the operational computer program. The Univac data processor can be configured with three major types of modules: a central processor module, an input/output processor (IOP), and memory banks. In the initial ARTS III, utilizing the beacon tracking level, analysis has shown that a central processor module is unnecessary. The combination of one or more IOP's and memory banks provides the system with a capability for arithmetic computation, logical decision making, data processing, and over-all system coordination. Accordingly, the basic DPS consists of an IOP with 8, 12, or 16 channels, a memory bank with 24,576 words, and peripheral equipment.

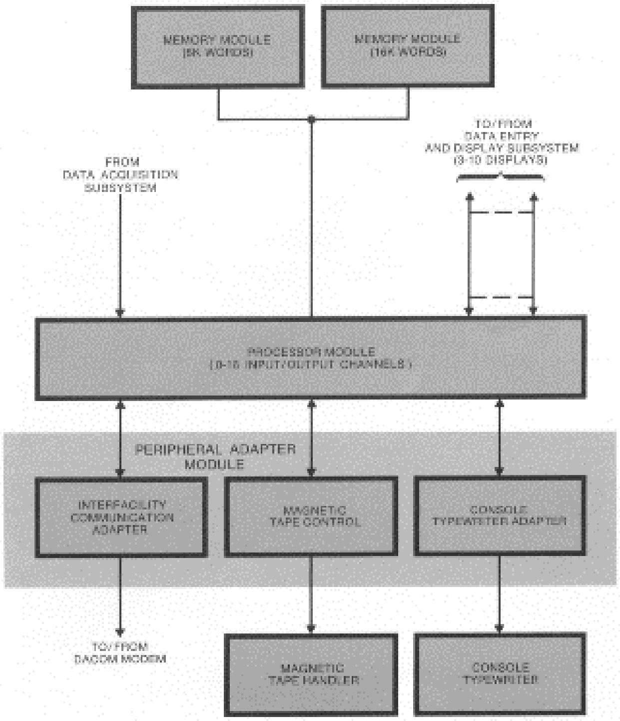
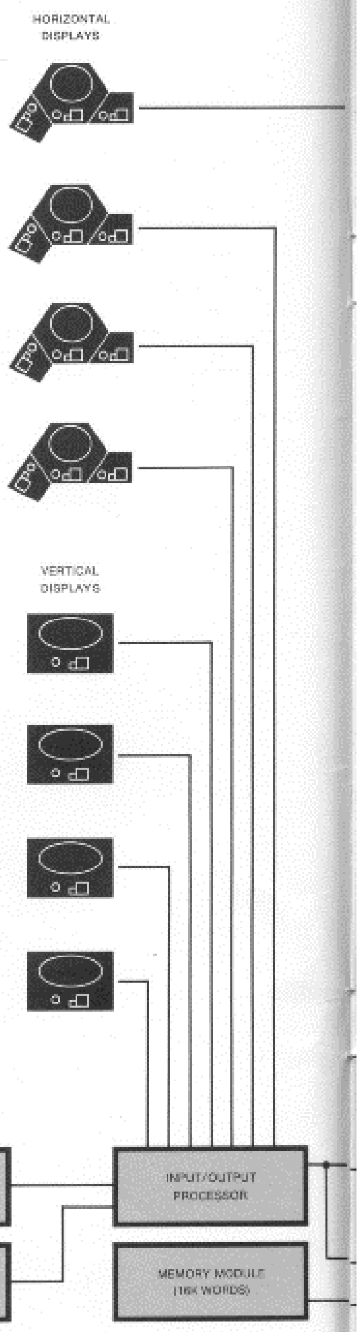
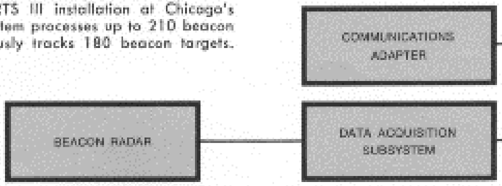


Fig. 4—ARTS III modularity allows for the system's three major subsystems to be added on to existing terminal area equipment. A simplified diagram for the basic beacon tracking system shows the primary paths of information flow. The configuration (Fig. 5, right) represents the expanded ARTS III installation at Chicago's O'Hare Airport. This system processes up to 210 beacon targets, and simultaneously tracks 180 beacon targets.





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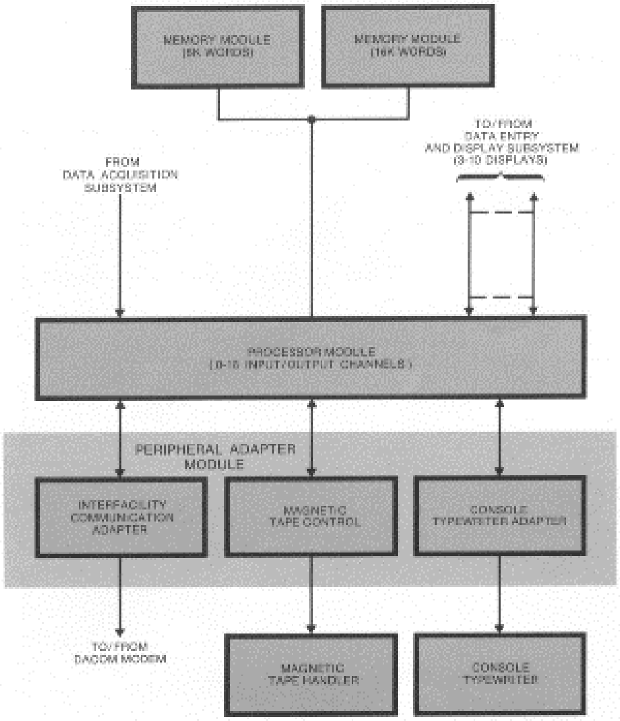

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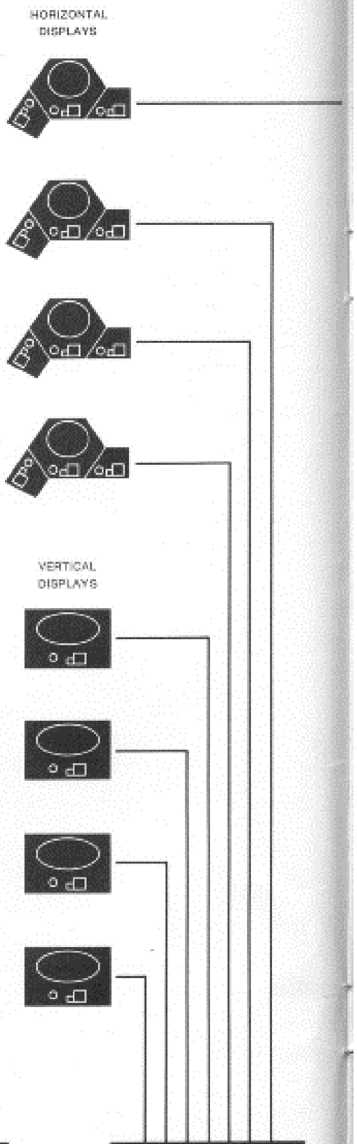
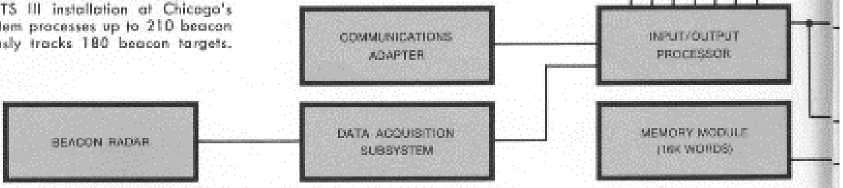


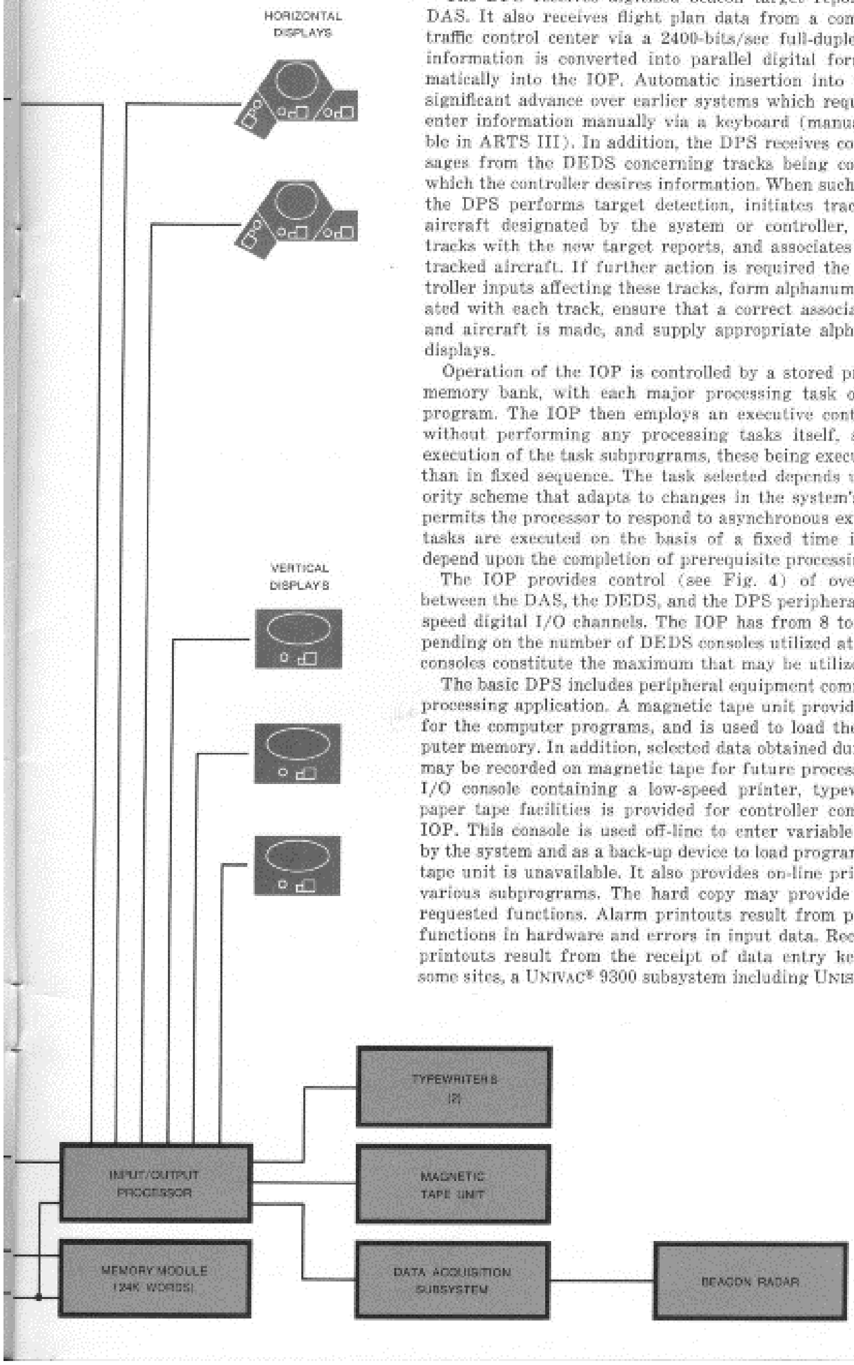


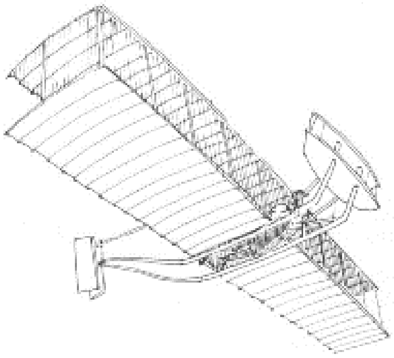
The DPS receives digitized beacon target report messages from the DAS. It also receives flight plan data from a computer in the enroute traffic control center via a 2400-bits/sec full-duplex circuit. This serial information is converted into parallel digital form and inserted automatically into the IOP. Automatic insertion into the IOP represents a significant advance over earlier systems which required the controller to enter information manually via a keyboard (manual entry is still possible in ARTS III). In addition, the DPS receives controller-initiated messages from the DEDS concerning tracks being controlled, or those for which the controller desires information. When such a message is received the DPS performs target detection, initiates tracking action on those aircraft designated by the system or controller, updates all assigned tracks with the new target reports, and associates flight plan data with tracked aircraft. If further action is required the DPS will accept controller inputs affecting these tracks, form alphanumeric tags to be associated with each track, ensure that a correct association between the tag and aircraft is made, and supply appropriate alphanumeric data to the displays.

Operation of the IOP is controlled by a stored program located in the memory bank, with each major processing task organized into a subprogram. The IOP then employs an executive control subprogram that, without performing any processing tasks itself, serves to control the execution of the task subprograms, these being executed as needed, rather than in fixed sequence. The task selected depends upon an assigned priority scheme that adapts to changes in the system's processing load and permits the processor to respond to asynchronous external demands. Some tasks are executed on the basis of a fixed time interval, while others depend upon the completion of prerequisite processing or external events.

The IOP provides control (see Fig. 4) of over-all communications between the DAS, the DEDS, and the DPS peripheral equipment via high-speed digital I/O channels. The IOP has from 8 to 16 I/O channels, depending on the number of DEDS consoles utilized at each site. Ten DEDS consoles constitute the maximum that may be utilized with a single IOP.

The basic DPS includes peripheral equipment commonly found in a data processing application. A magnetic tape unit provides permanent storage for the computer programs, and is used to load the programs into computer memory. In addition, selected data obtained during system operation may be recorded on magnetic tape for future processing and analysis. An I/O console containing a low-speed printer, typewriter keyboard, and paper tape facilities is provided for controller communication with the IOP. This console is used off-line to enter variable parameters required by the system and as a back-up device to load programs when the magnetic tape unit is unavailable. It also provides on-line printout capabilities for various subprograms. The hard copy may provide alarm, recording, or requested functions. Alarm printouts result from program-detected malfunctions in hardware and errors in input data. Recording and requested printouts result from the receipt of data entry keyboard messages. At some sites, a UNIVAC® 9300 subsystem including UNISERVO™ VIC magnetic





tape units is required to provide high-speed printing, punched-card processing, and additional capability for assembly and maintenance of computer programs.

data entry and display subsystem

The DEDS consists of a common equipment assembly, display consoles, and data entry sets. The common equipment assembly is the central interface between the display consoles and radar data, including radar and map video, radar triggers, and azimuth pulse generator signals. Both vertical and horizontal display consoles are used in ARTS III. Each utilizes a 22-inch cathode ray tube and solid state components. Both are time-shared and perform alphanumeric generation after each radar sweep, both are refreshed from the DPS at a 30-Hz rate. Equipped with additional circuit boards, they can provide an all-digital display. Controllers may enter display data manually by means of a data entry set composed of a keyboard, trackball, and quick-look switches.

As described previously, the DEDS provides the man-machine interface between the air traffic controllers and the ARTS III automation equipment. The DEDS receives target positional returns in analog form directly from the primary and beacon radars. It also receives tracking and other alphanumeric information from a DPS output channel and superimposes it over the broadband plan position indicator (PPI) display of radar, beacon, and map video. The keyboard of the data entry set permits the controllers to enter alphanumeric flight data into the display via the DPS, and to make modifications to the displayed information. The track ball is used to enter PPI coordinate information into the DPS by positioning a small movable cursor symbol on the display. Data corresponding to the cursor position is entered in conjunction with a keyboard message. It can specify the position of a track, of sensor video, or of an alphanumeric data item. The quick-look selector switch enables the controller to select and display at his own console the alphanumeric data pertaining to aircraft under the cognizance of a controller at another operating position. In the present ARTS III system, the quick-look function is performed only on an intrafacility basis.

System Configuration and Modularity

An expanded ARTS III installation utilizing dual-beacon input (Fig. 5) is in operation at Chicago's O'Hare Airport. The system processes up to 210 beacon targets at a given instant, and simultaneously tracks up to 180 beacon targets. An ARTS III configuration for a typical single-beacon site utilizing the elements described previously (and also shown in Fig. 5) will be installed at the Wold-Chamberlain Airport serving Minneapolis and St. Paul, Minnesota; it will allow processing of up to 192 beacon targets at a given instant and will track up to 40 beacon targets.

In order to provide the capability for growth of system functions at the same pace with increased requirements and resultant developments, ARTS III was designed within a modularly expanded concept. Because software is, of its own nature, modularly expandable when using the executive program-subprogram hierarchy, and also dependent on the hardware modularity, the primary design considerations were related to the hardware. Since the DPS is the heart of any automation system and therefore the key to expandability, the most significant modular design concepts were implemented in the DPS itself. The result is a system expandable to a maximum configuration consisting of four central processor modules, four IOP's, 262,144 32-bit storage locations, four DAS's, and 40 DEDS consoles.

The ARTS III equipment now in operation at Chicago's O'Hare Airport provides terminal area controllers with more information than was ever before possible—with the bonus capability of simpler display format, easier assimilation, and greater potential for automatic entry and updating. It is a system with modular flexibility and can be tailored to specific sites. Even more important, it is a system that can keep pace with the expanding air traffic volume. Thus ARTS III can be applied worldwide, adaptable as it is to the requirements of diverse nations needing a network of air traffic control facilities. ■

Automated Air Traffic Control: TOMORROW

Under the Federal Aviation Administration's ARTS expansion program, ARTS III is to be enhanced through design, development, and testing in the following areas: system simulation, radar tracking and beacon tracking, multisensor utilization, application of a fail-safe/soft multiprocessor executive program, display enhancements, associative processor evaluation, and a Level-1 redundancy program. This paper elaborates on those aspects of the above areas which specifically reflect ARTS expansion potential.

There are two main reasons for building *modular expandability* into ARTS. First, most general aviation aircraft (piston, turbine, rotorcraft, etc.) do not now have—and will not soon have—beacon-transponder tracking systems. Since they constitute such a large percentage of all aircraft, it is imperative that radar tracking systems be capable of handling them. A second reason is that the number of beacon-equipped commercial and military aircraft is expected to increase during the mid-late '70's. This increase in air population dictates that computer, display, and related equipment capabilities be enhanced at an accommodating pace.

System Simulation

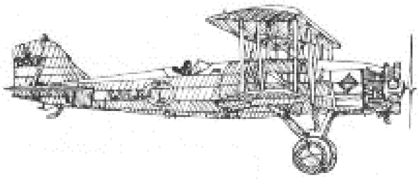
Univac is providing a simulation capability to determine the feasibility and capability of hardware and software configurations to be implemented during the ARTS expansion program. The models will be subjected to various operational parameters to investigate the performance of the proposed hardware and software in the ARTS environment. Two levels of simulation are being developed. The first, called the *simplex* group, consists of "slow time" models, with representation at the instruction or input/output (I/O) word level. Using these models, detailed hardware characteristics of the ARTS data processing system can be analyzed. The simplex models are applicable in determining the impact of additional I/O devices or changes to existing devices. The second level of simulation is called the *system* group. These models execute tasks as collective groups of instructions rather than at the individual instruction level, and the time required for simulation is much longer. The objective of the system models is to analyze system configurations and to scrutinize the multiprocessor executive. The system models can also provide data on executive overhead, resource utilization, I/O handling, and over-all system efficiency.

Computer simulation allows system evaluation under an arbitrary data load. This is essential to continuing efforts such as the ARTS expansion program, for it may not be possible to present projected workloads to a system at existing sites without interrupting normal operations.

Radar Tracking

The addition of radar tracking will provide automatic reporting and tracking of aircraft not equipped with beacons, which operate in most of the airspace on a "see and be seen" basis. Although it is true that certain high density areas are being restricted to beacon-equipped aircraft only, there is always the possibility of aircraft without beacons accidentally penetrating the airspace. For those aircraft equipped with beacons, the addition of the radar tracking system will provide reporting backup in the event of beacon fade or failure. In addition, the dual reporting capability (beacon and radar) will permit improved reporting accuracy by optimally combining the two reports into a single, more accurate estimate.

Although existing approaches are quite effective, a substantial improvement is required before automatic initiation of radar tracking can be performed with the same efficiency as is being accomplished with beacon replies. First of all, automatic track initiation requires that radar target reports be valid targets; and processors have not yet achieved a sufficiently high level of discrimination. Present processors are capable of achieving good target reporting with a minimum of false reports in a clutter-free environment. However, maintaining the level of performance in the presence of various forms of clutter has not been correspondingly successful.



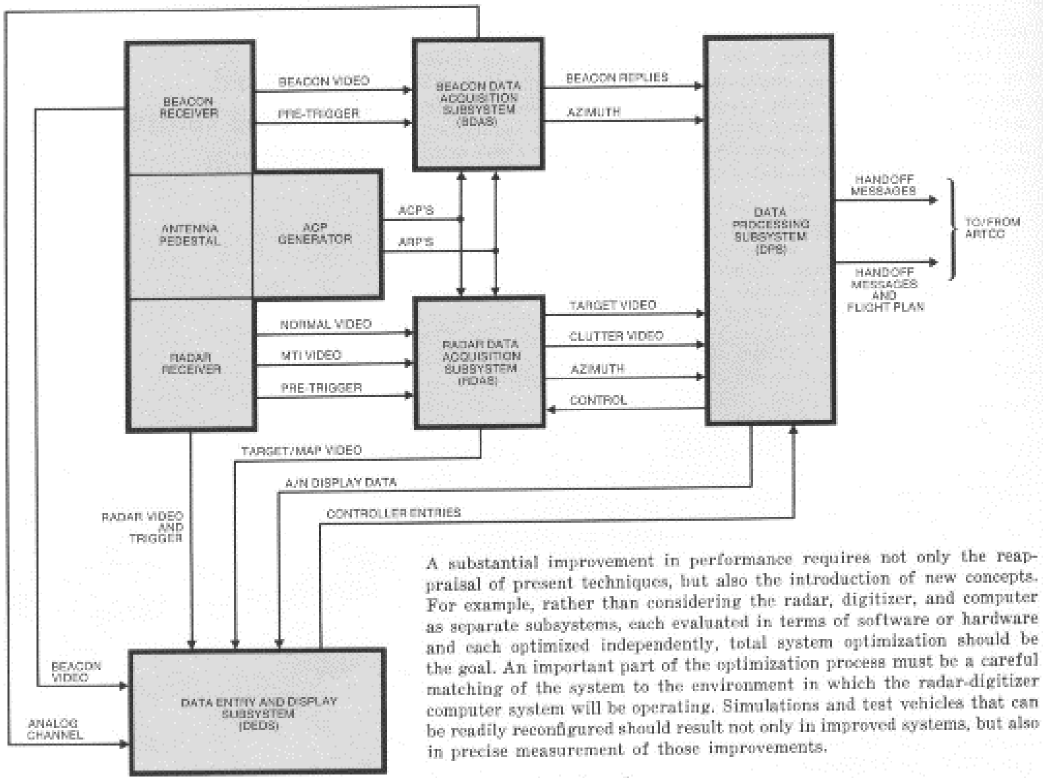


Fig. 1—The basic ARTS III radar-beacon tracking level system, shown here, consists of four major components: beacon data acquisition subsystem, radar data acquisition subsystem, data processing subsystem, and data entry and display subsystem.

A substantial improvement in performance requires not only the reappraisal of present techniques, but also the introduction of new concepts. For example, rather than considering the radar, digitizer, and computer as separate subsystems, each evaluated in terms of software or hardware and each optimized independently, total system optimization should be the goal. An important part of the optimization process must be a careful matching of the system to the environment in which the radar-digitizer computer system will be operating. Simulations and test vehicles that can be readily reconfigured should result not only in improved systems, but also in precise measurement of those improvements.

radar track test system

The initial addition of radar tracking will be provided by a test vehicle through which more advanced radar video processing and radar-beacon integration techniques can be developed and analyzed (see Fig. 1). The test vehicle will be developed utilizing current but improved video processing concepts. A principal change in this system (as compared to current equipment described in the foregoing article) will be in the implementation of the techniques.-Several of these changes, implemented in both software and hardware, will provide the opportunity to compare relative efficiency.

The DPS may be programed to perform the functions of video target report generation, target declaration, control of quantizer levels, control of clutter rejection techniques, and selection of available videos. Besides the radar and beacon video processing, the DPS will correlate the radar and beacon target reports to provide a single report on targets for which both echoes and beacon responses are received. In addition, the DPS will accept feedback of predicted track data and geographic description of the terminal area; then, using this information, will dynamically adjust control parameters to enhance the probability of detecting valid targets while minimizing false reports. Not only will this system serve as a test vehicle, but it will also make available an early model of a radar digitizing system for sites with excessive traffic loads.

radar environment measure

A detailed radar environment measurement program indicative of the total system concept will also be undertaken; it will utilize the ASR-5

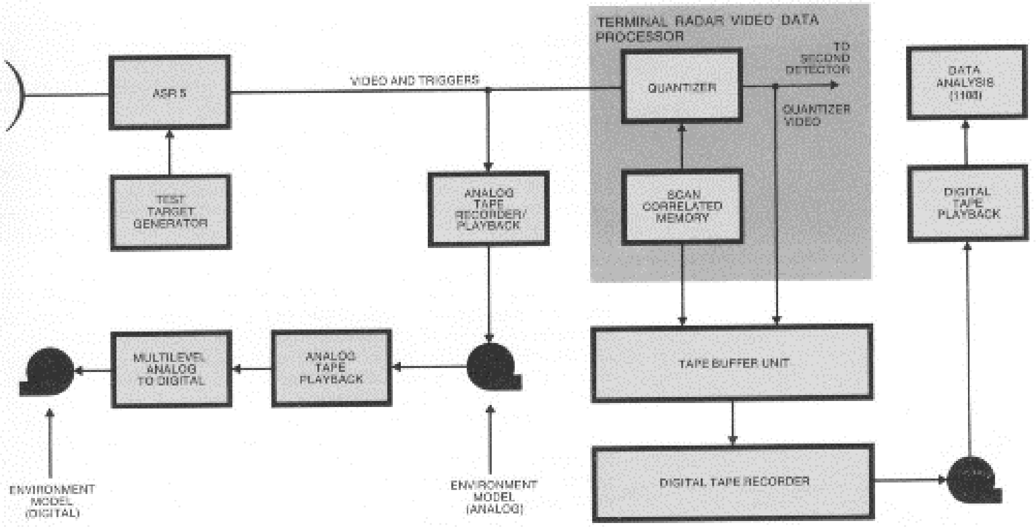


Fig. 2 (above)—Various videos are recorded for different radar environments and played back through the terminal radar video data processor. The software model of the radar data acquisition subsystem, shown in Fig. 3 (below), will also be used to investigate methods of amplitude control.

radar and the terminal radar video data processor (TRVDP) at the FAA's National Aviation Facility Experimental Center. With some radar modifications, video can be supplied to the TRVDP in a number of different forms. Because the radar environment takes on different characteristics depending on the type of receiver used to produce each form of video, the optimum receiver/processor combination will be determined by simultaneously recording videos for different radar environments, then playing them back through the TRVDP (Fig. 2).

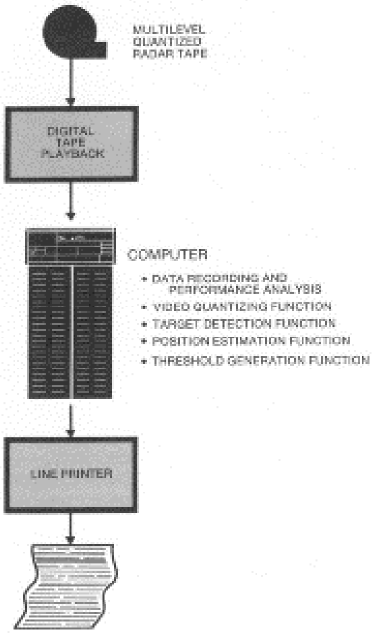
Another facet of this program will be the software model of a radar data acquisition subsystem (Fig. 3). This software model will make possible the investigation of many methods of processing the digitized radar video. A prime advantage of the model is its ability to vary any given parameter so as to establish the effect of that parameter on over-all system performance. Data recorded during the radar environment measurement study will be used to verify and exercise the software model. With the data obtained as a result of evaluating the early radar quantizer, the radar environment measurement program, and the radar data acquisition modeling study, a highly sophisticated radar data acquisition subsystem will be designed.

beacon tracking

In the operational ARTS III, when beacon data is digitized and tracking is attempted on the basis of this data, certain aberrant signals may occur on the screen in the form of ring-around or split targets. Some of the causes of these misleading aberrations include stray reflections from the ground or off surface objects, sidelobe returns, and "fruit." A study is under way to develop software filtering discrimination algorithms to help check the deficiencies in the beacon video. Based upon the information to be found in this study, improved beacon tracking programs will supplement the basic ARTS capability. The results of the study will also be used to incorporate improved beacon digitizing equipment into the improved radar beacon digitizer.

Multisensor Utilization

As the result of a separate multisensor study, design concepts will be developed and implemented for simultaneous utilization of two or more radar-beacon sensors. The design concepts will be implemented in two

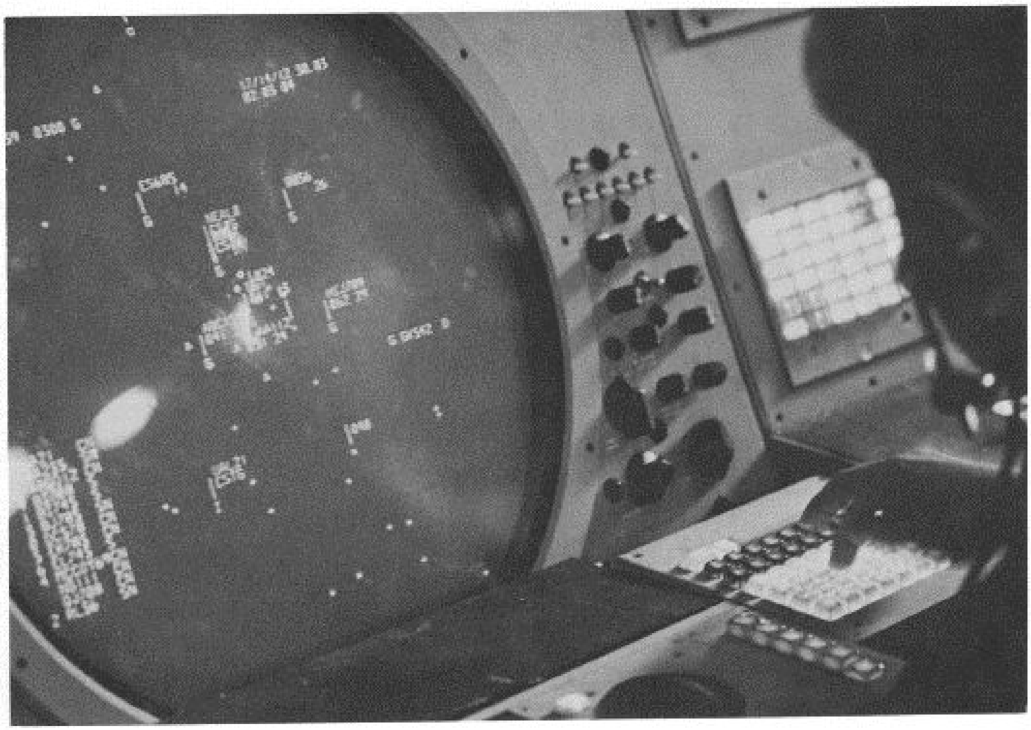


ecutive system will be expanded to include the fail-safe capability. This fail-safe/soft executive system utilizes an on-line hardware device, called the reconfiguration and fault detection unit (RFDU), to assist the executive in error detection and in the computer partitioning process. With the aid of the RFDU, the fail-safe/soft executive will detect a first order failure, partition the failed module from the system, and restart with *full* functional capability. After restart, the executive reverts to the fail-soft mode of operation.

The RFDU, a new piece of hardware, will monitor module power and cabinet temperature. These status indications will be held in system status registers located in the RFDU. The processors under program control will periodically read these status registers to determine if a malfunction has occurred. If the processors do not interrogate the RFDU within a specific time period, the RFDU will send a general "interrupt" to all processors, forcing them to examine the status registers. The executive will also perform on-line confidence tests, process memory parity and resume errors, monitor the RFDU status, evaluate error indications, perform partitioning, and maintain a system resources map. Monitoring the RFDU will be on a time-demand basis, while on-line confidence tests will operate on a time-available basis. Reconfiguration of the system in the event of an error will be accomplished by the executive program, updating the system configuration matrix in the RFDU. This update will simultaneously partition failed modules from the active system and replace them with back-up modules. The processor will then update the system resources map to reflect the current system configuration.

This three-stage approach is taken so that intermediate capabilities will be available for operational use during the development stage, and

ARTS III sharply reduces demands on a controller, since it provides information which was formerly obtained through voice communications or other means. It thus allows him to concentrate more fully on the job of safely directing air traffic.



so that each step in the development and proof of such a complex fail-safe/soft multiprocessor executive program is built on a firm predecessor. Further, inadequacies that may appear through operational use of an intermediate executive can be thoroughly examined in their own right and compensated for during the developmental stage. Operational tasks can be developed, tested, and installed after completion of the first phase, thus allowing operational capability concurrent with executive development and equipment installation.

Display Enhancements

Two areas of display enhancements are currently under way. The first, as previously mentioned, is a dual-channel modification for the basic ARTS, which allows a single display to interface with two I/O channels located on separate IOP's. This will provide flexibility in structuring complex systems and will allow automatic recovery from the failure of a processor. An external function will be used to effect the switch from one processor channel to the other. The display will monitor both I/O channel external function lines to allow either processor to control the switching.

Vector generation modification will be the second enhancement to the basic ARTS display. Raw video will be removed from the display, making possible the elimination of ground and weather clutter. Instead, weather systems will be outlined by appropriate symbols, and map data may be digitally displayed. As a consequence, eventual utilization of different phosphors will provide more acceptable display characteristics, since all data will be presented in digital form. Conflicts between video retention and alphanumeric clarity will thus be removed, allowing for viewing in higher ambient light conditions. Other long-term ARTS display enhancements will include multiphosphor cathode ray tubes (permitting multi-color display projections), and improved data entry devices (to allow easier, more natural communications between the air traffic controller and the data processing subsystem).

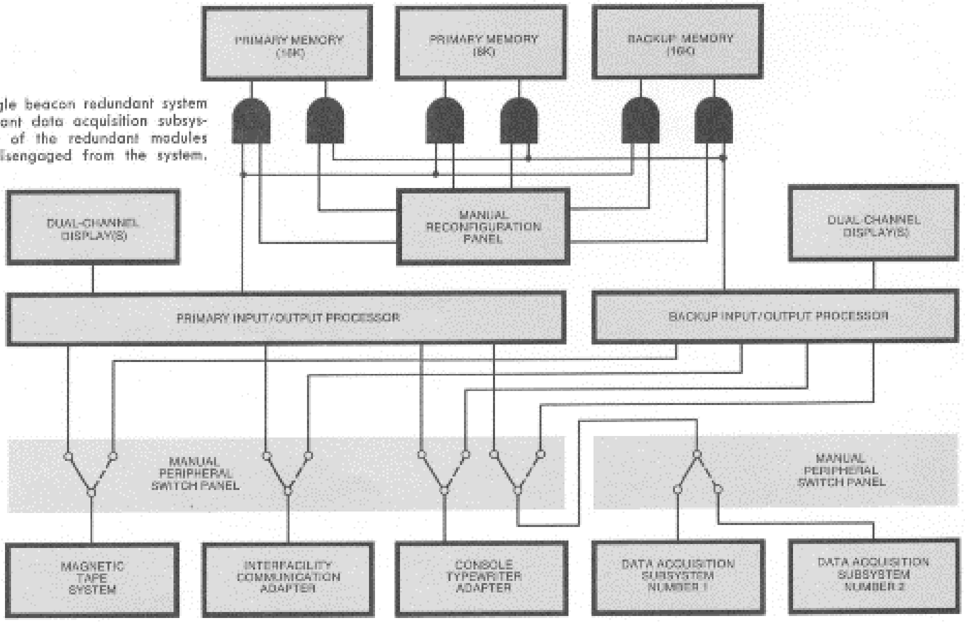


Fig. 4—Single beacon redundant system with redundant data acquisition subsystem. If one of the redundant modules fails it is disengaged from the system.

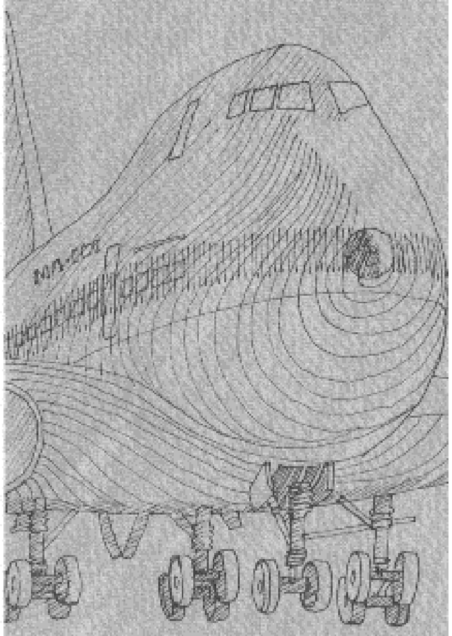
Associative Processor Evaluation

Projections have indicated that even the multiprocessor versions of the ARTS III equipment could become overburdened in accomplishing future functions in the terminal ATC system. These future functions may include capabilities such as conflict prediction and resolution, for which parallel processing is a suggested technique. An associative processor (AP) is one form of parallel processor that would seem to meet the computational requirements. Under the expansion program, this and other similar suggestions will be initially tested at the Knoxville, Tennessee airport terminal. An associative processor has already been built for the Air Force by Goodyear Aerospace, who has also conducted algorithm studies for the FAA based on this processor. Goodyear has been selected as a subcontractor to supply the hardware and software necessary to demonstrate AP operation in the areas of tracking, and conflict detection and resolution. The associative processor will be linked via an I/O channel to the already operational UNIVAC® 1230 computer system located at the Knoxville site. The traffic and test target numbers at Knoxville allow this I/O channel communication. If actual implementation were to be attempted, however, direct communication with the processor memory would probably be required. As a parallel effort, the Lambda Corporation, also under subcontract to Univac, will simulate the AP algorithms on the UNIVAC 1230 system. Lambda's primary task is to recommend the proper conflict resolution algorithm and interface requirements for the 1230/AP, based on existing 1230/AP algorithms.

Level-1 Redundancy

The purpose of the Level-1 Redundancy System program is to develop a failure recovery capability for early implementation at single- and dual-beacon operational ARTS III installations. Goal capability will provide for recovery of the ARTS system in the event of an operational module failure, within a period of five minutes. In essence, switching capabilities in this system will permit the manual transfer of peripherals from one IOP to another; the manual switching of the redundant data acquisition subsystem; the electronic switching of displays within the data entry and display subsystem from one IOP to another; and, finally, partitioning of the system to isolate the failed module from the operational system. A typical single-beacon redundant ARTS III installation is shown in Fig. 4. Both single- and dual-beacon redundant versions will be configured and demonstrated at the Minneapolis-St. Paul test facility.

The operational program for Level-1 redundancy will be adapted from the basic ARTS III operational program to permit recovery from an IOP and memory failure. Only the prime IOP's will exercise the operational program; the back-up IOP will periodically collect critical system data from the prime memory bank and store it in the back-up memory module. Redundant storage will be provided such that data collection will be controlled by the prime IOP; this insures that critical data will be retrieved only during a period of low operational (nonsaturated) activity, thereby preventing "lock-up" of operational tables by competing processors. In addition, the data collection technique will be structured so that a failure in either the back-up IOP or the back-up memory module will not interfere with the normal processing of the prime IOP's.



Conclusion

Inherent design modularity characteristics of the basic ARTS III permit extension of the system's capabilities by development of add-on modules. As a result, even as ARTS III is becoming operational (at 62 air terminals by 1973), the study, design, and testing of improved functions can be undertaken—with the confidence that they can be adapted simply, and at the earliest possible time, into basic and expanded ARTS systems of the late 1970's.

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