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THE FUTURE—ARTS* III

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DAILY RECORD OF FACILITY OPERATION	
TIME (GMT)	REMARKS
1640	Getting several erroneous altitude reports: two air carriers, both descending to 7,000, showing 3,600. South departure leaving 5,000, showing 3,400.
1710	More erroneous altitudes: Corporate aircraft at 7,000 showing 14,900 about every third sweep. Air carrier southbound departure, leaving 10,300, showing 3,700.
1751	Corporate aircraft, four northwest of field at 3,000; altitude readout showing 6,900 for three sweeps.

The above entries appeared in the Daily Log of a major control tower recently. The record indicates seven instances of major deviation in aircraft altitude readout on the controller's display in a little more than one hour. During that hour some 150 aircraft passed in and out of the terminal area. The separation of these aircraft depended to a great extent upon the accurate readout of altitude data on the controllers' display.

The printout of the altitude on the controller's display is a vital element in the terminal area system known as ARTS.[1] The counter-

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* Automated Radar Terminal Systems.

** J.D., American University; M.B.A., University of Chicago; President, Frank McDermott, Ltd.; Former Technical Advisor to the Director of Research, Federal Aviation Agency.

[1] Automated Radar Terminal Systems is the processing and displaying of aircraft identification, flight plan data, altitude, speed, and other data for the terminal controller.

part of ARTS is the NAS STAGE A[2] computer system used in Air Route Traffic Control (ARTC) Centers. The ARTC centers provide enroute flight information concerning aircraft once they have left the area surrounding the terminal serviced by the ARTS system. Although there are many technical differences in the two systems, they serve the same purpose. Thus, for purposes of this paper the term "ARTS" may be considered as the generic term for automation in air traffic control.[3]

History

About twenty-five years ago, a small group of experienced controllers were assigned to the Technical Development Center[4] of the Civil Aeronautics Administration (CAA), and given the task of developing a system capable of keeping track of and displaying flight data pertaining to aircraft flying on instrument flight plans in the air traffic control system. The principal tool in this research was the Dynamic Simulator.[5] The simulator also was used to develop radar procedures and train the nucleus of controllers from towers and centers about to be equipped with radar.[6] The simulator served the dual function of providing the procedures and training for the then current system, as well as preparing the air traffic control environment to cope with the commercial jet transports, soon to enter the system.

The equipment and procedures used for keeping track of aircraft at the time were quite primitive. Flight data was written on flight progress strips, and displayed in vertical racks. This data was passed by interphone from one controller to another, and from one traffic control facility to the next. Aircraft reported their position by radio, often through remote relay stations. As the speed of aircraft increased it was not uncommon for a flight to enter the con-

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[2] NAS STAGE A is the title of the computer system used in enroute centers.

[3] The symbology used in the controllers automated display can be found in FAA, AIRMAN'S INFORMATION MANUAL, Part 1, Fig. 1-5 at p. 1-12 and Fig. 1-6 at p. 1-13 (1978).

[4] The principal research center operated by the Civil Aeronautics Administration during the 1950's.

[5] The Dynamic Simulator is a system capable of simulating any air traffic control environment. It is used chiefly in the development of radar procedures and in the training of radar controllers.

[6] Up until this time the only radar available was surplus World War II equipment, and this was in limited supply.

troller's airspace before the flight data had been posted in that particular sector. Even in those facilities using the World War II surplus radar, however, the flight data lagged behind the airplane. Controllers using radar were faced with the additional problem of maintaining identity and altitude information on their radar targets.

In 1956 the CAA assembled the first Air Traffic Controllers' Conference on Automation. Controllers from towers and centers throughout the country met to brainstorm the critical problems in flight data handling, and to discuss how they might be alleviated through automation. From this conference came a set of general guidelines:

1. The radar target of the aircraft should be given some unique identification.
2. The altitude of the aircraft, and changes in altitude, should be displayed continuously to the controller.
3. The flight data should be automatically transferred between ATC facilities and displayed at the appropriate control positions.
4. The estimated time of arrival over specified reporting points along the airway should be calculated, displayed, and updated as necessary.

Crude as these concepts were, they represented a beginning.

Although the CAA's research budget was severely limited, computer specialists from IBM and UNIVAC[7] volunteered a great deal of aid and encouragement in getting the automation program underway. At one time there was also some suggestion that the obsolete vacuum tube computers in use in the SAGE[8] system might become available for use by the CAA.

As a first step in providing aircraft identity and altitude associated with the radar target, the research project at Indianapolis used overhead projectors[9] to display the basic radar data on a

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[7] The computer division of Remington Rand Corporation at the time.

[8] Semi-Automated Ground Environment facilities of the Air Defense Command. Studies between 1958 and 1960 indicated that the cost of converting this computer operation to civilian use would be prohibitive.

[9] The horizontal display permitted a team of controllers to use a common display, with a great improvement in the coordination process.

horizontal screen. "Shrimp boats"[10] were positioned alongside the radar target, and were moved manually as the target progressed across the display. The aircraft identity and altitude were written in grease pencil on the target marker. Later, more elaborate markers had digital counters to display current altitude. Of all the promises of automation, it was the altitude feature that held the greatest promise. Display of current altitude to the controller could reduce the hazard of midair collision, and virtually eliminate the incidence of aircraft flying into the terrain because of navigation or altimeter problems.

It was a midair collision over the Grand Canyon in 1956,[11] followed by a 1958 military/civil mid-air collision in Nevada,[12] that provided the major impetus for accelerating the effort to automate the ATC facilities. In addition, by 1957, Congress was aware that growth in aviation was being stifled. The CAA, buried in the basement of the Department of Commerce, had not effectively voiced the need for an effective air traffic control system.[13] In order to encourage modernization of ATC facilities, Congress enacted the Airways Modernization Act of 1957.[14] This legislation created the Airways Modernization Board (AMB)[15] as an interim agency, to concentrate on the research and development needed to modernize the system. The AMB was designed to be phased into the new, independent, Federal Aviation Agency, created by the Federal Aviation Act of 1958.[16]

By 1959 a sympathetic Congress, an independent FAA with a vastly increased budget, and the effective leadership of Elwood

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[10] Plastic markers with a pointed bow resembling a ship.

[11] TWA/United collision over Grand Canyon, Arizona, June 30, 1956.

[12] DC-7/F-100 collision, Las Vegas, Nevada, April 21, 1958.

[13] This condition was reported by Edward P. Curtis, Special Assistant for Aviation Facilities Planning, in his report to President Eisenhower in 1956.

[14] Airways Modernization Act of 1957, Pub. L. No. 85-133, 71 Stat. 349 (1958). The purpose of the Act was to establish the Airways Modernization Board (AMB) and to provide for the development and modernization of the national system of navigation and traffic control facilities to serve present and future needs of civil and military aviation. *Id.*

[15] A three-member board, appointed by the President, and drawing its staff from specialists in civil and military air traffic control, navigation, and related fields.

[16] Federal Aviation Act of 1958, 72 Stat. 731, *as amended*, 49 U.S.C. §§ 1301 *et seq.* (1976), *formerly* Civil Aeronautics Act of 1938, ch. 601, 52 Stat. 973.

R. Quesada,[17] had fostered an encouraging environment for the field of aviation. Aviation problems were being identified, and practical steps were being taken toward their solution. This environment made it possible to utilize computers to process all radar targets, transponder as well as primary.[18] The radar targets would be discretely identified, and accompanied with current altitude and other pertinent flight statistics. Flight data would be automatically processed and displayed throughout the entire route, from takeoff to touchdown. The computer could be utilized to search ahead for conflict, both in route and altitude, and thereby provide the controller with optimum solutions in ample time. Inbound traffic to the terminal area would be metered and spaced by the computer, providing maximum utilization of runways with minimum delays. Significant data would be automatically displayed to the pilot providing a more efficient means for pilot/controller resolution of air traffic control problems.[19]

The FAA's independence was short lived. In 1966, the Federal Aviation Agency became the Federal Aviation Administration,[20] and was incorporated into the newest addition to the cabinet, the Department of Transportation (DOT). While it would not be fair to compare the FAA's subjugated role in the DOT today with the plight of the CAA as part of the Department of Commerce in 1957, there are some interesting similarities. Many of the arguments for independence which were advanced then are valid today,[21] particularly in the area of the allocation of resources and technology for improvement of air safety.

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[17] "Pete" Quesada had served as Special Assistant to the President for Aviation Matters, and as the Chairman of the Airways Modernization Board, prior to being appointed first Administrator of the Federal Aviation Agency.

[18] The term "transponder" refers to aircraft equiped with a transponder that is capable of transmitting selective pulses conveying identity and altitude. The term "primary" refers to aircraft which do not possess the transponder and are therefore unable to convey data to the controller concerning its identity and altitude. In the case of the "primary target" the controller is required to "capture" the primary target through special input devices, inserting appropriate identity and altitude information into the computer.

[19] The importance of a data link from the ground computer to a cockpit display was recognized and planned for by the Airways Modernization Board (AMB) in 1958. FAA REPORT, RESEARCH AND DEVELOPMENT PROGRAM AND PROGRESS 92-93 (1959).

[20] Department of Transportation Act, Pub. L. No. 89-670, § 11, 80 Stat. 949 (1966).

[21] *See Study of Operation of Civil Aeronautics Administration, Hearings on*

Present System of Automation

It would not be possible in this short space to describe all the intricacies of the present ATC automation system. A brief description is in order, however, to permit a better understanding of how automatically derived data can be used to improve aviation safety.

The system of automation in ARTC Centers[22] is called NAS STAGE A.[23] It consists of a computer which is fed radar data from several remote long-range radar antennas, and which in turn feeds the displays of the controllers. Although maximum ultilization of the system occurs with aircraft equipped with altitude coded transponders,[24] the computer also can process targets from primary radar returns.[25] Aircraft identity, altitude, calculated ground speed, and other data are automatically displayed to the controller. The controller also has a terminal[26] which enables direct communication with the computer. The computer sorts out the data from all the various radar inputs, and composes a mosaic[27] display of the airspace for which the ARTC is responsible. Each controller's display is capable of calling out that portion of the airspace for which he is responsible, and excluding the rest. The computer also can be programed to feed information as to a stratified area of operation, displaying for the controller only that traffic between specified upper and lower limits of altitude. Where two or more remote radar antennas in areas of overlapping coverage capture the same target, the computer determines which of the sources should be used. Under such circumstances the controller does not know, nor does he need to know, which antenna is providing the data for his display.

The automation program in the terminal area is known as ARTS.[28] Because the terminal area is confined to a region which

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S. 2818 before the Aviation Subcomm. of the Senate Commerce Comm., 84th Cong., 2d Sess. (1956).

[22] Air Traffic Control Centers, providing air traffic control service to IFR aircraft during the en route phase of flight.

[23] *See* note 2 *supra.*

[24] *See* note 18 *supra.*

[25] *See* note 18 *supra.*

[26] Changes in altitude, route, etc., can be directed to the computer from each controller position.

[27] The display is an X,Y grid covering the entire ARTC center area.

[28] *See* note 1 *supra.*

is covered adequately by one central radar antenna, the composition of the terminal controller's display more nearly resembles the conventional radar display in terms of orientation around a central point of origin. However, the display can be off-centered, enabling a terminal controller to work within a small portion of the overall coverage of the terminal radar antenna.

These two computer systems are compatible, and their programs provide for automatic handoff[29] of targets to other facilities and displays. For example, in a typical flight through the ATC system a transponder equipped aircraft at the time of takeoff is told by the tower to "squawk"[30] a four-digit transponder code. The departure radar controller's display then presents a data block[31] alongside the radar target as it emerges from the end of the runway, showing the aircraft identity, and its altitude in 100 foot increments. Once tracked to the boundary of the terminal's jurisdiction, the aircraft is handed off from the ARTS computer to the NAS STAGE A computer in the ARTC Center. There it is displayed through the various sectors, handed off to adjacent centers, and then eventually handed off to the terminal ARTS computer at its destination.

Weather Data in the Computer System

Primary radar, based entirely upon the capacity of the radar antenna to capture reflected signals, in addition to aircraft, also displays clouds containing sufficient moisture to cause the radar energy to be reflected. The display from heavily laden clouds can be bothersome to a radar controller because such weather clutter will obscure radar targets of aircraft. The terminal controller with an ARTS display can eliminate the weather clutter by turning off the primary radar. This, however, produces two problems. Without the primary radar information the controller loses the ability to see non-transponder equipped aircraft. The controller is also un-

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[29] Symbology on the controllers display permits transfer of control jurisdiction from one controller to another without any oral communication.

[30] The transponder originated as a World War II secure reporting device. Affectionately known as a "parrot," it was inevitable that the transponder would be asked to "squawk."

[31] An arrangement of alpha-numeric data including aircraft identity, altitude, ground speed, and other symbols, written on the controller's display adjacent to the target and moving with the target.

able to offer weather advisories concerning areas of heavy precipitation. The radar does not show turbulence, but controllers generally are trained to recognize that turbulence is frequently associated with areas of heavy precipitation as shown on the radar.

NAS STAGE A computers have been programmed with a subsystem which allows precipitation returns to be converted into symbols on the synthetic display used by the controller. Areas of precipitation of varying intensity are displayed either as radial lines on the scope, or by a series of symbols in the form of the letter "H."[32] The latter signifies the heavier precipitation, generally representing a rainfall equivalent of approximately .5 inches per hour. If the remote radar antenna has a microwave or broadband link with the ARTC center, the controller can call up the primary radar information on his display and observe the actual precipitation areas. Without broadband capability the controller must rely upon the digitizing process of the radar information at the antenna site[33] and the symbolic presentation of the weather contours as computed in the data processer.

Additional Features of ARTS and NAS STAGE A

If the computer has sufficient capacity and speed there is virtually no limit as to the functions it may perform. Recently the FAA has programmed some interesting software routines into the ARTS and NAS STAGE A computers. These include a Minimum Safe Altitude Warning[34] wherein the computer examines a stored grid containing the minimum safe altitude for each two-mile square in the terminal area. Should an extrapolation of the flight path and altitude of an aircraft indicate an unsafe condition, the computer will cause both an aural and visual alarm to be communicated to the controller. A Terminal Conflict Alert[35] provides a similar analysis and warning with respect to conflict between two aircraft in the terminal area. A similar software routine is in

[32] *See* note 3 *supra.*

[33] Radar data at ARTC remote antennas is converted to digital form and transmitted to the NAS STAGE A computer via telephone lines. This is a great saving in cost over microwave transmission.

[34] FEDERAL AVIATION ADMINISTRATION ADVISORY CIRCULAR AC 90-72A (January 1, 1978).

[35] FEDERAL AVIATION ADMINISTRATION ADVISORY CIRCULAR AC 90-77 (September 1, 1977).

use in the enroute computers, known as the NAS STAGE A Conflict Alert Function.

Use of ARTS Data in Accident Reconstruction

There has been a great deal of discussion about the use of data stored in the ARTS and NAS STAGE A computer systems. The FAA has taken the position that the processed data stored on magnetic tape should be used only as a diagnostic tool in checking the reliability of the system. Whether diagnostic or reconstructive, the stored data has been used extensively by the FAA to analyze the handling of accident and near accident situations.

The data stored on magnetic tapes enables a complete reconstruction of the handling of an individual aircraft, several select aircraft, or all aircraft in the system. The data from the ARTS and NAS STAGE A tapes can be presented in tabular form by use of high speed printers. In such instances the printout provides two lines of digital data for each aircraft from each sweep of the radar. Typically this data will include:

1. Time in hours, minutes, seconds and thousandths of seconds;
2. Aircraft identity;
3. Transponder code assigned;
4. Transponder code reported;
5. Altitude reported by transponder;
6. Rho Theta information based upon the location of the radar antenna;
7. X, Y coordinates, based upon a grid centered on the radar antenna;
8. X, Y coordinates, based upon an origin expressed in latitude and longitude (NAS STAGE A mosaic display); and
9. Computed ground speed.

In addition, the printout will contain technical data pertaining to the reliability and degree of confidence attributed to the report.

The magnetic tape data also records computer response in effectuating handoffs from one facility or sector to another. Also recorded on the tape are the computer input reflecting changes in altitude, route of flight, and other data. All NAS STAGE A computers have this magnetic tape storage and retrieval capability. Most of the ARTS installations also are equipped with the modular unit permitting tape storage.

The FAA procedures for record retention require that these computer tapes be held for fifteen days.[36] The instructions issued to center and tower chiefs concerning the retention of computer tapes in the event of an accident are somewhat ambiguous. Whereas voice recorder tapes involved in an accident are required to be saved, there is no corresponding rule governing the ARTS and NAS STAGE A computer tapes.[37] Indeed, the FAA's current accident investigation manual,[38] completely rewritten and issued in 1976, is silent on the subject of computer tape retention and use. With respect to the ARTS computer tapes, the Facility Management Manual,[39] at paragraph 1546(f) reads: "Tapes and console typewriter printouts pertaining to accidents shall be retained at the facility until released by AAT-20. DO NOT make these tapes and printouts part of the accident package."[40] Since the National Transportation Safety Board usually limits its inquiry of air traffic control data to that material assembled by the FAA in its Accident Package, failure to include the computer data effectively denies the NTSB a most valuable source of reconstruction material.

The reconstruction of flight paths based upon the computer printout of stored data is a laborious, but effective, process. The physical process requires the creation of an X, Y grid on a plastic overlay with incremental units of one nautical mile. The scale selected should be that of the appropriate underlying aeronautical or topographic chart. The X, Y mileage values are given in thousandths of a mile, with each decimal unit equivalent to approximately six feet. Since the manner of presenting the stored data is merely a function of programming the extraction routine, the FAA has developed a variety of methods of reconstructing and displaying the flight information.

The same highspeed printer which is used to print the tabular data also can serve as the output device for a reconstructed grid, showing aircraft position information, navigational fixes, airports,

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[36] U.S. DEP'T OF TRANSPORTATION, RECORDS ORGANIZATION, TRANSFER AND DESTRUCTION STANDARDS 88 (1971).

[37] U.S. DEP'T OF TRANSPORTATION, FACILITY MANAGEMENT 42-48 (1975) [hereinafter cited as FACILITY MANAGEMENT].

[38] U.S. DEP'T OF TRANSPORTATION, AIRCRAFT ACCIDENT AND INCIDENT NOTIFICATION, INVESTIGATION, AND REPORTING (1976).

[39] FACILITY MANAGEMENT, *supra* note 37, at 163.

[40] *Id.*

and other data in a plain view. The product of this printout is crude and lacks topographic data necessary for a complete analysis, but it does serve as a useful tool in determining the proper portions of the flight to be studied in detail. Finally, the tape containing the stored data can be played through a computer to reconstruct the flight situation on a controllers display—exactly as it appeared to the controller in its original state. This capability is a closely guarded secret within the FAA, yet is used extensively by the FAA in analyzing accident situations.

Although there always will be a question of proof as to whether the data processed by the computer actually was displayed to a particular controller, the absence of any indication of equipment failure or misalignment should weigh heavily in favor of the assumption that the data was actually available to the controller. For example, when Eastern Flight 401[41] was ordered to hold over the Everglades at an altitude of 2,000 feet, and was observed by the controller at an altitude of 900 feet, the controller did not give a warning. The controller later testified that his attention had been diverted to other traffic, and he did not observe any further altitude reports on the ARTS display. The computer storage showed that the altitude reports continued (and presumably were displayed) in descending 100 foot increments down to 300 feet, prior to the aircraft disappearing from the radar display. This computer tape was reviewed by a select group of FAA personnel, but was never shown to the NTSB.

That accident, along with the crash of a TWA 727 on approach to Dulles[42] and the collision of a King Air with a radio tower at American University in Washington, D.C.,[43] provided the impetus for FAA's Minimum Safe Altitude Warning program. In each of these three accidents the unsafe altitude was displayed to the controller, the controller saw the altitude, but no warning was given. It remains to be seen if the addition of an aural alarm to the controllers display will provide a better response.

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[41] Accident Report, NTSB-AAR-73-14, Eastern Airlines at Miami, Florida, December 29, 1972.

[42] Accident Report, NTSB-AAR-75-16, Trans World Airlines at Berryville, Virginia, December 1, 1974.

[43] Accident Report, NTSB-AAR-76-4, Wolfe Industries, Inc., at Washington, D.C., January 25, 1975.

Conclusion

Perhaps there has been an overemphasis placed on software routines in providing additional alerts and alarms for the controller. Despite all of the sophistication of ground equipment, the pilot is denied access to the computer unless the controller passes the proper information along by radio. The FAA has made it clear that there are many limitations in terms of workload, equipment and even discretion, that might prevent, or at least delay the controller in passing important information to the pilot. The capability to communicate data directly to the pilot from the computer exists. Critical alert information could thus be displayed in the cockpit of the aircraft where it can be evaluated and acted upon by the pilot. This does not suggest that the controller's role might be eliminated or even diminished. However, there have been too many instances of disasters that occurred because essential data was not forwarded to the pilot by the controller. Post accident arguments as to whether the controller had a duty to warn can be avoided by automatically communicating important information to the pilot by use of computers.

There can be no question as to the value of the ARTS and NAS STAGE A computer data in reconstructing aviation accidents. The ARTS data provides a precise position for each aircraft in the system every four seconds. This data includes aircraft identity, altitude, ground speed, and an account of whatever computer input was made by the controller. The NAS STAGE A computer data permits extraction of similar data at a repetition rate of six times per minute. In addition, the NAS computer will provide information as to weather conditions displayed to the controller.

The voice recorder tapes in both centers and towers permit transcribing all conversations, radio and interphone, and correlating specific transmissions to precise positions of aircraft as determined from the computer readout. The data from aircraft derived from cockpit voice recorders and flight data recorders also can be correlated with the data from the ARTS and NAS computers, and from the voice tapes in centers and towers.

All of this data should be readily available to responsible aviation accident investigators. The end product would be a more accurate determination of the cause of aviation mishaps, and more importantly, future accidents could be prevented.