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U.S. GENERAL ACCOUNTING OFFICE
STAFF STUDY
[ARTS III]

DEPARTMENT OF TRANSPORTATION

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CONTENTS

ABBREVIATIONS

ARTS	Automated Radar Terminal System
FAA	Federal Aviation Administration
IFR	Instrument Flight Rules
IOC	Initial Operating Capability
ORD	Operational Readiness Demonstration
Q&R	Quality and Reliability
VFR	Visual Flight Rules

SUMMARY

PROGRAM DESCRIPTION AND STATUS

The Federal Aviation Administration (FAA) is responsible for ensuring the safe and efficient use of our national airspace. Marked increases in air traffic have occurred during the last few years and are predicted for the future. One of the recommendations of a presidential task force, established in 1961, called for the application of computer technology to the air traffic control system. The FAA's automation efforts have been in two broad, but related, areas--the enroute system and the terminal system.

The purpose of the Automated Radar Terminal System (ARTS III) is to increase safety and to provide better service to the user by providing for (1) alphanumeric information on the terminal area air traffic controller's radar display and (2) the automatic transfer of flight data between computers in the terminal areas and the Air Route Traffic Control Centers.

The ARTS III system consists of three subsystems: (1) a data acquisition subsystem; (2) a data processing subsystem; and (3) a data entry and display subsystem. Sixty-four (64) of these systems are being procured for locations throughout the country. As of February 1, 1973, 63 systems had been delivered; initial operating capability had been achieved by 56; and operational readiness demonstration had been achieved by 48.

COMING EVENTS

FAA officials estimated that delivery of all 64 systems would be completed in February 1973; that initial operating capability would be achieved

on the last system in November 1973; and that the operational readiness demonstration for the last system would be achieved in December 1973. Three of the systems (Dallas/Fort Worth, Sacramento, and San Antonio) are being held in storage by Univac pending completion of site preparation. One system (San Francisco/Oakland) will be shipped to the FAA Depot for temporary storage awaiting completion of construction of a new building.

COST

The planning estimate, prepared in October 1968, and the program cost estimate at time of contracting (February 1969) was $51.3 million. The total estimated cost for the program was changed to $64.5 million in mid-1970 and has since remained at that level. The $13.2 million increase is attributed to additional requirements (approximately $10 million) system configuration changes, additional operating positions, functional changes, and delivery order changes. The total amount appropriated is $64.5 million.

CONTRACT DATA

On February 20, 1969, the FAA awarded a firm fixed-price multi-year contract to the Univac Federal Systems Division of Sperry Rand Corporation for the production and installation of 64 ARTS III systems. The ARTS III system consists of three subsystems: (1) a data acquisition subsystem, (2) a data processing subsystem; and (3) a data entry and display subsystem. Univac, the prime contractor, is producing the data processing subsystem, the computer software and is also responsible for integrating the subsystems with the software, installing, and completely testing each system through Initial Operating Capability. The current value of the FAA contract with Univac is about $60.9 million. Univac has a multi-year fixed-price subcontract with the Burroughs Corporation for the production of the data

acquisition subsystems. This subcontract has a value of about $2.9 million. The production of the data entry and display subsystem was subcontracted to Texas Instruments, Inc., under a multi-year fixed-price contract. The current value of this subcontract is about $15.3 million.

The contractor submitted an index of drawings and technical memoranda, contract financial reports, narrative progress reports and Program Evaluation and Review Technique reports on a monthly basis to the FAA.

PERFORMANCE

The one major technical problem encountered during the ARTS III program was with the display device. Although major problems did occur during the development of the display subsystem they were solved through the combined efforts of FAA, Univac and Texas Instruments, Inc.

While a number of other minor problems have occurred after installation, it appears that the ARTS III equipment has been operationally successful and has met with enthusiastic acceptance on the part of the user.

PROGRAM MILESTONES

The major milestones in the ARTS III program were (1) the delivery date,

(2) the completion of initial operating capability, and (3) the operational readiness demonstration for each of the 64 systems.

Generally, the ARTS III systems have been close to their scheduled milestones, with most of any major delays experienced being attributed to site preparation problems. We noted that site preparation problems at three locations significantly affected overall schedule performance, and that if these three could be disregarded the actual and projected milestones for the remainder would be in close alignment with the schedule. (See p. 19.)

RELATIONSHIP TO OTHER SYSTEMS

The ARTS III program is a follow-on system of the earlier ARTS I and ARTS IA systems installed at Atlanta and New York respectively.

The ARTS II system is an automation system being designed for smaller airports served by FAA radar-equipped control towers. A contract was recently awarded by the FAA for delivery of prototype systems for testing and evaluation.

SELECTED ACQUISITION REPORTING

ARTS III is being acquired and operated by the FAA, a civil agency, and is therefore not reported in the Selected Acquisition Reporting system.

MATTERS FOR CONSIDERATION

There is a definite need for an effective air traffic control system, and the ARTS III appears to have been a highly successful stepping stone to such a system. In our opinion, the program office approach employed by the FAA has had a considerable influence on the degree of success they have

enjoyed in meeting the cost, schedule and performance criteria established for the ARTS III program. With its enroute and terminal automation programs apparently near completion the FAA abolished the National Airspace System Program Office on July 26, 1972. In examining the National Aviation System Policy Summary (prepared by the FAA) it appears that the automation efforts undertaken by the FAA in the enroute and ARTS III programs are merely the first of a number of programs.

Based on the success and experience of the National Airspace System Program Office in managing the ARTS III program, the Congress should question the FAA's abolishment of that office when their air traffic control automation efforts are not complete.

CHAPTER 1

INTRODUCTION

Simplistically speaking, air traffic control brings safe and efficient order to what could be a chaotic situation. The extent of increase in air transportation in the United States is common knowledge. Less well known are the estimates for future demand. In 1960, there were 62 million passenger enplanements for domestic and international flights. Enplanements in 1971 reached 170 million. The Federal Aviation Administration (FAA) of the Department of Transportation estimates this will increase to 435 million by 1982. Without the coordination provided by the air traffic control system, the amount of delays and collisions would reach horrendous heights.

The FAA is charged with ensuring the safe and efficient use of the nation's airspace, by military as well as civil aviation, and with fostering civil aeronautics and air commerce (emphasis added). In this regard, the FAA has been engaged in automating the air traffic control subsystem of the National Airspace System since the appearance of the Project Beacon Report in 1961. These efforts have been directed toward meeting the expected air traffic growth by increasing the capacity and efficiency of the air traffic control subsystem and by relieving the air traffic controller of those tasks that could be better performed by machines. Essentially, these efforts have been in two broad, but related, areas--the enroute system and the terminal system. As an analogy, one might relate the enroute system to our interstate highways and the terminal system to the beltways and major arterial streets through our larger cities.

Prior to 1936 all air traffic control centers in the United States were operated by private airlines as a joint venture. In July of that year the Federal Government, under the auspices of the Bureau of Air Commerce, took over these operations. There were only three enroute traffic control facilities at that time--Newark, Cleveland and Chicago. Enroute traffic control facilities are described as having responsibility for the separation of aircraft within a great expanse of airspace. Contrasted to this are the terminal facilities which are concerned with aircraft in the immediate vicinity of an airport. Following the Civil Aeronautics Act of 1938, the Federal Government expanded its control to include responsibility for the operation of terminal air traffic control towers.

The Federal Aviation Act of 1958 charged the Federal Aviation Agency (now Federal Aviation Administration) with the responsibility for ensuring safe and efficient use of the nation's airspace by civilian and military aircraft. In accordance with this Act, all aircraft operating in this airspace must adhere to the rules and regulations of the FAA. Of approximately 12,000 aircraft in flight daily over the United States during the daylight hours, 80 percent fly under Visual (see and be seen) Flight Rules (VFR). Under these rules the task of maintaining separation from all other aircraft is the pilot's responsibility. The remaining 20 percent, mostly commercial and military, operate under Instrument Flight Rules (IFR). Under these rules air traffic controllers located at one of the nation's 20 Air Route Traffic Control Centers (hereinafter referred to as enroute centers) rely on radar to keep these aircraft separated from other IFR operating aircraft. Effective control occurs when the ground controller is able to identify each airplane by position, altitude and speed.

While the control of all IFR aircraft during all phases of flight is necessary, it becomes even more critical in the terminal areas. A terminal area may be described as that airspace from five to 60 or more miles in diameter in which one or more airports are located. Due to the congestion of arriving and departing planes the likelihood of delay or collision is greater there. The separation of IFR aircraft operating in the terminal area is the responsibility of air traffic controllers in one of the air traffic control towers within the terminal area. Again, these controllers rely on radar in maintaining separation of aircraft. In early 1972 FAA employed approximately 16 thousand air traffic controllers at the enroute centers and terminal areas.

This report is primarily concerned with a review of the actions taken by the FAA to introduce automation into the control of air traffic operating within a terminal area.

History of Automated Air Traffic Control

In 1961, President Kennedy asked for a long-range plan to insure safe and efficient control of all air traffic within the United States. A task force was established by the Administrator of the FAA to prepare this plan. The task force report, under the name "Project Beacon," submitted an analysis of the existing methods of air traffic control, recommended a number of near term improvements, and presented an advanced concept for an air traffic control system to meet future needs. The task force recognized the huge demand for air transportation and the implications the rapid rate of increase would have on the air traffic controller, who were already considered

to be operating at capacity. One solution to this problem obviously, would have been to steadily increase the number of controllers. Terminal facilities are limited by space however, and this answer would have prompted more problems than solutions. An alternative, which "Project Beacon" recommended, called for the application of computer technology to the system. The Automated Radar Terminal System (ARTS) is one outgrowth of this proposal. In addition, they recommended IFR aircraft be equipped with a transponder which would electronically provide the aircraft's identity and altitude to the controller.

Control of aircraft in the terminal airspace requires that each aircraft be precisely identified by position, altitude and speed. Prior to automation, the controller identified each "blip" on his radar display by extensive radio communications with the pilot. Not only was this time consuming; it was also arduous and inefficient as the controller either relied on his memory or wrote all this data on paper or plastic strips ("shrimp boats") which were then placed on the radar display adjacent to its associated blip. As the aircraft and its corresponding blip moved on the radar display, the controller then physically moved the associated shrimp boat.

ARTS was conceived to eliminate these manual chores and reduce the amount of radio communications required to establish aircraft identity. Continuous positive aircraft identity, ground speed and altitude would now be obtained via the transponder and computer and shown in code (alphanumerics) directly on the radar display. As a result, the controller would be free to effectively serve more aircraft than before. Safety hazards

inherent in the old system would also be overcome. The FAA completed a system implementation plan in June 1962 and work was then begun on the development of a workable automated air traffic control system for use in high volume terminal areas. The first installation (ARTS-I), at Atlanta, served as an operational test system. Later, an automated terminal system (ARTS I-A) was installed in a common IFR room established to provide airports in the New York City area with radar control capability.

Originally, the FAA planned to use the same type of terminal automated air traffic control equipment as that being developed for the enroute centers. However, the requirements for terminal operations are significantly different than those for enroute centers. For instance, terminal controllers are primarily interested in the actual position and identity of each aircraft. Enroute controllers, though, are concerned more with the reconciliation of planned position to the actual position. Another difference, due to greater concentration of aircraft in the terminal airspace, is that a higher radar antenna rotation rate is required in the terminal areas. Also, obtaining physical space for the installation of automation equipment presented more of a problem at the terminals than it did at the enroute centers.

In February, 1969, the FAA awarded a contract to the Univac Federal Systems Division of Sperry Rand Corporation for development, production and installation of an automated radar terminal system (ARTS-III). The ARTS III consists of three subsystems: (1) a data acquisition subsystem; (2) a data processing subsystem; and (3) a data entry and display subsystem. The data acquisition subsystem receives beacon video and control signals

from which it detects beacon replies, generates range and azimuth data, and transmits reply messages to the data processing subsystem. The latter performs target detection, tracking, processing of flight data, transfer of control, controller message processing, and display processing consisting of "formatting" display data and refreshing the data entry and display subsystem. This last subsystem displays the analog representation of both the radar and beacon video, displays the alphanumeric data, and transmits controller-entered keyboard data to the data processing subsystem. Univac, the prime contractor, is producing the data processing subsystem and computer software. The data acquisition subsystem is built by the Burroughs Corporation and the data entry and display subsystem by Texas Instruments Incorporated, as Univac subcontractors. Sixty-four (64) of these systems will be installed throughout the country. As the demand for service increases at each airport and as more functions are required, these systems can be expanded modularly. The first system was delivered on December 22, 1970. Since then an additional 62 have been delivered (as of February 1, 1973) and current projections are that the last system will be tested and in use by late-1973.

Scope

Information on this program was obtained by reviewing plans, reports, correspondence, and other records and by interviewing officials at contractor plants, various FAA locations (Headquarters offices, Regional offices, air terminals, and enroute centers), and the officials formerly assigned to the National Airspace System Program Office. We evaluated management

policies and the procedures and controls related to the decision-making process, but we did not make detailed analysis or audits of the basic data supporting program documents. We made no attempt to: (1) assess the technology involved, (2) develop technological approaches, or (3) involve ourselves in decisions while they were being made.

CHAPTER 2

PROGRAM STATUS

Since this is our initial review of the ARTS III program, this chapter will highlight the cost, schedule, and performance experience of the overall program.

Program Cost Experience

The current estimated cost of the ARTS III program is $64.5 million. This compares with an initial program estimate of $33 million made in June 1967, and a $51.3 million planning estimate made in October 1968, and again in February 1969, when the contract was awarded. The $64.5 million estimate, made in September 1970, has remained unchanged since that date. In addition to the fact that the program estimate and the planning estimate made no provision for inflation, various reasons were noted for the increase in total cost and are given below.

From Initial Program Estimate to Time of Contracting

The initial program estimate of $33 million was based on the premise that the alphanumeric capability would be added to the display devices then in operation at 62 terminals. By the time a contract was awarded (February 1969) two additional locations had been added to the requirement--one at the FAA Academy in Oklahoma City for training purposes and one at the National Aviation Facilities Experimental Center in Atlantic City for the development of enhancement programs. In addition, the concept had been expanded to include (1) new display devices (rather than modifying

the existing display devices as originally planned), (2) additional display devices, (3) additional capabilities, and (4) revised support concepts (both operational and supply support).

From Time of Contracting Through November 1972

In February 1969, Univac was awarded a firm fixed-price multi-year contract for the procurement and installation of hardware and software for 64 ARTS III systems. The contract provided for three lots of 17, 23, and 24 systems respectively. The program cost estimate at the time of contracting included $15.7 million for Lot 1, $21.8 million for Lot 2, and $13.8 million for Lot 3, for a total of $51.3 million. The Lot 1 estimate of $15.7 million was higher than the budget estimate for Lot 1 of $14.2 million submitted in August 1967 to the Department of Transportation. The appropriation passed in August 1968 was for $14.2 million. In view of this reduced funding, and the requirement for additional equipment described above, the FAA reduced the number of systems being procured in Lot 1 from 17 to 12 and adjusted the system locations in Lots 2 and 3 to maintain the delivery order. The revised quantities in the 3 lots were changed to 12, 23, and 29 respectively in January 1970.

The $13.2 million increase in program cost since the planning estimate was prepared is attributed to additional requirements (which accounted for approximately $10 million of the increase), system configuration changes, additional operating positions, functional changes requiring more core memory, and delivery order changes.

The total amount appropriated for the ARTS III program is $64.5 million.

Program Schedule Experience

The major milestones in the ARTS III program were (1) the delivery date; (2) the completion of installation and checkout, i.e. initial operating capability (IOC); and (3) the operational readiness demonstration (ORD), for each of the 64 systems. The delivery date and IOC date for each system were established in the basic contract. Subsequent modifications to the contract in January 1970, May 1971, and November 1971, however, have changed the delivery schedule, the IOC schedule, some of the locations involved, and the relative order in which certain locations were to receive the systems. Key events (including the three milestones mentioned above) in the ARTS III program for each of the 64 locations were prepared by the FAA in October 1971 and subsequently updated on a monthly basis. The ORD date for each system has generally been established as four months after the IOC date.

Major Milestones

Major milestones for delivery, IOC and ORD for each of the 64 systems in the ARTS III program are listed in Appendix I and are expressed as the number of months after contract award (February 20, 1969) that an event was scheduled to occur or actually occurred. In those instances where delivery, IOC, or ORD had not occurred as of February 1, 1973, we have listed the scheduled date and the currently estimated date for that event.

Summary information regarding the delivery, IOC and ORD milestones is shown in Figure I.

SUMMARY INFORMATION

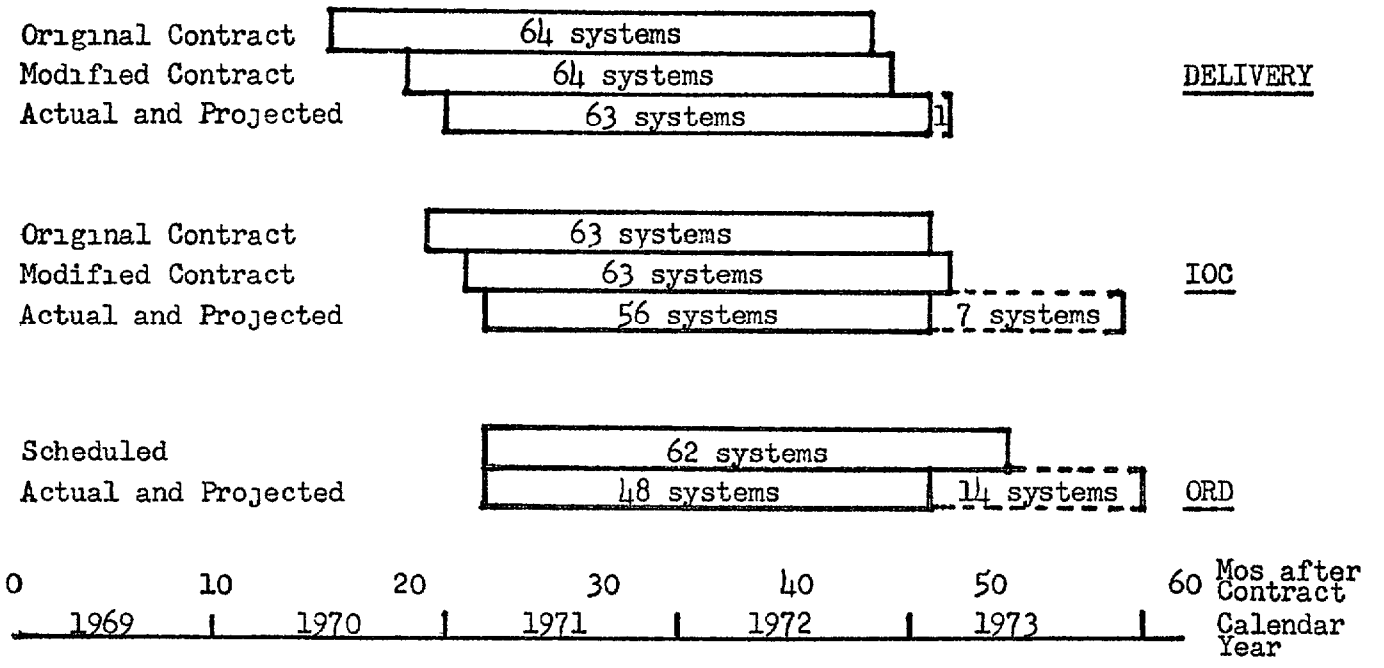

FIGURE I

Delivery

The first ARTS III system was delivered to the FAA Academy in Oklahoma City on December 22, 1970. A second system was delivered to Chicago's O'Hare Terminal on December 27, 1970. While the first delivery slipped six months in comparison with the milestones established in the original contract, it was only two months late in comparison with the modified contract. One of the 64 systems was undelivered as of February 1, 1973. Three of the systems (Dallas/Fort Worth, Sacramento, and San Antonio) are being held in storage by Univac pending completion of site preparation.

The system for the San Francisco/Oakland terminal will be shipped to the FAA Depot for temporary storage while awaiting completion of construction of a new building. FAA officials estimated that delivery of all 64 systems would be completed in February 1973, which is only four months later than the completion date specified in the original contract. Note that the total delivery time

for the 64 systems has been compressed from 28 months (i.e. from 16 to 44 months after contract award as shown in Figure I for the original contract) to 26 months (i.e., from 22 to 48 months after contract award as shown for actual and projected delivery). The average delivery date for an ARTS III system (computed from the delivery information contained in Appendix I) has increased from 33.2 months after contract award in the original contract to 35.2 months in the modified contract, and is projected to be 36.7 months if delivery is completed in February 1973. We were advised that the major factor delaying delivery of the initial ARTS III systems was associated with the development of the data entry and display subsystem. This problem area is discussed further under the Program Performance Experience.

We were informed that during production of the data entry and display subsystem, Texas Instruments, Inc., encountered problems with two of its suppliers. These were solved by purchase of the suppliers' production facilities in one case and by advancing funds to the supplier in the second case. In addition, Texas Instruments used a second shift during a portion of the production phase in order to maintain the delivery schedule which had been compressed because of the development delays.

Initial Operating Capability

Initial operating capability (IOC) was first achieved by an ARTS III system on February 19, 1971, at the FAA Academy. While this is a slippage of three months when compared with the milestone established in the original contract, it is only one month late when compared with the modified

contract. Based on the original contract the average IOC date for an ARTS III system is 36.9 months after contract award (computed from the IOC information contained in Appendix I). This average increases to 38.8 months in the modified contract and is projected to be 39.3 months for the entire program.

Operational Readiness Demonstration

The first operational readiness demonstration (ORD) of an ARTS III system was also held at the FAA Academy in February 1971. While the ORD milestone was not included in the original contract, FAA officials informed us that the first ORD was on schedule. Based on the National Airspace System Program Office Official Schedules, dated October 1, 1971, the average ORD date for an ARTS III system is 42.9 months after contract award. As of February 1, 1973, ORD has been achieved by 48 systems with the average ORD date being 41.2 months after contract award. It is projected that the average ORD date for the entire program will be 43.5 months after contract award.

Observation

In examining the information presented in Appendix I it is apparent that the overall ARTS III schedule performance is significantly affected by delays involving three systems (see information for systems 57, 61, and 64 in Appendix I).

We found that the delays involving systems 57, 61, and 64 were attributed to site preparation (an FAA responsibility) and were not related to performance by the ARTS III contractor or subcontractors. FAA officials told us that contractual difficulties were delaying site preparation at the Dallas/Fort Worth, San Francisco/Oakland and San Antonio terminals (scheduled to receive systems 57, 61, and 64 respectively).

Program Performance Experience

The ARTS III is an outgrowth of the "Project Beacon" Report which was submitted to the FAA and then to President Kennedy in September 1961. Two significant recommendations of that report were (1) utilization of an Air Traffic Control Radar Beacon System for data acquisition and (2) utilization of general-purpose digital computers to provide air traffic controllers with aircraft position information. Subsequently, design concepts developed by the FAA's system design team resulted in an experimental model of an automated radar terminal system, known as ARTS I, installed in the Atlanta terminal. While this model was initially used to provide a field environment for appraisal of early concepts, it has been used for routine operational service since 1966.

The air-traffic congestion problem in the New York metropolitan area in the mid-1960's led to the ARTS IA, an improved version of the ARTS I, which was installed at the John F. Kennedy Airport in New York between late 1966 and early 1968 and placed into routine operational service in June 1969.

The experience gained in the design, installation, and operation of the ARTS I, and the analysis of the air traffic situation leading to the

ARTS IA, permitted the FAA's Systems Research and Development Service to clearly identify the task to be performed by the follow-on system--the ARTS III--which was to be installed at the nation's busier air terminals. (Note: The ARTS II is an automation system being designed for smaller airports served by FAA radar-equipped control towers.)

A comprehensive operational and technical description of the ARTS III is contained in FAA document "ARTS III System Description (SPO-MD-600)." In addition, a description of the equipment and services to be procured is also contained in the ARTS III Procurement Plan, dated May 17, 1968. FAA officials advised us that their experience with ARTS I and ARTS IA also permitted preparation of comprehensive performance specifications for the ARTS III. While the performance specifications were developed by the Systems Research and Development Service they were reviewed by the users of the system (the Air Traffic Service and the Airway Facilities Service) and the contracting officials (the Logistics Service).

While a number of operational problems did arise during development and the early months of the program (e.g. excessive number of data acquisition subsystem alarms, inoperative power supplies in the data processing subsystem, display tubes that had a halo effect and were difficult to read, overheated display keyboards, circuit board failures, integration of ARTS III equipment with the radar surveillance systems, etc.,) it appears that the ARTS III equipment has been operationally successful and has met with enthusiastic acceptance on the part of the user.

We found that during the lifetime of the ARTS III contract there

have been only 14 modifications made that reflected changes in performance or technical characteristics of the system. We were advised that these changes were made to correct errors, reflect newer technology, or to meet modified requirements and that they have improved the operation, maintenance and reliability of the system.

FAA and Univac officials told us that the major performance problems of the ARTS III could be attributed to the data entry and display subsystem. Univac officials said that at the beginning of the ARTS III program they considered that the system was reasonably well defined and the technical goals were reasonable. The one major problem area that they did envision was with the display device which was subcontracted to Texas Instruments Incorporated. This device was a new development item and consequently considered a risk area. When major problems did occur during the development of the display device, the FAA and Univac obtained the attention of Texas Instrument's top management who in turn assigned their most highly qualified people to the program. In addition, Univac assigned a program manager in residence at the subcontractor's plant during the most critical period of the development. FAA officials confirmed that problems did exist in the early development of the display device. Through combined actions the major problems were solved; however, a slight schedule delay did result.

Texas Instruments officials advised us that the data entry and display subsystem was to be manufactured in accordance with performance specifications developed by Univac and the FAA. They stated that the specification was very strict, but well defined; and while the data entry

and display subsystem was not ahead of the state-of-the-art it was a new piece of equipment and some problems were encountered during its development. A Texas Instruments official closely associated with the subsystem stated that the basic problem was that Texas Instruments grossly underestimated the time and effort required for development. The first data entry and display subsystems were scheduled for delivery approximately one year after the company entered into a subcontract with Univac on March 20, 1969.

In early 1970, Univac and the FAA informed Texas Instruments that its contract was not on schedule and, in fact, that it might be terminated. It was at this time that Texas Instruments changed project managers and upgraded the entire project.

One of the first decisions of the new project manager was to change the development approach being used. While the first project manager had been attempting to develop a subsystem which would fulfill all specification requirements prior to beginning production of equipment for delivery, the second project manager started developing a system meeting as many of the specification requirements as possible but which could later be upgraded to comply fully with all specifications, either during the production phase or retrofitted at the site.

Selected Acquisition Reporting

The Automated Radar Terminal System (ARTS III) is being acquired and operated by the Federal Aviation Administration (FAA), a civil agency, and is therefore not reported in the Selected Acquisition Reporting system.

CHAPTER 3

TEST AND EVALUATION

Tests and evaluation are the primary methods whereby a program manager receives assurance that contract end items will meet performance specifications and that program objectives will be achieved. To obtain this assurance, an effective test plan requiring an orderly, phased progression of tests must be developed and implemented. We found that the ARTS III Test Plan, prepared by Univac--and reviewed by the FAA--was consistent with this requirement.

In the ARTS III program we noted various levels of testing, inspection, and acceptance. These levels include the inspection of components delivered from vendors; the factory inspection and testing of the subassemblies and subsystems; the integration of the subsystems into a system at each site with appropriate tests and checks at each stage of implementation; the stages of initial operating capability, operational readiness demonstration, and operational changeover; and eventually the commissioning of the facility.

In addition to these various levels of testing, we found that the test plan provided for several classes of testing to include (1) design qualification, (2) production, (3) support software, (4) reliability, (5) maintainability, and (6) type. The ARTS III tests were further categorized as either factory tests or on-site tests. The on-site tests were classed as site acceptance, system shakedown, and operations changeover.

The factory tests on the ARTS III equipment and software were designed to demonstrate specification compliance to the FAA Resident Quality and Reliability Representative. These tests have been conducted at the Univac facilities in St. Paul, Minnesota and Salt Lake City, Utah and also at the Burroughs and Texas Instruments, Inc. (subcontractors) factories in Paoli, Pennsylvania and Dallas, Texas respectively.

The FAA has had Quality and Reliability (Q&R) Representatives assigned at each of the contractor or subcontractor facilities engaged in the ARTS III program. Some of the more important duties and responsibilities of the Q&R representatives are to execute effectively the FAA quality control program and monitor the contract quality control program for adequacy and to determine the compliance of equipment, materials, and services to the contract requirements. In accomplishing these duties the Q&R representative is expected to (1) assist the contractors in establishing and installing acceptable inspection systems, (2) recognize and analyze defects in equipment produced to ascertain causes of deficiencies, and recommend any changes necessary in manufacturing techniques, quality control procedures, or inspection practices; and (3) authorize any necessary deviation in equipment and material provided they did not affect price, delivery, or end use.

In integrating the ARTS III systems with the on-site equipment the on-site tests are conducted in three phases and, in our opinion, have been as extensive as the factory tests. Phase I testing consists of the physical installation of the systems to the greatest degree possible and static electrical checks of these equipments to demonstrate system integrity prior to

interconnection with site facilities. Phase II testing demonstrates the ARTS III performance after interconnection with the site facilities. Phase III testing demonstrates complete site adaptation of an ARTS III system. This test includes a final check on operating controls and the operational computer program. Initial Operating Capability (IOC) is attained upon satisfactory completion of Phase III testing. Univac, the prime contractor, is responsible for the integration of the three subsystems with the necessary software and for site installation and testing of each system through the achievement of IOC.

FAA officials explained that system shakedown, which begins after IOC, is a learning and optimization process wherein personnel become familiar with the system and the system is tailored to the specific needs of the terminal. Shakedown tests for the ARTS III were designed to be compatible with the normal control of air traffic yet had to be conducted with the least possible interference to ongoing air traffic control operations. The system shakedown activities are directed toward bringing the entire system, including personnel and procedures, to a state of operational readiness and culminate in an operational readiness demonstration (ORD). Satisfactory completion of the operational and maintenance tests in the ORD indicate that necessary performance standards have been met and the ARTS III is ready for operational use. Successful completion of ORD is also the point at which the National Airspace System Program Office turns the ARTS III system over to the user--the Air Traffic Service--for operations changeover, which is that phase of implementation wherein the system is phased into the ongoing air traffic control operations at a facility on a commissioned basis.

CHAPTER 4

COST ESTIMATING AND PROGRESS MEASUREMENT

Cost Estimating

The primary objective of cost estimating is to provide management with a tool for program evaluation and cost control during the system acquisition process. An effective management system normally has key points of decisionmaking and control that provide a reliable basis for deciding initially upon the specific system to be developed and later as a means for evaluating progress to determine if a program should be continued, discontinued, or modified. Cost estimating and progress measurement should support this decisionmaking process by providing credible and valid information to the decision-maker.

Generally, we found that total cost for the ARTS III program was of prime interest during the preparation of both the initial program estimate and the planning estimate, and at the time the FAA Budget Estimates were submitted to the Department of Transportation for each of the three lot buys. After the budget estimates had been approved and the appropriations bills had been passed, it appears that the emphasis shifted and the estimates were then used to determine how much of a system could be obtained without exceeding the total amount approved.

We found that the June 1967 initial program estimate of $33.0 million was increased to $51.3 million when the planning estimate was prepared in October 1968. The estimated cost for the three lot program at the time of contracting (February 20, 1969) was also $51.3 million. FAA officials advised us that their ARTS III budget estimates were submitted

to the Department of Transportation over a 3-year time span (August 1967, June 1970 and September 1970 for Lots 1, 2 and 3 respectively). The exercise of contract options for equipment and services created funding problems and forced the acquisition of a number of systems to be delayed during the early months of the program. Five systems were transferred from Lot 1 to Lot 2 and five systems were transferred from Lot 2 to Lot 3 necessitating an increase in the cost estimate for Lots 2 and 3. The total estimated cost for the program was changed to $64.5 million in mid-1970 and has since remained at that level. Further reasons for this increase were described previously in the Program Cost Experience section of Chapter 2 (see p. 14). In our opinion the increase was the result of a change in concept (i.e., additional equipment requirements, system configuration changes, etc.) and was not indicative of poor cost estimating practices.

The $64.5 million estimate for the ARTS III program included the site preparation costs. FAA Regional Offices were responsible for site preparation work, including installation planning and preparation of cost estimates. We examined the site preparation cost data for 9 terminals where the ARTS III was either operational or had passed ORD. We found the average cost estimate for ARTS III installation of these terminals was approximately $69.2 thousand and the average cost to date was approximately $61.4 thousand. Projecting this average actual cost to the 64 locations involved indicates the total site preparation cost will be approximately $3.9 million. This amount, when added to the $60.9 million current value of the ARTS III contract results in an overall projected cost of $64.8 million for the ARTS III program.

Progress Measurement

The following prerequisites for an effective progress measurement system were evident in the ARTS III program: (1) The personnel involved understood what had been contracted for and what the end product was to accomplish. We were advised that the system was within the state-of-the-art and was relatively uncomplicated in comparison with some of the electronic systems being produced. (2) The system was such that it could be divided into various subsystems, components and pieces. A prime contractor and two subcontractors were involved with each being responsible for a particular subsystem. (3) A system was employed whereby actual work performed and problems encountered were made known to higher levels, i.e., subcontractors to prime contractor to the FAA Program Manager.

The contractor was required to submit an index of drawings and technical memoranda, contract financial reports, narrative progress reports and Program Evaluation and Review Technique reports on a monthly basis to the FAA. Formal program reviews were also held at the contractor's and subcontractor's plants and the FAA Headquarters on an unscheduled basis. Univac officials informed us that these program reviews were very beneficial in that they kept all parties aware of the status of the entire program. The Univac Program Manager was responsible for determining the degree of surveillance that Univac exercised over the subcontractors and for phasing the subcontract milestones in with those of the prime contract. The subcontractors provided monthly reports to Univac with sections pertaining to technical problems, program status, reliability status and financial status.

In addition to the contractor reports, the FAA received weekly reports

from their Quality and Reliability representatives at each of the contractor/subcontractor facilities.

Based on our discussions with FAA and contractor officials it seemed that the formal progress measurement reports were generally "after the fact" type reports submitted in compliance with the contract. It appeared that the really meaningful information was exchanged by telephone calls between the program managers.

CHAPTER 5

PROGRAM MANAGEMENT

As increasing emphasis was placed on automating the enroute system, a National Airspace System Program Office was established by the FAA in April 1966. The mission of the System Program Office was to manage the effort required to define, develop, acquire, test and turn over to the user, designated elements of the air traffic control automation program.

In late 1966, when it became apparent that automation of the terminal system was lagging, the Air Traffic Service and the Systems Research and Development Service began a joint exploratory project to develop a modular terminal automation system. By June 1967 a decision had been reached to provide alphanumeric capability at all FAA terminal radar approach control facilities and FAA-operated military radar approach control facilities. The directive announcing this decision assigned the primary responsibility for the major efforts to various offices and services of the FAA. Technical program management, preparation of engineering requirements, specifications, etc., in support of contractual actions and provision of applications engineering field guidance were assigned to the Systems Research and Development Service. Operational requirement, determination of priorities, and review of facility operational plans were assigned to the Air Traffic Service. System procurement was assigned to the System Program office.

During 1967 and 1968, the system documentation (specifications, system description, etc.) for the ARTS III was prepared within the Systems

Research and Development Service and in early 1968 a procurement plan for the ARTS III was prepared by an Advance Procurement Techniques Group. These actions culminated in the award of the ARTS III contract in February 1969.

We were advised that the late start of the terminal automation program (in comparison with the enroute automation program), the emphasis assigned to the program by FAA senior officials, the urgent need to automate the busier terminals, and the fact that a system program office was in existence were all factors leading to the assignment of the ARTS III program to the System Program Office in September 1969. We noted evidence of the high-level emphasis attached to the automation programs by the fact that coincident with this assignment, the System Program Office was placed under the executive direction of the Office of the Administrator. The System Program Office was responsible for providing a single unified management for coordinating the development, planning and acquisition of an air traffic control system capable of meeting the expanding needs of the aviation community. Two distinct divisions were established within the System Program Office--one for the enroute and one for the terminal system. In examining the position descriptions we found that the Chief, Terminal System Division was "...responsible for supervising the programming and management of the establishment and implementation of terminal automation systems and equipment and the development of in-service improvements to such systems and equipment from both the technical and planning standpoints." Therefore, for this report, we have considered the Chief, Terminal System Division as the Program Manager for the ARTS III program

and the Director of the National Airspace System Program Office as the Program Manager for the overall air traffic control automation program. Unless noted otherwise, further references to the Program Manager will refer to the Chief, Terminal System Division.

The ARTS III Program Manager

The Terminal System Division, headed by the Program Manager, was organized into three Branches--an Engineering Branch, a Deployment Branch, and an Integration and Test Branch--and at one time 26 people were assigned to the Division. The Program Manager advised us that this size staff was sufficient only because he had quick access to additional personnel resources outside the organization when the need arose.

In examining the degree of control held by the Program Manager, we found that he had primary responsibility for or played a part in designing the system, determining the type of contract, inserting key provisions in the contract (i.e. the options, testing requirements, etc.), determining the project milestones, proving out the system, advancing to the next stage of deployment or production, accepting the systems, changing the delivery schedule, recommending options to be exercised, determining quantities of items required, maintaining surveillance over contractors' and subcontractors' progress, etc. We were advised that with few exceptions, all ARTS III program decisions were made within the System Program purview and with the Program Manager having direct and daily access to the Director of that office, most decisions were made quickly. Certain decisions, such as the go-ahead notices for Lots 2 and 3 and the change

in certain locations that were to receive the ARTS III, required action outside their purview and some proved to be quite time consuming. At the time cognizance over the ARTS III program was transferred to the System Program Office, the contracting responsibility (for automation projects) was moved from that office to the FAA's Logistics Service. Therefore, neither the Program Manager nor the Director of the System Program Office had full control over the ARTS III contracting activities.

Additional Management Responsibilities

In addition to the Program Manager and the Director of the System Program Office, others involved in the management of the FAA's air traffic control automation program included the Chief of the System Program Field Office at each conterminious Air Route Traffic Control Center, the FAA Regional Offices, and the Terminal On-Site Representative. The latter was the key on-site representative for monitoring the preparation for, and installation, testing, and acceptance of the ARTS III system.

Program Management by the Contractors

We found that both Univac and Texas Instruments appointed Program Managers for the ARTS III program. (Our review did not include activities at the third contractor involved, Burroughs; therefore, their omission does not imply that they did not have a Program Manager.)

Comparison of FAA and Contractor Program Management Concept

In our discussions with FAA and Univac officials we found many similarities

in their views and their approach toward program management. For example:

--While neither made use of any formal methods to establish program office workload, they did establish the program management concept with a small staff, with the Program Manager having immediate access to specialists in various disciplines in other divisions of the organization.

--Neither had a formal operating plan at the beginning of the program. We found that 10 months after the program started the FAA did issue a System Program Plan which set forth management direction for the ARTS III program. We were advised that while this document was not crucial to good management, it did become a useful tool. At Univac we were advised that the program was managed to the contract, and that a formal plan is not crucial to good management.

--Both have had more than one Program Manager or Director. In the ARTS III program Univac has had three program managers. While the FAA has had only one Program Manager, they have had four System Program Office Directors. The key factor used by both the FAA and Univac in selecting their Directors and Program Managers appeared to be experience.

--In both cases the Program Manager was the final decisionmaker in many aspects of the program and reported to a high level in the organizational structure. At Univac, the Program Manager reported to the Vice President, Program and Product Management. The Program Manager at the FAA reported to the System Program Office Director, who initially reported directly to the Administrator.

This was changed in March 1970 when the System Program Office was placed under the Associate Administrator for Engineering and Development.

--We were advised by the Program Managers at both Univac and the FAA that they were able to devote a considerable amount of their time (90 percent and 80-85 percent respectively) to the essential management functions and were not burdened with excessive administrative and personnel matters.

While there were many similarities in the program management concept at Univac and the FAA, we were advised by the Univac Program Manager that program management techniques in industry differ from those in government. According to Univac, Government program managers deal in futures (budgeting, program planning and program changes), the present (technical problems, test problems, cost problems and current milestones), and overall results (schedule, cost and performance) in approximately that order of precedence; in contrast, industry program managers deal in present, results and futures in approximately that order of precedence. The measurements of a program manager's efficiency and effectiveness, according to Univac, are whether or not (1) the cost, schedule and performance milestones are being met; (2) the necessary communications are being satisfactorily achieved, and (3) the program is profitable.

Another dissimilarity we noted was in the timing of the establishment of the program management office. Univac appointed an ARTS III Program Manager upon receipt of the contract in February 1969; however, the FAA did not place the ARTS III program under the program office concept until September 1969. There was FAA program continuity, however, since many of the Systems Research and Development Service personnel involved in the early phases of the ARTS III program, became the nucleus of the ARTS III program office when it was placed under the System Program Office.

Success of Program Management

In our discussions with FAA officials we were advised that the ARTS III program received project office status for several reasons, one of which was the emphasis assigned to the program by top management. In our opinion, the program office approach employed by the FAA for the ARTS III program has had a considerable influence on the degree of success they have enjoyed in meeting their cost, schedule, and performance criteria established for this program. Univac officials lauded the merits of the FAA's System Program Office organization and informed us that the interface of that office with the Univac program management organization allowed for meaningful communication in that Univac was kept informed of the user's desires and always knew where to go if they had a problem on the ARTS III.

Abolishment of National Airspace System Program Office

By mid-1972, 50 of the 64 ARTS III systems had been delivered. With its enroute and ARTS III automation programs apparently near completion the FAA abolished the National Airspace System Program Office on July 26, 1972. The implementation functions of the office for the enroute and ARTS III program were transferred to the newly established Air Traffic Control Systems Division in the Systems Research and Development Service. While the system program office concept was abolished, we were informed that this management concept would continue to be applied until the enroute and ARTS III programs were completed. We learned that the FAA's plans for future programs are centered around functional management for the development and acquisition phases. The development work will be done in the Systems Research and Development Service and directed

by a program manager; however, his efforts will be limited to the development of a prototype. Program implementation will be done by the Airway Facilities Service, who will procure and install using the other functional agencies, i.e. procurement, regions, etc.

Follow-On Automation Programs

In examining The National Aviation System Policy Summary (prepared by the FAA) it appears that the automation efforts undertaken by the FAA in the enroute and ARTS III programs are merely the first of a number of programs. For example: (1) in the enroute system some of the areas being considered for a greater degree of automation are conflict detection and resolution, flow control and sequencing, and metering in high density areas; (2) the modular concept of the basic ARTS III provides for expansion to provide radar tracking for aircraft (whether or not they are equipped with transponders), multiple radar processing, flow control, metering and spacing, fail soft and fail safe, an all digital display, conflict prediction, etc.; (3) the ARTS II program will provide the basic automation system for lower density terminals not qualified for ARTS III systems. In addition, we found that the ARTS is intended for operational use in the 1972-80 time frame and that a contract was awarded to Unviac in 1970 for the development of radar tracking, multi-processing, multi-sensor tracking and conflict prediction/resolution. Thus, it appears that the automation efforts of the FAA are not near completion at this time.

CHAPTER 6

AGENCY REVIEW

A draft of this staff study was reviewed by FAA officials associated with the management of this program and comments were coordinated at the Headquarters level. The FAA's comments are incorporated as appropriate. As far as we know there are no residual differences in fact.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

There is a definite need for an effective air traffic control system. The ARTS III program appears to have been a highly successful (based on cost, schedule and performance criteria) stepping stone to such a system. We believe that the good working relationship between the acquiring agency and the contractor, and the rapport that developed between the various program managers, contributed immeasurably to the success of the program.

The ARTS III systems have been delivered close to schedule with most of the major delays experienced being attributed to site preparation problems. The ARTS III equipment has been operationally successful and has met with enthusiastic acceptance on the part of the user, once the user has become familiar with its operations and uses. The efforts exerted by FAA personnel to keep the ARTS III program within the $64.5 million cost estimate are commendable.

The decision to appoint a program manager for the ARTS III program was based on similar criteria as that used by the military, i.e., large resources needed and long delivery schedule. The program manager's responsibilities were also quite similar to those of the military in that he must meet cost estimates and performance and schedule requirements. His staffing was similar to that of Navy program managers, in that, he had a small staff assigned but could draw on the permanent functional organizations for support when necessary. In this regard the program manager was able to direct most of his time to the accomplishments of the ARTS III program rather than to administrative detail.

Placement of the program manager in the organizational structure differed from that found in the military. There were few managerial layers between the program manager and the Administrator.

The strong point noted in the FAA program management concept was the wide latitude given the program manager to insure a successful program. The one weak point noted was that neither the program manager nor the Director of the System Program Office had direct control over the ARTS III contractual efforts.

Based on the present volume of air traffic and the projected rate of increase, we believe that additional automation efforts, similar to those contained in the National Aviation System Policy Summary, will be forthcoming, and, that centralized management (such as that formerly exercised under the National Airspace System Program Office Concept) may be desirable for such a program, rather than the functional approach now planned.

ARTS III MAJOR MILESTONES

(Expressed as number of months after contract award--Feb. 20, 1969--
that an event was scheduled to occur or actually occurred)

	DELIVERY			IOC			ORD	
System Number	Original Contract	After Mod.	Actual	Original Contract	After Mod.	Actual	Scheduled(a)	Actual
1	16	20	22	21	23	24	24	24
2	18	22	22	23	27	28	32	31
3	20	24	28	25	29	31	37	38
4	21	25	29	26	30	31	37	38
5	22	26	30	27	31	31	38	39
6	23	26	31	28	31	32	37	38
7	24	27	28	29	32	31	37	34
8	24	27	30	29	32	31	36	38
9	25	28	30	30	33	32	37	36
10	25	28	30	30	33	33	37	38
11[b]	26	29	24	30	--[b]	--[b]	--[b]	--[b]
12[b]	26	29	31	--[b]	33	33	37	37
13	27	29	31	31	33	33	37	38
14	27	29	31	31	33	33	37	37
15	28	30	32	32	34	34	38	38
16[c]	28	30	31	32	34	34	--[c]	--[c]
17	29	30	32	33	34	35	38	43
18	29	31	32	33	35	36	39	39
19	29	31	33	33	35	35	39	39

20	30	31	33	34	35	36	39	41
21	30	32	33	34	36	35	40	40
22	30	32	34	34	36	36	40-49	--
23	31	32	34	35	36	36	40	41
24	31	33	34	35	36	37	40	41
25	31	33	35	35	36	37	40	40
26	32	34	35	36	37	37	41	41
27	32	34	35	36	37	37	41	42
28	32	35	35	36	38	37	42	41
29	33	35	36	36	38	38	42	41
30	33	35	36	36	38	38	42	42
31	33	36	36	36	39	40	43	44
32	34	36	37	37	39	38	43	43
33	34	36	37	37	39	40	43	45
34	34	37	37	37	40	39	44	41
35	35	37	38	38	40	39	44	43
36	35	37	38	38	40	40	44	43
37	35	37	38	38	40	40	44	44
38	36	38	38	39	41	40	45	44
39	36	38	39	39	41	41	45	43
40	36	38	39	39	41	41	45	45
41	37	38	39	40	41	40	45	44
42	37	39	44	40	42	45	46-49	--
43	37	39	40	40	42	41	46	45
44	37	39	40	40	42	42	46	46

45	38	39	40	41	42	42	46	48
46	38	40	40	41	43	42	47	47
47	38	40	40	41	43	41	47	46
48	39	40	41	42	43	43	47	47
49	39	40	41	42	43	43	47	47
50	39	41	41	42	44	44	48	47
51	40	41	41	43	44	43	48	45
52	40	41	41	43	44	44	48	47
53	40	41	45	43	44-48	--	48-51	--
54	41	42	42	44	45	45	49-49	--
55	41	42	44	44	45	47	49-49	--
56	41	42	44	44	45	46	49-50	--
57[d]	42	43	44	45	46-51	--	49-54	--
58	42	43	45	45	46	46	50-50	--
59	42	44	46	45	47	47	50-50	--
60	43	44	47	46	47-47	--	50-50	--
61	43	44-48	--	46	47-57	--	50-58	--
62[d]	43	45	47	46	48-51	--	51-52	--
63	44	45	46	47	48-48	--	51-51	--
64[d]	44	45	47	47	48-52	--	51-57	--

a--Based on FAA Official Schedules RD-1800.9 Chg. 1, 1 February 1973.

b--System 12 in the original contract (changed to system 11 in modification 11) is a research and development system located at the National Aviation Facilities Experimental Center and is used for ARTS III enhancement work. This system did not have an IOC or ORD.

c--System 16, also located at the National Aviation Facilities Experimental Center, is a system support facility which supports ongoing field systems (hardware and software). This system did not have an ORD.

d--This system was in storage as of February 1, 1973.

ARTS III SYSTEM – BASIC OPERATION