*The multiprocessing system is viewed within the frame of the intended air-traffic-control application.*

*Functions of the five application-oriented programs, as well as the main features of the input/output environment, are discussed.*

# An application-oriented multiprocessing system

# VI Programs for the intended application

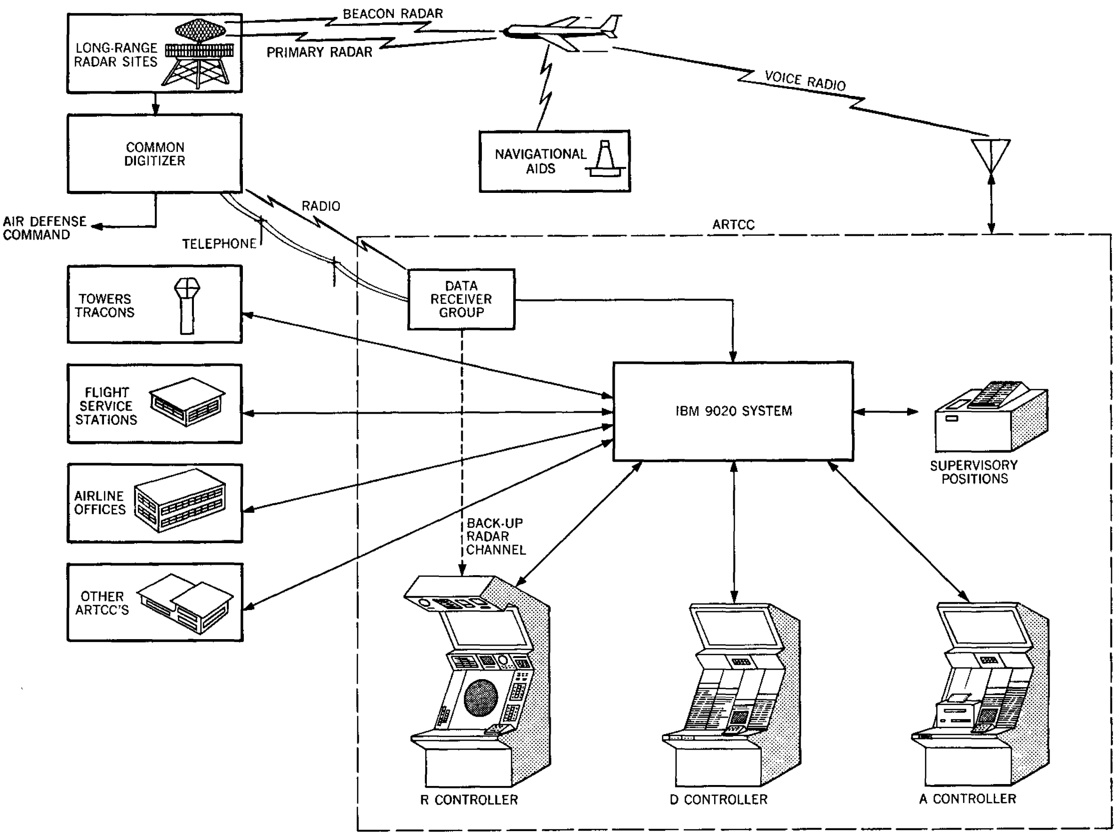
**by F. K. Seward**

The IBM 9020 multiprocessing system, described in Parts II to V, was designed to meet the Federal Aviation Administration's specifications for the Central Computer Complex of the National Air Space (NAS) system. In order to round out a picture of the whole system, this Part presents a brief discussion of the intended application and the related programs (subsequently called operational programs).

When employed in air traffic control, the 9020 system will handle many of the routine functions that now burden the air traffic controller. Each Central Computer Complex will maintain the geographical position, altitude, and flight data for all controlled aircraft within its area of jurisdiction. Displays driven by the Central Computer Complex contain flight information which is automatically updated. Coordination between control positions, such as the "handing off" of aircraft while traveling from one control sector to another, will be computer-assisted. Upon request, the Central Computer Complex will provide the requested flight control information in real time. With the computer handling most of the bookkeeping, coordination, and "remembering" activities, the controllers will be able to devote more of their time to conflict-resolving decisions.

Initially, the new level of automation is projected for Air-Route Traffic Control Centers (ARTCC's). The ARTCC's are Federal Aviation Administration facilities that control IFR (instrument flight rules) flights enroute between the points of takeoff and landing

Figure 1 NAS enroute




within controlled airspace. There are about twenty of these ARTCC's in the United States. Although the first operational site is scheduled for the ARTCC in Jacksonville, Florida, in 1968, a similar complement of equipment and programs is being installed at the National Aviation Facilities Experimental Center in Atlantic City, New Jersey, for use in development, testing, and evaluation. The operational program subsystem is designed with flexibility as one of its goals, so that it may be adapted to various ARTCC's with little additional programming effort. The capabilities provided by the operational programs in conjunction with the 9020 equipment and its control program are schematically indicated in Figure 1.

## The application environment

As a center for enroute air-traffic control, an ARTCC will be equipped with a 9020 Central Computer Complex, the operational programs, controller displays and keyboards, and other peripheral input/output equipment. The flight plans, which are submitted by the pilots prior to takeoff, are error-checked, acknowledged, stored, and updated by the computer until needed. In addition, data from beacon (transponder) and primary (reflecting) radar are received by the system, processed, and classified. This information is matched with the previously received flight plans and identified. The position data are then displayed with identifying and supporting information.

Prior to entry into a sector's area of jurisdiction, "flight strips" are printed at the control position. These strips provide the controllers with such information as aircraft identification, aircraft route, expected arrival times, cleared altitudes, and expected altitudes at selected geographical locations. Updated data are forwarded to relevant sectors as the system recognizes or receives information about deviations from the projected flight plans. To aid in maintaining a smooth traffic flow, anomalies and summary data are brought to the attention of supervisory controllers.

control sectors

The enroute control function within an ARTCC is normally subdivided into control sectors on the basis of geography, altitude, and major functional responsibility. Each center's control area covers hundreds of thousands of square miles and may have an area of interest of over a million square miles. For example, with dimensions of approximately 500 × 600 nautical miles, the Jacksonville center has twenty-nine sectors. These irregular sectors are laid out to equalize the traffic load as much as possible. Each sector is normally staffed by a team of three controllers:

*The R controller* who uses a display (a radar plan view) as his primary source of information.

*The D controller* who relies primarily upon flight plans, flight strips, and non-radar data.

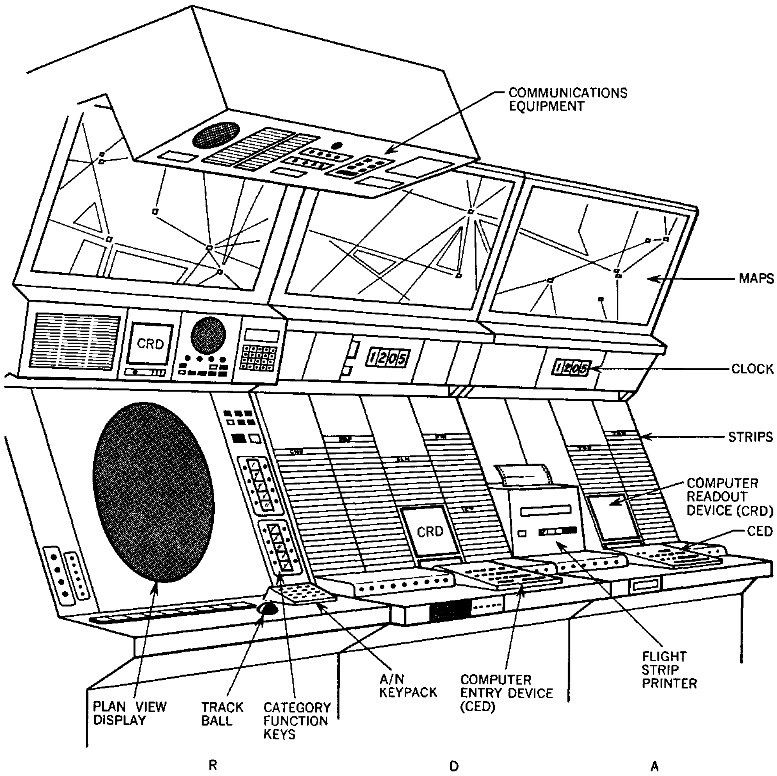
*The A controller* who supports the D and R controllers as required.

sector equipment

Supporting input/output equipment at each sector position facilitates communication among the controllers, the 9020 system at the ARTCC, and the airspace environment. Figure 2 shows the layout for a sector at Jacksonville. The following computer-related equipment is typically available at a control sector: plan-view display, keyboard message organizer, three computer readout devices, two computer entry devices (keyboards), and one typewriter-like flight-strip printer. The plan-view display is a 22-inch cathode-ray tube used by the R controller to view processed radar or display data from the 9020 system. Under program control, the tube can also display alphanumeric tags associated with tracks and flight plans, map symbols, and other information.

The keyboard-message organizer permits the R controller to enter data; symbols are buffered until a complete message is ready. The device interrupts the 9020 system, which sets up a READ instruction and subsequently interprets the message. The keyboard message organizer has three components: the category-function

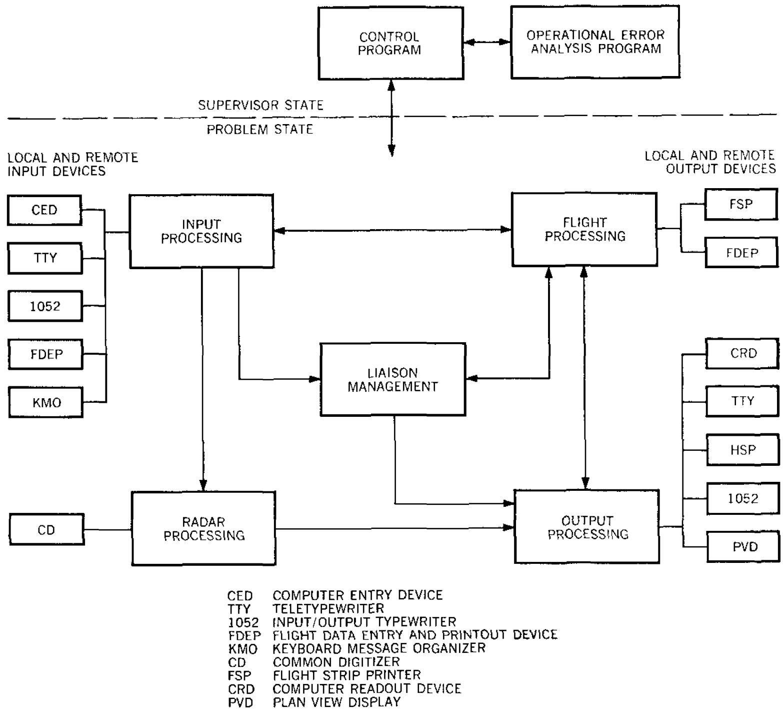
Figure 2 Typical controller positions




keys, the alphanumeric keypack, and the track ball. The category-function keys allow rapid input of frequently used data into the 9020 system: depression of one button defines a class of actions, and depression of a second button indicates a particular action within the class. The R controller enters supporting data with the alphanumeric keypack. The track ball permits the controller to indicate a point on his plan-view display.

The computer readout device for all three controllers is a small cathode-ray tube that displays tabular information on a 25-character by 20-line raster. The device is used to present weather observations, altimeter settings, flight plans, and other tabular data. The computer entry device at the D and A controller positions consists of a keyboard with alphanumeric keys, control keys, format keys used to define message type, and four lamps that indicate device status and message availability. The device is used to enter flight plans, amendments, progress reports, and requests for computer data. Sector equipment is supplemented with IBM 1052 input/output typewriters or high-speed printers for generating summary data on system operation.

Figure 3 Operational programs




Teletype equipment at flight service stations, airline offices, and military operation offices may communicate with the 9020 system. High-speed circuits are used to pass data to and from adjacent computer-equipped centers, to and from flight-data entry and printing devices at airport control towers and Terminal Radar Approach Control Facilities (TRACON's), and from the special devices that provide digital radar data from each radar site.

## Program functions

In addition to the 9020 control program and Operational Error Analysis Program (discussed in Parts III and IV of this paper), ARTCC's make use of five application-oriented operational programs:

- Input Processing Program
- Radar Processing Program
- Flight Processing Program
- Output Processing Program
- Liaison Management Program

The general relationships among the various programs is shown in Figure 3. The seven programs comprise approximately 150 thousand machine instructions, 115 thousand words of tables, and 20 thousand words for buffers and working storage. Each program consists of one or more subprograms. As the logical unit of coding, a subprogram handles one or more functionally related tasks independently of other subprograms. Subprogram executions are sequenced by the scheduling algorithm in the control program. Within the logical restraints inherent in the application, subprograms may be processed in parallel. Tasks within a subprogram are processed in programmer-designated sequence. The five application-oriented operational programs consist of 27 subprograms and *system subroutines* (which differ from subprograms in that they can be directly called by one or more subprograms).

In the initial analysis, functions in the work load were classified by time of need (some functions, such as those associated with radar scans, are periodic whereas others are aperiodic) and, where major equipment restraints exist (as in the case of polling), by device. The major elements of the data base were divided into tables requiring access protection and tables simultaneously accessible by multiple Computing Elements. Once these major guidelines were established, most of the programming could proceed as if only one Computing Element existed in the system. The main restriction imposed was that each subprogram had to request its own storage resources (areas, blocks, and lines). The control program was given the responsibility for avoiding interference between Computing Elements.

input processing

The Input Processing Program is made up of subprograms operating at the demand of a device that has completed an input. The program accepts, checks, and stores input messages from most of the peripheral input devices. Table 1 contains a summary of the device types, and corresponding personnel or positions, that enter data through the Input Processing Program.

Approximately one hundred different message types can be handled by the Input Processing Program. In many cases, a given

**Table 1 Input Processing Program interface**

| *Device* | *Personnel/position* |
|---|---|
| Computer entry device | D controllers<br>A controllers |
| Keyboard message organizer | R controllers |
| IBM 1052 | Supervisory controllers |
| Teletypewriter | Other centers<br>Flight service stations<br>Military operations<br>Airline offices |
| Flight data entry positions | Tower cabs<br>TRACONS |
| Interfacility In | Adjacent NAS centers |

type can be entered from any of the several device types and in any of several formats with different optional fields. For example, a flight plan can be entered from the D or A controller positions via computer entry devices; from several supervisory controller positions via IBM 1052's; from towers via flight-data entry and printout devices; from flight service stations, airline operational offices, and military operation offices via remote teletypewriter; and from other centers. Four of the eleven fields of a flight plan are optional, with each field having several permissable formats; e.g., altitude may be defined in nine different ways.

After receipt and decoding of the input message, the program stores various indicators defining the input or action requested. When a message is entered in error, it is held in storage and an error indication is returned (via the appropriate output subprogram) to an output device at the position, whereupon a correction can be entered.

The Input Processing Program consists of three subprograms and one system subroutine; it contains roughly fifty-two thousand instructions.

radar processing

The Radar Processing Program addresses the data handling of primary and beacon radar returns as well as the development and maintenance of radar tracks. Simulation of radar returns, as well as on-line real-time quality control of radar data, is also provided.

All radar data received from the common digitizers are processed on a cyclic basis, once a second, as timed by the control program. Data is error-checked and converted to system coordinates; filtered to produce single-site coverage over the entire ARTCC area; correlated to determine the best radar datum and track pairing (based on track/datum separation and a scoring system called Correlation Preference Value); and forwarded for display on the appropriate R controller's plan-view display.

Every five seconds, the position and velocity of every track in the system are calculated. Where possible, stored flight plan data are used in conjunction with beacon or primary radar data to establish position and velocity of a track. New tracks are established, where possible, on the basis of flight plans, controller inputs and/or discrete beacon responses.

Every ten seconds, simulated radar data for training purposes are extrapolated on the basis of instructions from a controller at a simulation designated console. Primary-radar and beacon-radar test messages, radar-site status messages, and radar-site data counts are monitored for quality control of the radar data. Deviations are printed at supervisory positions. Registration and collimation correction factors are calculated on demand.

The Radar Processing Program consists of six subprograms and 12,000 words of code.

flight processing

The Flight Processing Program is generally concerned with stored flight plans, the actual position of an aircraft relative to its flight plan, and the production of flight progress strips reflecting the flight plan and the estimated aircraft progress on that plan.

Table 2 Output Processing Program interface

| Device | Personnel/position |
|---|---|
| Computer readout devices | R controllers<br>D controllers<br>A controllers |
| Plan-view display | R controllers |
| IBM 1052 | Supervisory controllers |
| Teletypewriter | Other centers<br>Flight service stations<br>Military operations<br>Airline offices |
| Interfacility Out | Adjacent NAS centers |

Through three system subroutines, the program provides—on demand—several services to other subprograms. These services include: (1) interpreting the route data of a flight plan and translating it into a series of fixes that describe the line of flight, (2) calculating the arrival time at each fix for all flight plans that have at least one fix at the ARTCC, (3) assigning a discrete beacon code to beacon-equipped aircraft within the control area and ensuring that the same code is not used by more than one aircraft simultaneously, and (4) extrapolating the flight plan position and associating this position with matched track positions.

One subprogram in the Flight Processing Program produces all the local and remote flight strips for the system. Every strip contains information relative to a flight at a given fix, such as time of arrival, altitude, speed, etc., as well as summary data on the flight, such as route and type of aircraft.

The Flight Processing Program consists of three subprograms and three system subroutines using approximately 20,000 words of code.

output processing

The Output Processing Program formats, filters, and generates output data to the various peripheral output devices. Table 2 lists the devices and positions communicated with.

The Output Processing Program consists of seven subprograms for (1) accepting data sent from other subprograms, (2) formatting and routing this data, and (3) sending it to the proper output devices. The subprogram handling the output communication with the plan-view displays is more complex. Because of the continuously changing nature of the diverse information available to the R controller via his plan-view display (PVD), a fairly elaborate approach is required. Three broad classes of data can be displayed on PVD's:

*Automatic display data.* These data go to all PVD's but include only a small subset of the total output. An example is a data list that reports which radar sites are off.

*Controller-requested data.* These go only to the PVD from which requested; samples of this class are radar-track information from other sectors, flight-plan route displays, and beacon-code displays. *Sector-related aircraft data.* These are routed on the basis of PVD-to-sector and aircraft-to-sector relationships. The displays are complicated by the fact that PVD-to-sector relationships are dynamic, more than one sector may be controlled at one PVD, two PVD's may view the same sector, and an aircraft may be eligible for display in more than one sector.

Because of this complex interrelationship, small units of information (called data blocks) are made up once for each type of display in the system and stored. Then, on the basis of controller requests, aircraft location, time, and sector geography, a chain of I/O instructions are made up to ensure that each data block gets to the proper PVD(s). Thus, data on a specific radar track or flight plan are only stored once, although its data block may appear on many different PVD's.

The Output Processing Program contains seven subprograms and uses 29,000 instructions.

liaison management

The Liaison Management Program maintains the large tables of the operational component. Conceptually clockwatchers, housekeepers, and recording secretaries, the four subprograms making up liaison management accomplish several major functions. At the proper time, they move flight plans that have been stored on tape into main storage. They update flight-plan and tracking tables to eliminate cancelled flight plans and obsolete radar data from the system. At intervals, they signal output subprograms to produce periodic reports and they record on magnetic tape for legal and analysis purposes selected data from operational tables and buffers.

The Liaison Management Program contains four subprograms and 10,000 words of code.

## Summary

Although many of the techniques defined for the NAS Enroute system have been tried on a limited scale elsewhere, and so can be considered "proven," their combination in the air-traffic-control environment—with its unusually varied and close man/machine relationships—constitutes an integrated system test of importance to future large real-time systems. By sketching the overall aspects of the application from a data-processing point of view, this paper complements the earlier discussions of the equipment, control program, on-line error analysis program, and off-line diagnostic monitor.