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AUTOMATION APPLICATIONS IN AN ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

Volume IVB: Automation Requirements (Concluded)

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FINAL REPORT

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PREFACE

This is the second of two books which together contain the automation requirements of the Advanced Air Traffic Management System (AATMS) program.

The first book (Volume IVA) includes Sections 1.0 through 4.3; the present book (Volume IVB) contains Sections 5.0 through Appendix C and References.

The Table of Contents, List of Illustrations and the List of Tables for this book follows.

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5.0 FAILURE MODE REQUIREMENTS

The manpower and data processing requirements derived thus far have pertained to system operation in a normal state. In this chapter, attention is turned to the question of system failure and the requirements to carry on operation in a degraded state. Two aspects of failure mode operation are examined: (1) the effects on safety and capacity-efficiency produced by functional component failures and (2) the methods by which the system can muster resources to overcome or compensate for failures. Here, as throughout the study, the delineation of failure mode requirements is presented in generic functional terms, yet at a level of detail which provides a distinct picture of the system design goals to be met.

5.1 OBJECTIVES

In its traditional form, failure mode analysis is an exercise carried out during subsystem and component design. The raw material consists of design detail of the equipment itself and estimated (or empirically derived) reliability data which indicate the probability of specific malfunctions and the likely course of their consequences. This kind of information lies far downsteam from the present state of AATMS. There are, as yet, no specific subsystem designs and none but the most speculative estimates of reliability. In fact, there is nothing upon which to base a failure mode analysis of the sort customarily performed by systems engineers.

Nevertheless, it is possible to deal with the question of functional failure and to set forth requirements for degraded-state operation in generic terms. This involves two assumptions about the nature of failure. First, the failure of a system resource, whatever the equipment characteristics of that resource might be, produces a loss of functional capability. Thus, it is possible to define failure not in terms of how something has malfunctioned but in terms of what specific system capability has been lost. Just as system operation can be described by its outputs, system failure can be described as the absence of those outputs. The second assumption derives from the first. If the system is considered to consist of functional entities (defined at any appropriate level of detail), then each entity, or functional component, can be said to be the locus of some activity necessary for system operation. In effect, each functional component (function, subfunction, or task) constitutes the equivalent of an equipment module, and it is possible to speak of failure of a functional component in much the same way as one would speak of module malfunction.

Accepting these two assumptions permits failure analysis to be carried out generically, with each loss of output traceable to a specific functional component. Diagrams of system functions and information flow can be regarded as analogous to engineering drawings and wiring diagrams in the world of equipment. Modular elements of the system (i.e., subfunctions or tasks) can be subjected to failure singly or in combination and the loss of outputs can be followed along the paths of information flow to determine the effect on system operation and, ultimately, on service to airspace users. This technique can be extended further to identify ways in which the system can be made more resistant to failure by means of alternate functional units, parallel lines of information flow, or redundant functional capability.

The failure mode analysis performed in this study was based on this rationale. The objectives were:

1. To determine the effects of functional component failure, measured in terms of loss of service to airspace users;
2. To identify remedial strategies which could be employed in system design to ameliorate the effects of failure;
3. To evaluate the degree to which these remedial features could serve to restore the system to its original operating state.

To put it another way, the failure mode analysis was addressed to answering, in generic functional terms, three questions. What are the consequences of functional component failure? What can be done to overcome or compensate for these failures? Will these measures return the system to its normal level of safety and capacity-efficiency?

5.2 METHOD

The method used for failure mode analysis took as its point of departure the function analysis performed in Phases A and B of the study, where the system had been described at three progressively greater levels of detail (function, subfunction, and task). It was assumed that the eventual of design of data processors would be modular in nature and that modules would most closely correspond to subfunctions. The implication was that, when failure occurred, it would be within a subfunctional module and this would be manifested as a loss of output. It was further assumed that failure of one subfunctional module would not directly produce failure in others. This was analogous to designing equipment in such a way that subsystems are compartmentalized and protectively isolated to avoid cascading malfunctions. Thus, failure of one module (subfunction) would not induce loss of functional capability in others, although they would, of course, be affected by the loss of inputs normally received from the failed module.

This chain of failure effects (loss of output leading to loss of input) could ultimately be traced through the paths of information flow until it resulted in the inability to provide some service to users of the airspace. The effect of a failure was thus defined not by its proximate consequences but by its eventual impact on service. Because services had been ranked in terms of their importance for the safety and capacity-efficiency of the system (see Chapter 2, page 2.1-5), it was possible to establish the criticality of the effect of subfunctional module failure. By this method the specific effects of failure could be identified and assessed. Application of the method to each of the applicable 57 AATMS subfunctions fulfilled the first objective of failure analysis. That is, what are the consequences of functional component failure? The results of this analysis are presented in Section 5.3 below.

The next step beyond identification and assessment of failure effects was to devise appropriate strategies to restore the capability of the system. A total of seven types of remedial action were defined, including full functional redundancy, manual back-up, and various methods for drawing on internal reserves of computer capability. Along with the strategies, criteria for their adoption were specified and a logical sequence for considering them was developed. This allowed the optimum remedial strategy to be identified for each failure. When considered collectively, the strategies also served to indicate a scheme of requirements for failure mode operation to be recommended for incorporation in system design.

The development of strategies for response to failure involved an additional assumption about the nature of failure in the system. Thus, in addition to identifying that an output had been lost and isolating the failure to a subfunctional component, it was also necessary to establish in a general way what was the cause of failure. It was postulated that a subfunction could fail to produce an output for one of three basic reasons:

1. Failure of an automated resource to perform a task or tasks within the subfunction (including both complete loss of output and out-of-tolerance outputs);

2. Human failure or error in performance of manual tasks within the subfunction;

3. Breakdown in the lines of communication between the subfunction and others depending on it for inputs.

Only the first of these three causes was considered in the failure analysis. That is, failure was defined to be an event occurring only in the machine portion of the system. It was recognized, of course, that human error could result in loss of output. However, the nature of human-induced failure depends heavily on the kind of equipment the man has to work with. Since the details of the man-machine interface are as yet undefined, it was felt that there was no meaningful way to treat human error in the failure analysis. Breakdown of communication links was likewise excluded from consideration. It was assumed that the system would be designed with sufficient redundancy in the lines of communication for there to be alternate paths of information flow available if any given link were severed.

After identification of the appropriate strategies to cope with failure, the final step in the analysis was to assess the effectiveness of each response for restoring a normal operating state. This involved a reexamination of safety and capacity/efficiency effects, this time in light of how machine resources had been reconfigured and reassigned to deal with the original failure. To this end, three levels of recovery were defined, each describing the state of the system after remedial measures had been taken in response to failure. They were:

> Fail-Operational - The system is able to continue operation with no loss of safety and no loss of capacity/efficiency for a finite time interval (at) after the occurrence of a failure, i.e., the system has been restored to its normal operating state. (The time interval is not a constant value due to the fact that is is related to the dependent system criticality associated with various subsystems). Within a specified Δt, the achieved levels of safety and capacity that existed at the time of failure(s) are maintained.
>
> Fail-Soft - The system has suffered some loss of capacity and efficiency, but no loss of safety, i.e., capacity and efficiency have been sacrificed to maintain the normal level of safety.
>
> Fail-Hard - The system has lost capacity and efficiency, perhaps beyond that of the Fail-Soft level, but it has also lost safety. This is not to say that the system is unsafe, just not as safe as it normally is. The system is weak because both safety and capacity-efficiency have had to be sacrificed in order to continue operation.

Some explanation must be provided for the terms used above to describe the state of the system after the occurrence of a failure. It is realized that the three (3) terms used here may be somewhat incongrous to each other. The words fail-soft and fail-hard tend to imply the manner in which the system responds to a failure, whereas fail-operational is more in the nature of what condition the system is in after the failure. This minor deficiency might have been alleviated by creating new terms, however, there already exists a large set of terminology on this subject and it was decided to use existing words with an implicit explanation given as to their meaning and usage in this report. Again, the intent here is to utilize the terms in order to connote varying degrees or levels of degradation as a consequence of a functional failure and after corrective measures have been taken.

Secondly, a term that has been used quite frequently with various meanings in failure modes is "fail-safe". This expression was deliberately not used above since the overall protective design philosophy for AATMS is called fail-safe. It is noted that the nomenclature of fail-safe does not refer to a specific state of the system but rather to a design goal, characteristic, or capability of the system.

The results of the analysis of remedial strategies and assessment of their effectiveness are presented in Section 5.4. Together, the constitute fulfillment of the remaining two objectives of failure analysis: identification of remedial actions in response to failure and estimation of their restorative effect.

5.3 FAILURE EFFECTS

The ultimate consequence of failure of a functional component is the loss or restriction of service to users of the system. The relationship of functions to services was established in Phase B of the study and discussed earlier in Section 2.2 of this volume. This relationship was characterized in terms of information, decisions, and actions as follows:

I - A function produces information outputs needed to provide a service.

D - A function produces decisions directly associated with a service.

A - A function produces actions by which a service is directly implemented.

For the purpose of failure effects analysis, which treated failure at the level of subfunctional components or modules, it was necessary to expand the Phase B service-function matrix to identify the particular contribution made by each subfunction. This made it possible to specify in a systematic way the consequences of subfunction failure as the loss of information, decisions, or actions related to a given service.

Table 5.3-1 shows the I-D-A relationships of subfunctions to services. The subfunctions have been grouped by the operator position to which they have been assigned as a responsibility. The table also indicates those subfunctions which are entirely manual, i.e., all tasks within the subfunction are assigned to man at the recommended level of automation. These subfunctions were subsequently factored out of the failure analysis since, by definition, only machine failures were to be considered.

After tracing subfunction-service relationships, the next step was to establish the criticality of the effect on services produced by failure of each subfunction. It will be recalled that services had been grouped into three categories in relation to safety and capacity-efficiency:

<u>Safety-Related Services</u> - Separation Assurance, Spacing Control, Navigation, Emergency Assistance

<u>Capacity/Efficiency-Related Services</u> - Flight Plan Conformance, Flight Advisory, Flow Control, Flight Planning Information

TABLE 5.3-1 RELATIONSHIP OF SUBFUNCTIONS TO SERVICES

POSITION IA: DATA BASE OFFICER

(Functions 14, 17)

		SERVICES									
		SEPARATION ASSURANCE	SPACING CONTROL	AIRBORNE, LANDING & GROUND NAVIGATION	EMERGENCY SERVICES	FLIGHT PLAN CONFORMANCE	FLIGHT ADVISORY SERVICES	AIRPORT/AIRSPACE USE PLANNING	INFORMATION SERVICES	ANCILLARY SERVICES	RECORD SERVICES
14.1	Prepare Operational Reports										IDA
14.2	Compile and Store System Records										IDA
14.3	Prepare and Maintain Statistical and Special Reports										DA
17.1	Determine Current and Forecast Weather		I		I	I	I	I	I		I
17.2	Update Rules and Procedure Information	I	I			I	I	I	I	I	I
17.3	Update Airspace Structure and Jurisdictional Boundary Information					I		I	I		I
17.4	Update Route Information					I	I	I	I		I
17.5	Update Airspace Restriction Information					I	I	I	I	I	I
17.6	Update Hazards to Flight Information	I	I			I	I	I	I	I	I
17.7	Determine Capability and Status of COMM-NAV System			I	I	I	I	I	I		I
17.8	Determine Capability and Status of Ground Facilities		I		I	I	I	I	I	I	I
17.9	Maintain User Class Information	I	I		I	I	I		I		I
17.10	Compile Traffic Summaries							I			I
17.11	Prepare Preformatted Data Modules						I		I		I

TABLE 5.3-1 RELATIONSHIP OF SUBFUNCTIONS TO SERVICES (Cont'd)

SERVICES

	POSITION IB: FLIGHT INFORMATION SERVICES OFFICER (Functions 1, 12)	SEPARATION ASSURANCE	SPACING CONTROL	AIRBORNE, LANDING & GROUND NAVIGATION	EMERGENCY SERVICES	FLIGHT PLAN CONFORMANCE	FLIGHT ADVISORY SERVICES	AIRPORT/AIRSPACE USE PLANNING	INFORMATION SERVICES	ANCILLARY SERVICES	RECORD SERVICES
1.1	Receive Requests for Flight Planning Information								I		
1.2	Select Information to Service the Request								D		
1.3	Format and Display the Requested Information								A		I
12.1	Service Request for Information				I		IDA				I
12.2	Issue Flight Advisories and Instructions				I		IDA				I
12.3	Notify Pilot of Imminent Encounter with Hazardous Weather Phenomena				I		IDA				I

POSITION IIA: FLIGHT PLANS

(Functions 4, 15)

		SEPARATION ASSURANCE	SPACING CONTROL	AIRBORNE, LANDING & GROUND NAVIGATION	EMERGENCY SERVICES	FLIGHT PLAN CONFORMANCE	FLIGHT ADVISORY SERVICES	AIRPORT/AIRSPACE USE PLANNING	INFORMATION SERVICES	ANCILLARY SERVICES	RECORD SERVICES
4.1	Develop Time-Position Profile		I			I		I			I
4.2	Review Flight Plan					ID		ID		I	
4.3	Propose Modified Flight Plan					IDA	I		I		
4.4	Determine Responsibility for Control and Communication				(ENTIRELY MANUAL)						
15.1	Determine Nature of Service Required				(ENTIRELY MANUAL)						
15.2	Initiate Action to Provide Service				(ENTIRELY MANUAL)						

TABLE 5.3-1 RELATIONSHIP OF SUBFUNCTIONS TO SERVICES (Cont'd)

SERVICES

	POSITION IIB: FLOW CONTROL (Function 2)	SEPARATION ASSURANCE	SPACING CONTROL	AIRBORNE, LANDING & GROUND NAVIGATION	EMERGENCY SERVICES	FLIGHT PLAN CONFORMANCE	FLIGHT ADVISORY SERVICES	AIRPORT/AIRSPACE USE PLANNING	INFORMATION SERVICES	ANCILLARY SERVICES	RECORD SERVICES
2.1	Determine System Capacity				(ENTIRELY MANUAL)						
2.2	Determine System Demand		I					ID			
2.3	Determine and Resolve Capacity Overload Situations		I			I		DA			

POSITION III: FLIGHT SURVEILLANCE AND CONTROL

(Functions 5,6,7,8,9*,11,13, and 16)

*Function 9 for Terminals only

		SEPARATION ASSURANCE	SPACING CONTROL	AIRBORNE, LANDING & GROUND NAVIGATION	EMERGENCY SERVICES	FLIGHT PLAN CONFORMANCE	FLIGHT ADVISORY SERVICES	AIRPORT/AIRSPACE USE PLANNING	INFORMATION SERVICES	ANCILLARY SERVICES	RECORD SERVICES
5.1	Check Clearance Status		ID			ID					
5.2	Determine Clearance to be Issued		D			D					
5.3	Compile and Issue Clearance		A			A					I
6.1	Determine Present Position	I	I		I	I	I				
6.2	Compile Aircraft Time-Position Profile	I	I		I	I					I
6.3	Predict Future Positions/ETA's of Aircraft	I	I		I	I	I	I		I	
6.4	Determine Aircraft Capability and Status	I	I		ID	I				I	I
7.1	Detect Long-Term Conflicts Among Flight Plans		I			ID		I			I
7.2	Determine Current Deviations from Flight Plan	I	I			ID		I			I
7.3	Predict Deviations from Flight Plan	I	I			ID					

TABLE 5.3-1 RELATIONSHIP OF SUBFUNCTIONS TO SERVICES (Cont'd)

	POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Continued)	SERVICES: SEPARATION ASSURANCE	SPACING CONTROL	AIRBORNE, LANDING & GROUND NAVIGATION	EMERGENCY SERVICES	FLIGHT PLAN CONFORMANCE	FLIGHT ADVISORY SERVICES	AIRPORT/AIRSPACE USE PLANNING	INFORMATION SERVICES	ANCILLARY SERVICES	RECORD SERVICES
7.4	Determine Appropriate Resolution of Deviations	I	I			DA					I
8.1	Predict Conflicts	ID	I			I					I
8.2	Resolve Conflicts	DA	I			I					I
9.1	Maintain Predicted Arrival/ Departure Schedule for Each Airport		I					I			
9.2	Determine Requirement for Spacing Control		ID								
9.3	Establish Runway Configuration Schedule		IDA								
9.4	Determine Most Efficient Arrival/Departure Sequence/ Schedule for Runway		IDA								
9.5	Initiate Implementation of Sequence/Schedule		DA			I		I			
11.1	Initiate/Terminate Guidance	ID	ID		ID	ID					
11.2	Compute Vector Requirements	I	I		I	I					
11.3	Compute Air Vector	I	I		I	I					
11.4	Compute Guidance Commands	DA	DA		DA	DA					
11.5	Compile and Transmit Guidance Instructions	A	A		A	A					I
13.1	Determine Handoff Responsibility Requirements	ID	ID			ID					
13.2	Determine Communication Channel Assignment	ID	ID			ID					
13.3	Effect Transfer of Responsibility	A	A			A					I
16.1	Describe Emergency Situation				(ENTIRELY MANUAL)						
16.2	Determine Required Response				(ENTIRELY MANUAL)						

Supporting Services - Ancillary and Special, Record-keeping

This ranking of services was combined with the concept of function-service relationships (information, decision, action) to produce a hierarchy of failure criticality, with five levels or classes, shown below in the order of most to least severe.

Class 1 - The subfunction produces decisions or actions related to any of the four safety-related services.

Class 2 - The subfunction produces information for two or more safety-related services.

Class 3 - The subfunction produces decisions or actions related to any of the four capacity/efficiency-related services.

Class 4 - The subfunction produces information for one safety-related service or two or more capacity-efficiency-related services.

Class 5 - The subfunction produces information, decisions, or actions only for supporting services or for one capacity/efficiency-related service.

Table 5.3-2 is a schematic representation of the system of classification for criticality of failure effects.

TABLE 5.3-2 CLASSIFICATION OF FAILURE CRITICALITY

	SERVICES		
	SAFETY	CAPACITY/ EFFICIENCY	SUPPORTING
SUBFUNCTION OUTPUTS	FAILURE CLASS		
Decisions or Actions	1	3	5
Information for two or more services	2	4	5
Information for one service	3	5	5

Table 5.3-3 on the following two pages presents a list of subfunctions according to failure class. Basically, this table is a condensation of the subfunction-service matrix given earlier (starting on page 5.3-2), with the ten individual services reduced to three major service categories and the subfunctions identified by code number only. However, Table 5.3-3 does preserve an indication of the number of services in each category receiving information outputs from each subfunction. This was done to assist the reader in understanding the assignment of subfunctions to failure classes, i.e., to clarify the basis for assigning subfunctions to classes 2, 4 and 5.

Table 5.3-3 is to be interpreted as identification of the specific service-related effects which would be produced by individual subfunction failure. The failure class assignment for each subfunction serves to indicate how critical it is for the operation of the system and, hence, to describe the consequence of subfunction failure. Table 5.3-3 also shows the relative importance of subfunctional failure within and between operator positions. For example, Position IA (Data Base) performs subfunctions whose criticality ranges from Class 2 to Class 5. By contrast, Position III (Flight Surveillance and Control) ranges from Class 1 to Class 3, but -- more important -- it includes all the subfunctions of Failure Class 1 and a large proportion of the Class 2 subfunctions. Thus, in terms of the safety of system operation, Position III has a much more critical role than Position IA.

A more consolidated view of the distribution of failure criticality across positions and subfunctions is provided in Table 5.3-4. For each position, the table lists the number of assigned subfunctions according to their failure criticality class. (The figures in parenthesis below the principal entry indicate the respective number of automated and semi-automated subfunction.) Manual subfunctions are tabulated separately since they are not relevant to the failure analysis. It can be seen that of the 51 subfunctions containing automated tasks, 30 are placed in the safety-related failure classes (1 and 2), and 16 are in the capacity/efficiency-related classes (3 and 4). It can be seen again that, as a whole, Position III (Flight Surveillance and Control) has the most crucial role with

TABLE 5.3-3 SUBFUNCTION FAILURE CRITICALITY

POSITION		SUBFUNCTIONS	SERVICE RELATIONSHIP			FAILURE CLASS
			SAFETY	CAP./EFF.	SUPPORT	
POSITION	IA DATA BASE	14.1			IDA	5
		14.2			IDA	5
		14.3			DA	5
		17.1	II	IIII	I	2
		17.2	II	IIII	II	2
		17.3		III	I	4
		17.4		IIII	I	4
		17.5		IIII	II	4
		17.6	II	IIII	II	2
		17.7	II	IIII	I	2
		17.8	II	IIII	II	2
		17.9	III	III	I	2
		17.10		I	I	5
		17.11		II	I	4
	IB FLT. INFO. SERVICES	1.1		I		5
		1.2		D		3
		1.3		A	I	3
		12.1	I	IDA	I	3
		12.2	I	IDA	I	3
		12.3	I	IDA	I	3
	IIA FLIGHT PLANS	4.1	I	II	I	3
		4.2		IID	I	3
		4.3		IIIDA		3
		4.4	ENTIRELY MANUAL			NA
		15.1	ENTIRELY MANUAL			NA
		15.2	ENTIRELY MANUAL			NA
	IIB FLOW CONT.	2.1	ENTIRELY MANUAL			NA
		2.2	I	ID		3
		2.3	I	IDA		3

NA = NOT APPLICABLE

TABLE 5.3-3 SUBFUNCTION FAILURE CRITICALITY (Cont'd)

	SUBFUNCTIONS	SERVICE RELATIONSHIP			FAILURE CLASS
		SAFETY	CAP./EFF.	SUPPORT	
POSITION III FLIGHT SURVEILLANCE AND CONTROL	5.1	ID	ID		1
	5.2	D	D		1
	5.3	A	A	I	1
	6.1	III	II		2
	6.2	III	I	I	2
	6.3	III	III	I	2
	6.4	IIID	I	II	1
	7.1	I	IID	I	3
	7.2	II	IID	I	2
	7.3	II	ID		2
	7.4	II	DA	I	2
	8.1	IID	I	I	1
	8.2	IDA	I	I	1
	9.1	I	I		3
	9.2	ID			1
	9.3	IDA			1
	9.4	IDA			1
	9.5	DA	II		1
	11.1	IIID	ID		1
	11.2	III	I		2
	11.3	III	I		2
	11.4	DA	DA		1
	11.5	A	A	I	1
	13.1	IID	ID		1
	13.2	IID	ID		1
	13.3	A	A	I	1
	16.1	ENTIRELY MANUAL			NA
	16.2	ENTIRELY MANUAL			NA

NA = NOT APPLICABLE

respect to safety. This position has a concentration of 24 of the 30 safety-related failure possibilities. By contrast, the possible capacity/efficiency-related failures are spread rather evenly across all positions.

TABLE 5.3-4 FAILURE CRITICALITY OF SUBFUNCTIONS BY POSITION

POSITION	ASSIGNED SUBFUNCTIONS						
	AUTOMATED OR SEMI-AUTOMATED						ENTIRELY MANUAL
	FAILURE CLASS					TOTAL BY POSITION	
	1	2	3	4	5		
IA Data Base	0	6 (4/2)*	0	4 (4/0)	4 (2/2)	14 (10/4)	0
IB Flight Info.	0	0	5 (1/4)	0	1 (0/1)	6 (1/5)	0
IIA Flight Plans	0	0	3 (0/3)	0	0	3 (0/3)	3
IIB Flow Control	0	0	2 (2/0)	0	0	2 (2/0)	1
III Flight Surveil. and Control	16 (12/4)	8 (6/2)	2 (1/1)	0	0	26 (19/7)	2
TOTAL BY FAILURE CLASS	16	14	12	4	5	51	6 / 57

*Figures in parenthesis indicate, respectively, the number of automated and semi-automated subfunctions.

5.4 FAILURE MODE RESOURCE REQUIREMENTS

The detailed definition of failure effects, ranked in terms of their criticality for the safety and capacity-efficiency of the system, constituted fulfillment of the first of the three objectives of the failure analysis performed in this study. Failure effects also served as the point of departure for examination of man-machine requirements in failure modes, where the remaining two objectives were met.

Failure mode resource requirements are contained in the answers to two questions. First, what is the response required of man and machine resources to cope with functional component failure? This entails specification of the ways in which man and machine resources can be recombined and reallocated to overcome or compensate for failure and restore system services. Second, how successful will this response be? This involves assessment of the level of service which will result from application of remedial and restorative measures. In some cases the system will be able to reconfigure or to draw on available reserves and thereby return to an essentially normal state, with a full complement of services. In other cases, however, it will not, and some degradation of services will occur. Taken together, the answers to these questions indicate (1) the amount and kind of resources required to make the system resistant to failure effects, (2) the required flexibility in resource configuration and deployment, and (3) the level of service which can be maintained in the face of functional component failure. These three kinds of statements can be taken as requirements in the sense that they are theoretical expressions of what the system must be able to do; and, hence, they represent goals to be attained in the system engineering and development process.

The treatment of failure mode resource requirements is carried out at two levels. First is a detailed statement of requirements in the event of individual subfunction failure within an operator position. These can be called localized failures, and they will probably be the most common. At the second level is a treatment of the more massive form of failure in which operational capability is lost within an entire facility or some major block of a facility. While considerably less common, these failures pose such potentially grave consequences for the system that they must be accounted for in the system design requirements.

5.4.1 Machine Resources

Before proceeding with the analysis of failure mode requirements, it is first necessary to establish in more detail the characteristics of the man-machine resource team available at the various system facilities. Operator positions, it will be recalled, were defined in terms of functional responsibilities. Each position can therefore be described by a set of tasks, some assigned to man and the remainder to machines. Thus, the basic unit of resources at any position or facility in the system is made up of a human operator, a data processor, and an input-output device which permits the two to interact in carrying out their respective tasks.

The required number and type of operators at each facility were established in the course of developing system manning requirements (Chapter 3). The pattern of manning was derived from computation of the man-hours needed to perform the manual tasks at each position for a postulated level of demand. This same series of computations also developed a system-wide estimate of the data processing requirements for automated tasks and for the induced tasks of display generation and control input processing. The machine resource requirements were not at that time differentiated and distributed across facilities. It will be necessary to do so now in order to complete the picture of the man and machine resource capabilities in each part of the system.

The basic data for each automated generic task and for each induced display and control task consisted of estimates of the frequency of performance and the number of machine instructions required. Combining these estimates by the method described in Chapter 3 resulted in an expression of machine resource requirements to accomplish each function or task component thereof for all aircraft using the system. Since the basic computation was a product of instructions times frequency, the unit of machine capability was a rate, instructions per second. Further, because the instruction handling rate was broken down on a function by function basis, it was possible to associate data processing requirements with positions, which were also defined in functional terms. Thus, the overall data processing rate for the machine assigned to each position could be established. This, in turn, could be further refined by one more series of calculations in order to reach a statement of machine capacity required to support each operator at each position of each facility.

This last calculation proceeded as follows:

1. Sum the instruction rates for each automated task in all functions in each position.
2. Sum the instruction rates for each induced control and display task in all functions in each position.
3. Sum (1) and (2) to obtain total instruction rate for each position system-wide.
4. For Position III only, divide (3) into shares proportionate to the part of the total demand handled by each type of facility (en route, primary terminal, manned secondary terminal, transition hub center).
5. For Position III divide (4) and for other positions divide (3) by the number of facilities of the appropriate type to obtain the instruction rate per facility.
6. Divide (5) by the number of operators of the appropriate type at each facility to obtain the instruction rate for the data processor associated with each operator.

This chain of calculations produced a statement of the data processing required to support each operator in the system. These requirements ranged from a low of 353 instructions per second for an operator in Position IB (Flight Information Services) to slightly over 36,000 instructions per second for Position III (Flight Surveillance and Control) in an en route sector.

Because of the great disparity among the data processing requirements for the various positions, it was necessary to postulate a more nearly uniform capacity (processing rate) for the computers to be assigned to each man-machine resource unit at each position. Therefore, it was assumed that the basic machine module would have a capacity of 7200 instructions per second (ips). In effect, this meant that operator positions with data processing requirements smaller than 7200 ips would share a computer resource within their facility.

A computer with a rate of 7200 ips is, of course, very small. Therefore, the term machine module should not be taken as a synonym for computer. The basic 7200 ips module represents only a fraction of the total capacity of a computer, even by today's standards. Thus, the module stands not as an expression of computer capacity, but a unit of computer allocation. It is the building block for the automated portion of the system, just as operators are the building blocks for the manned position.*

At each facility, 7200 ips modules were assigned in sufficient number to accomplish all the machine tasks, and integral numbers of operators were assigned as needed to carry out man tasks. Thus, the basic man-machine resource unit at each position and facility was assumed to be an operator and a 7200 ips machine module, the latter including the input-output device needed for display generation and input instruction processing. Where positions had small data processing requirements (i.e., less than 7200 ips), operators were assumed to share a machine module. Where the data processing requirements of the position exceeded 7200 ips, the appropriate number of extra modules were assigned.

Since the basic purpose of this exercise was to further the investigation of failure mode requirements, the assignment of modules to positions and facilities not only took into account normal operations but also made allowance of a certain reserve for anticipated failures. This allowance was made in two ways: reserve capacity within modules, and provision of spare modules. In doing so, it was assumed that the module would have an appropriate multi-mode processing capability such that reserves and spares could undertake any task necessary provided they had the available data processing rate to handle the assignment.

Table 5.4-1 describes the allocation of data processing modules to positions and facilities. Reading from left to right, the table shows by position and site the number of modules required for normal operations. The next column indicates the spares allotted for failure situations. This is followed by the total modules allocated per site and then for the whole system. The last four columns indicate the manner in which modules are allotted to serve normal and failure mode needs, showing respectively the

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*The aggregation of modules into computers of appropriate capacity and the assignment of computers to facilities are left as open questions at this point. They are matters of computer sizing and computer architecture which lie outside of the scope of the present discussion. See, however, Chapter 7 of this report.

TABLE 5.4-1 DATA PROCESSING MODULE REQUIREMENTS BY POSITION AND FACILITY

POSITION	MACHINE MODULES REQUIRED[1]					NO. MEN SERVED BY EACH PROCESSOR	CAPACITY (IPS) REQUIRED BY EACH MAN	EXCESS PER MODULE	TOTAL IPS EXCESS PER SITE 3
	SITE	NO.[2]	SPARES	TOTAL PER SITE	TOTAL FOR SYSTEM				
IA DATA BASE	CCC	91	9	100	100	1	7,231	-	64,800
IB FLIGHT INFORMATION	THC	2	0	2	40	17	353	1,200	2,400
IIA FLIGHT PLANS	THC	7	1	8	160	12	575	-	7,200
IIB FLOW CONTROL	CCC	5	0	5	5	5	1,281	800	5,300[6]
III FLIGHT SURVEILLANCE AND CONTROL	RCC	1000	10	1010	2020	.2[4]	35,049	190	250,000
	PRI.TERM.	4	0	4	532	1	6,725	425	1,900
	SEC.TERM.	1	0	1	359	2	3,046	1,100	1,100
	THC	10	0	10	200	.9[5]	7,812	-	1,700

1. Each module has a processing rate of 7,200 ips.
2. Number required for normal operations per site.
3. Includes excess for all modules and capacity of spares.
4. Each operator requires 5 7,200 ips modules for normal operations.
5. Each of the 9 operators requires more capacity than that available in a single module. Therefore, each operator must share part of the tenth module.
6. Includes 4,000 excess (5 modules x 800 excess each) plus 1,280 excess because there are modules sufficient for 25 operators but only 24 are assigned per shift.

number of operators served by each module, the capacity (in ips) required for normal operations by each operator and the excess available per module and per site for failure mode operations.

The allocation of machine resources shown in Table 5.4-1 represented the final element of system description needed to investigate the possible forms of response which the system can make to failure of functional components. Since this scheme of machine resource deployment indicates the location and amount of available reserves, it can be used as a framework for assessing the applicability of the various response strategies which are described in the following section.

5.4.2 Failure Mode Strategies

A modern, complex system can respond to failures in a variety of ways. It can make use of reserve capacity; it can reconfigure and redeploy its human and automated resources; it can reduce involvement in marginally important activities; it can reduce the level of output (service). The practicability of any of these types of response is, of course, highly dependent on the characteristics of computer equipment and its programming. These features of AATMS are as yet undetermined, and it is beyond the scope of this study (and the power of the investigators) to predict the specifics of the system which will ultimately be designed.

However, it is possible to delineate certain basic strategies of response to failure and to assess their applicability for a system with the general characteristics outlined above. These strategies should not be taken as set procedures to be followed if such and such fails. Rather, they should be understood as recommended forms of failure response, which can be used by system engineers as guideposts in designing a system which is resistant to the effects of failure and flexible in its manner of surmounting adversity.

Seven strategies were devised for response to system failure. Each strategy included a description of how it was to be carried out and a statement of the criteria for assessing its appropriateness in any given failure situation. These strategies are enumerated in Table 5.4-2.

TABLE 5.4-2 STRATEGIES FOR RESPONSE TO FAILURE

STRATEGY	DESCRIPTION	CRITERIA FOR ADOPTION
Draw on Internal Reserves	Excess capacity within the data processing module where the failure has occurred is put to use to perform automated tasks.	The module must have sufficient excess to handle all automated tasks of the failed component and all its associated display generation and control input processing tasks.
Reduce to Essentials	Subfunctions resulting in outputs to low priority services are no longer performed and the excess capacity thus generated is put to use in restoring the outputs of the failed component.	a) Services of criticality Class 5 <u>must</u> be sacrificed to restore services of a higher class (1-4). b) If no services of criticality Class 5 are performed at the position, services of Class 3 or 4 <u>may</u> be sacrificed to restore Class 1 and 2 services. c) Under no circumstances can a higher class service be sacrificed for a lower.
Lateral Borrowing	Excess capacity from functionally similar modules at adjacent positions in the same facility is put to use in performing automated tasks associated with the failed component.	Modules must have sufficient excess, either singly or in combination, to handle all automated tasks of the failed component and all its associated display generation and control input processing tasks. (This strategy may be used in combination with "Draw on Internal Reserves".)

TABLE 5.4-2 STRATEGIES FOR RESPONSE TO FAILURE (Cont'd)

STRATEGY	DESCRIPTION	CRITERIA FOR ADOPTION
Manual Backup	The operator intervenes to perform manually those tasks which were performed by the automated resource prior to failure.	If a) the Automation Index shows that the tasks are suitable for human performance (i.e., the task ranks in automation levels III, IV or V), And if b) the frequency of task performance is low (i.e., not more than twice per flight or 40 times per hour per facility), And if c) the manual performance time is brief (i.e., 10 seconds or less), the tasks of the failed module may be reallocated to the human operator.
Vertical Borrowing	Excess capacity at a facility of equal or higher centralization is put to use in performing automated tasks associated with the failed component.	a) The loaning facility must have functionally similar modules in reserve with sufficient capacity to carry out the automated tasks and the induced display and control tasks of the failed component. b) If not, modules with dissimilar functional assignments but with sufficient capacity may be used. c) Modules associated with more critical services may not be loaned to perform less critical services. d) More centralized facilities may not borrow from less centralized facilities.

TABLE 5.4-2 STRATEGIES FOR RESPONSE TO FAILURE (Cont'd)

STRATEGY	DESCRIPTION	CRITERIA FOR ADOPTION
Redundancy	A spare module, unused in normal operating modes, is provided to restore service.	a) If none of the preceding strategies is adequate, spares may be provided at the facility so long as they do not exceed 20% of the capacity required for normal operations. b) If the 20% limit would be exceeded, spares should be provided at a more centralized location.
Do Without	No attempt is made to compensate for the loss of outputs from the failed component, and services associated with these outputs are allowed to degrade.	This strategy is appropriate only for failures affecting services of Critical Class 5 and should be adopted only when manual backup is not feasible.

As an accompaniment to these strategies, a paradigm was developed for analysis of failure situations. This paradigm took a form much like the conventional fault-isolation tree, with a series of dichotomous decision points leading to selection of a unique strategy. The failure analysis procedure begins with determination of the criticality of the particular failure. This produces a major branch which separates the high and low criticality cases. Thereafter, strategies are considered in a set order. If the criteria for selection of the first strategy are met in the given failure case, the strategy is recommended for adoption. If not, the next strategy in the sequence is considered, and so on until the appropriate strategy is found. The procedure for fault analysis is illustrated schematically in Figure 5.4-1.

The failure analysis paradigm follows the principle of resolving failure situations from "the inside out." Thus, the first recourse considered is within the operator position and its associated data processing modules ("internal reserves"). If this is not suitable, the next recourse is to reallocate resources within the module ("reduce to essentials"). The next two options involve solutions which lie outside the affected module but within the facility. In order of preference, they are to borrow capacity from like modules doing the same work at the facility ("lateral borrowing") or to draw on the capabilities of human operators ("manual backup"). Only when none of these strategies is adequate, is consideration given to borrowing resources from outside the facility ("vertical borrowing"), either at a similar facility or at a more centralized location. The last recourse is to call on spare resources ("redundancy"). Placing this strategy last reflects the general concern to resolve failures as parsimoniously as possible. Redundancy is considered to be the least economical form of remedial action. Thus, the general pattern of failure response proceeds from position, to facility, to outside the facility and, finally when nothing else is appropriate, to redundant resources.

5.4.3 Resource Requirements for Individual Failures

The analysis of failures of individual subfunctional elements and the recommended strategies for resolving them are presented in Tables 5.4-4 through 5.4-11 beginning on Page 5.4-17. Since a case by case discussion of failures would be tedious, the tables will be allowed to carry

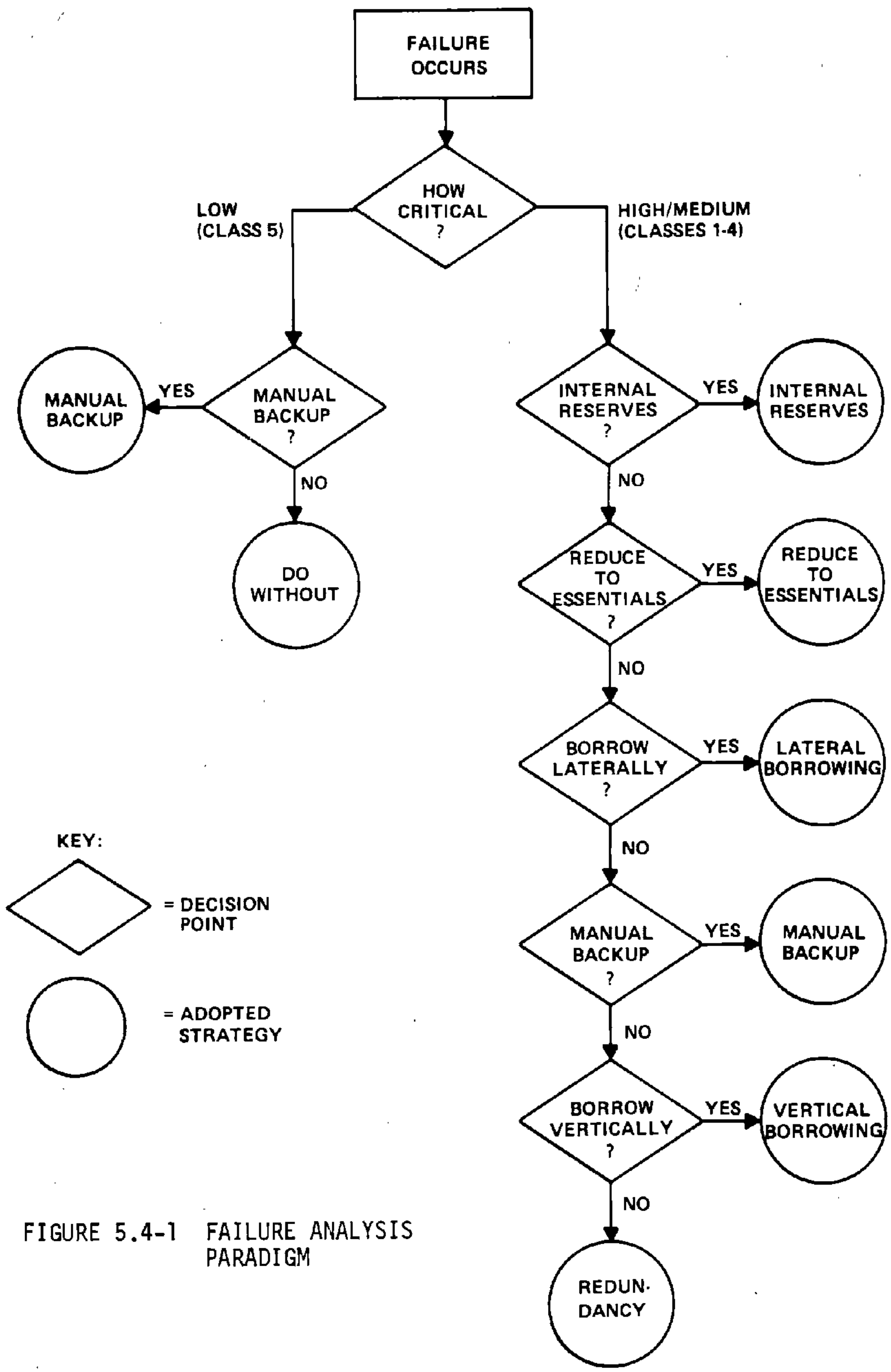

FIGURE 5.4-1 FAILURE ANALYSIS PARADIGM

the burden of explanation. The comments that follow are intended to assist the reader in interpreting the tables to whatever level of detail his interest may dictate.

A failure analysis is presented for each operator position, with Position III (Flight Surveillance and Control) being further divided into four separate tables according to the type of facility (RCC, Primary Terminal, Secondary Terminal, and THC). Each of the eight tables has the same format. The first two columns identify the subfunctions assigned to each position and indicate the Criticality Class of the service receiving outputs from the subfunctions. (See page 5.3-6 above for an explanation of these classes.) The next two columns identify (by code number only) the tasks which make up the subfunction and indicate whether they are manual (M) or automated (A) at the recommended level of automation. The column headed AI (Automation Index) indicates the ranking of the task according to the five incremental levels of man-machine performance capability (I = most machine-like, V = most man-like). It will be recalled that the recommended automation level lies between III and IV on this scale.

The next column, headed Performance Data, is subdivided into three listings: Man Task Time - the time (in seconds) required to perform the task manually; IPS - the number of instructions per second required to perform the task by automated means for all aircraft under the authority of an individual operator and his associated machine resource; Freq. - the frequency with which the task must be performed. Frequencies are expressed as per flight, per facility (all installations of the system), per terminal, or per jurisdiction (airspace subdivision), as appropriate. Note also that the instruction count in the IPS column includes that required to perform automated tasks and all induced display and control tasks within the subfunction.

The last two columns indicate the recommended failure strategy and the system operating state which will result from application of the strategy. In general, the application of a remedial strategy will restore the system to one of three states:

Fail-operational - no loss of safety or capacity/efficiency;

Fail-soft - no loss of safety, but at some sacrifice of capacity/efficiency;

Fail-hard - loss of safety (to an acceptable limit) and loss of capacity/efficiency.

This determination was made by examining the effect which the selected strategy would have on the overall disposition of resources at the position, among adjacent positions, within the facility or more remotely at a centralized facility. If resolution of the failure involved reassignment of resources, then the cost of the remedial action could be measured by the safety and capacity/efficiency relationship of those activities which had to be given up in order to compensate for the original failure.

Thus, by reading across the tables, the reader can recapitulate the steps of the failure analysis for each subfunction since the data needed for each decision point of the failure analysis paradigm are available. Alternatively, the reader can skip over the intermediate details and read directly the recommended strategy and its anticipated effect on system state.

In general, the results of the analysis indicate that the system is highly resistant to the effects of individual failures. (See Table 5.4-3.) In all cases but two, which will be examined below, the system can be restored to a fail-operational state after loss of a single component. In all but 13 of the 126 cases considered, the fail-operational state can be attained without resorting to redundancy, manual backup, or elimination of services.* The most commonly applied strategies are drawing on internal reserves (66) and lateral borrowing (39). The vertical borrowing strategy is not required to deal with any instance of single-component failure. These findings suggest that the allocation and configuration of resources within facilities is such that the facilities are entirely self-sufficient

*There are three additional cases (Subfunctions 7.1, 7.2 and 8.1) in Position III at RCC en route sectors where redundancy is a possible second-choice strategy; but these are not included in the 13 cases referred to above.

TABLE 5.4-3 SUMMARY OF INDIVIDUAL FAILURE ANALYSIS

POSITION AND FACILITY	RECOMMENDED STRATEGY						
	MANUAL BACKUP	DO WITHOUT	INTERNAL RESERVES	REDUCE TO ESSENTIALS	LATERAL BORROWING	VERTICAL BORROWING	REDUNDANCY
IA - Data Base (CCC)	1	4	0	8	0	0	1
IB - Flight Info. (THC)	1	0	5	0	0	0	2
IIA - Flight Plans (THC)	0	0	0	0	0	0	3
IIB - Flow Control (CCC)	0	0	1	0	1	0	0
III - Flt. Surv. & Control (RCC)	0	0	11	0	10*	0	0
III - Flt. Surv. & Control (Primary Terminal)	0	0	23	0	3*	0	0
III - Flt. Surv. & Control (Secondary Terminal)	0	0	26	0	0	0	0
III - Flt. Surv. & Control (THC)	0	0	0	1	25	0	0

*Redundancy is recommended as a second choice in three cases at RCC's and once at Primary Terminals.

in overcoming individual failures. In 8 cases (all in Position IA at the CCC) failures cause the system to cut back to essentials by eliminating supporting services (suspending the preparation of statistical and special reports), but this is not regarded as a significant weakness in the resource allocation for the CCC.

There are two failures where the remedial strategy reduces the system to a fail-soft state, i.e., where capacity/efficiency are sacrificed in order to continue operations. One is in connection with failure of Subfunction 7.1 (Detect Long-term Conflicts Among Flight Plans) at a primary terminal. Failure of 7.1 can be resolved by lateral borrowing, but to do so would use up half of the total reserve of the facility, and this may not be prudent in view of the high safety-related criticality of other functions performed by Position III. Subfunction 7.1 (along with 9.1) has the lowest failure class rating in Position III; all others are failure class 1 or 2. Therefore, the strategy of reducing to essentials by eliminating Subfunction 7.1 is suggested as a second choice, even though it entails some sacrifice of capacity and efficiency. This sacrifice, however, is not complete since 7.1 is backed up functionally by 7.3, 8.1 and 8.2. Still, it may be argued that the second-choice strategy represents a needless penalty in capacity/efficiency. If this is the prevailing view, then the first choice of lateral borrowing can be adopted, but at a serious cost in the total available reserve of the facility.

Failure of Subfunction 7.3 (Predict Deviations from Flight Plan) at a Transition Hub Center is a more clear-cut case. The reserves of the THC are not sufficient to remedy the failure by lateral borrowing. Subfunction 7.3 requires 2052 ips, and a reserve of only 1700 ips is available. Since 7.3 is a subfunction of failure class 2, it must be restored if the system is to continue to operate safely, i.e., if the system is not to fail hard. The only subfunction in Position III with a lower failure class and with a sufficient instruction rate is 7.1 (Class 3, 1101 ips). Therefore, the recommended strategy is a combination of drawing on internal reserves (which provides 1700 ips) and reducing to essentials by eliminating 7.1 (which makes an additional 1101 ips available). This results in a fail-soft condition. However, as noted above in the discussion of failure of 7.1 at a primary terminal, functional back-up is provided by Subfunction 7.3 (here restored to service), 8.1 and 8.2 -- so there is only a partial sacrifice of capacity and efficiency.

The item by item tabulation of individual failures begins on page 5.4-17. The discussion resumes on page 5.4-40 with an analysis of large-scale failures.

TABLE 5.4-4 INDIVIDUAL FAILURE ANALYSIS - POSITION IA: DATA BASE

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA: MAN TASK TIME	PERFORMANCE DATA: IPS	PERFORMANCE DATA: FREQUENCY	FAILURE STRATEGY	RESULT
14.1 PREPARE OPERATIONAL REPORTS	5	14.1.1 14.1.2 14.1.3 14.1.4 14.1.5	M A A A M	IV III III III III	2.6 9.1 720 11.5 24.2	24	.5/facility/hr. each task	MANUAL BACKUP	FAIL-OPERATIONAL
14.2 COMPILE AND STORE SYSTEM RECORDS	5	14.2.1 14.2.2 14.2.3 14.2.4 14.2.5	A A A A A	III II II II I	3.0 3.0 1.5 45.0 6.0	5834	284/flt. + .5/facility/hr. + 24/juris./hr. each task	DO WITHOUT	FAIL-OPERATIONAL
14.3 PREPARE AND MAINTAIN STATISTICAL AND SPECIAL REPORTS	5	14.3.1 14.3.2 14.3.3 14.3.4 14.3.5 14.3.6	A A M A A A	III III IV III II II	3.0 3.0 180 180 720 1440	114	.125/facility/hr. each task	DO WITHOUT	FAIL-OPERATIONAL
17.1 DETERMINE CURRENT AND FORECAST WEATHER	2	17.1.1 17.1.2 17.1.3 17.1.4 17.1.5 17.1.6 17.1.7 17.1.8	M M M M A A A M	IV IV IV V IV IV IV I	11.5 11.5 22.5 45.0 480 11.5 90.0 45.0	123	1 1 .125 .5 1 1 40 1 } /term./hr.	REDUCE TO ESSENTIALS (eliminate 14.1&14.3) OR REDUNDANCY	FAIL-OPERATIONAL
17.2 UPDATE RULES AND PROCEDURE INFORMATION	2	17.2.1 17.2.2 17.2.3 17.2.4 17.2.5 17.2.6	A A A A A A	III I III IV III I	22.0 45.0 6.0 3.0 90.0 45.0	77	.125/facility/hr. each task	REDUCE TO ESSENTIALS (eliminate 14.3) OR REDUNDANCY	FAIL-OPERATIONAL

TABLE 5.4-4 INDIVIDUAL FAILURE ANALYSIS - POSITION IA: DATA BASE (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
17.3 UPDATE AIRSPACE STRUCTURE AND JURISDICTIONAL BOUNDARY INFORMATION	4	17.3.1 17.3.2 17.3.3 17.3.4 17.3.5 17.3.6	A A A A A A	III I III IV III I	22.0 45.0 6.0 3.0 90.0 45.0	8	.0125/facility/hr. each task	REDUCE TO ESSENTIALS (eliminate 14.3)	FAIL-OPERATIONAL
17.4 UPDATE ROUTE INFORMATION	4	17.4.1 17.4.2 17.4.3 17.4.4 17.4.5 17.4.6	A A A A A A	III I III IV III I	22.0 45.0 6.0 3.0 90.0 45.0	8	.0125/facility/hr. each task	REDUCE TO ESSENTIALS (eliminate 14.3)	FAIL-OPERATIONAL
17.5 UPDATE AIRSPACE RESTRICTION INFORMATION	4	17.5.1 17.5.2 17.5.3 17.5.4 17.5.5 17.5.6	A A A A A A	III I III IV III I	22.0 45.0 6.0 3.0 90.0 45.0	8	.0125/facility/hr. each task	REDUCE TO ESSENTIALS (eliminate 14.3)	FAIL-OPERATIONAL
17.6 UPDATE HAZARDS TO FLIGHT INFORMATION	2	17.6.1 17.6.2 17.6.3 17.6.4 17.6.5 17.6.6	A A A A A A	III I III IV III I	22.0 45.0 6.0 3.0 90.0 45.0	8	.0125/facility/hr. each task	REDUCE TO ESSENTIALS (eliminate 14.3)	FAIL-OPERATIONAL
17.7 DETERMINE CAPABILITY AND STATUS OF COMM/NAV SYSTEM	2	17.7.1 17.7.2 17.7.3 17.7.4 17.7.5	A A A A A	II III III III I	7.3 45.0 45.0 90.0 45.0	104	.125/facility/hr. each task	REDUCE TO ESSENTIALS (eliminate 14.3)	FAIL-OPERATIONAL

TABLE 5.4-4 INDIVIDUAL FAILURE ANALYSIS - POSITION IA: DATA BASE (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
17.8 DETERMINE CAPABILITY AND STATUS OF GROUND FACILITIES	2	17.8.1 17.8.2 17.8.3 17.8.4 17.8.5	A A A A A	II III III III I	7.3 45.0 45.0 90.0 45.0	69	4/term./hr. .0125/term./hr. each task	REDUCE TO ESSENTIALS (eliminate 14.3)	FAIL-OPERATIONAL
17.9 MAINTAIN USER CLASS INFORMATION	5	17.9.1 17.9.2 17.9.3 17.9.4 17.9.5 17.9.6	A A A M A A	IV II III IV II I	11.5 45.0 6.0 90.0 90.0 45.0	1	10/month each task	DO WITHOUT	FAIL-OPERATIONAL
17.10 COMPILE TRAFFIC SUMMARIES	5	17.10.1 17.10.2 17.10.3	A A A	I I I	3.0 90.0 45.0	325			
17.11 PREPARE PREFORMATTED DATA MODULES	4	17.11.1 17.11.2	A A	II II	22.5 180	528	1.33/facility/hr.	REDUNDANCY	FAIL-OPERATIONAL

TABLE 5.4-5 INDIVIDUAL FAILURE ANALYSIS - POSITION IB: FLIGHT INFORMATION SERVICES

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA: MAN TASK TIME	PERFORMANCE DATA: IPS	PERFORMANCE DATA: FREQUENCY	FAILURE STRATEGY	RESULT
1.1 RECEIVE REQUESTS FOR FLIGHT PLANNING INFORMATION	5	1.1.1	A	III	11.5	26	1/Flt	MANUAL BACKUP	FAIL-OPERATIONAL
		1.1.2	M	V	11.5		1/Flt		
		1.1.3	M	IV	8.5		2/Flt		
1.2 SELECT INFORMATION TO SERVICE THE REQUEST	3	1.2.1	A	IV	9.1	22	1/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		1.2.2	M	II	8.8		1/Flt		
1.3 FORMAT AND DISPLAY THE REQUESTED INFORMATION	3	1.3.1	M	IV	15.7	80	2/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		1.3.2	A	III	12.1		1/Flt		
		1.3.3	M	V	9.4		1/Flt		
12.1 SERVICE REQUEST FOR INFORMATION	3	12.1.1	M	IV	12.8	72	2/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		12.1.2	M	V	2.5		2/Flt		
		12.1.3	A	III	9.1		1.8/Flt		
		12.1.4	A	II	8.8		.2/Flt		
		12.1.5	M	IV	15.7		.2/Flt		
		12.1.6	A	V	8.5		1.8/Flt		
		12.1.7	M	V	8.5		.2/Flt		
12.2 ISSUE FLIGHT ADVISORIES AND INSTRUCTIONS	3	12.2.1	A	II	6.0	148	1/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
		12.2.2	A	III	10.8				
		12.2.3	A	III	3.0				
		12.2.4	A	III	7.4				
		12.2.5	A	III	7.4				
		12.2.6	A	III	90.0				
		12.2.7	M	IV	8.6				
12.3 NOTIFY PILOT OF IMMINENT ENCOUNTER WITH HAZARDOUS WEATHER PHENOMENA	3	12.3.1	A	III	10.8	5	.1/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		12.3.2	A	II	15.7		.002/Flt		
		12.3.3	A	V	4.3		.002/Flt		
		12.3.4	A	V	3.1		.002/Flt		

TABLE 5.4-6 INDIVIDUAL FAILURE ANALYSIS - POSITION IIA: FLIGHT PLANS

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA: MAN TASK TIME	PERFORMANCE DATA: IPS	PERFORMANCE DATA: FREQUENCY	FAILURE STRATEGY	RESULT
4.1 DEVELOP TIME-POSITION PROFILE	3	4.1.1 4.1.2	M A	V III	9.1 59.4	23	1.37/Flt each task	REDUNDANCY	FAIL-OPERATIONAL
4.2 REVIEW FLIGHT PLAN	3	4.2.1 4.2.2 4.2.3 4.2.4 4.2.5 4.2.6 4.2.7 4.2.8 4.2.9 4.2.10 4.2.11 4.2.12 4.2.13	M M A M M M M M M M A M M	V IV III IV V IV V V V IV III V V	10.2 8.0 22.5 11.5 11.5 16.5 6.0 11.5 12.6 6.0 6.3 11.5 6.0	478	1.37/Flt each task except 4.2.6 .01/Flt	REDUNDANCY	FAIL-OPERATIONAL
4.3 PROPOSE MODIFIED FLIGHT PLAN	3	4.3.1 4.3.2 4.3.3 4.3.4	A M M M	III V V IV	59.3 6.0 22.5 180	74	.137/Flt .137/Flt .07/Flt .067/Flt	REDUNDANCY	FAIL-OPERATIONAL
4.4 DETERMINE RESPONSIBILITY FOR COMMUNICATION AND CONTROL	(E	N T I R	E L	Y	M A N U A L)				
15.1 DETERMINE NATURE OF SERVICE REQUIRED	(E	N T I R	E L	Y	M A N U A L)				
15.2 INITIATE ACTION TO PROVIDE THE SERVICE	(E	N T I R	E L	Y	M A N U A L)				

TABLE 5.4-7 INDIVIDUAL FAILURE ANALYSIS - POSITION IIB: FLOW CONTROL

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
2.1 DETERMINE SYSTEM CAPACITY	(E	N T I R	E L	Y	M A N U A L)				
2.2 DETERMINE SYSTEM DEMAND	3	2.2.1 2.2.2 2.2.3 2.2.4	A A A A	II II II II	720 22.5 22.5 1440	877	1/term./hr. each task	LATERAL BORROWING	FAIL-OPERATIONAL
2.3 DETERMINE AND RESOLVE CAPACITY OVERLOAD SITUATIONS	3	2.3.1 2.3.2 2.3.3 2.3.4 2.3.5	A A A A A	III III II II I	45.0 720 360 360 360	404	1. .04 .04 .04 .04 } /term./hr.	INTERNAL RESERVES	FAIL-OPERATIONAL

TABLE 5.4-8 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Regional Control Center, En Route)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
5.1 CHECK CLEARANCE STATUS	1	5.1.1 5.1.2 5.1.3	M A M	IV II V	8.6 8.6 13.9	1013	1.2/Flt 20/Flt .01/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
5.2 DETERMINE CLEARANCE TO BE ISSUED	1	5.2.1 5.2.2 5.2.3 5.2.4	A A A A	II III II II	6.1 10.5 7.3 22.5	2206	1/Flt 5/Flt 5/Flt 8/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
5.3 COMPILE AND ISSUE CLEARANCE	1	5.3.1 5.3.2 5.3.3	A A A	II V V	22.5 15.3 2.8	1820	8/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
6.1 DETERMINE PRESENT POSITION	2	6.1.1 6.1.2 6.1.3 6.1.4 6.1.5	A A A M M	I I III V IV	6.7 14.8 4.0 3.2 3.8	588	216/Flt 24/Flt 24/Flt 2/Flt .01/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
6.2 COMPILE AIRCRAFT TIME-POSITION PROFILE	2	6.2.1 6.2.2	A A	III II	7.4 11.3	762	1/Flt 240/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
6.3 PREDICT FUTURE POSITIONS/ETAs OF AIRCRAFT	2	6.3.1 6.3.2 6.3.3	A A A	II I I	10.0 5.3 4.1	2018	240/Flt 240/Flt 24/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
6.4 DETERMINE AIRCRAFT CAPABILITY	1	6.4.1 6.4.2 6.4.3 6.4.4 6.4.5 6.4.6 6.4.7	A A A A A A A	II II II III IV III III	2.6 2.6 2.6 2.6 3.8 2.6 3.8	568	10/Flt .001/Flt .001/Flt .1/Flt .1/Flt .1/Flt .2/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL

TABLE 5.4-8 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Regional Control Center, En Route) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA: MAN TASK TIME	PERFORMANCE DATA: IPS	PERFORMANCE DATA: FREQUENCY	FAILURE STRATEGY	RESULT
7.1 DETECT LONG-TERM CONFLICTS AMONG FLIGHT PLANS	3	7.1.1	M	IV	3.0	5030	.5/juris./hr.	LATERAL BORROWING OR REDUNDANCY	FAIL-OPERATIONAL
		7.1.2	A	I	45.0		4/juris./hr.		
		7.1.3	A	III	22.5		8/Flt		
		7.1.4	A	II	22.5		8/Flt		
		7.1.5	A	II	45.0		.1/Flt		
7.2 DETERMINE CURRENT DEVIATIONS FROM FLIGHT PLAN	2	7.2.1	A	III	9.0	166	24/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		7.2.2	A	I	6.0		24/Flt		
7.3 PREDICT DEVIATIONS FROM FLIGHT PLAN	2	7.3.1	A	II	7.3	9398	24/Flt each task	LATERAL BORROWING OR REDUNDANCY	FAIL-OPERATIONAL
		7.3.2	A	I	11.5				
		7.3.3	A	I	11.5				
7.4 DETERMINE APPROPRIATE RESOLUTION OF DEVIATIONS	2	7.4.1	A	II	11.5	87	24/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		7.4.2	M	V	6.0		1/Flt		
		7.4.3	M	IV	2.8		1/Flt		
		7.4.4	A	III	15.6		.1/Flt		
8.1 PREDICT CONFLICTS	1	8.1.1	A	II	1.5	5341	.125/juris./hr.	LATERAL BORROWING OR REDUNDANCY	FAIL-OPERATIONAL
		8.1.2	A	I	10.0		24/juris./hr.		
		8.1.3	A	I	8.8		24/juris./hr.		
		8.1.4	A	I	45.0		24/juris./hr.		
		8.1.5	A	I	11.0		24/juris./hr.		
		8.1.6	A	I	11.0		24/juris./hr.		
		8.1.7	A	I	3.0		24/juris./hr.		
		8.1.8	A	II	7.3		120/juris./hr.		
		8.1.9	A	III	4.1		120/juris./hr.		
8.2 RESOLVE CONFLICTS	1	8.2.1	A	II	3.0	2187	1/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
		8.2.2	A	I	4.3				
		8.2.3	A	II	3.0				
		8.2.4	A	IV	3.3				
		8.2.5	A	III	4.5				

TABLE 5.4-8 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Regional Control Center, En Route) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
9.1 MAINTAIN PREDICTED ARRIVAL/DEPARTURE SCHEDULE FOR EACH AIRPORT	(NOT REQUIRED IN EN ROUTE SECTORS)								
9.2 DETERMINE REQUIREMENT FOR SPACING CONTROL	(NOT REQUIRED IN EN ROUTE SECTORS)								
9.3 ESTABLISH RUNWAY CONFIGURATION SCHEDULE	(NOT REQUIRED IN EN ROUTE SECTORS)								
9.4 DETERMINE MOST EFFICIENT ARRIVAL/DEPARTURE SEQUENCE-SCHEDULE FOR RUNWAY	(NOT REQUIRED IN EN ROUTE SECTORS)								
9.5 INITIATE IMPLEMENTATION OF SEQUENCE/SCHEDULE	(NOT REQUIRED IN EN ROUTE SECTORS)								
11.1 INITIATE/TERMINATE GUIDANCE	1	11.1.1 11.1.2	A A	II II	3.0 3.0	594	10/Flt 10/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
11.2 COMPUTE VECTOR REQUIREMENTS	2	11.2.1 11.2.2 11.2.3 11.2.4	A A A A	III II I I	6.0 3.0 6.0 3.0	561	10/Flt 6.67/Flt 6.67/Flt 6.67/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
11.3 COMPUTE AIR VECTOR	2	11.3.1 11.3.2 11.3.3	A A A	I I I	6.0 1.3 6.0	330	6.67/Flt 3.33/Flt 6.67/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL

TABLE 5.4-8 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Regional Control Center, En Route) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
11.4 COMPUTE GUIDANCE COMMANDS	1	11.4.1 11.4.2 11.4.3	A A A	II II II	1.5 1.5 3.0	395	3.33/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
11.5 COMPILE AND TRANSMIT GUIDANCE INSTRUCTIONS	1	11.5.1 11.5.2 11.5.3	A A A	III IV II	3.0 3.1 2.6	989	10/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
13.1 DETERMINE HANDOFF RESPONSIBILITY REQUIREMENTS	1	13.1.1 13.1.2 13.1.3 13.1.4 13.1.4	A A A M A	IV III III IV III	8.6 3.0 8.6 7.3 7.8	556	7/Flt 7/Flt 7/Flt .02/Flt 14/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
13.2 DETERMINE COMMUNICATION CHANNEL ASSIGNMENT	1	13.2.1 13.2.2 13.2.3	M A A	IV IV III	3.0 6.7 10.1	181	7/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
13.3 EFFECT TRANSFER OF RESPONSIBILITY	1	13.3.1 13.3.2	A A	V III	9.4 6.0	346	14/Flt 7/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
16.1 DESCRIBE EMERGENCY SITUATION	(ENTIRELY MANUAL)								
16.2 DETERMINE REQUIRED RESPONSE	(ENTIRELY MANUAL)								

TABLE 5.4-9 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Primary Terminal)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
5.1 CHECK CLEARANCE STATUS	1	5.1.1 5.1.2 5.1.3	M A M	IV II V	8.6 8.6 13.9	188	1.2/Flt 20/Flt .01/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
5.2 DETERMINE CLEAR-ANCE TO BE ISSUED	1	5.2.1 5.2.2 5.2.3 5.2.4	A A A A	II III II II	6.1 10.5 7.3 22.5	410	1/Flt 5/Flt 5/Flt 8/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
5.3 COMPILE AND ISSUE CLEARANCE	1	5.3.1 5.3.2 5.3.3	A A A	II V V	22.5 15.3 2.8	338	8/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
6.1 DETERMINE PRESENT POSITION	2	6.1.1 6.1.2 6.1.3 6.1.4 6.1.5	A A A M M	I I III V IV	6.7 14.8 4.0 3.2 3.8	110	216/Flt 24/Flt 24/Flt 2/Flt .01/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
6.2 COMPILE AIRCRAFT TIME-POSITION PROFILE	2	6.2.1 6.2.2	A A	III II	7.4 11.3	141	1/Flt 240/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
6.3 PREDICT FUTURE POSITIONS/ETAs OF AIRCRAFT	2	6.3.1 6.3.2 6.3.3	A A A	II I I	10.0 5.3 4.1	375	240/Flt 240/Flt 24/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
6.4 DETERMINE AIRCRAFT CAPABILITY	1	6.4.1 6.4.2 6.4.3 6.4.4 6.4.5 6.4.6 6.4.7	A A A A A A A	II II II III IV III III	2.6 2.6 2.6 2.6 3.8 2.6 3.8	106	10/Flt .001/Flt .001/Flt .1/Flt .1/Flt .1/Flt .2/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL

TABLE 5.4-9 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Primary Terminal) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
7.1 DETECT LONG-TERM CONFLICTS AMONG FLIGHT PLANS	3	7.1.1 7.1.2 7.1.3 7.1.4 7.1.5	M A A A A	IV I III II II	3.0 45.0 22.5 22.5 45.0	948	.5/juris./hr. 4/juris./hr. 8/Flt 8/Flt .1/Flt	LATERAL BORROWING OR REDUCE TO ESSENTIALS (eliminate 7.1)	FAIL-OPERATIONAL FAIL- SOFT
7.2 DETERMINE CURRENT DEVIATIONS FROM FLIGHT PLAN	2	7.2.1 7.2.2	A A	III I	9.0 6.0	31	24/Flt 24/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
7.3 PREDICT DEVIATIONS FROM FLIGHT PLAN	2	7.3.1 7.3.2 7.3.3	A A A	II I I	7.3 11.5 11.5	1763	24/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
7.4 DETERMINE APPROPRIATE RESOLUTION OF DEVIATIONS	2	7.4.1 7.4.2 7.4.3 7.4.4	A M M A	II V IV III	11.5 6.0 2.8 15.6	16	24/Flt 1/Flt 1/Flt .1/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
8.1 PREDICT CONFLICTS	1	8.1.1 8.1.2 8.1.3 8.1.4 8.1.5 8.1.6 8.1.7 8.1.8 8.1.9	A A A A A A A A A	II I I I I I I II III	1.5 10.0 9.8 45.0 11.0 11.0 3.0 7.3 4.1	992	.125/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 120/juris./hr. 120/juris./hr.	LATERAL BORROWING	FAIL-OPERATIONAL
8.2 RESOLVE CONFLICTS	1	8.2.1 8.2.2 8.2.3 8.2.4 8.2.5	A A A A A	II I II IV III	3.0 4.3 3.0 3.3 4.5	406	1/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL

TABLE 5.4-9 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Primary Terminal) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA: MAN TASK TIME	IPS	FREQUENCY	FAILURE STRATEGY	RESULT
9.1 MAINTAIN PREDICTED ARRIVAL/DEPARTURE SCHEDULE FOR EACH AIRPORT	3	9.1.1	A	II	14.9	12	6/term./hr. each task	INTERNAL RESERVES	FAIL-OPERATIONAL
		9.1.2	A	III	14.9				
		9.1.3	A	II	90.0				
9.2 DETERMINE REQUIREMENT FOR SPACING CONTROL		9.2.1	A	*	11.2	59	1/term./hr.	INTERNAL RESERVES	FAIL-OPERATIONAL
		9.2.2	A	III	360		6/term./hr.		
9.3 ESTABLISH RUNWAY CONFIGURATION SCHEDULE	1	9.3.1	A	II	45.0	12	6/term./hr.	INTERNAL RESERVES	FAIL-OPERATIONAL
		9.3.2	A	IV	22.5		6/term./hr.		
9.4 DETERMINE MOST EFFICIENT ARRIVAL/DEPARTURE SEQUENCE-SCHEDULE FOR RUNWAY	1	9.4.1	A	II	45.0	18	6/term./hr.	INTERNAL RESERVES	FAIL-OPERATIONAL
		9.4.2	A	II	45.0		1/term./hr.		
9.5 INITIATE IMPLEMENTATION OF SEQUENCE/SCHEDULE	1	9.5.1	A	III	3.0	66	.1/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		9.5.2	A	III	3.0		.2/Flt		
		9 5.3	A	II	4.3		.2/Flt		
		9.5.4	A	II	11.5		.1/Flt		
		9.5.5	M	V	11.0		.09/Flt		
		9.5.6	M	IV	15.6		.01/Flt		
		9.5.7	M	V	17.9		.01/Flt		
11.1 INITIATE/TERMINATE GUIDANCE	1	11.1.1	A	II	3.0	110	10/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		11.1.2	A	II	3.0		10/Flt		
11.2 COMPUTE VECTOR REQUIREMENTS	2	11.2.1	A	III	6.0	104	10/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
		11.2.2	A	II	3.0		6.67/Flt		
		11.2.3	A	I	6.0		6.67/Flt		
		11.2.4	A	I	3.0		6.67/Flt		

* Task 9.2.1 not rated

TABLE 5.4-9 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Primary Terminal) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
11.3 COMPUTE AIR VECTOR	2	11.3.1 11.3.2 11.3.3	A A A	I I I	6.0 1.3 6.0	61	6.67/Flt 3.33/Flt 6.67/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
11.4 COMPUTE GUIDANCE COMMANDS	1	11.4.1 11.4.2 11.4.3	A A A	II II II	1.5 1.5 3.0	73	3.33/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
11.5 COMPILE AND TRANSMIT GUIDANCE INSTRUCTIONS	1	11.5.1 11.5.2 11.5.3	A A A	III IV II	3.0 3.1 2.6	184	10/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
13.1 DETERMINE HANDOFF RESPONSIBILITY REQUIREMENTS	1	13.1.1 13.1.2 13.1.3 13.1.4 13.1.5	A A A M A	IV III III IV III	8.6 3.0 8.6 7.3 7.8	105	7/Flt 7/Flt 7/Flt .02/Flt 14/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
13.2 DETERMINE COMMUNICATION CHANNEL ASSIGNMENT	1	13.2.1 13.2.2 13.2.3	M A A	IV IV III	3.0 6.7 10.1	33	7/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
13.3 EFFECT TRANSFER OF RESPONSIBILITY	1	13.3.1 13.3.2	A A	V III	9.4 6.0	64	14/Flt 7/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
16.1 DESCRIBE EMERGENCY SITUATION	(E	N T I R	E L	Y	M A N U A L)				
16.2 DETERMINE REQUIRED RESPONSE	(E	N T I R	E L	Y	M A N U A L)				

TABLE 5.4-10 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Secondary Terminal)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
5.1 CHECK CLEARANCE STATUS	1	5.1.1 5.1.2 5.1.3	M A M	IV II V	8.6 8.6 13.9	85	1.2/Flt 20/Flt .01/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
5.2 DETERMINE CLEARANCE TO BE ISSUED	1	5.2.1 5.2.2 5.2.3 5.2.4	A A A A	II III II II	6.1 10.5 7.3 22.5	185	1/Flt 5/Flt 5/Flt 8/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
5.3 COMPILE AND ISSUE CLEARANCE	1	5.3.1 5.3.2 5.3.3	A A A	II V V	22.5 15.3 2.8	153	8/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
6.1 DETERMINE PRESENT POSITION	2	6.1.1 6.1.2 6.1.3 6.1.4 6.1.5	A A A M M	I I III V IV	6.7 14.8 4.0 3.2 3.8	51	216/Flt 24/Flt 24/Flt 2/Flt .01/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
6.2 COMPILE AIRCRAFT TIME-POSITION PROFILE	2	6.2.1 6.2.2	A A	III II	7.4 11.3	64	1/Flt 240/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
6.3 PREDICT FUTURE POSITIONS/ETAs OF AIRCRAFT	2	6.3.1 6.3.2 6.3.3	A A A	II I I	10.0 5.3 4.1	169	240/Flt 240/Flt 24/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
6.4 DETERMINE AIRCRAFT CAPABILITY	1	6.4.1 6.4.2 6.4.3 6.4.4 6.4.5 6.4.6 6.4.7	A A A A A A A	II II II III IV III III	2.6 2.6 2.6 2.6 3.8 2.6 3.8	48	10/Flt .001/Flt .001/Flt .1/Flt .1/Flt .1/Flt .2/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL

TABLE 5.4-10 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Secondary Terminal) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA: MAN TASK TIME	PERFORMANCE DATA: IPS	PERFORMANCE DATA: FREQUENCY	FAILURE STRATEGY	RESULT
7.1 DETECT LONG-TERM CONFLICTS AMONG FLIGHT PLANS	3	7.1.1 7.1.2 7.1.3 7.1.4 7.1.5	M A A A A	IV I III II II	3.0 45.0 22.5 22.5 45.0	429	.5/juris./hr. 4/juris./hr. 8/Flt 8/Flt .1/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
7.2 DETERMINE CURRENT DEVIATIONS FROM FLIGHT PLAN	2	7.2.1 7.2.2	A A	III I	9.0 6.0	14	24/Flt 24/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
7.3 PREDICT DEVIATIONS FROM FLIGHT PLAN	2	7.3.1 7.3.2 7.3.3	A A A	II I I	7.3 11.5 11.5	800	24/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
7.4 DETERMINE APPROPRIATE RESOLUTION OF DEVIATIONS	2	7.4.1 7.4.2 7.4.3 7.4.4	A M M A	II V IV III	11.5 6.0 2.8 15.6	8	24/Flt 1/Flt 1/Flt .1/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
8.1 PREDICT CONFLICTS	1	8.1.1 8.1.2 8.1.3 8.1.4 8.1.5 8.1.6 8.1.7 8.1.8 8.1.9	A A A A A A A A A	II I I I I I I II III	1.5 10.0 9.8 45.0 11.0 11.0 3.0 7.3 4.1	448	.125/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 120/juris./hr. 120/juris./hr.	INTERNAL RESERVES	FAIL-OPERATIONAL
8.2 RESOLVE CONFLICTS	1	8.2.1 8.2.2 8.2.3 8.2.4 8.2.5	A A A A A	II I II IV III	3.0 4.3 3.0 3.3 4.5	183	1/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL

TABLE 5.4-10 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Secondary Terminal) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA: MAN TASK TIME	PERFORMANCE DATA: IPS	PERFORMANCE DATA: FREQUENCY	FAILURE STRATEGY	RESULT
9.1 MAINTAIN PREDICTED ARRIVAL/DEPARTURE SCHEDULE FOR EACH AIRPORT	3	9.1.1 9.1.2 9.1.3	A A A	II III II	14.9 14.9 90.0	5	6/term./hr. each task	INTERNAL RESERVES	FAIL-OPERATIONAL
9.2 DETERMINE REQUIREMENT FOR SPACING CONTROL	1	9.2.1 9.2.2	A A	* III	11.2 360	27	1/term./hr. 6/term./hr.	INTERNAL RESERVES	FAIL-OPERATIONAL
9.3 ESTABLISH RUNWAY CONFIGURATION SCHEDULE	1	9.3.1 9.3.2	A A	II IV	45.0 22.5	5	6/term./hr. 6/term./hr.	INTERNAL RESERVES	FAIL-OPERATIONAL
9.4 DETERMINE MOST EFFICIENT ARRIVAL/DEPARTURE SEQUENCE -SCHEDULE FOR RUNWAY	1	9.4.1 9.4.2	A A	II II	45.0 45.0	8	6/term./hr. 1/term./hr.	INTERNAL RESERVES	FAIL-OPERATIONAL
9.5 INITIATE IMPLEMENTATION OF SEQUENCY/SCHEDULE	1	9.5.1 9.5.2 9.5.3 9.5.4 9.5.5 9.5.6 9.5.7	A A A A M M M	III III II II V IV V	3.0 3.0 4.3 11.5 11.0 15.6 17.9	31	.1/Flt .2/Flt .2/Flt .1/Flt .09/Flt .01/Flt .01/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
11.1 INITIATE/TERMINATE GUIDANCE	1	11.1.1 11.1.2	A A	II II	3.0 3.0	50	10/Flt 10/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
11.2 COMPUTE VECTOR REQUIREMENTS	2	11.2.1 11.2.2 11.2.3 11.2.4	A A A A	III II I I	6.0 3.0 6.0 3.0	47	10/Flt 6.67/Flt 6.67/Flt 6.67/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL

* Task 9.2.1 not rated

TABLE 5.4-10 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Secondary Terminal) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
11.3 COMPUTE AIR VECTOR	2	11.3.1 11.3.2 11.3.3	A A A	I I I	6.0 1.5 6.0	28	6.67/Flt 3.33/Flt 6.67/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
11.4 COMPUTE GUIDANCE COMMANDS	1	11.4.1 11.4.2 11.4.3	A A A	II II II	1.5 1.5 3.0	33	3.33/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
11.5 COMPILE AND TRANSMIT GUIDANCE INSTRUCTIONS	1	11.5.1 11.5.2 11.5.3	A A A	III IV II	3.0 3.1 2.6	83	10/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
13.1 DETERMINE HANDOFF RESPONSIBILITY REQUIREMENTS	1	13.1.1 13.1.2 13.1.3 13.1.4 13.1.5	A A A M A	IV III III IV III	8.6 3.0 8.6 7.3 7.8	48	7/Flt 7/Flt 7/Flt .02/Flt 14/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
13.2 DETERMINE COMMUNICATION CHANNEL ASSIGNMENT	1	13.2.1 13.2.2 13.2.3	M A A	IV IV III	3.0 6.7 10.1	15	7/Flt each task	INTERNAL RESERVES	FAIL-OPERATIONAL
13.3 EFFECT TRANSFER OF RESPONSIBILITY	1	13.3.1 13.3.2	A A	V III	9.4 6.0	29	14/Flt 7/Flt	INTERNAL RESERVES	FAIL-OPERATIONAL
16.1 DESCRIBE EMERGENCY SITUATION	(E	N T I R	E L	Y	M A N U A L)				
16.2 DETERMINE REQUIRED RESPONSE	(E	N T I R	E L	Y	M A N U A L)				

TABLE 5.4-11 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Transition Hub Center)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA: MAN TASK TIME	PERFORMANCE DATA: IPS	PERFORMANCE DATA: FREQUENCY	FAILURE STRATEGY	RESULT
5.1 CHECK CLEARANCE STATUS	1	5.1.1	M	IV	8.6	218	1.2/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
		5.1.2	A	II	8.6		20/Flt		
		5.1.3	M	V	13.9		.01/Flt		
5.2 DETERMINE CLEARANCE TO BE ISSUED	1	5.2.1	A	II	6.1	476	1/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
		5.2.2	A	III	10.5		5/Flt		
		5.2.3	A	II	7.3		5/Flt		
		5.2.4	A	II	22.5		8/Flt		
5.3 COMPILE AND ISSUE CLEARANCE	1	5.3.1	A	II	22.5	392	8/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
		5.3.2	A	V	15.3				
		5.3.3	A	V	2.8				
6.1 DETERMINE PRESENT POSITION	1	6.1.1	A	I	6.7	127	216/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
		6.1.2	A	I	14.8		24/Flt		
		6.1.3	A	III	4.0		24/Flt		
		6.1.4	M	V	3.2		2/Flt		
		6.1.5	M	IV	3.8		.01/Flt		
6.2 COMPILE AIRCRAFT TIME-POSITION PROFILE	2	6.2.1	A	III	7.4	164	1/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
		6.2.2	A	II	11.3		240/Flt		
6.3 PREDICT FUTURE POSITIONS/ETAs OF AIRCRAFT	2	6.3.1	A	II	10.0	435	240/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
		6.3.2	A	I	5.3		240/Flt		
		6.3.3	A	I	4.1		24/Flt		
6.4 DETERMINE AIRCRAFT CAPABILITY	1	6.4.1	A	II	2.6	123	10/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
		6.4.2	A	II	2.6		.001/Flt		
		6.4.3	A	II	2.6		.001/Flt		
		6.4.4	A	III	2.6		.1/Flt		
		6.4.5	A	IV	3.8		.1/Flt		
		6.4.6	A	III	2.6		.1/Flt		
		6.4.7	A	III	3.8		.2/Flt		

TABLE 5.4-11 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Transition Hub Center) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA MAN TASK TIME	PERFORMANCE DATA IPS	PERFORMANCE DATA FREQUENCY	FAILURE STRATEGY	RESULT
7.1 DETECT LONG-TERM CONFLICTS AMONG FLIGHT PLANS	3	7.1.1 7.1.2 7.1.3 7.1.4 7.1.5	M A A A A	IV I III II II	3.0 45.0 22.5 22.5 45.0	1101	.5/juris./hr. 4/juris./hr. 8/Flt 8/Flt .1/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
7.2 DETERMINE CURRENT DEVIATIONS FROM FLIGHT PLAN	2	7.2.1 7.2.2	A A	III I	90.0 6.0	36	24/Flt 24/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
7.3 PREDICT DEVIATIONS FROM FLIGHT PLAN	2	7.3.1 7.3.2 7.3.3	A A A	II I I	7.3 11.5 11.5	2052	24/Flt each task	LATERAL BORROWING PLUS REDUCE TO ESSENTIALS (eliminate 7.1)	FAIL-SOFT
7.4 DETERMINE APPROPRIATE RESOLUTION OF DEVIATIONS	2	7.4.1 7.4.2 7.4.3 7.4.4	A M M A	II V IV III	11.5 6.0 2.8 15.6	19	24/Flt 1/Flt 1/Flt .1/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
8.1 PREDICT CONFLICTS	1	8.1.1 8.1.2 8.1.3 8.1.4 8.1.5 8.1.6 8.1.7 8.1.8 8.1.9	A A A A A A A A A	II I I I I I I II III	1.5 10.0 8.8 45.0 11.0 11.0 3.0 7.3 4.1	1152	.125/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 24/juris./hr. 120/juris./hr. 120/juris./hr.	LATERAL BORROWING	FAIL-OPERATIONAL

TABLE 5.4-11 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Transition Hub Center) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
8.2 RESOLVE CONFLICTS	1	8.2.1 8.2.2 8.2.3 8.2.4 8.2.5	A A A A A	II I II IV III	3.0 4.3 3.0 3.3 4.5	471	1/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
9.1 MAINTAIN PREDICTED ARRIVAL/DEPARTURE SCHEDULE FOR EACH AIRPORT	3	9.1.1 9.1.2 9.1.3	A A A	II III II	14.9 14.9 90.0	14	6/term./hr. each task	LATERAL BORROWING	FAIL-OPERATIONAL
9.2 DETERMINE REQUIREMENT FOR SPACING CONTROL	1	9.2.1 9.2.2	A A	* III	11.2 360	68	1/term./hr. 6/term./hr.	LATERAL BORROWING	FAIL-OPERATIONAL
9.3 ESTABLISH RUNWAY CONFIGURATION SCHEDULE	1	9.3.1 9.3.2	A A	II IV	45.0 22.5	14	6/term./hr. 6/term./hr.	LATERAL BORROWING	FAIL-OPERATIONAL
9.4 DETERMINE MOST EFFICIENT ARRIVAL/DEPARTURE SEQUENCE-SCHEDULE FOR RUNWAY	1	9.4.1 9.4.2	A A	II II	45.0 45.0	21	6/term./hr. 1/term./hr.	LATERAL BORROWING	FAIL-OPERATIONAL
9.5 INITIATE IMPLEMENTATION OF SEQUENCE/SCHEDULE	1	9.5.1 9.5.2 9.5.3 9.5.4 9.5.5 9.5.6 9.5.7	A A A A M M M	III III II II V IV V	3.0 3.0 4.3 11.5 11.0 11.0 17.9	77	.1/Flt .2/Flt .2/Flt .1/Flt .09/Flt .01/Flt .01/Flt	LATERAL BORROWING	FAIL-OPERATIONAL

* Task 9.2.1 not rated

TABLE 5.4-11 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Transition Hub Center) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
11.1 INITIATE/TERMINATE GUIDANCE	1	11.1.1 11.1.2	A A	II II	3.0 3.0	128	10/Flt 10/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
11.2 COMPUTE VECTOR REQUIREMENTS	2	11.2.1 11.2.2 11.2.3 11.2.4	A A A A	III II I I	6.0 3.0 6.0 3.0	121	10/Flt 6.67/Flt 6.67/Flt 6.67/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
11.3 COMPUTE AIR VECTOR	2	11.3.1 11.3.2 11.3.3	A A A	I I I	6.0 1.3 6.0	71	6.67/Flt 3.33/Flt 6.67/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
11.4 COMPUTE GUIDANCE COMMANDS	1	11.4.1 11.4.2 11.4.3	A A A	II II II	1.5 1.5 3.0	85	3.33/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
11.5 COMPILE AND TRANSMIT GUIDANCE INSTRUCTIONS	1	11.5.1 11.5.2 11.5.3	A A A	III IV II	3.0 3.1 2.6	213	10/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
13.1 DETERMINE HANDOFF RESPONSIBILITY REQUIREMENTS	1	13.1.1 13.1.2 13.1.3 13.1.4 13.1.5	A A A M A	IV III III IV III	8.6 3.0 8.6 7.3 7.8	121	7/Flt 7/Flt 7/Flt .02/Flt 14/Flt	LATERAL BORROWING	FAIL-OPERATIONAL
13.2 DETERMINE COMMUNICATION CHANNEL ASSIGNMENT	1	13.2.1 13.2.2 13.2.3	M A A	IV IV III	3.0 6.7 10.1	38	7/Flt each task	LATERAL BORROWING	FAIL-OPERATIONAL
13.3 EFFECT TRANSFER OF RESPONSIBILITY	1	13.3.1 13.3.2	A A	V III	9.4 6.0	75	14/Flt 7/Flt	LATERAL BORROWING	FAIL-OPERATIONAL

TABLE 5.4-11 INDIVIDUAL FAILURE ANALYSIS - POSITION III: FLIGHT SURVEILLANCE AND CONTROL (Transition Hub Center) (Cont'd)

SUBFUNCTION	FAILURE CLASS	TASKS	M/A	AI	PERFORMANCE DATA			FAILURE STRATEGY	RESULT
					MAN TASK TIME	IPS	FREQUENCY		
16.1 DESCRIBE EMERGENCY SITUATION	(E N T I R E L Y M A N U A L)								
16.2 DETERMINE REQUIRED RESPONSE	(E N T I R E L Y M A N U A L)								

5.4.4 Large-Scale Failures

As a final step in failure analysis, an examination was made of situations in which there would be a large-scale loss of automated resources. Each position at each facility was subjected to more and more massive failures, starting with the loss of an entire module of data processing capacity and increasing to a level where all modules serving the position were presumed to have failed. The method of analysis and the procedure for selecting the appropriate remedial strategy were the same as for individual failures. The general findings are discussed below. A case-by-case tabulation is presented beginning on page 5.4-45.

Except for facilities conducting traffic surveillance and control (Position III), which are discussed later, the system can be maintained at the fail-operational level even in the face of massive failures involving the loss of all modules for a position-facility combination. This resillience is brought about by two factors. First is the ability of the Continental Control Center (CCC) to back up the flight information and flight plan processing functions of the Transition Hub Centers (THC). The data base needed for these functions at THC's (Positions IB and IIA) is maintained at the CCC; and, in a sense, the THC's act as distribution and individualized processing centers for CCC generated information. Thus, it represents no great reconfiguration of the system to have the CCC extend its range of functions to embrace those performed by Position IB or Position IIB at a THC afflicted with massive failure. The second factor is the centralized placement of reserve capacity at RCC's and the CCC. Because these reserves are centralized, they can be committed as blocks to provide mutual support in the event of large-scale losses. Thus, the RCC's can back up the CCC and vice versa. Also, the CCC can back itself up, in the sense that the reserves of one position can be used to replace those lost by another.

The CCC conducts two types of operations: maintenance of the system data base (Position IA) and flow control (Position IIB), with the former requiring about twenty times the data processing capacity of the latter. All the reserves of the CCC are nominally associated with Position IA and amount to 10% of that required for normal data base activities. If there is a failure of all modules performing Position IIB activities, the reserves associated with Position IA are, therefore, more than adequate to assume these activities and restore the system to a fail-operational state. Failure of modules associated with Position IA calls for a more complicated set of strategies. If 1-9 modules are lost, the reserves of the CCC are called into play (Redundancy). If between 10 and 89 modules are lost, the strategy is a combination of redundancy (use of CCC reserves) and reduction to essential operations. If all 100 modules associated with Position IA are lost, the strategy of vertical borrowing is employed, and the reserves of both RCC's are committed to performing essential Position IA functions. In all cases, the system is able to maintain a fail-operational state since the only operations eliminated are those related to Class 5 services, which are by definition critical to neither safety nor capacity/efficiency.

The back up facility for Position IB and Position IIA operations at Transition Hub Centers is the CCC. The reserves of the CCC are adequate to make up for the complete loss of modules for either THC activity or even both. Position IB requires 2 module per THC, and Position IIA requires 7 modules. Thus, even if both positions suffered massive failure, vertical borrowing of the 9 reserve modules of the CCC would be sufficient to restore the system to a fail-operational condition.

Position III functions (flight surveillance and control) are performed at four types of facilities: RCC's for enroute traffic, Primary Terminals, Secondary Terminals, and THC's for secondary terminals with unmanned towers. Large-scale failures at each type of facility were examined.

For loss of up to 10 modules, each RCC is able to compensate by drawing on its own reserves. For failures of 11-20 modules, the reserves of both RCC's are required. Loss of 21-29 modules necessitates the commitment of reserves from both RCC's and the CCC. In all cases, the system can be restored to a fail-operational state, although in the last case (loss of 21-29 modules) it is at the cost of committing all the available centralized reserves of the system. Failures beyond this level, the loss of up to 100 modules, require a combination of strategies -- use of the RCC's own reserves, vertical borrowing of reserves from the other RCC and the CCC, and reduction to essential operations at the RCC where the failure has occurred.

It will be recalled that each RCC was assumed to consist of 100 enroute sectors, grouped into ten operating divisions made up of ten sectors each. Failure of 100 modules amounts to loss of automated resources in one entire ten sector division. This is a massive failure; and to restore operations requires cutting back to a fail-soft condition in the affected division and six others, making a total of 70 sectors that are forced to operate at some reduced capacity and/or efficiency. However, this condition is stable, in that no services of Class 1 or 2 are eliminated, and the reduction of capacity and/or efficiency would probably not be great. The activities eliminated in order to compensate for failure are those in Subfunction 7.1, Predict Long-Term Conflicts Among Flight Plans. This subfunction is backed up functionally by 7.2, 7.3, 8.1, and 8.2, which leads to the conclusion that the fail-soft condition can be maintained and that the overall efficiency of the use of enroute airspace would not be seriously impaired.

Failures of more than 100 modules in Position III at the RCC were not considered. Good design practice indicates that a facility this large should have its resources compartmentalized, perhaps along divisional lines, so that failure effects can be kept isolated. For this reason, simultaneous massive failure in two divisions was considered to be a low probability event which need not be investigated. For the same reason, catastrophic failure of the entire RCC was not treated as a credible possibility.

Large-scale failures at primary and manned secondary terminals result in shut-down of the facility, with the rerouting of traffic being assumed by the RCC having jurisdiction over the area. Primary terminals require 4 modules to conduct flight surveillance and control functions, and manned secondary terminals require 1 module. Thus, the RCC with 10 reserve modules would be adequate to deal with simultaneous massive failures at 2 primary terminals or up to 10 secondary terminals. The immediate condition at the terminal suffering complete failure would be fail-hard, but as the RCC intervention began to make itself felt, the level of service would gradually upgrade to fail-soft and then fail-operational as the area of the affected terminal was cleared of traffic.

If this eventuality seems unattractive, there is an alternative. Completely redundant, stand-by data processing resources could be provided at all terminals, at selected terminals, or for clusters of terminals. This would be a rather uneconomical use of resources; but if the cost seemed justified on safety grounds, full redundancy could be the way to shore up the system at a vulnerable point. No recommendation is offered on this matter since it is a question of design philosophy and system economics, which lie outside the scope of the present investigation. However, it will be mentioned, as a way of setting the question in perspective, that providing fully redundant resources at all terminals to guard against massive failures would entail almost a 32% increase in the machine complement of the system.

Large-scale failure of machine resources at a Transition Hub Center can be dealt with in a slightly more flexible manner, largely because the THC is a more centralized facility than either a primary or secondary terminal. Each THC will be responsible for about 11 or 12 low-volume secondary terminals with unmanned towers. Loss of 1 module (of the 10 available) would allow the THC to continue operations at a fail-soft level by making use of its remaining resources and eliminating Subfunction 7.1, Predict Long-Term Conflicts Among Flight Plans. Similarly, loss of 2-5 modules (i.e., up to half of the resources of the THC) could be dealt with by the facility itself. This would involve shutting down some terminals in its jurisdiction and rerouting traffic to the others. The initial result would be a fail-hard condition at the closed terminals and a fail-soft condition elsewhere, with the situation gradually rising to fail-soft for all airspace users in the THC area as the traffic was sorted out. Failures of more than 5 modules would be tantamount to losing the entire facility, and the strategy to be followed would be like that for primary and manned secondary terminals. All terminals in the THC area would be closed and the rerouting of traffic would be transferred to the appropriate RCC.

Tables 5.4-12 through 5.4-19 on the following pages present the details of the large-scale failure analysis for each position and facility.

TABLE 5.4-12 LARGE-SCALE FAILURE ANALYSIS - POSITION IA

POSITION IA: DATA BASE

SITE: CCC

FAILURE CLASS RANGE: 2-5

AVAILABLE MODULES: 91 + 9 spares = 100

IPS REQUIRED BY EACH OPERATOR: 7231

NO. OPERATORS SERVED BY EACH MODULE: 1

NATURE OF FAILURE	STRATEGY	BACK-UP FACILITY	RESULT	IMPACT ON BACK-UP FACILITY
Loss of 1-9 modules	Redundancy	CCC	Fail-Operational	All CCC reserves used up
Loss of 10-88 modules	Redundancy <u>Plus</u> Reduce to Essentials	CCC	Fail-Operational	Subfunction 17.10 (Compile Traffic Summaries) eliminated
Loss of 89-100 modules	Vertical Borrowing	RCC's	Fail-Operational	All RCC reserves committed to performing Class 2-4 functions for CCC with Class 5 functions eliminated

TABLE 5.4-13 LARGE-SCALE FAILURE ANALYSIS - POSITION IB

POSITION IB: FLIGHT INFORMATION

SITE: THC

FAILURE CLASS RANGE: 3-5

AVAILABLE MODULES: 2 per Site

IPS REQUIRED BY EACH OPERATOR: 353

NO. OPERATORS SERVED BY EACH MODULE: 17

NATURE OF FAILURE	STRATEGY	BACK-UP FACILITY	RESULT	IMPACT ON BACK-UP FACILITY
Loss of 1 module	Vertical Borrowing	THC (Position IIA)	Fail-Operational	All reserves of THC committed
Loss of 2 modules	Vertical Borrowing	RCC or CCC (Position IA)	Fail-Operational	2 spare modules of RCC or CCC committed to THC

TABLE 5.4-14 LARGE-SCALE FAILURE ANALYSIS - POSITION IIA

POSITION IIA: FLIGHT PLANS

SITE: THC

FAILURE CLASS RANGE: 3

AVAILABLE MODULES: 7 + 1 spare = 8 per site

IPS REQUIRED BY EACH OPERATOR: 593

NO. OPERATORS SERVED BY EACH MODULE: 12

NATURE OF FAILURE	STRATEGY	BACK-UP FACILITY	RESULT	IMPACT ON BACK-UP FACILITY
Loss of 1 module	Redundancy	THC	Fail-Operational	All reserves of THC committed
Loss of 2-7 modules	Vertical Borrowing	RCC or CCC (Position IA)	Fail-Operational	Up to 7 spares of RCC or CCC committed to THC

TABLE 5.4-15 LARGE-SCALE FAILURE ANALYSIS - POSITION IIB

POSITION IIB: FLOW CONTROL

SITE: CCC

FAILURE CLASS RANGE: 3

AVAILABLE MODULES: 5

IPS REQUIRED BY EACH OPERATOR: 1281

NO. OPERATORS SERVED BY EACH MODULE: 5

NATURE OF FAILURE	STRATEGY	BACK-UP FACILITY	RESULT	IMPACT ON BACK-UP FACILITY
Loss of 1-5	Vertical Borrowing	CCC (Position IA)	Fail-Operational	Up to 5 spares of CCC (Position IA) committed to flow control activities

TABLE 5.4-16 LARGE-SCALE FAILURE ANALYSIS - POSITION III (RCC)

POSITION III: FLIGHT SURVEILLANCE AND CONTROL

AVAILABLE MODULES: 1000 + 10 spares per site

SITE: RCC

IPS REQUIRED BY EACH OPERATOR: 35,140

FAILURE CLASS RANGE: 1-3

NO. MODULES REQUIRED PER OPERATOR: 5

NATURE OF FAILURE	STRATEGY	BACK-UP FACILITY	RESULT	IMPACT ON BACK-UP FACILITY
Loss of up to 10 modules	Redundancy	RCC	Fail-Operational	Up to 10 of RCC spares committed
Loss of 11-20 modules	Redundancy	RCC #1 Plus RCC #2	Fail-Operational	All reserves of both RCC's committed
Loss of 21-29 modules	Redundancy Plus Vertical Borrowing	RCC #1, RCC #2 Plus CCC	Fail-Operational	All reserves of the system committed
Loss of 100 modules	Redundancy Plus Vertical Borrowing Plus Reduce to Essentials	RCC #1 RCC #2, CCC RCC #1	Fail-Soft	All reserves of the system committed and RCC #1 reduced to Fail-Soft condition in 70 of 100 sectors

TABLE 5.4-17 LARGE-SCALE FAILURE ANALYSIS - POSITION III (Primary Terminal)

POSITION III: FLIGHT SURVEILLANCE AND CONTROL

SITE: PRIMARY TERMINAL

FAILURE CLASS RANGE: 1-3

AVAILABLE MODULES: 4 per site

IPS REQUIRED BY EACH OPERATOR: 6725

NO. OPERATORS SERVED BY EACH MODULE: 1

NATURE OF FAILURE	STRATEGY	BACK-UP FACILITY	RESULT	IMPACT ON BACK-UP FACILITY
Loss of 1 module	Internal Reserves Plus Reduce to Essentials	Self	Fail-Soft	All reserves of terminal committed and operations reduced to fail-soft level
Loss of 2-4 modules	Close terminal and Transfer control of aircraft to RCC	RCC	Fail-Hard	4 modules at RCC committed to rerouting traffic from closed terminal

TABLE 5.4-18 LARGE-SCALE FAILURE ANALYSIS - POSITION III (Secondary Terminal)

POSITION III: FLIGHT SURVEILLANCE AND CONTROL

AVAILABLE MODULES: 1 per site

SITE: SECONDARY TERMINAL

IPS REQUIRED BY EACH OPERATOR: 3046

FAILURE CLASS RANGE: 1-3

NO. OPERATORS SERVED BY EACH MODULE: 2

NATURE OF FAILURE	STRATEGY	BACK-UP FACILITY	RESULT	IMPACT ON BACK-UP FACILITY
Loss of 1 module	Close terminal and transfer control of aircraft to RCC	RCC	Fail-Hard	1 module of RCC committed to rerouting traffic from closed terminal

TABLE 5.4-19 LARGE-SCALE FAILURE ANALYSIS - POSITION III (THC)

POSITION III: FLIGHT SURVEILLANCE AND CONTROL

AVAILABLE MODULES: 10

SITE: SECONDARY TERMINAL

IPS REQUIRED BY EACH OPERATOR: 7812

FAILURE CLASS RANGE: 1-3

NO. OPERATORS SERVED BY EACH MODULE: 0.9

NATURE OF FAILURE	STRATEGY	BACK-UP FACILITY	RESULT	IMPACT ON BACK-UP FACILITY
Loss of 1 module	Reduce to Essentials	Self	Fail-Soft	Operations reduced to fail-soft level by elimination of Subfuncton 7.1
Loss of 2-5 modules	Close terminals as necessary and absorb traffic at remainder or reroute	Self	Fail-hard at closed terminals Fail-soft elsewhere	Operations reduced to safety essentials for the remainder
Loss of 10 modules	Close all terminals under THC jurisdiction and transfer control of aircraft to RCC	RCC	Fail-Hard	All reserves of RCC committed to handling THC traffic

6.0 CONTROL AND DISPLAY REQUIREMENTS

This chapter presents the results of an analysis of the requirements for operator displays and controls in an extensively automated air traffic management system. After a statement of the objective and description of the method of analysis, the information requirements for displays and the action requirements for controls are given for each AATMS operator position. The chapter concludes with a brief characterization of the AATMS man-machine interface.

6.1 OBJECTIVE

The objective of the control and display requirements analysis was to produce a generic description of the requirements for the AATMS man-machine interface. The term "generic" implies, as in the case with other study products, a set of guidelines for functional performance rather than a specific physical design. The principal utility of the generic approach is that preemptive suppositions about the physical nature of the system are avoided. Thus, maximum freedom is given in the exploration of different design approaches without altering the basic statement of requirements for interactions between human operators and machines.

6.2 DERIVATION OF CONTROL AND DISPLAY REQUIREMENTS

For purposes of analysis, the system was defined to consist of a particular set of tasks, some of which are to be performed by human operators and some by machines. Tasks are the constituents of functions; to perform a function thus requires carrying out a number of tasks. Because some will be done by machines and others by men, the men and machines in the system have, therefore, a form of symbiosis, or joint partnership. The relationship is schematically illustrated in Figure 6.2-1.

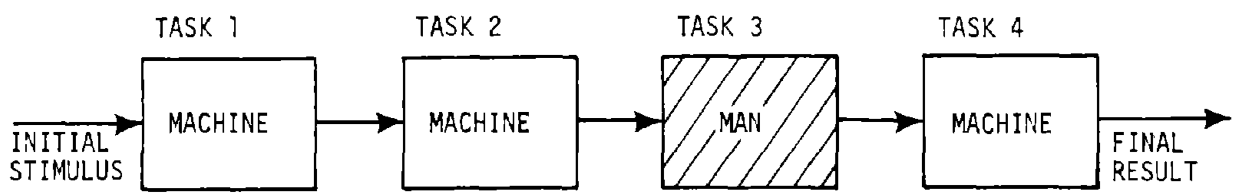

FIGURE 6.2-1 SCHEMATIC MAN-MACHINE TASK ALLOCATION

The boxes in the figure represent tasks, the arrows represent the flow of a product or process. The state of affairs that elicits the performance, called the initial stimulus, is at the left. Carrying out Tasks 1, 2, 3 and 4 transforms that initial state to a final result. A simplified example in an air traffic management system might be that a machine senses present aircraft position and direction (Task 1); a machine compares that information with the aircraft's flight plan (Task 2) -- finding that if the situation continues, the aircraft will deviate from its planned path; a man (Task 3) has the responsibility for finding the pilot's preference, i.e., does the pilot want to change his plan or to correct for the predicted deviation; and a machine is assigned to implement the resulting decision (Task 4).

The effect of such a sharing of responsibility between men and machines is that the two system resources become linked in a chain of interim processes extending from a given initial situation to the final outcome. Neither can function in isolation. The man who does Task 3 in the example cannot perform if he is not given the information that a predicted deviation from the aircraft's flight plan exists. The machine responsible for carrying out Task 4 cannot perform unless some means are provided for the man to communicate the pilot's decision either to return to the original flight plan or to get a new flight plan.

Thus, there exists a set of tasks that are not inherent in the management of air traffic. Instead, they are induced by the man-machine allocations. These induced tasks were the basis for the determination of generic display and control requirements in AATMS.

6.2.1 Induced Tasks

There are four kinds of induced tasks in the system:

- Display
- Control
- Coordinate
- Communicate

Figure 6.2-2 illustrates the nature of these induced tasks.

The boxes in the figure show human and automated system resource units, with the aircraft pilot represented by a circle. A, B, and C designate the various induced task relationships. In "A", a task has been allocated to a machine with its successor to be performed by a man. An induced display task is created. In situation B, a human operator does a task, with a machine doing the next. The man passes data and instructions to the machine in an induced control task. Situation C represents the interchange of information between human operators (coordinate) and between a ground operator and the pilot (communicate). It should be noted that while both coordination and communication will likely be done through a mechanized subsystem, the arrows do not imply specific physical means. They simply indicate that some information required by a man to do his task is obtained from another operator or the pilot or that some product of a manual task is given to another human operator or the pilot, not to a machine.

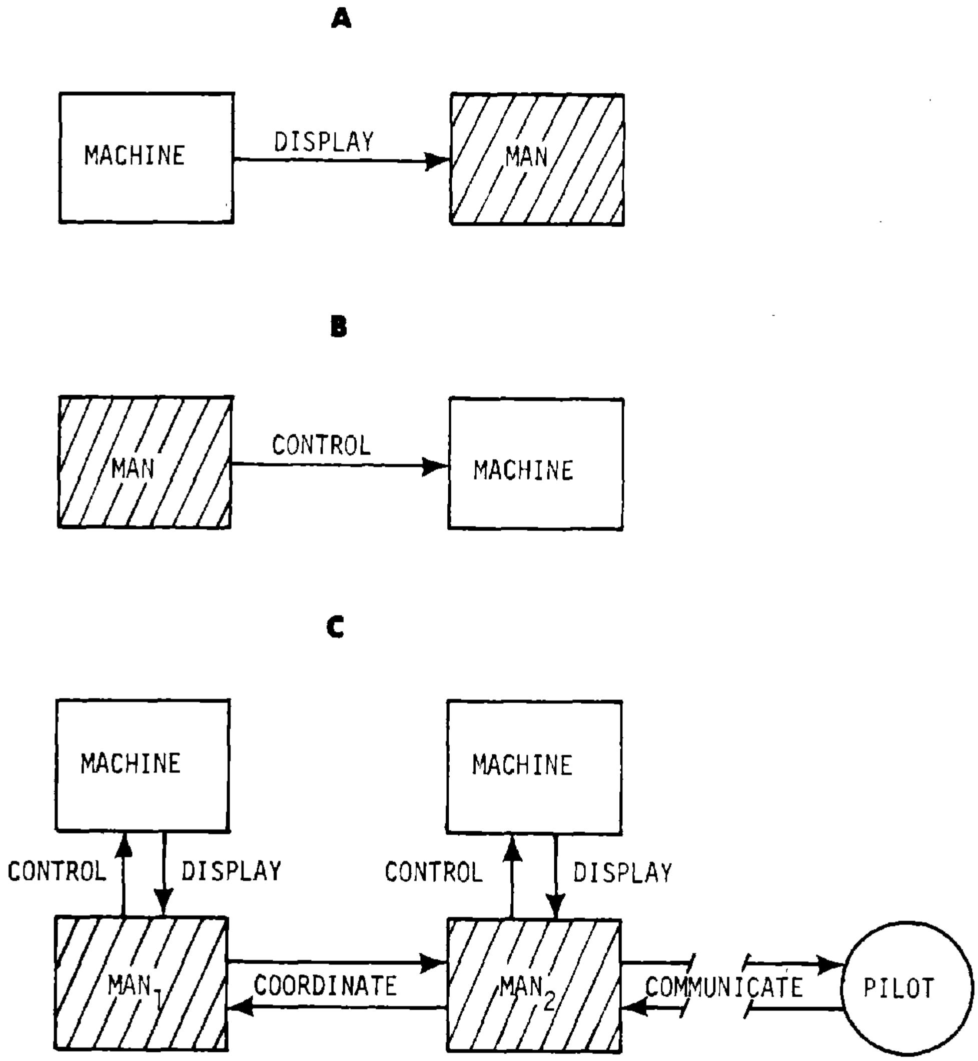

FIGURE 6.2-2 INDUCED TASKS

6.2.2 Position Descriptions

Position descriptions for each system resource unit (human operator and machine) were derived in this study. (The derivation is discussed in Chapter 2 of this volume.) The descriptions provide, in detail, the functional responsibilities assigned to each resource unit. Since the functions encompass all generic tasks, enumeration of the induced tasks was done using the position descriptions as one input.

6.2.3 Generic Automation Level

The other input for enumerating induced tasks was the recommended automation level, which allocates each generic task either to men or machines. Since the task interrelationships are an explicit part of the system functional description, each of the types of induced tasks, display, control, coordinate and communicate, could be defined for the interface between human operators and machines of each of the specified system operator positions. Thus, the necessary data base from which to derive system control and display requirements was created.

6.3 DISPLAY REQUIREMENTS

On the basis of induced display tasks identified for each operator position, two types of display requirements were derived: a listing of the required information for each display and recommendations concerning display format.

Information requirements were obtained by specifying the content of information inputs for each display task. This was done by studying system flow diagrams and task input-output matrices developed in the function analysis. Display format recommendations were drawn from a format classification rubric, illustrated schematically in Figure 6.3-1.

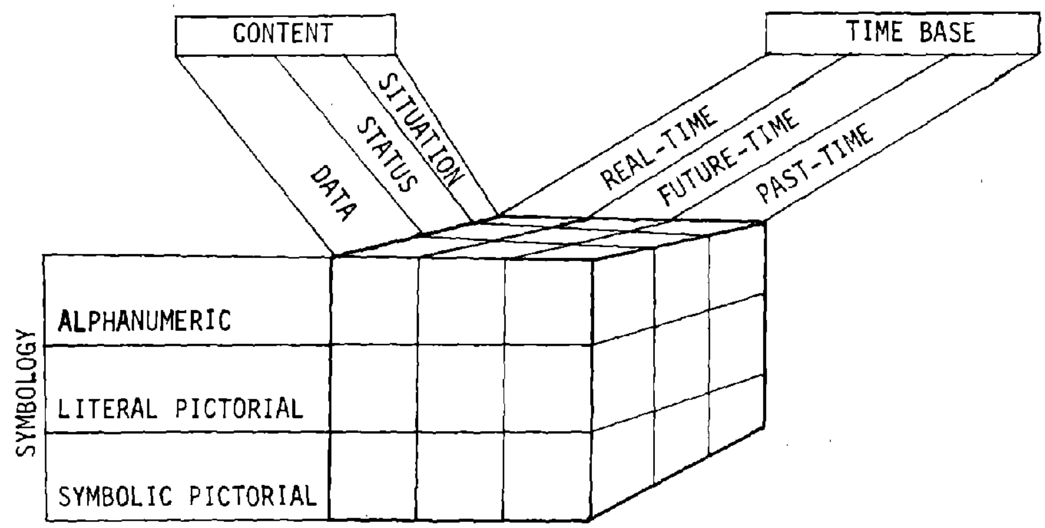

FIGURE 6.3-1 DISPLAY FORMAT ATTRIBUTIONS

While avoiding specific discussion of physical design, it was felt that each display specification should include a recommended set of attributions concerning its format. Figure 6.3-1 shows the three kinds of attributions which were made. First, the content of the display was categorized by determining whether the display information related to a situation, to the status of the system or its users, or to operational data of some sort. Next, the time base of the display was determined by indicating whether the display relates to real-time or non-real time, past or future. Finally, a recommended symbology was ascribed to each display. The symbology relates to the basic encoding scheme for each displayed information item. "Alphanumerics" includes decimal-coded arabic numbers and the English alphabet with related symbols. Alphanumerics also include verbal displays like speech. A "literal pictorial" display is a target return from the system's sensors, or similar real-world pictorial presentation. Symbolic pictorial displays are synthetic: route symbols, velocity vectors, and the like.

The tables beginning on the following page present the system display requirements and recommendations by operator position. Each operator responsibility is listed, with all tasks that involve displays given for each responsibility. Next, the tables present the information item or items required for each display. The display format recommendations are given in columnar form. The column headings indicate the symbological basis (or bases) of the display. Multiple column entry indicate requirements for several symbologies for single item. Entries pertaining to the nature and time-base of the display are presented within columns, according to the following key:

D = Data

SI = Situation

ST = Status

RT = Real Time

FT = Future Time

PT = Past Time

Note that the tables also indicate whether the task is performed routinely or in exceptional circumstances. "Coordination" tasks with other positions and "communication" with pilots are labelled.

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION

POSITION NUMBER AND NAME: IA, DATA BASE

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
• PREPARE REPORTS				
(R) a) Detect information requiring operational report (14.1.1)	1) Operational report information (exog.)	SI,RT/PT	SI,RT/PT	SI,RT/PT
	2) Rules and procedures	D,RT	D,RT	D,RT
	3) Transmitted clearance	ST,RT/PT	ST,RT/PT	ST,RT/PT
	4) Current ACFT status	ST,RT		
	5) Present out-of-tolerance deviations		SI,RT	SI,RT
	6) High-imminence conflict pairs	SI,RT	SI,RT	SI,RT
	7) Not responding, retransmit	SI,RT	SI,RT	SI,RT
	8) Actual time-position profile		SI,RT/PT	SI,RT/PT
(R) b) Retrieve additional information (14.1.5)	1) Identification of missing information	D,RT		
(N) c) Develop format (14.3.3)	1) No report format available	SI,RT		
	2) Request for special format (exog.)	SI,RT		
• MAINTAIN WEATHER INFORMATION				
(R) a) Determine if weather observation report required (17.1.1)	1) PIREPS	D,RT*		
	2) Weather sensor data (exog.)	D,RT		D,RT
	3) Weather observation/report schedule (exog.)	D,FT		
(R) b) Determine if supplemental data required (17.1.2)	1) Weather observation/report criteria (exog.)	D,RT		

SI = Situation   RT = Real Time   R = Routine Task

ST = Status   FT = Future Time   N = Non-Routine Task

D = Data   PT = Past Time   * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IA, DATA BASE

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
(R) c) Request PIREP (17.1.3)	1) Correlated position/I.D. (6.1.5C)		D,RT	D,RT
(R) d) Receive supplemental data (17.1.4)	1) PIREPS	D,RT*		
(R) e) Make weather observation report (17.1.5)	1) Weather sensor data (exog.) 2) Weather observation report schedule (exog.)	D,RT D,FT		D,RT
● MAINTAIN DATA BASE				
(N) a) Purge affected user class data base item (17.9.4)	1) Affected data base item	D,RT		

SI = Situation   RT = Real Time   R = Routine Task
ST = Status   FT = Future Time   N = Non-Routine Task
D = Data   PT = Past Time   * = From Pilot
C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IB, FLIGHT INFORMATION SERVICES

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
• FLIGHT PLANNING INFORMATION AND RELATED INFORMATION				
(R) a) Accept "telephone" request (1.1.2)	1) Request for information	SI,RT*		
(R) b) Retrieve information requested (1.2.2)	1) Stored weather sequences	D,RT		
	2) Stored severe weather phenomena	D,RT	D,RT	D,RT
	3) Stored weather forecasts	D,FT		
	4) Stored weather charts	D,RT		D,RT
	5) Stored traffic data	D,RT/PT		
	6) Rules and procedures	D,RT	D,RT	D,RT
	7) COMM/NAV system status	ST,RT		
	8) Ground facilities status	ST,RT		
	9) Stored user class data base items	D,RT		
	10) Flight hazards information	D,RT	D,RT	D,RT
	11) Route information	D,RT	D,RT	D,RT
	12) Stored route summaries	D,RT	D,RT	D,RT
(R) c) Compile non-preformatted response (1.3.1)	1) Message format (exog.)	D,RT		
(R) d) Transmit requested information via "telephone" (1.3.3)	1) Preformatted reply, or	D,RT/FT*		
	2) Displayed information (flight planning)	D,RT/FT	D,RT/FT	D,RT/FT

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IB, FLIGHT INFORMATION SERVICES

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
● PROVIDE INFLIGHT ADVISORIES AND INSTRUCTIONS				
(R) a) Receive pilot's request for information (12.1.1)	1) Pilot's information request	SI,RT*		
(R) b) Acknowledge pilot's request (12.1.2)	1) Response message format (exog.)	D,RT		
(N) c) Compile special response to request (12.1.5)	1) Message format (exog.) 2) Information for response, or 3) Information requested not available	D,RT D,RT SI,RT		
(N) d) Transmit special response to pilot (12.1.7)	1) Planned distribution position of ACFT	D,FT	D,FT	D,FT
(R) e) Correlate present position with distribution position (12.2.7)	1) Present position/I.D. (comes both from 6.1.5C and 6.1.1, 6.1.3)		D,RT	D,RT
	2) Advisory distribution list of positions	D,RT	D,RT	D,RT

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
● FLIGHT PLAN REVIEW/APPROVAL				
(R) a) Determine ETOV computation points (4.1.1)	1) Submitted flight plan, or	D,FT*		
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT
	4) Proposed revised flight plan (9.5.7C)	D,FT	D,FT	D,FT
(R) b) Compare flight plan with ACFT capability and status (4.2.1)	1) Submitted flight plan, or	D,FT*		
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT
	4) Proposed revised flight plan (9.5.7C), and	D,FT	D,FT	D,FT
	5) Stored user class data	D,RT		
(R) c) Compare flight plan with operational and environmental conditions (4.2.2)	1) Submitted flight plan, or	D,FT*		
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT
	4) Proposed revised flight plan (9.5.7C), and	D,FT	D,FT	D,FT
	5) Stored weather sequences	D,RT		
	6) Stored weather forecasts	D,FT		
	7) Ground facilities status	ST,RT		
	8) COMM/NAV system status	ST,RT		

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT ALPHA-NUMERIC	DISPLAY FORMAT LITERAL PICTORIAL	DISPLAY FORMAT SYMBOLIC PICTORIAL
	9) Flight hazard information	D,RT	D,RT	D,RT
	10) Route information	D,RT	D,RT	D,FT
	11) Airspace restrictions	D,RT	D,RT	D,FT
	12) Airspace structure and jurisdiction information	D,RT	D,RT	D,RT
(R) d) Compare flight plan with flow control directives and guidelines (4.2.4)	1) Submitted flight plan, or	D,FT*		
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT
	4) Proposed revised flight plan (9.5.7C), and	D,FT	D,FT	D,FT
	5) Terminal release quotas	D,FT		
	6) Enroute release quotas	D,FT		
(R) e) Compare flight plan with rules and procedures (4.2.5)	1) Submitted flight plan, or	D,FT*		
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT
	4) Proposed revised flight plan (9.5.7C), and	D,FT	D,FT	D,FT
	5) Rules and procedures	D,RT	D,RT	D,RT
(N) f) Compare flight plan with flight progress (4.2.6)	1) Submitted flight plan, or	D,FT*		
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
	4) Proposed revised flight plan (9.5.7C), and	D,FT	D,FT	D,FT
	5) Intended time-position profile		D,FT	D,FT
	6) Correlated position/I.D. (6.1.5C)		D,RT	D,RT
	7) Predicted long-range time-position profile		D,FT	D,FT
	8) Present ACFT position		SI,RT	
(R) g) Compare flight plan with user class/pilot qualifications (4.2.7)	1) Submitted flight plan, or	D,FT*		
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT
	4) Proposed revised flight plan (9.5.7C), and	D,FT	D,FT	D,FT
	5) Rules and procedures	D,RT	D,RT	D,RT
(R) h) Compile list of discrepancies between traffic and other flight plans (4.2.8)	1) Traffic and other approved flight plans	D,RT/FT	D,RT/FT	D,RT/FT
(R) i) Determine flight plan priority (4.2.9)	1) Submitted flight plan, or	D,RT/FT		D,RT/FT
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT
	4) Proposed revised flight plan (9.5.7C), and	D,FT	D,FT	D,FT
	5) Rules and procedures	D,RT	D,RT	D,RT

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
	6) Prioritizing criteria (exog.)	D,RT		
(R) j) Determine acceptability of flight plan (4.2.10)	1) Submitted flight plan, or	D,FT*		
	2) Proposed revisions to flight plan, or	D,FT	D,FT	D,FT
	3) Single revision to flight plan, or	D,FT	D,FT	D,FT
	4) Proposed revised flight plan (9.5.7C), and	D,FT	D,FT	D,FT
	5) Approval criteria (exog.)	D,RT		
(R) k) Determine special services required (4.2.13)	1) Rules and procedures	D,RT	D,RT	D,RT
• <u>MODIFY OR ASSIST PILOT TO MODIFY FLIGHT PLANS</u>				
(N) a) Determine responsibility to modify flight plan (4.3.2)	1) Changes in flight plan to make it acceptable	D,FT	D,FT	D,FT
	2) Rules and procedures	D,RT	D,RT	D,RT
(N) b) Inform pilot of unacceptable flight plan (4.3.3)	1) Changes to flight plan that will make it ok	D,FT	D,FT	D,FT
(N) c) Compile modified flight plan (4.3.4)	1) Changes to make flight plan ok	D,FT	D,FT	D,FT

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
● ASSIGN RESPONSIBILITY FOR CONTROL, ASSIGN COMMUNICATIONS CHANNELS				
(N) a) Receive/enter pilot's response (4.4.1)	1) Pilot's response	D,RT*		
(R) b) Designate responsible ATM jurisdiction (4.4.3)	1) Airspace structure and jurisdiction information	D,RT	D,RT	D,RT
	2) Ground facilities status	ST,RT		
	3) Intended time-position profile	D,FT	D,FT	D,FT
(R) c) Designate communications links between ATM and ACFT (4.4.4)	1) Airspace structure and jurisdiction information	D,RT	D,RT	D,RT
	2) Ground facilities status	ST,RT		
	3) COMM/NAV system status	ST,RT		
	4) Intended time-position profile	D,FT	D,FT	D,FT
● REVIEW/APPROVE REQUESTS FOR SPECIAL/ANCILLARY SERVICES				
(N) a) Compile/update description of special services required (15.1.1)	1) Request for special service	D,RT*		
● ACT TO PROVIDE SPECIAL/ ANCILLARY SERVICES, MONITOR PROGRESS				
(N) a) Monitor progress of service (15.1.2)	1) Progress of service (ACFT or Exog.)	D,RT/PT*		

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
(N) b) Determine requirement for special flight plan priority (15.2.1)	1) Rules and procedures	D,RT	D,RT	D,RT
(N) c) Establish area of restriction (15.2.2)	1) Rules and procedures	D,RT	D,RT	D,RT
(N) d) Determine guidance service required (15.2.3)	1) Rules and procedures	D,RT	D,RT	D,RT
(N) e) Determine special separation minima (15.2.4)	1) Rules and procedures	D,RT	D,RT	D,RT
(N) f) Determine advisories required (15.2.5)	1) Rules and procedures	D,RT	D,RT	D,RT
(N) g) Determine necessity for issuance of NOTAMS (15.2.6)	1) Rules and procedures	D,RT	D,RT	D,RT

SI = Situation RT = Real Time R = Routine Task
ST = Status FT = Future Time N = Non-Routine Task
D = Data PT = Past Time * = From Pilot
C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIB, FLOW CONTROL

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
● DETERMINE CAPACITY				
(R) a) Select terminal/jurisdiction and time period (2.1.1)	1) Terminal/jurisdiction information	D,RT	D,RT	D,RT
	2) Time period range	D,RT		
(R) b) Determine effects of weather on capacity (2.1.2)	1) Stored weather sequences	D,RT		
	2) Stored severe weather phenomena	D,RT	D,RT	D,RT
	3) Stored weather forecasts	D,FT		
	4) Stored route summaries	D,RT	D,RT	D,RT
	5) Rules and procedures	D,RT	D,RT	D,RT
(R) c) Determine effects of airspace restrictions on capacity (2.1.3)	1) Airspace restrictions	D,RT	D,RT	D,RT
	2) Rules and procedures	D,RT	D,RT	D,RT
(R) d) Determine effects of ground equipment capabilities and status on capacity (2.1.4)	1) Ground facilities status	D,RT		
	2) Rules and procedures	D,RT	D,RT	D,RT
(R) e) Determine effects of flight hazards on capacity (2.1.5)	1) Flight hazards information	D,RT	D,RT	D,RT
	2) Rules and procedures	D,RT	D,RT	D,RT
(R) f) Determine total effect on capacity (2.1.6)	1) Rules and procedures	D,RT	D,RT	D,RT

SI = Situation   RT = Real Time   R = Routine Task

ST = Status   FT = Future Time   N = Non-Routine Task

D = Data   PT = Past Time   * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: III, FLIGHT SURVEILLANCE AND CONTROL

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
• COMPILE, ISSUE CLEARANCES				
(R) a) Determine if I.D. code is required (5.1.1)	1) Clearance issued	ST,RT/FT	ST,RT/FT	ST,RT/FT
	2) Accepted flight plan (4.4.1C)	D,RT/FT		D,RT/FT
	3) I.D. code usage procedures (exog.)	D,RT		
(N) b) Determine pilot intent following missed approach (5.1.3)	1) Missed approach indicator		SI,RT	SI,RT
	2) Pilot intent (from ACFT)	SI,RT/FT*		
• MONITOR FLIGHT PROGRESS				
(N) a) Request I.D. (6.1.4)	1) Request message format (exog.)	D,RT		
	2) Present ACFT position		SI,RT	
	3) No correlation indicator			SI,RT
(N) b) Assign arbitrary I.D. (6.1.5)	1) No response to request indicator	SI,RT		SI,RT
	2) Present ACFT position		SI,RT	
	3) No correlation indicator			SI,RT
• FLIGHT PLANS CONFORMANCE				
(R) a) Specify time period to be checked (7.1.1)	1) System capability to perform check (exog.)	D,RT		
	2) Active flight plan count	D,RT		
(N) b) Inform pilot of present deviations from flight plan (7.4.2)	1) Short-range deviations		SI,FT	SI,FT
	2) Present deviations		SI,RT	SI,RT
	3) Long-range deviations		SI,FT	SI,FT

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: III, FLIGHT SURVEILLANCE AND CONTROL

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
(N) c) Receive pilot's response on deviation (7.4.3)	1) Correct to original flight plan, or	SI,RT*		
	2) Revise flight plan	SI,RT*		
• SPACING CONTROL				
(N) a) Submit performance changes to clearance function (within flight plan) (9.5.5)	1) Performance change ok within existing flight plan	SI,FT	SI,FT	SI,FT
(N) b) Propose revised flight plan to implement sequence/schedule change (9.5.6)	1) Performance change requires flight plan modification	SI,FT	SI,FT	SI,FT
	2) Accepted flight plan (4.4.1C)	D,RT/FT		D,RT/FT
	3) Current ACFT capabilities	D,RT		
• HANDOFF				
(N) a) Receive pilot request for transfer of responsibility (13.1.4)	1) Pilot request	SI,RT*		
	2) Rules and procedures	D,RT	D,RT	D,RT
	3) Airspace structure		D,RT	D,RT
(R) b) Determine if communication channel change is required (13.2.1)	1) Accepted flight plan (4.4.1C)	D,RT		D,RT
	2) Airspace structure		D,RT	D,RT
	3) COMM/NAV system status	ST,RT		
	4) Assignment paradigm (exog.)	D,RT		
	5) Handoff acceptable	SI,RT	SI,RT	SI,RT

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: III, FLIGHT SURVEILLANCE AND CONTROL

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
• EMERGENCIES				
(N) a) Determine adequacy of emergency description (16.1.1)	1) Description of emergency	SI,PT/RT/FT		
(N) b) Request additional information on emergency (16.1.2)	1) Description of emergency	SI,PT,RT*/FT*		
(N) c) Compile/update description of emergency (16.1.3)	1) "Unable to issue clearance" indicator	SI,RT	SI,RT	SI,RT
	2) Not responding, declare emergency	SI,RT		
	3) Description of emergency	SI,PT,RT,FT*		
	4) Information not available (12.1.4C)	SI,RT		
	5) Information regarding progress (from ACFT/exog.)	D,RT*	D,RT	D,RT
	6) Additional required information (from ACFT/exog.)	D,RT*		
	7) Emergency ended (6.4.2C)	SI,RT*		
(N) d) Determine ACFT to provide assistance (16.2.3)	1) Current ACFT capability	D,RT		
	2) Correlated I.D., position (6.1.5C)		D,RT	D,RT

SI = Situation RT = Real Time R = Routine Task
ST = Status FT = Future Time N = Non-Routine Task
D = Data PT = Past Time * = From Pilot
C = Coordination with another position

TABLE 6.3-1 DISPLAY REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: III, FLIGHT SURVEILLANCE AND CONTROL

APPLICABLE RESPONSIBILITY/ TASK	INFORMATION ITEM	DISPLAY FORMAT		
		ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
(N) e) Develop emergency flight plan (16.2.6)	1) Proposed revision to emergency flight plan	D,FT	D,FT	D,FT
	2) Accepted flight plan (4.4.1C)	D,RT/FT		D,RT/FT
	3) Ground facilities status	ST,RT		
	4) Stored weather sequences	D,RT		
	5) Stored weather forecasts	D,FT		
(N) f) Determine requirement for use of emergency communications link (16.2.7)	1) Communications links to be used between ACFT and ATM (4.4.4C)	D,RT		

SI = Situation RT = Real Time R = Routine Task

ST = Status FT = Future Time N = Non-Routine Task

D = Data PT = Past Time * = From Pilot

C = Coordination with another position

6.4 CONTROL REQUIREMENTS

System control requirements, by operator position, are presented in Table 6.4-1, which follows. For convenience in associating displays and controls, the table of control requirements is formatted in the same way as the display table, with the same conventions for indicating routine/non-routine task performance, and coordination with other operators and communications with pilots. Since a different paradigm was used for deriving control recommendations, the columnar presentation at the right of the table is not the same as that used for displays.

A given control can be any of three types, or some combination. It can be an alpha-numeric control, like a keyboard. It might also be a discrete control, like a mode switch or an on-off control. Third, it might be an analog control, with some continuously variable value. Control recommendations are classified according to this scheme by the three column headings in Table 6.4-1.

Whatever the control type might be, it can be used for one of two purposes: (1) passing data to the machine for use in performing some routine or calculation, or (2) passing to the machine instructions that are the results of a calculation or decision made by the operator. Accordingly each control is identified by type and also by use - "D" for data, "I" for instructions.

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION

POSITION NUMBER AND NAME: IA, DATA BASE

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
o PREPARE REPORTS				
a) Detect information requiring operational report (14.1.1)	1) Operational report required	D	D	
b) Retrieve additional information (14.1.5)	1) Request additional information (to exog.)	D		
c) Develop format (14.3.3)	1) Report format	D		
o MAINTAIN WEATHER INFORMATION				
a) Request PIREP (17.1.3)	1) Request for PIREP	I*		
b) Make weather observation report (17.1.5)	1) Weather observation report	D		

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IB, FLIGHT INFORMATION

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
● FLIGHT PLANNING INFORMATION AND RELATED INFORMATION				
a) Enter request into system (1.1.3)	1) Category of information	D	D	
	2) Location or geographic area	D		D
b) Compile non-preformatted response (1.3.1)	1) Compile response	D/I		D/I
c) Transmit requested information via "telephone" (1.3.3)	1) Transmitted telephone message	D/I*		
● PROVIDE INFLIGHT ADVISORIES AND INSTRUCTIONS				
a) Enter pilot request (12.1.1)	1) Pilot request	I		
b) Acknowledge pilot request for information (12.1.2)	1) Acknowledgement of request	D*		
c) Transmit special response to pilot (12.1.7)	1) Specially formatted message (goes also to 14.2.1)	D/I*		
d) Correlate present position with distribution position (12.2.7)	1) ACFT at distribution position	D	D	D

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
• FLIGHT PLAN REVIEW/ APPROVAL				
a) Determine ETOV computation points (4.1.1)	1) Points for computation of ETOVs	D		D
b) Compile list of discrepancies (4.2.8)	1) List of discrepancies	D		
c) Determine flight plan priority (4.2.9)	1) Priority of proposed flight plan	D		
d) Determine acceptability of flight plan (4.2.10)	1) Unacceptable flight plan 2) Approved flight plan	D D	D D	
e) Inform pilot of flight plan approval (4.2.12)	1) Flight plan approval information	D*		
• MODIFY OR ASSIST PILOT TO MODIFY FLIGHT PLANS				
a) Inform pilot flight plan unacceptable (4.3.3)	1) Flight plan disapproval information	D		
b) Compile modified flight plan (4.3.4)	1) Modified flight plan	D		

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
● ASSIGN RESPONSIBILITY FOR CONTROL, ASSIGN COMMUNICATIONS CHANNELS				
a) Revise/enter pilot's response (4.4.1)	1) Accepted flight plan (5.1.1C, 9.5.6C, 13.2.1C, 16.2.6C)	D		
b) Cancel flight plan (4.4.2)	1) Cancellation of flight plan	I		
c) Designate communications links between ATM and ACFT (4.4.4)	1) Communications links between ATM and ACFT (7.4.2C, 16.2.7C)	D		
● ACT TO PROVIDE SPECIAL/ ANCILLARY SERVICES, MONITOR PROGRESS				
a) Monitor progress of service (15.1.2)	1) Service no longer required 2) Cease action because of safety	D I*		
b) Establish area of restriction (15.2.2)	1) Definition of area of restriction	D		D
c) Determine guidance service required (15.2.3)	1) Description of guidance required	D		D
d) Determine special separation minima (15.2.4)	1) Definition of special separation minima	D		D

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIA, FLIGHT PLANS

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
e) Determine advisories required (15.2.5)	1) Description of required advisories	D		
f) Determine necessity for issuance of NOTAMS (15.2.6)	1) Description of NOTAM requirements	D		

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: IIB, FLOW CONTROL

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
● DETERMINE CAPACITY				
a) Select terminal/jurisdiction and time period (2.1.1)	1) Terminal/jurisdiction to be considered	D	D	
	2) Time period selected	D	D	
b) Determine total effect on capacity (2.1.6)	1) Actual capacity of terminal/ jurisdiction in ACFT/unit time	D	D	

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: III, FLIGHT SURVEILLANCE AND CONTROL

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
● COMPILE/ISSUE CLEARANCES				
a) Determine if I.D. code assignment required (5.1.1)	1) I.D. code assignment not required		D	
	2) I.D. code assignment required		D	
b) Determine pilot's intention following missed approach (5.1.3)	1) Request new approach		I*	
	2) Proceed to alternate (see Function 3)		I*	
● MONITOR FLIGHT PROGRESS				
a) Request ACFT I.D. (6.1.4)	1) I.D. request	I*		
b) Assign arbitrary ACFT I.D. (6.1.5)	1) Correlated position arbitrary I.D. (4.2.6 and 17.1.3C)	D		I
● FLIGHT PLANS CONFORMANCE				
a) Specify time period to be checked (7.1.1)	1) Time period to be checked	D	D	
b) Inform pilot out-of-tolerance (7.4.2)	1) Out-of-tolerance deviations	D		D
	2) Request pilot preference in re resolution	I*		
c) Receive pilot's response in re resolving deviations (7.4.3)	1) Prefer return to flight plan		I*	
	2) Prefer revised flight plan		I*	

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: III, FLIGHT SURVEILLANCE AND CONTROL

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
• SPACING CONTROL				
a) Submit performance change within existing flight plan to clearance (9.5.5)	1) Performance necessary to implement sequence change	D		D
b) Submit revised flight plan for approval (9.5.7)	1) Proposed revised flight plan (4.1.1, 4.2.1, 4.2.2, 4.2.4, 4.2.5, 4.2.7, 4.2.9 and 4.2.10)	D		D
• HANDOFF				
a) Receive pilot's request for transfer of responsibility (13.1.4)	1) Air-ground/ground-air handoff required		I	I
b) Determine if communications channel change is required (13.2.1)	1) New channel required, or 2) Use present channel		I I	
• EMERGENCIES				
a) Request additional required information (16.1.2)	1) Information request (to ACFT or exog.)	I*		
b) Compile description of emergency (16.1.3)	1) Emergency ended	I		
c) Issue instructions to ACFT providing assistance (16.2.4)	1) Emergency ended, cease assistance 2) Instructions for assistance	I* I*		

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

TABLE 6.4-1 CONTROL REQUIREMENTS BY OPERATOR POSITION (Cont'd)

POSITION NUMBER AND NAME: III, FLIGHT SURVEILLANCE AND CONTROL

APPLICABLE RESPONSIBILITY/ TASK	ENTRY ITEM	CONTROL FORMAT		
		ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
d) Determine required technical instructions to ACFT in emergency situation (16.2.5)	1) Description of required technical instructions (to exog.)	I		
e) Determine emergency flight plan (16.2.6)	1) Emergency flight plan, or	D		
	2) Revised emergency flight plan	D		
f) Inform pilot of change to emergency frequency link (16.2.8)	1) Instructions to change to emergency link	I*		
g) Determine required guidance assistance (16.2.9)	1) Description guidance assistance required	I		
h) Issue instructions to ground support facility (16.2.10)	1) Instructions to provide assistance, or	I		
	2) Instructions to cancel assistance	I		

* = To Pilot

D = Data

C = Coordination with another position

I = Instructions

6.5 CHARACTERISTICS OF THE MAN-MACHINE INTERFACE

In the preceding sections, the display and control items required by the operator at each of the AATMS positions were tabulated. In this section, display and control requirements for the system as a whole will be considered, across operator positions, in a characterization of the interface between man and machines.

6.5.1 System Displays

Table 6.5-1, which begins on the next page, is a consolidation of the display requirements by information item. Each information item is described in terms of its content; for example, "operational report information", or "present aircraft position." The table next shows, by appropriate markings in five columns, the operator position or positions at which the display is required. In the last three columns the display format is identified, using the same scheme as in the individual operator position tables of the previous section. It will be noted that the display information requirements are thus both reformatted and consolidated. Requirements for a total of 114 "displays"* can be generated from the 86 unique information items listed in Table 6.5-1.

As Table 6.5-1 shows, the 114 separate displays require only 86 unique information items, because several items are displayed at more than one operator position. The distribution of unique and common displays by operator position is presented in Table 6.5-2.

From Table 6.5-2 it can be seen that Position III has the largest individual number of displays (38). This stems partly from the number of exceptional situations that can arise in the highly-automated active control function. For example, four displays are needed in maintaining flight plan conformance by resolving deviations, and three in determining the flight plan implications of exercising spacing control. The other

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* The term "display", as it is used here, should not be taken to mean an entire array or construct of information, formatted and presented to an operator at a console, such as a PPI or an annunciator panel. Display is used in the more elemental sense of information components or constituents which make up such a construct, i.e., items to be displayed. Thus, the operator may have at his console one, two, or more devices by which he receives 10 or 20 of the "displays" identified in this chapter.

TABLE 6.5-1 SYSTEM DISPLAY REQUIREMENTS CONSOLIDATION

INFORMATION ITEM	DISPLAYED AT POSITION:					DISPLAY FORMAT		
	IA	IB	IIA	IIB	III	ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
Operational report information	●					SI,RT/PT	SI,RT/PT	SI,RT/PT
Rules and procedures	●	●	●	●	●	D,RT	D,RT	D,RT
Transmitted clearance	●					ST,RT/FT	ST,RT/FT	SI,RT/FT
Current aircraft status	●					ST,RT		
Present deviations	●				●		SI,RT	SI,RT
High imminence conflict pairs	●					SI,RT	SI,RT	SI,RT
Not responding, retransmit	●					SI,RT	SI,RT	SI,RT
Actual time position profile	●						SI,RT/PT	SI,RT/PT
Identification of missing information	●					D,RT		
No report format available	●					SI,RT		
PIREPs	●					D,RT		
Weather sensor data	●					D,RT		D,RT
Weather observation report schedule	●					D,FT		
Weather observation report criteria	●					D,RT		
Correlated position and identification	●	●	●		●		D,RT	D,RT
Affected data base item	●					D,RT		
Request for information (telephone)		●				SI,RT		
Stored weather sequences		●	●	●	●	D,RT		
Stored severe weather phenomena		●		●		D,RT	D,RT	D,RT
Stored weather forecasts		●	●	●	●	D,FT		
Stored weather charts		●				D,RT		D,RT

TABLE 6.5-1 SYSTEM DISPLAY REQUIREMENTS CONSOLIDATION

INFORMATION ITEM	DISPLAYED AT POSITION:					DISPLAY FORMAT		
	IA	IB	IIA	IIB	III	ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
Stored traffic data		●				D,RT/FT		
COMM/NAV system status		●	●		●	ST,RT		
Ground facilities status		●	●	●	●	ST,RT		
Stored user class data		●	●			D,RT		
Flight hazards information		●	●	●		D,RT	D,RT	D,RT
Route information		●	●			D,RT	D,RT	D,RT
Stored route summaries		●		●		D,RT	D,RT	D,RT
Message format (non-preformatted response)		●				D,RT		
Preformatted reply (flight planning)		●				D,RT/FT		
Displayed information (flight planning)		●				D,RT/FT	D,RT/FT	D,RT/FT
Pilot's information request (advisory)		●				SI,RT		
Response message format (advisory/instruction)		●				D,RT		
Information for response		●				D,RT		
Information requested not available		●				SI,RT		
Planned distribution position of aircraft		●				D,FT	D,FT	D,FT
Advisory distribution list of positions		●				D,RT	D,RT	D,RT
Submitted flight plan			●			D,FT		
Proposed revisions to flight plan			●			D,FT	D,FT	D,FT
Single revision to flight plan			●			D,FT	D,FT	D,FT
Proposed revised flight plan (spacing)			●			D,FT	D,FT	D,FT
Airspace restrictions			●	●		D,RT	D,RT	D,RT

TABLE 6.5-1 SYSTEM DISPLAY REQUIREMENTS CONSOLIDATION

INFORMATION ITEM	DISPLAYED AT POSITION:					DISPLAY FORMAT		
	IA	IB	IIA	IIB	III	ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
Airspace structure and jurisdictional boundaries			●		●	D,RT	D,RT	D,RT
Terminal release quotas			●			D,FT		
En route release quotas			●			D,FT		
Intended time position profile			●				D,FT	D,FT
Predicted long-range time-position profile			●				D,FT	D,FT
Present aircraft position			●		●		SI,RT	
Traffic and other flight plans			●			D,RT/FT	D,RT/FT	D,RT/FT
Flight plan prioritizing criteria			●			D,RT		
Flight plan approval criteria			●			D,RT		
Changes to make flight plan acceptable			●			D,FT	D,FT	D,FT
Pilot's response (flight planning)			●			D,RT		
Request for special service			●			D, T		
Information regarding progress of service			●			D,RT/PT		
Terminal and jurisdiction information				●		D,RT	D,RT	D,RT
Time period range				●		D,RT		
Clearance issued					●	ST,RT/FT	ST,RT/FT	ST,RT/FT
Accepted flight plan					●	D,RT/FT		D,RT/FT
I.D. code usage procedures					●	D,RT		
Missed approach indicator					●		SI,RT	SI,RT
Pilot intent (after missed approach)					●	SI,RT/FT		
I.D. request message format					●	D,RT		
No correlation indicator					●		SI,RT	SI,RT

TABLE 6.5-1 SYSTEM DISPLAY REQUIREMENTS CONSOLIDATION

INFORMATION ITEM	DISPLAYED AT POSITION:					DISPLAY FORMAT		
	IA	IB	IIA	IIB	III	ALPHA-NUMERIC	LITERAL PICTORIAL	SYMBOLIC PICTORIAL
No response to request indicator							SI,RT	SI,RT
System capability to perform check					●	D,RT		
Active flight plan count					●	D,RT		
Short range deviations					●		SI,FT	SI,FT
Long range deviations					●		SI,FT	SI,FT
Correct to original flight plan					●	SI,RT		
Revise flight plan					●	SI,RT		
Performance change ok within existing flightplan					●	SI,FT	SI,FT	SI,FT
Performance change requires flight plan modifi-					●	SI,FT	SI,FT	SI,FT
cations					●			
Current aircraft capabilities					●	D,RT		
Pilot request (for handoff)					●	SI,RT		
Communications channel assignments paradigm					●			
Handoff acceptable to accepting jurisdiction					●	SI,RT		SI,RT
Description of emergency					●	SI,FT,RT,PT		
Unable to issue clearance indicator					●	SI,RT	SI,RT	SI,RT
Not responding, declare emergency					●	SI,RT	SI,RT	SI,RT
Information not available					●	SI,RT		
Information regarding progress of emergency					●	D,PT/RT/FT	D,PT/RT/FT	D,PT/RT/FT
Additional required information					●	D,PT/RT/FT		
Emergency ended					●	SI,RT		
Proposed revisions to emergency flight plan					●	D,FT	D,FT	D,FT
Communication links in use					●	D,RT		

contributor to the large number of displays at Position III is the performance of manual tasks connected with emergencies; nine displays are required for that function alone.

TABLE 6.5-2 DISTRIBUTION OF DISPLAYS SERVING AATMS OPERATOR POSITIONS

OPERATOR	POSITION	INFORMATION DISPLAYS		
		UNIQUE	COMMON	TOTAL
Data Base	IA	13	3	16
Flight Information, Flight Advisories	IB	12	11	23
Flight Planning and Special Services	IIA	15	12	27
Flow Control	IIB	2	8	10
Flight Surveillance and Control	III	29	9	38
TOTALS		71	43	114

Like emergencies, the function of providing special and emergency services is a completely manual function. That function is allocated to Position IIA, but it accounts only for two displays. Most of the 27 display requirements for Position IIA derive from responsibilities in flight planning; 13 of the 15 displays that are unique to Position IIA relate to flight plan processing (review, approval, and revision).

The flight information/flight advisories position (IB), the data base position (IA) and flow control (IIB), account for the remaining system displays, requiring 23, 16 and 10, respectively.

Table 6.5-2 also reflects something of the nature of each AATMS position, in that it shows how displays are shared. The data base position (IA), for example, shares only three displays with other system positions. On the whole, the data base position deals with parameters that are not formatted in operational terms. For example, Position IA deals not with weather sequences and forecasts, but with weather sensor data and weather observation schedules.

The flow control position (IIB), on the other hand, shares most of his displays. Of the 10 displays at Position IIB, 8 are common to other positions, for example, systems and facilities status, stored weather data, and airspace restrictions. The two unique displays at the flow control position provide nominal capacities and time-period selection for his flow planning activities.

Positions IB and IIA, responsible respectively for providing flight information services and for flight plan processing, also have many displays in common with other positions.

For example, nine displays relating to rules and procedures, weather, and system status appear at both the flight information services and flight plans processing positions.

Position III has, as was mentioned earlier, many displays unique to the responsibilities of managing active traffic, especially in dealing with emergencies. The Position III displays that are common to other positions include rules, weather, and systems status - as well as displays of current traffic, with symbology for airspace structure and jurisdictional boundaries.

As display content and display distribution among operator positions were derived, display format and coding recommendations were also made. (The scheme for making attributions about content, time base, and encoding was discussed in Section 6.3 above.) Two members of the human factors staff with experience in air traffic control reviewed each display information item to decide on the attributions of the display. The following assumptions were made:

- Basic 1995 display coding will be tabular and/or pictorial, although not necessarily presented on two scopes or in a two-dimensional mode.
- Information from the pilot will be coded alphanumerically, although not necessarily verbal; data link or voice or both can be inferred.
- Display subsystems will be capable of presenting real time, history, or extrapolated data.

Table 6.5-3 is a summary of display items according to the attributes of content, time base and format. For example, 27 display items describe particular situations, like "high imminence conflict" or "intends to correct to original flight plan." Except for the flow control position (IIB), all AATMS operators receive one or more "situation" inputs. Information items like "communications/navigation systems status" or "ground facilities status" were given the attribution, "status." All positions receive one or more of the five "status" control information items. The attribution "data" was given to information items like "submitted flight plan," "stored weather forecasts," or "communications channel assignment." Displays involving "data" appear at all AATMS positions.

TABLE 6.5-3 SYSTEM DISPLAY ATTRIBUTES

ATTRIBUTION	NUMBER OF DISPLAYS
Display Content	
Situational Information	27
Status Information	5
Data	12
Display Time Base	
Real Time	55
Future Time	17
Real/Future Time Modes	8
Real/Past Time Modes	3
All Time Base Modes	3
Display Encoding	
Alphanumeric	44
Alphanumeric/Symbolic Pictorial	4
Symbolic/Literal Pictorial Hybrid	10
Literal Pictorial (i.e., Surveillance)	1
Alpha/Literal/Symbolic Hybrid	27

Given that the physical design of an AATMS display subsystem will entail decisions about providing human operators with displays whose time base may involve history ("past time"), present events ("real time") or future possibilities ("future time"), it was felt to be desirable to make judgements about time base attributions for each display item. Where the item clearly inferred a present state of affairs, e.g., "present aircraft position," "rules and procedures," "weather sensor data," the attribution "real time" was given to the display. In situations where human operators might require extrapolations to make decisions, like "proposed revisions to flight plan," or "predicted long-range deviations from flight plan," the display time base was made "future time." As Table 6.5-3 shows, most display items were accounted for in one of these time base categories. Some items, like "clearance issued," inferred both real-time and future modes. Others, like "operational report information" implied present and past time. All modes were assigned to items like "information regarding progress of emergency." History, present states of affairs, and predicted or extrapolated time bases are involved in one or more displays at all AATMS positions except IIB (flow control), which deals with real and future time items but not with histories.

Basic display encoding was assumed to be either tabular (alphanumeric) or pictorial. Pictorial displays were further characterized as being literal, as in a surveillance data display, or symbolic, as in a direction-speed vector indicator. It can be seen that most display information items have tabular alphanumeric bases or components. Of the 86 display items, 76 fall in this category; and of the 76, 44 are purely tabular alphanumeric, that is, they have no pictorial component requirement. All AATMS positions receive one or more tabular alphanumeric-encoded display items.

All AATMS positions also receive pictorial displays. However, the flow control position does not deal with pictorial displays involving actual traffic, such as "present aircraft position" or "correlated position and identity". The absence of these displays from the flow control position is a reflection of the functional assignments for this operator, in that flow control deals with traffic summaries expressed as numbers of aircraft per unit time (demand) and with en route and terminal capacity, again expressed as numbers of aircraft per unit time. Thus, the analysis of display/control requirement for the flow control position supports the expectations engendered by the nature of the flow control function.

Also, as would be expected, those involved directly in AATMS traffic management receive pictorial displays about aircraft. While Position III, flight surveillance and control, is the only one at which a "pure" surveillance display is present (that is, the literal pictorial representation of present aircraft position), the flight information and flight plan processing positions receive "correlated position and identification" displays in connection with their activities as does the flight surveillance/control position. This form of display is a hybrid, with symbolic pictorial information, e.g., vector symbology and alphanumeric identification, appearing in conjunction with surveillance data.

A second form of hybrid display is one which has an alphanumeric tabular component plus a symbolic pictorial component, but no literal pictorial data. An example of this type is the display of an accepted flight plan, which may show an aircraft's future intent in tabular and/or pictorial form before the aircraft itself is under surveillance. In the same way, stored weather might be displayed in tabular and pictorial form.

The third form of hybrid encoding involves all three components: alphanumeric, literal, and symbologic pictorialization. Examples of this type include displays of "rules and procedures," "stored severe weather phenomena," or "information regarding emergencies."

From 86 basic information elements, 114 system display items are thus derived. These displays constitute the body of information which the automated portion of the system must provide to the human operator so that he can carry out his assigned tasks. However, this is only half of the man-machine interface. Just as the machine communicates information to the man through displays, so must the man provide data and instructions to the machine. That is the topic of the discussion in the section on system controls which follows.

6.5.2 System Controls

This presentation of AATMS control requirements at the recommended automation level parallels the discussion just completed. The controls identified for each induced task in the various AATMS functions, presented earlier by operator position (Table 6.4-1), are tabulated here across positions to provide a system-level analysis. This is followed by a brief concluding discussion of control applications.

Before examining the table of system control requirements, the reader may find it useful to review the method by which control requirements were derived. It will be recalled that when a particular generic task is allocated to the human operator for performance and the next task to be carried out is allocated to a machine, the operator must be given some means to communicate his task performance output to the machine. In general, human operator tasks in AATMS culminate in one of two ways: (1) in establishing, altering, or confirming some system parameter (like specifying variations from normal terminal or jurisdictional capacity in flow control) or (2) in reaching some decision about exceptional situations (like determining whether a pilot will attempt another approach or proceed to an alternate airport after a missed approach). Thus, the two basic control purposes are either to furnish the automated system resource with data or to provide it with instructions. The first step in analyzing the system control requirement was to examine and relate the system functional analysis, the recommended automation level, and the operator position descriptions and functional responsibilities. This formed the basis for enumeration of tasks allocated to human operators at each position, derivation of the induced "control" tasks for each operator, and identification of whether the nature of the task was to provide data or instructions to the system.

The next step was to determine recommendations as to control format. The intent was to create functional statements of requirements that would combine the key features of integration in the display-control concepts with early identification of possible time saving or work reduction for the human operator at the man-machine interface. The most critical aspect of integrated displays and controls that applies at the generic level is that the encoding base of displays and controls must minimize requirements for the human operator to decode, encode, and interpolate. Accordingly, provision was made for alphanumeric encoding, with associated symbols given meaning according to a set of conventions like those used in present systems. Wherever the nature of the task suggested it, identification was made of opportunities for the use of discrete control devices (such as switch settings) or dynamic/analog devices (such as light pens).

Table 6.5-4, beginning on the next page, is a consolidation of the system control entry requirements and formats. The table shows that some 59 entry items are required for the five AATMS operator positions at the recommended automation level. It will be noted that while many display items are common to more than one situation and hence appear across operator positions, control entries are nearly always unique to the task in question. The single exception is the entry "description of guidance required", which is made both by the flight information position (IA) and by the flight planning position (IIA). However, most control entry items are alphanumerically encoded. The implication is that some standard keyboard will, therefore, suffice at all positions.

The manual tasks to be performed are such that several opportunities were found to take advantage of discrete or dynamic/analog input methods. Discrete controls might be appropriate, for example, in cases like "operational report required". The control could be a two-position switch (yes/no) that also enables a keyboard mode when the switch is set to "yes", allowing the keyboard to function as a video switcher, channeling information from some operational activity to a data storage device. Another case where a discrete control seems appropriate is "ID code assignment not required/required". Given that some sort of discrete-address beacon system is to be the primary surveillance mode, the identification of aircraft will normally be automatic. Indeed, if the performance of future beacon systems justifies it, the task of identification might be altogeher eliminated. However, such basic assumptions inferred from specific hardware were, it will be recalled, outside the scope of the study. Therefore, the task exists as a generic task, normally automated at the recommended level. The manual performance is to determine <u>if</u> an identification code assignment is required, and normally it would not be. A control is provided to account for any exceptions. However, it seems unlikely for a failure to occur in such a way that it would disable only the identity-sending portion of an aircraft's transponder, or only the identity-sensing portion of the system's surveillance device. Therefore, it would be appropriate to investigate the concept of a "yes/no" control set normally at "no".

TABLE 6.5-4 SYSTEM CONTROL REQUIREMENTS CONSOLIDATION

CONTROL ITEM	ENTERED BY POSITION:					CONTROL METHOD		
	IA	IB	IIA	IIB	III	ALPHA-NUMERIC	DISCRETE	DYNAMIC/ ANALOG
Operational report required	●					D	D	
Request for additional information	●					D		
Report format	●					D		
Request for PIREP	●					I		
Weather observation report	●					D		
Location or geographic area		●				D		D
Category of information		●				D	D	
Compiled response (flight planning information request)		●				D/I		D/I
Transmitted telephone message		●				D/I		
Pilot request (flight planning information request)		●				I		
Acknowledgement of request		●				D		
Specially formatted message		●				D/I		
Aircraft at distribution position		●				D	D	D
Points for computation of ETOVs			●			D		D
List of discrepancies			●			D		
Unacceptable flight plan			●			D	D	
Approved flight plan			●			D	D	
Flight plan approval information			●			D		
Flight plan disapproval information			●			D		
Modified flight plan			●			D		
Accepted flight plan			●			D		

TABLE 6.5-4 SYSTEM CONTROL REQUIREMENTS CONSOLIDATION

CONTROL ITEM	ENTERED BY POSITION:					CONTROL METHOD		
	IA	IB	IIA	IIB	III	ALPHA-NUMERIC	DISCRETE	DYNAMIC/ANALOG
Cancellation of flight plan			●			I		
Communication links between ATM and aircraft			●			D		
Service no longer required			●			D		
Cease action because of safety			●			I		
Definition of area of restriction			●			D		
Description of guidance required	●		●			D		
Definition of special separation minima			●			D		D
Description of required advisories			●			D		
Description of NOTAM requirements			●			D		
Terminal/jurisdiction to be considered				●		D	D	
Time period selected				●		D	D	
Actual capacity of terminal/jurisdiction in number of aircraft per unit time				●		D	D	
I.D. code assignment not required					●		D	
I.D. code assignment required					●		D	
Request new approach					●		I	
Proceed to alternate					●		I	
Identification request					●	I		
Correlated position and arbitrary I.D.					●	D		I
Time period to be checked					●	D	D	
Out-of-tolerance deviations					●	D		D

TABLE 6.5-4 SYSTEM CONTROL REQUIREMENTS CONSOLIDATION

CONTROL ITEM	ENTERED BY POSITION:					CONTROL METHOD		
	IA	IB	IIA	IIB	III	ALPHA-NUMERIC	DISCRETE	DYNAMIC/ANALOG
Request pilot's preference regarding resolution of					●	I		
deviations								
Preference to return to flight plan					●		I	
Preference for revised flight plan					●		I	
Performance necessary to implement sequence change					●	D		D
Proposed revised flight plan					●	D		D
Air-ground/ground-air handoff required					●		I	I
New channel required					●		I	
Use present channel					●		I	
Information request (regarding emergency)					●	I		
Emergency ended					●	I	I	
Emergency ended, cease assistance					●	I		
Instructions for assistance					●	I		
Description of required technical instructions					●	I		
Emergency flight plan					●	D		
Revised emergency flight plan					●	D		
Instructions to change to emergency communication link					●	I		
Instructions to provide assistance					●	I		
Instructions to cancel assistance					●	I		

Discrete controls involving multiple rather than dual settings could be used in tasks like "(select) category of information", or "specify time period to be checked." Such controls could also be used to advantage in application like "prefers new approach". This is the branch of the "missed approach" situation in which the pilot elects to go around and try again. The assumption here is that at a given terminal there might be several possible paths the pilot could follow in order to return to and be merged with the stream of incoming aircraft. Suppose the "prefers new approach" control to have two "new approach" settings: "standard" and "other". Setting the control to "standard" would result in a display of the procedural (that is, previously defined and agreed) vectors appropriate for the original runway, the weather, and the traffic situation, with the merge point selected by the computer. Setting the control to "other" would allow the operator to see several merge points and, by changing the aircraft's landing sequence priority, to select one.

It can be seen from the examples given that the recommendations for discrete control methods constitute guidelines for study in the process of selecting physical means for the performance of the generic induced tasks. The same intent can be inferred where a "dynamic/analog" recommendation is made for a particular control entry item. For example, "identifying area of restriction" could be done expediently if a keyboard entry alerted the machine that an area of restriction is to be defined, then a pointer or light pen type of device were used to draw the area on a pictorial display. The same combination of keyboard/light pen might be used to present "proposed modifications to flight plan" or to indicate to the machine a "description of guidance required". (For example, to avoid clear-air turbulence, the operator could indicate that he would like the aircraft to be vectored in thus and such a fashion from this point to that.)

The examples just presented are, perhaps, sufficient to illustrate the nature of the system control requirements and to convey the intent of the recommendations made on control methods. Having considered system displays and system controls separately, it is appropriate to conclude the chapter with a brief synopsis of their use in system operations.

6.6 THE MAN-MACHINE INTERFACE IN SYSTEM OPERATION

To allow maximum freedom in future choices of equipment subsystems and methods of mechanization, this study treated all aspects of the advanced air traffic management system in a way which emphasized generic functions and independence from specific physical means. Yet, in attempting to communicate functional concepts and operational characteristics of a complex system, there is always a strong temptation to refer to some notional equipment design as an example of how things might work. Thus, finding ways to illustrate AATMS control and display concepts without trespassing unduly into matters of hardware and physical means posed a challenge. The issue was resolved in discussions among project team members, in which it was agreed that appropriate qualifiers would be attached to the terms "display" and "control" and that pictures or sketches of operator consoles would not be included as illustrative examples. Thus, the discussion of controls and displays in this chapter has been held at a very general level of abstraction. However, some concession must be made to the desire for the concrete. If the reader will temporarily accept the assertion that it is possible to draw a "generic console", Figure 6.6-1 may be of use in assessing the AATMS man-machine interface.

6.6.1 Position/Interface Relationships

Figure 6.6-1 is based on the functional interrelationships of the system, and the allocation of function to position given in Chapter 2 of this volume. At each operator position, the circles represent pictorial displays, the squares represent tabular displays. Note that the flow control positions (IIB) is not provided with a situation-type pictorial display, but it does have a tabular display. Each operator also has a control capability, represented by the small checkerboard at each position. Dynamic/analog and discrete controls are not illustrated, but should be considered as present in some form.

The man-machine interface is thus represented as seen from the "man" side. The labels superimposed on each position characterize the input/output relationships at the position in terms of operational parameters and

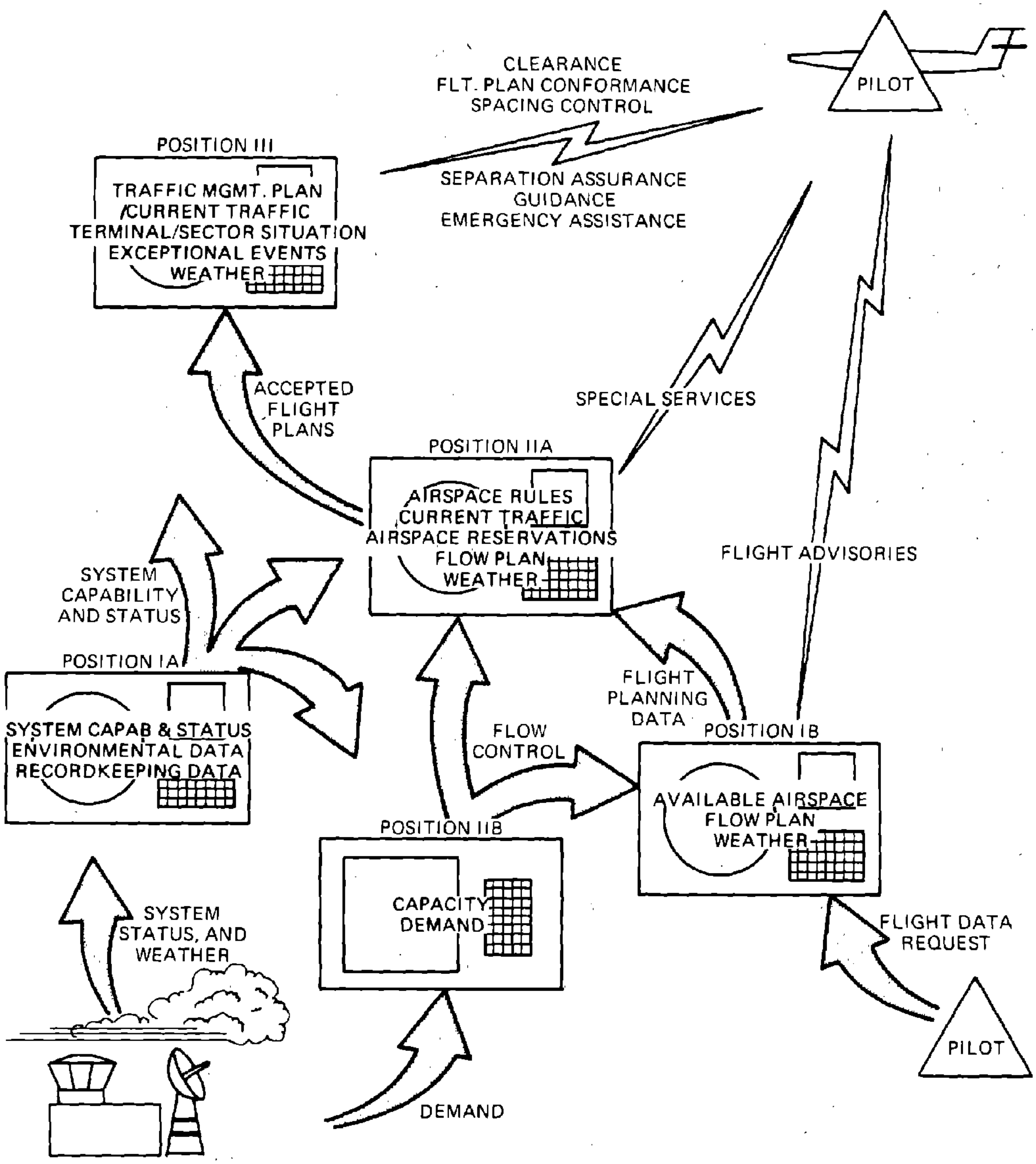


FIGURE 6.6-1 AATMS MAN-MACHINE INTERFACE

processes. The arrows between positions and the links to the aircraft are a simplified representation of the relationships among positions, with appropriate products and services labelled.

The system data base is maintained through the activities of Position IA. The processes that are carried out involve recording and updating information on the status and capabilities of the system -- for example, the ground facilities, the communication and navigation subsystems, and user characteristics. Position IA also deals with environmental data, specifically with weather sensor data, weather observation schedules and reports, and with other sources of weather information like pilot reports (PIREPS). The data base position is also the keeper of system records. For that purpose, Position IA can receive on his pictorial display all current, predicted, or historical traffic data that relates to making reports. In addition, there are tabular displays such as traffic count, summaries of operations, and facilities down time.

Position IIB (flow control) deals basically with demand for services and with predicted system capacity as affected by weather, facilities status, and other factors impinging on nominal values. He derives, according to an overall paradigm, the match between capacity and demand over time, called in the figure the system "flow plan".

Flight information and flight plan preparation services are provided by Position IB. The operator at this position deals with available airspace on given routes between points of origin and destination. The Position IB operator must also take into account the flow plan established by flow control, and current and forecast weather, required not only for flight plan preparation but also to perform the function related to providing inflight advisories.

Position IIA processes and approves flight plans. He also makes provision for and monitors the progress of special and ancillary services offerred by the air traffic management system. He receives inputs and makes outputs that involve "airspace rules" -- structure, usage, areas of restriction, and so on. Position IIA deals also with current traffic, firm airspace reservations, the flow plan as created and updated by the flow control position, and with the weather.

Accepted flight plans, the "contract" between system and user, are fed to operators and machines at Position III, the flight surveillance and control position. The human operator at position III deals, in his role as manager, with the overall traffic management plan as originally created by flight planning and flow control and as modulated or revised by changing demand, changing intentions, and exigencies. Position III works with the current traffic situation, and with the present and near-term future situation both in en route jurisdictions and at terminal facilities. Position III deals also with exceptional events: unforeseen effects of weather (e.g., icing or turbulence), unexpected deviations from flight plan, runway reversals, and emergencies.

Something of the complexity that surrounds the management of air traffic can be seen in this simplified characterization of the system man-machine interface. Even at the recommended automation level, which implies extensive performance of routine tasks by machines, the human operator must manipulate information items and control entries in some fourteen distinguishable categories relating to the system, its users, and the environment. In theory, the combined capabilities of the system resource teams made up of machines and human operators suffice to deal with the anticipated demand. But it seems clear that, in practice, reaching the level of automation required to achieve the recommended task allocations to man and machine will be necessary, but not sufficient, to meeting the desired goals of system performance. It will be required not only that the basic apportionment of tasks to human operators and machines is an appropriate one, but also that the combined power of men and machines is not constrained or vitiated by the effects of conditions at the man-machine interface. Some of the factors affecting the character of the man-machine interface are discussed below.

6.6.2 <u>Other Considerations Affecting the Man-Machine Interface</u>

In this study, the resource unit in an advanced air traffic management system was defined to consist of a human operator, an automated processor, and an input-output device. In this chapter of the report, attention has focused, so far, on the input-output device. The number and nature of the generic displays and controls that are the functional implication of system automation have been identified. It would be remiss, however, not to include some perspective on the results. This is best accomplished by pointing out some of the factors that must be considered by the system designer in arriving at a physical specification of display-control devices and subsystems for AATMS. Each of these factors has, it should be noted, implications for and repercussions on the man-machine interface at every level of detail in the design process.

Foremost among these design considerations is the effect of actual physical automation capabilities, as they will be in the 1990 era. A fairly detailed discussion of this factor is given in the chapter on implementation strategy (Chapter 6, Volume I), and the topic is further addressed in the RDT&E plan included in Appendix B of this volume. In the end, the tasks actually allocated to machines will reflect the extent to which machines can actually perform them. That will be the fundamental determinant of the nature of the relationship between man and machine, hence also of the input-output requirements at the man-machine interface. Deciding that a machine can "actually perform" a task should be taken to mean that the machine can be built, that its cost will not be prohibitive, and that when operated and maintained in field conditions by field personnel its reliability will be such that failures are neither a real nor a perceived-as-real problem.

In that connection, the value of this project is that a method has been derived for defining and updating the basic control/display requirement attendant to a given level of system automation. Studies and comparisons can be made as required when suggestions and proposals for system configurations and equipment designs are put forward, so that the basic effects of a particular approach on man-machine interactions can be addressed.

A second major factor that will affect the man-machine interface in the advanced air traffic management system also has to do with machines. It encompasses, however, not only the machines required for internal system processes but also the machines used for communications, surveillance, and navigation. It also embraces the airspace structure, the system procedures, and the system concept actually pertaining at the time of AATMS implementation. The factor is termed "homogeneity". The extent to which the system is actually homogeneous in its make-up will greatly influence how much it can be centralized and how uniform its rules and procedures are. For example, consider the problems inherent in human performance in a non-homogeneous system. The air traffic controller of today must learn a very large number of "ground rules" (perhaps "air rules" would be a better term) to qualify for unassisted responsibility in a given sector. These rules relate to the influence of airspace structure, surveillance/navigation/communication anomalies, and local procedural arrangements on acceptable control strategies, tactics, and individual decisions. One reason for centralizing the human operators in the AATMS system concept was to be able to make relatively large shifts of resources in response to changing patterns of demand. However, this can only be accomplished to the extent that human intervention to solve some problem in one jurisdiction can be made in the same way as human intervention in another. In other words, a homogeneous system is one in which the system resources are disentangled from local "ground rules" that require special performance from jurisdiction to jurisdiction.

The third major factor affecting the man-machine interface relates mainly to functional management and human resource development. In maintaining an appropriate number of qualified human operators, it will be necessary to carry out training activities. If some training is to be done on the job, it may be necessary to design special display modes. Such modes would be required, for instance, in order to simulate operational activity or in order to allow a trainee to step through some problem-solving process that is ordinarily carried out in a continuous fashion. Similarly, it will almost certainly be necessary to create special display modes (and perhaps even special displays and operator positions) to exercise functional management and resource control, i.e., to assess the quality of performance of a given system resource unit and to shift resources to meet varying patterns of capacity and demand. Since these system management activities lie outside the inventory of generic operational tasks derived in this study, specific controls and displays for such purposes are not delineated here, but the need for them can be clearly foreseen.

Several recommendations for research and development in the area of system management and resource control are provided in the discussion of implementation strategy and in the RDT&E plan. However, for the convenience of the reader, two examples will be given here to save cross-referral.

Consider that, in a "management by exception" system, many of the exceptional conditions and situations that may develop are probabilistic in nature. For instance, the incidence of unplanned deviations from original flight intentions and the incidence of missed approaches could both be expressed as probabilities, the value of the probability being greatly influenced by factors like weather. Whenever either or both of these situations arises, i.e., whenever a pilot deviates from his flight plan or misses an approach, a certain quantity of machine and human resources is required to deal with the circumstances.

Suppose that the probability of these exceptions can be predicted -- that enough data about major interactive factors like weather have been collected to be able to predict with some certainty that in a given system jurisdiction when the weather becomes inclement, the expectation is that some knowable number of deviations and missed approaches will occur. Given a display of the forecast weather and some set of controls for marshalling resources, a system resource manager could use such a predictive paradigm to assign additional machines and operators to the jurisdiction in question.

Consider as a second example the same situation, where weather conditions increase the number of exceptional operator interventions due to flight plan deviations or missed approaches. The resource manager might also operate on a real-time basis. The number of control actions an operator makes per unit time is a measure of how busy he and his machine "partner" are. Displaying this measure in a dynamic form would give a resource manager the means to diagnose overloads and provide relief.

7.0 IMPLICATIONS FOR OTHER ASPECTS OF SYSTEM DESIGN

The objective of this study was to investigate advanced levels of automation in an air traffic management system and to delineate system design requirements which stem from an increased allocation of system functions to machine resources. This volume of the study report has presented the design requirements under four major headings: man-machine resource requirements, estimated operator productivity, failure mode requirements, and control/display requirements.

The implications of the study, however, go beyond these areas and touch upon other fundamental aspects of the future air traffic management system. The purpose of this chapter is to sketch these implications briefly and thereby to help set the findings of the study in the broader perspective of concerns which will influence the design and implementation of the system.

Four topics are considered:

- Air/Ground Functional Responsibility
- Computer Architecture
- Training
- Cost Factors
- RDT&E Implications

In each case, the treatment is informal and intended only to suggest the relationship between the major outcomes of the study and these other areas of concern. Each topic is, of course, deserving of much more detailed investigation as the design and development of AATMS progresses. In fact, it seems likely that each by itself could well become the subject of a major study of the proportions of this one. Therefore, the brief treatment accorded here should be taken not as a measure of the importance of these implications but as a recognition that, however significant, they lie outside the central question of automation applications which was addressed in this study.

7.1 AIR/GROUND FUNCTION RESPONSIBILITY

The central question of this study was to determine the automatability of generic air traffic management tasks. The determination was made primarily on the basis of task performance requirements in relation to man and machine capabilities and only secondarily on the relation of one task to another. Therefore, the location at which the task was performed (i.e., in the ground system or in aircraft) had minor impact on the recommendation as to whether it would be automated. However, it was evident early in the study that the future perturbations in the current assignment of air-ground responsibility would be of considerable interest. Therefore, the generic functional analysis was deliberately structured to allow examination of these possible shifts in allocation.

The functional analysis deliberately recognized the requirement to treat this division of responsibility by describing the totality of functions required to perform air traffic management, including several now performed in the airborne portion of the system and several others which are candidates for allocation to aircraft in various future AATMS concepts. Thus, a firm groundwork was laid for consideration of future adjustments of air-ground assignment since all candidate tasks were included in the functional analysis.

The man-machine allocation methodology, described in Volume III of this report, does not differentiate between the performance of the task in the air or on the ground. The capabilities required to perform the task (e.g., monitoring, sensing, decision-making) are independent of the location of the human operator or computer. Therefore, as a first approximation, the assignment of a task to man or machine is compatible with either an air or ground allocation. However, in the real world, second-order effects must be considered. The following is a discussion of the implications for AATMS concept that would be produced by a shift in responsibilities to the pilot.

In studying reassignment of responsibilities, one must first consider the recommended automation level, described earlier in this volume. This recommended automation level is consistent with the assignment of functional responsibility as expressed in the AATMS operational concept. Therefore, as a first approximation one can consider that the automation recommendation is still valid. One can then proceed as follows in determining if a change is required.

1. Determine from the variations in the operational concept which tasks will have to be reallocated from ground to air

2. Calculate a 2 x 2 matrix for each task as below:

	Existing Automation Allocation	Reversed Automation Allocation
Air	$+ \Delta t$ $+ \Delta IPS$*	$+ \Delta t$ $+ \Delta IPS$
Ground	$- \Delta t$ $- \Delta IPS$	$- \Delta t$ $- \Delta IPS$

* IPS = instructions per second

3. Calculate impact on information flow across ground/air interface because of task transfer

4. Calculate impact on induced tasks for reversed allocation

5. Assess impact, if any, on failure mode requirements.

Based on the above, all of which is easily calculable from material in this report, it would be possible to assess the impact on automation allocation changes due to variations in AATMS operational concepts which result in changes of assignment in air-ground responsibility. From this assessment of impact, it will then be possible to make one of the following recommendations:

- Retain responsibility for performance of the task on the ground.

- Transfer responsibility for performance to the air and retain the current automation recommendation for the task or tasks involved.

- Transfer responsibility for performance to the air, but change the automation recommendation for one or more of the tasks to be transferred.

While the foregoing discussion was oriented to quantitative procedures and methodology that can be applied once variations are made from the current AATMS operational concept, it is probably also conceptually helpful to address the same problem utilizing an essentially qualitative approach. While such a qualitative analysis does not obviate the requirement for subsequent quantitative analysis such as those outlined above, it does perhaps help in the visualization and illustration of the impact of variation in the reassignment of responsibility for performance of a function between air and ground.

In attempting to provide such a qualitative description it is helpful to determine which functions might be candidates for reassignment of the air/ground responsibility. Such a list of functions might include but would not necessarily be limited to:

- 3.0 - Prepare Flight Plan
- 6.0 - Monitor Aircraft Progress
- 8.0 - Assure Separation of Aircraft
- 9.0 - Control Spacing of Aircraft
- 11.0 - Provide Aircraft Guidance
- 13.0 - Handoff

While the air/ground reassignment of responsibility for such functions does not necessarily result in changes in the study results it does require examination for implications. The study results to be examined include the following:

- Manpower Requirement
- Data Processing Requirements
- Failure Mode Analysis
- Productivity
- Control and Display Requirements
- Training

Finally the impetus for such reassignment of air/ground responsibility would be generated by the following elements of an ATC concept:

- En Route Airspace Management Concept
- Terminal Airspace Management Concept
- Traffic Mix
- Sensor Characteristics
- Facilities

Obviously an exhaustive treatment of all permutations of the 3 variables is neither necessary nor desirable. Therefore, four cases out of the 180 permutations will be treated to illustrate the technique.

Consider first the case where the impetus for the reassignment of the air/ground responsibility is provided by the ATC concept element of Terminal Airspace Management. What would be the impact on the control and display requirements study results if the responsibility for performing the Control Spacing of Aircraft Function were to be assigned to the pilot?

It should be noted that the Control Spacing of Aircraft Function includes those tasks today characterized by the terms metering, sequencing, and spacing. It would probably be very difficult to shift the metering and sequencing requirement to the air since this effort requires a centralized optimization technique. However, the maintaining spacing in the narrow sense of the term could be legitimately transferred to the pilot. This would require a situation display within the cockpit. If such a situation display were to be based on ground-based or space-based surveillance it would be desirable to accept the data processing requirement to make such data appear in an aircraft centered format on the display.

Consider next the case where the impetus for the reassignment of the air/ground responsibility is provided by the ATC concept element of Sensor Characteristics such as airborne collision avoidance. What would be the impact on data processing requirements study results if the responsibility for performing the Assure Separation of Aircraft Function were to be assigned to the pilot?

Since the performance of the Assure Separation of Aircraft Function is a very major contributor to the ground based data processing load, the transfer of responsibility would greatly reduce the data processing requirements on the ground.

Consider next the case where the impetus for the reassignment of the air/ground responsibility is provided by the ATC concept element of Traffic Mix. In particular, assume aircraft that did not wish to communicate intentions were segregated in airspace.

What would be the impact on the manpower requirement study results if the responsibility for performing the Assure Separation of Aircraft Function were to be assigned to the pilot?

Since the Assure Separation of Aircraft Function is fully automated on the ground, there would be no impact on ground based manpower requirement. There would, however, be an increase in the airborne manpower requirements since it is not necessarily true that the airborne function would be fully automated. It may well be, however, that any increased manpower requirement in the air might be absorbed as additional workload by existing pilots rather than by increasing of crew size.

Finally consider the case whose impetus for the reassignment of the air/ground responsibility is provided by the ATC concept element of En Route Airspace Management. What would be the impact on control and display requirements if the responsibility for performing the Assure Separation of Aircraft Function were to be assigned to the pilot?

A requirement would exist to present proximity warning alerts which would be generated by conflict detection algorithms. Additionally it may be that conflict resolution suggestions such as climb or turn right may have to be displayed. It should be noted that the display requirements for this case are somewhat different from the first case discussed since the requirements of Assure Separation of Aircraft Function differs considerably from the requirements of Control Spacing of Aircraft Functions.

7.2 COMPUTER ARCHITECTURE

Computer architecture is, of course, more heavily dependent upon the AATMS operational concept than upon the automation level *per se*. Such implications as can be drawn from the automation applications study lie primarily in the area of computer sizing and not in the general configuration or the detailed layout of the system. Those factors which will probably have the most significant impact on computer architecture for AATMS are listed below in the order of their approximate effect:

1. Future variations in the slope of the curve relating costs to capacity and information processing rate of CPU systems,
2. Future variations in MTBF for CPU systems,
3. Future trends in telecommunications cost,
4. Recommended level of automation for AATMS.

Despite the relatively minor impact on computer architecture, it still seems worthwhile to note a few of the implications that the recommended automation level will have for data processing resources to support air traffic operations in the 1995 environment. These implications apply strictly, of course, only to an advanced air traffic management system composed of a CCC-RCC-THC complex as described earlier in Chapter 2 of this volume.

There will be a requirement for a very large computer complex at the two RCCs, each of which will have to have resources capable of handling 7 to 8 million instructions per second. Depending upon the final decision as to how to meet requirements for failure modes, the size of the RCC complex could vary, with any decrease at the RCCs reflected in an increase of the size of the installation at the CCC.

The relatively small data processing requirements at primary and secondary terminals (29,000 and 7,200 instructions per second, respectively) suggest the application of a new generation of mini-computers and/or a time-shared system possibly centered at the THC. The final tradeoff cannot be made until telecommunication versus time-shared CPU costs become more clearly known. In any case, either solution poses no technological problems.

Finally, the requirements derived from the failure mode analysis strongly point out the desirability of modularity and capability for rapid reconfiguration of existing capability. If modularity is employed, the results of the failure modes analysis suggest a module of 7200 ips or some small multiple of this capability would be a suitable size. The desirability of a module of this size can be seen in Table 7.2-1, which is an extract of that presented earlier in the failure mode analysis. (Chapter 5).

TABLE 7.2-1 ESTIMATED COMPUTER MODULE SIZE REQUIREMENTS

POSITION		MODULE SIZE*	MODULES PER SITE	SITE LOCATION
IA	DATA BASE	7,200	100	CCC
IB	FLIGHT INFORMATION	7,200	2	THC
IIA	FLIGHT PLANS	7,200	8	THC
IIB	FLOW CONTROL	7,200	5	CCC
III	RCC	36,000 (5x7,200)	202 (1,010)	RCC
III	PRIMARY	7,200	4	PRIMARY TERMINAL
III	SECONDARY	7,200	1	SECONDARY TERMINAL
III	THC	7,200	10	THC

* Expressed as required rate in instructions per second

In this area of computer architecture one can consider, in addition to implications of the study results on computer processing location and arrangement, a parallel question of the implications of the study results on the location and arrangement of the computer data base. The data base required by the AATMS will of necessity be both large and dynamic in order to retain the flexibility of coping with myriad changes in operational and environmental conditions.

The question then arises as to desired degree of centralization of the data base. It is perhaps best to consider centralization in terms of both strategic and tactical functions, subfunctions and tasks. The study results imply that certain functions such as Control Traffic Flow are because of their inherant nature candidates for centralization. This arises since decisions made for one jurisdiction often have significant impact on other widely separated jurisdictions. Conversely the performance of the Assure Separation of Aircraft Function only requires access to a data base covering a small geographical area. Additionally, decisions and actions in a single jurisdiction rarely impact other jurisdictions at widely separated geographical locations.

Finally the question of failure does enter into decisions to centralize data bases. In the failure mode analysis in no case did the preferred strategy call for back-up of a failure by utilizing computing resources from a non-collocated site (e.g. vertical borrowing). This suggests that a failure would not imply a requirement to transmit large data blocks from a non-collocated site. If such transmission is not then required to compensate for data processing failure, then this perhaps implies that one should consider that failure modes analysis results support a somewhat decentralized data base if all other things remain equal.

7.3 TRAINING

Corson et al. (1970), in an assessment of the air traffic controller career, included this description of the controller's job.

> "The successful controller appears to require--at least--the following special talents and aptitudes:
>
> - A highly developed capacity for spatial perception
> - A keenly developed, quick, and retentive memory
> - A capacity for articulate and decisive voice communication
> - A capacity for rapid decision making, combined with mature judgement."

Earlier in this report (Volume I), these observations were used to illustrate a brief discussion of the air traffic controller's job in the present ATC system. They are repeated here to give perspective to the changes in selection and training associated with man's role in the advanced system.

If the extent of system homogeneity and the degree of machine aiding implied in the AATMS automation concept are in fact achieved, there will be a significant change in human performance requirement, and hence, in the areas of selection and training. But it is important to keep in mind that certain factors inherent in the nature of an air traffic control system will still apply.

For example, human operators must still man the system whenever services are required, and since aircraft fly day and night, some form of shift work will continue to be necessary. The selection of individuals who have good tolerance for such imposition on diurnal cycles and living styles will still, therefore, be required. Also, in the case of the active control position at least, human operators will still be directly responsible for intervention in exceptional circumstances, such as aircraft emergencies. Therefore, the selection of persons who can function well in these situations will still be an important consideration in the advanced system. Thus, the capability for decision making and judgement that Corson described will still apply, and in cases where direct voice contact with aircraft is involved, so will the voice communications capability which is so important for the controllers of today.

However, the requirement for spatial perception and memory capabilities cited also in Corson's sketch of the successful controller should be reduced greatly by the re-allocation of tasks as a result of system automation. Much of the information about user characteristics, system rules and procedures, and airspace structure that controllers now commit to memory and recall when needed will be stored in the system data base, obtainable by AATMS operators for display as required. While the ability to understand a situation display (spatial perception) and the ability to remember applicable information and procedures in handling a given task (memory) will still apply, the effect of automation will be to simplify the training required in these areas since the quantities of data involved will be much smaller than they are today.

The automation of air traffic management activities wil produce quantitative differences in the number and type of operators needed to man the system. This is evident from the manpower requirements presented in Chapter 3. However, there are also qualitative differences which emerge from the AATMS position descriptions. Positions IIA (Flight Planning) and III (Flight Surveillance and Control) correspond roughly to controller options and positions to the present system; and in these areas it is not difficult to discern a direct evolutionary path from the controllers of today to those of 1995. The same does not appear to be true for the remaining positions (IA - Data Base, IB - Flight Information Services, and IIB - Flow Control). For example, operators in these positions are not involved in tasks connected with aircraft emergencies. It seems reasonable, therefore, to postulate two major career paths in air traffic management where the system is configured as in the AATMS concept. One path would involve positions IIA and III; the other would be positions IA, IB, and IIB. Higher selection criteria for those performance capabilities peculiar to active control might then be set for the IIA-III path than for the non-control operator positions. Similarly, training tailored to each path could be established, so that overall training would include familiarization with activities in the other path, but emphasize content specific to a given operator's own activities and related to his own career path.

In addition to the strategic effects of a training approach based on separating career paths by option, training content requirements will be influenced at the levels of learning objectives and instructional strategy by several other factors. Again assuming (1) that the extent of automation has been achieved, (2) that there is a concommitant degree of machine aiding for those tasks still reserved for human performance, and (3) that there exists the uniformity of performance requirements entailed in a homogeneous system, the principal factors are:

- The System Concept - The way in which the system management concept evolves will have an effect on instructional emphasis and course content. For example, is functional management to be handled by individual operators or centralized in a special position specific to the purpose?
- The System Hardware - The particular choices made in surveillance, communications, navigation, and system-internal hardware will dictate specific training content, e.g., display interpretation and control operation.
- The System Operating Procedures - The regulations and rules pertaining to the airspace structure, to users, and to the system itself will have a substantial effect on operator training in areas such as user class and capabilities versus basis of flight and airspace restrictions, procedural arrangement governing climb-out course, speed, and rate of ascent after a missed approach, system reconfiguration procedures, and requirements for qualified operators to give on-the-job training to new personnel.

It can be seen, then, that the effect of automation to higher levels will not produce an undiluted reduction in training requirements or training time. Whereas the AATMS operator may have less to learn about routine control tasks than he does today, he will have more to learn about how particular automated routines work, so that he can make intelligent use of the data processing resources at his disposal. Even though the system may be much more homogeneous than that of today, it is difficult to foresee a completely uniform system (for example, military mission service requirements will, it would seem, always necessitate local variations in procedure). Since the AATMS operator is envisioned to be dealing with a larger volume of airspace than today's controller, the net effect may be that training time required will be similar to that of the present system, i.e., fewer "ground rules" but a larger airspace volume approximates the training content and time requirement of today, given equivalent teaching methodology.

Having assessed in a general way the similarities and differences between present air traffic controller training requirements and those implied in AATMS, it is also in order to consider for a moment the possibilities for training method offered by extensive automation. Two aspects of the system merit continued study as the system design evolves. They are (1) making use of the system's data processing resources for training purposes, and (2) finding ways to keep system operators prepared for events that are (or at least should be) by nature infrequent.

In the discussion of system controls and displays (Chapter 6 of this volume), it was pointed out that special display modes might well be appropriate for training purposes. In the same vein, it may be justified to examine ways to use the extra data processing capabilities provided at each system facility to generate training exercises for AATMS operators. To the extent that system procedures are indeed uniform, the content of the exercises may be stable enough to justify the cost of computer-based or perhaps computer-mediated instructional programming. Given such methods, it is conceivable that the present necessity for extended training at a central facility followed by a further period of qualification training after assignment in the field may be obviated. Reduction or elimination of this extended apprenticeship could have important cost implications by tending to defray the extra data system software costs involved in generating the necessary training sequences.

In any case, the system data processing capability may be critical to providing simulated "refresher" training exercises for those AATMS operators (Position III) who deal with unusual situations and aircraft emergencies. Since these events occur very infrequently, such training may be vital in minimizing the effects of "forgetting" and in keeping "warm-up" time requirements within tolerable limits.

To summarize, the principal implications for training which emerge from the characteristics of an advanced air traffic management system are:

- Operators at flight surveillance and control positions will require training comparable in several ways to today's controllers because of their problem-solving role.

- This comparability does not necessarily extend to other AATMS positions. If separate career paths can be established for Option I and Position IIB in one case and Positions IIA-III in the other, the potential exists for economies in operator training.

- In general, operators will not have to learn as much about routine tasks as they do today. But this reduction will be partly counterbalanced by requirements to learn about the data processing subsystems and to learn about local variations in large volumes of airspace.

- Detailed training requirements will be influenced by the system hardware, the operating procedures, and the system concept.

- Specific training methods will be a function of 1990 instructional technology and funds. However, the presence of a large data processing capability within the operational system offers a clear opportunity for exploration of computer-based or computer-mediated training, particularly for the purpose of maintaining critical skill levels at the flight surveillance and control positions.

7.4 COST FACTORS

The major inputs for estimation of cost factors are contained in the detailed manpower and data processing requirements associated with the recommended automation level. (See Chapter 3 of this volume.) However, there are perhaps certain other implications for cost which may be derived from this study. They are set forth briefly below.

- Software Development - This has an extremely large impact on the system cost. By the 1995 time period the impact of this cost factor may well exceed that of the computer hardware. The recommended automation level does not involve software development which is beyond the state of the art. In particular, the decision to recommend that special and emergency services remain manual tasks has greatly reduced the difficulty of software development from a system which is fully automated.

- Facility Configuration - The recommended automation level requires that certain tasks be performed at the THC, primary and selected secondary terminals. Since the data processing requirements are small at the primary and secondary hubs and many hubs exist, a possible trade-off exists between a time-shared versus mini-computer system in terms of computer architecture. This suggests that cost factor inputs data relating to computer costs versus size and telecommunications costs be carefully derived.

- Operations and Maintenance - The fact that such a large portion of the data processing load is concentrated at the CC and the RCCs in the current AATMS facility concept implies that considerable economies of scale will be achieved in the area of operations and maintenance.

- Hardware Development - The requirement for computational speed created by air traffic management demands is minimal. Of course, increases in CPU speed increase programs throughput. However, since many of the problems can be worked in parallel, no fundamental requirement exists for high CPU speeds. The problem of memory size does appear to require attention. The manifold advantages accruing from programming in higher level languages can only be realized if memory capacity is sufficient. For programming at the complexity level associated with the recommended automation level, the implication is that increases in cost due to large memory requirements will probably be more than offset by reductions in software development costs.

- Training - Since the recommended automation level results in the human operator being assigned a management role, the training requirements will change from today's system. Cost factors for training should take account of increase in cost for more sophisticated instructors, higher wage level demanded by individuals capable of being trained as managers, and possible increases in training time requirements.

- RDT&E - Much of the RDT&E required for AATMS automation is already included in FAA plans. It is imperative to develop cost factors which result in RDT&E costs being calculated once and only once in order to insure evaluation of the AATMS program on a consistent and accurate basis.

- Implementation Plans - In preparing cost factors for system implementation, it is imperative that the program costs for the demonstration facility described in Chapter 6 of Volume I be properly attributed to existing FAA programs as opposed to an AATMS-exclusive requirement. Since much of the data base would exist regardless of the AATMS program, implementation plan cost factors should properly account for this duality of data base usage.

Finally, while the detailed costing of alternative was deliberately not included in the scope of the study, some implications can perhaps be drawn as to gross impact of automation on manpower costs.

Based on the data presented in Section 3.5 of this volume, the salary costs for the Air Traffic Operations would decrease by approximately $350M per year in 1995 relative to similar costs in 1982. It should also be noted that this decrease would be taking place during a period when the demand is increasing by approximately 50% (Section 2.1 of this report). The combination of a total salary cost decrease of better than 50% in the face of a 50% increase in demand indicates the salary cost reduction potential available from additional automation.

However, it should be recognized that any discussion of costs inevitably must be based on many assumptions. Therefore, the reader interested in detailed examination of costs (which was beyond the scope of the TRW Automation Application Study) is referred to other studies performed during the AATMS concept formulation effort where the question of costs is addressed in detail.

7.5 RDT&E IMPLICATIONS

7.5.1 Introduction

The purpose of this section is to delineate the implications and impact that certain automation application study results would have on the RDT&E plan contained in Appendix B of Volume IV. Since the RDT&E plan was deliberately prepared so that it was capable of presentation as a stand alone document, it does not reference the remaining portions of the study. The inclusion of this section (7.5) will result in providing the reader with some insight into the implications and impact of various study results on the stand alone RDT&E plan.

7.5.2 Interrelationships Between Automation Applications Study Results and Recommended RDT&E Subprogram Items

Specific Automation Study results (e.g. Implementation Plan, Failure Mode Analysis, etc.) have implication and impact on the individual subprogram items (e.g., 222-101 Man-Machine Interface, 222-203 Computer Programming, etc.) The relationship due to impact and implications of the study results is illustrated in Figure 7.5-1. In this figure the inclusion of an indicator dot represents the fact that implications for a particular RDT&E subprogram element can be drawn from the study result indicated.

7.5.3 Impact and Implications of Study Result on Specific RDT&E Sub-Program Elements

The discussion of the impact and implication of the study results has been organized so that each subprogram element is discussed in turn. This will facilitate comparison with the RDT&E plan contained in Appendix B of Volume IV.

AATMS AUTOMATION STUDY RESULTS / AATMS AUTOMATION RDT&E SUBPROGRAM ELEMENTS		222-100 HUMAN FACTORS RDT&E				222-200 OPERATIONAL SOFTWARE			222-300 OPERATIONAL HARDWARE			
VOLUME	RESULT	222-101 Man-Machine Interfaces	222-102 Personnel Subsystems	222-103 Human Engineering	222-104 System-User Interface	222-201 Redundant Operations	222-202 Operational Algorithms	222-203 Computer Programming	222-301 Redundant Operations	222-302 Communications	222-303 Displays	222-304 Computer Sizing
I	Implementation Strategy (6.3)	●	●	●							●	
	Implementation Strategy Application (6.4)	●	●	●								
	Implementation Development Priorities (6.7)				●		●					
IV	Recommended Automation Level	●		●		●	●	●				●
	System Manning Requirements									●		
	Operator Positions Tasks and Duties		●									
	Failure Mode Analysis								●			
	Control Requirements										●	
	Display Requirements										●	

FIGURE 7.5-1 IMPACT AND IMPLICATIONS OF AUTOMATION APPLICATION STUDY RESULTS ON RDT&E

7.5.3.1 Man-Machine Interfaces (222-101)

Some of the implications for the Man-Machine Interface subprogram element are discussed in the implementation strategy (see 6.3 of Volume I). In particular the importance of developing techniques for displays of management information is discussed. The tentative conclusions suggest that RDT&E will be necessary to develop supression of extraneous data and the development of non-situation displays. In particular, emphasis in RDT&E should be placed on development of non-pictorial displays for non-product oriented assessments of machine operations (e.g. input/output rates, current core usage, predicted core usage maintenance status etc.)

In the discussion of the application of the implementation strategies (Sec. 6.4 of Volume I) indicates the impact of the implementation strategies on the man-machine interface RDT&E subprogram element. In particular, during the translation from the functional theoretical treatment detailed in this document to the specifications of the prototype it will be necessary to do RDT&E with a view to confirming man/machine allocations such as some of the manual tasks in Function 6 associated with inputting of flight surveillance information.

Finally while for the purposes of this automation applications study it was necessary and proper to quantize a task as either manual or automated, it is recommended that during the specification preparation phase of the implementation it would be appropriate to initiate a pilot program to determine for selected tasks the impact of quantization at the subtask level. This then might result in certain tasks being recommended as machine aided manual tasks. Such further optimization of the allocation via RDT&E efforts would be quite appropriate and expeditious during that phase of the implementation plan.

The requirement for the RDT&E detailed above is a direct implication of the study results detailing the recommended level of automation (sec. 3.4 of Volume IV). Examination of the character and content of the tasks recommended for automation resulted in the realization that the role of man as a manager will be sufficiently different from the role as executed today that simple extrapolation of the man/machine interface research will not suffice and that RDT&E will, in fact, be required.

7.5.3.2 Personnel Sub-Systems (222-102)

This subprogram element is impacted by three specific sections of the study results. Based on the results presented in the discussion of implementation strategy (See 6.3.1), the early RDT&E will be required to develop the prototype staffing plan. In other words, the first RDT&E, leading to implementation of the total system, will be the development of a system-like staffing plan scaled down for the prototype.

Based on the results presented in the section on application of the implementation strategy (Sec. 6.4.4 of Volume I), there will be a requirement for additional RDT&E in the personnel subsystem subprogram area. Prior to the final design of the prototype facility, investigations will be required to determine the appropriate allocation between centralized and decentralized management of the certain automated resources. Finally, after the prototype facility becomes available there will be a requirement for RDT&E studies in determining optimum size of teams or groups of human operators together with optimum sizing of the system geographical subdivisions.

Finally, the RDT&E will be impacted by the requirement to plan for an entirely new set of tasks, duties, and operational procedures associated with the human operators. The pertinent study results which are discussed in Section 2.5 of Volume IV point out the fact that the new role for the human operator is in considerable variance with today's accepted role model for todays controller. In particular, RDT&E will be required to substantiate the feasibility of including some of the duties currently performed by FSS personnel as a subset of the set of duties recommended for inclusion as part of the role for Position IB, Flight Information Officer.

7.5.3.3 Human Engineering (222-103)

This subprogram element is impacted by three specific sections of the study results. Based on the results presented in the discussion of implementation strategy (Sec. 6.3 of Volume I) the early RDT&E in this subprogram area will be concentrated on insuring the compatibility of displays, controls and consols with human operator needs. In particular, this RDT&E will serve as the basis for generation of the human engineering portion of the prototype facility specification.

Based on the results presented in the discussion of implementation strategy application (Sec. 6.4 of Volume I), additional RDT&E will be required in the pre-prototype phase for study of the display and control needs required for system failures other than automation failures (e.g. sensors, communication links, etc.)

Finally, there are significant implications for this subprogram elements based on the results contained in the discussions on the recommended automation level. For this level approximately 40% of the human operator workload was associated with the induced tasks of reading displays and entering data. In actuality this is a low percentage due to attempts in the study to minimize induced tasks. Since these estimates for induced tasks were necessarily based on conventional techniques, it appears that RDT&E oriented to novel data entry and display concept would be desirable if further reductions in manpower requirements are desired.

7.5.3.4 <u>System User Interface (222-104)</u>

This subprogram element is impacted by the results contained in the discussion of implementation development priorities (Sec. 6.7 of Volume I). As can be seen in Table 6.7-1, many of the user-interface tasks occur late in the development priority listing (e.g., subfunction 1.1, Receive Requests for Flight Planning Information; 12.3, Notify Pilot of Imminent Encounter with Hazardous Weather Phenomenon). While these subfunctions are vital, in terms of scheduling, RDT&E can probably be deferred on many of the subfunctions associated with the system-user interface if such delay is necessary to expedite RDT&E on subfunctions occurring earlier in the development priority list.

7.5.3.5 <u>Redundant Operations in Operating Software (222-201)</u>

The study results presented in the portion of the report which discusses the recommended automation level (Sec. 3.0 of Volume IV) have important implications for this subprogram element. The high level of automation which is recommended, particularly in the providing of separation assurance service, suggests the requirement for error free software. While redundant software operations offer considerable promise of providing such error free operation, the technique is still undeveloped and considerable RDT&E will be required.

7.5.3.6 Operational Algorithms (222-202)

This subprogram element is impacted by two specific sections of the study results. Based on the results presented in the discussion of implementation development priorities (sec. 6.7 of Volume I) there is an early requirement for work in this subprogram area. As can be seen in Table 6.7-1 conflict detection and resolution subfunctions occur very early in the list of development priorities. Thus RDT&E in the subprogram area should be initiated/continued at an early date.

Additional implication for this subprogram area can be drawn from the study results discussed in the section detailing the recommended automation level (Sec. 3.4 of Volume IV). As can be seen in Figure 3.4-5 a large amount of the data processing requirements are associated with functions 6, 7, 8. These functions include the conflict detection and conflict resolution algorithms. Any increases in efficiency of execution of those algorithms will thus provide major payoffs in reducing data processing requirements.

7.5.3.7 Computer Programming (222-203)

This RDT&E subprogram element is impacted by the results discussed in the section on the recommended level of automation (Sec. 3.4 of Volume IV). The implications that can be drawn from the high (70%) level of automation which is recommended is that RDT&E leading to increased programming efficiency (instructions/programmer-Day) would be quite cost effective.

Also the fact that it is recommended that the safety-critical separation assurance function be automated implies that RDT&E will definitely be required to support more efficient process for generation of error free code.

7.5.3.8 Redundant Operations in Operational Hardware

This RDT&E subprogram element has been significantly impacted by the results presented in the section of the study results detailing the failure modes analysis (Sec. 5.0 of Volume IV). This section indicates the feasibility of applying a failure mode strategy that minimizes the requirement for redundant hardware. As can be seen in Table 5.4.3 there exists a requirement under this strategy for hardware redundancy for equipment to execute only 3 of the subfunctions. Based on this study result the RDT&E on redundant operations in operational hardware can be deemphasized unless a different failure modes strategy is selected.

7.5.3.9 Communications in Operational Hardware (222-300)

This subprogram element is impacted by the study results discussed in the section of the report detailing system manning (Sec. 3.5 of Vol. IV). This section points out some of the inherent inefficiencies associated with any decentralized system having human operators at multiple locations. However, any attempt to reduce the inefficiencies of decentralized siting will require additional RDT&E in order to evaluate properly the possibility of offsetting communications costs incurred by the centralization of the system.

7.5.3.10 Displays (222-303)

This RDT&E subprogram element is impacted by three specific sections of the study results. The results detailed in the section of Implementation Strategy (6.3 of Volume I) indicate that timely RDT&E will be required in order to produce control and display specifications for the prototype facility. In particular, as pointed out in this section, RDT&E will be required in order to evaluate the desirability of supressed displays, large size displays and non-situational displays.

The study results discussed in the section of the report detailing control requirements (Sec. 6.5 of Volume IV) have implications for RDT&E. As can be seen in Figure 6.5-4 the majority of control inputs involve alpha-numeric information. Therefore, utility of RDT&E concentrating on increasing the efficiency of inputting such data can be implied from the study results.

Finally, the study results relating to display requirements (Sec. 6.5 of Volume IV) have implications for RDT&E. As can be seen in Figure 6.5.2 a considerable number of the information items displayed to the various operator positions are common to more than one position. If many of the display items are common this implies that RDT&E on establishing feasibility of "commonality" and modularity in console design should prove cost effective in reducing subsequent development costs.

7.5.3.11 Computer Sizing (222-304)

The study results discussed in the section on Recommended Automation Level (Sec. 3.4 of Volume IV) indicate that the required computer resources will be extensive (about 24 MIPS). In addition these resources may be further increased depending on the specific computer system architecture selected. Since the study results indicate that the basic computer requirement is relatively large, they imply that RDT&E on optimization of system architecture is required in light of the total size of the system.

APPENDIX A

CONTROLLER ACTIVITIES LISTINGS

Chapter 3, the discussion of manpower and data processing requirements in AATMS, includes a description of the method of estimation for manpower requirements: task frequency multiplied by manual performance time equals man-hours required. Wherever possible, the task performance times for manual tasks were drawn (by match or by analogy) from empirical data. The sources of empirical data were relevant studies of controller activities observed, tabulated by source:

Section A-1, Davis and Wallace (1961), Davis et al. (1963).

Section A-2, NAFEC (1970). This section includes the data categories used in published studies, and in the unpublished work whose source data were kindly furnished to the study team.

Section A-3, Staffing Standards Branch, Office of Management Services, FAA. These activity categories were used for observation of ATC personnel at Flight Service Stations, in connection with the preparation of a staffing standard. The standard had not been promulgated at the time of report preparation for this study, but the source data were kindly furnished to the study team.

A-1 DAVIS AND WALLACE (1961), DAVIS ET AL. (1963)

A-1.1 Controller Gives Information

A-1.1.1 Within Sector

Pass position information to C-8/tracker
Request position from C-8
Request altitude from C-8
Pass clearance to radar
Give handoff to radar
Give information to radar
Request information from radar
Request position from D
Pass altitude from D

A-1.1.2 To Sector

Pass position information to sector
Pass change altitude to sector
Pass clearance to sector
Gives handoff to sector
Pass departure to sector
Pass cancellation to sector
Pass request for ADP approach clearance to sector
Request position information from sector
Request altitude information from sector
Pass progress to coordinator
Pass information to coordinator
Pass altitude information to coordinator
Pass traffic to coordinator
Request coordinator to confirm altimeter set

A-1.1.3 To Center

Pass position information to center
Pass altitude information to center
Pass clearance information to center
Pass departure information to center

Pass cancellation information to center
Pass change frequency information to center
Request center to verify position
Request progress from center
Request change altitude from center
Request EAC from center
Gives handoff to center

A-1.1.4 To Pilot

Pass position information to pilot
Advise unable to change altitude/route
Advise radar contact unable/lost beacon
Advise beacon OK
Radar contact
Advise radar separation being used
Radar service terminated
Entering/leaving pathfinder
Gives EAC to pilot
Gives NOTAM to pilot
Gives NOTAM and EAC to pilot
Traffic advisory
Flight advisory service
Advise pilot of back-up frequency
Give altimeter setting to pilot
Time check
Give pilot reason for slowing aircraft

A-1.1.5 To FSS

Request position information from FSS

A-1.2 Controller Receives Information

A-1.2.1 Within Sector

Receive position information from coordinate/radar
Receive altitude information from coordinate/radar
Receive request for position information from coordinate
Receive position information from C-8
Receive altitude approval request from C-8
Receive clearance from C-8
Receive departure from C-8
Receive weather from D

A-1.2.2 From Sector

Receive position information from sector
Receive altitude information from sector
Receive change altitude from sector
Receive change route from sector
Receive progress and change route from sector
Receive departure from sector
Receive handoff from sector
Receive traffic from sector
Receive request for position information from sector
Receive request for altitude information from sector
Receive request for altitude approval information from sector
Receive request for clearance information from sector
Receive progress and request for clearance information from sector

A-1.2.3 From Center

Receive position information from center
Receive altitude information from center
Receive change altitude from center
Receive route from center
Receive position information and route from center
Receive handoff from center
Receive request for position information from center

Receive request for altitude information from center
Receive request for route from center
Receive request for vector from center
Receive request for information from center

A-1.2.4 From Pilot

Receive position information from pilot
Receive altitude information from pilot
Receive change altitude from pilot
Receive heading and altitude from pilot
Receive altitude and holding preference from pilot
Receive report leaving altitude from pilot
Receive route and altitude request from pilot
Receive route information from pilot
Receive change route from pilot
Receive heading from pilot
Receive traffic information from pilot
Receive weather from pilot
Pilot advises presently thirking
Receive request to verify position from pilot
Receive request for altitude assignment from pilot
Receive request for altitude information from pilot
Receive request for change altitude from pilot
Receive request for verify heading from pilot
Receive request for change route from pilot
Receive request for vector from pilot
Pilot asks if in radar contact
Receive request re: EAC from pilot
Receive request for traffic from pilot
Receive request for flight advisory service from pilot
Receive request for information on another aircraft from pilot
Receive request for equipment information from pilot
Receive request for information from pilot
Receive request for altimeter setting from pilot

Receive request for frequency from pilot
Receive request to change frequency from pilot
Receive request to leave frequency from pilot
Receive request for reason for slowing from pilot

A-1.2.5 From Tower

Receive position information from tower
Receive weather from tower

A-1.3 Coordination

A-1.3.1 Within Sector

Coordinates position information with tracker/radar/D/or C-8
Coordinates altitude/change altitude with track/radar/D/or C-8
Coordinates route with tracker/radar/D/or C-8
Coordinates route and altitude with tracker/radar/D/or C-8
Coordinates change frequency with tracker/radar/D/or C-8
Coordinates departure with tracker/radar/D/or C-8
Coordinates possible conflict with tracker/radar/D/or C-8
Coordinates holding with tracker/radar/D/or C-8
Coordinates handoff with tracker/radar/D/or C-8
Coordinates clearance with tracker/radar/D/or C-8
Coordinates EAC/route and EAC with tracker/radar/D/or C-8
Coordinates separation with tracker/radar/D/or C-8
Coordinates traffic information with tracker/radar/D/or C-8
Coordinates strip information with tracker/radar/D/or C-8
Coordinates mission information with tracker/radar/D/or C-8
Coordinates frequency with tracker/radar/D/or C-8
Coordinates equipment with tracker/radar/D/or C-8
Coordinates instructions with tracker/radar/D/or C-8
Coordinates aircraft identity with tracker/radar/D/or C-8
Coordinates on who worked aircraft with tracker/radar/D/or C-8
Coordinates NOTAM with tracker/radar/D/or C-8
Coordinates beacon with tracker/radar/D/or C-8
Coordinates position and route with tracker/radar/D/or C-8
Coordinates flight information with tracker/radar/D/or C-8
Coordinates time with tracker/radar/D/or C-8
Coordinates MAC areas use with tracker/radar/D/or C-8

A-1.3.2 With Sector

Coordinates position information with sector coordinator
Coordinates altitude information with sector coordinator
Coordinates change altitude with sector coordinator
Coordinates route and altitude with sector coordinator

Coordinates altitude and instructions with sector coordinator
Coordinates route with sector coordinator
Coordinates altitude approval request with sector coordinator
Coordinates change route with sector coordinator
Coordinates route and frequency with sector coordinator
Coordinates vector with sector coordinator
Coordinates clearance with sector coordinator
Coordinates departure with sector coordinator
Coordinates handoff with sector coordinator
Coordinates radar separation with sector coordinator
Coordinates mission with sector coordinator
Coordinates beacon with sector coordinator
Coordinates EAC with sector coordinator
Coordinates traffic information with sector coordinator
Coordinates frequency with sector coordinator
Coordinates radio with sector coordinator
Coordinates equipment with sector coordinator
Coordinates block with sector coordinator
Coordinates strip information with sector coordinator
Coordinates instructions with sector coordinator
Coordinates weather with sector coordinator
Coordinates identity or type unknown with sector coordinator
Coordinates NOTAM with sector coordinator

A-1.3.3 With Center

Coordinates position information with center
Coordinates altitude information with center
Coordinates change altitude information with center
Coordinates position and change altitude with center
Coordinates altitude approval request with center
Coordinates altitude release with center
Coordinates route with center
Coordinates change route with center
Coordinates heading with center
Coordinates vector with center

Coordinates hold/delays with center
Coordinates possible conflict with center
Coordinates clearance with center
Coordinates handoff with center
Coordinates traffic with center
Coordinates traffic advisory with center
Coordinates identity with center
Coordinates equipment with center
Coordinates separation with center
Coordinates EAC with center
Coordinates military mission with center
Coordinates aircraft information with center
Coordinates frequency with center
Coordinates change frequency with center
Coordinates communications with center
Coordinates radio with center
Coordinates call back with center
Coordinates instructions with center
Coordinates speed with center
Coordinates NOTAM with center

A-1.3.4 With Tower

Coordinates position information with tower
Coordinates altitude information with tower
Coordinates route with tower
Coordinates clearance with tower
Coordinates EAC with tower
Coordinates frequency with tower
Coordinates change frequency with tower
Coordinates NOTAM with tower

A-1.3.5 With Pilot

Coordinates altitude information with pilot
Coordinates route with pilot

A-1.3.6 With Flight Data

Coordinates position information with flight data
Coordinates altitude with flight data
Coordinates altitude and position with flight data
Coordinates instructions and altitude with flight data
Coordinates equipment with flight data
Coordinates strip information with flight data
Coordinates instructions with flight data

A-1.3.7 Other

Coordinates equipment with flow control
Coordinates NOTAM with watch supervisor
Coordinates frequency with maintenance
Coordinates equipment with maintenance
Coordinates equipment check with maintenance
Coordinates aircraft identity with SAGE

A-1.4 Controller Gives Control Instructions

Request position
Request altitude
Change altitude
Change altitude and vector
Change altitude and altimeter setting
Maintain altitude
Request altitude and issue traffic advisory
Clearance and change altitude
Request route
Request heading
Change route
Vector
Hold
Vector and beacon instructions
Advise pilot to expect clearance
Clearance
Clearance and altimeter setting
Disregard last clearance
Beacon for identification
Beacon for identification, radar contact, and clearance
Beacon instructions
Leaving pathfinder and beacon instructions
Radar contact
Radar contact and change altitude
Radar contact and request altitude
Radar contact, change altitude and vector
Radar contact, change altitude and clearance
Radar contact and clearance
Radar contact, clearance, change altitude, altimeter setting
Radar contact and beacon identification
Radar contact and unable beacon identification
Change frequency (including sector and center)
Change frequency center and leaving pathfinder

Beacon instructions and change frequency

Beacon instructions, change frequency and radar service termination

Beacon instruction, change frequency, radar service termination, flight advisory

Radar service terminated and change frequency

EAC and change frequency

Slow and EAC

Slow to hold speed

A-1.5 Manual Controller Activities

Scans strips
Scans strips (secondary)
Sequences strips
Marks strips
Removes strips
Removes and sequences strips
Scans, removes and sequences strips
Checks block strips
Deliver strips
Scans scope
Clear scope
Note Chaff marks on scope
Move targets
Move targets (secondary)
Prepare targets
Erase targets
Note possible conflict
Scan adjacent board
Check frequency chart
Equipment
Change equipment
Compute estimate
Compute ETA
Check map
Draw map
Check NOTAM
Check refueling schedule

A-1.6 Controller Communications

Unsuccessful communication
Radio
Standby/waiting
Wrong sector
NOTAM
Disregard

A-2 NAFEC STUDIES

A-2.1 Controller Activities

Code	Explanation
AB	Adjusts radar beacon controls
AF	Adjusts radio controls
AR	Adjusts radar display controls
BL	Bundles flight progress strips
BR	Controller briefing during position change
BS	Buckets, bundles, files, counts, or checks flight progress strips
CA	Coordination with "A" position
CC	Coordinates manually with coordinator
CCI	Coordinates via interphone with coordinator
CD	Coordinates with "D" position
CF	Coordination with adjacent facility
CM	Depresses CRD MWL key
CR	Coordination with "R" position
CS	Coordinates via interphone with adjacent sector, position, or tower cab within the facility
CSM	Coordinates manually with adjacent sector, position, or tower cab within facility
DS	Delivers strips to sectors
FS	Fills flight progress strip holders
GHF	Gives handoff via interphone to another facility
GHM	Gives the handoff manually to adjacent sector or position within the facility
GHS	Gives handoff via interphone to adjacent sector or position within the facility
GI	Interphone transactions of general non-operational information
ID	Issues departure clearance
INT	Interphone transactions containing operational information not defined under any activity codes
ITM	Interphone transactions related to maintenance of navaid or facility equipment

Code	Explanation
LC	Covers manual activities such as looking at charts, maps, wall or overhead displays, weather indicators, clock, telautograph, adjacent scope, etc.
MS	Marks/sequences flight progress strips
OF	Communicating with aircraft or vehicle via radio
PEF	Passes estimates or related information via interphone to another facility
PES	Passes estimates or related information via interphone to sectors or positions with the facility
PRF	Passes revisions via interphone to another facility
PRS	Passes revisions via interphone to sectors or positions within the facility
PS	Prepares, receives, delivers strips or fills strip holders
RD	Receives departure times
RE	Receives flight plans
QL	Quick look on/off entry (ARTS III)
REF	Receives estimates or related information via interphone from another facility
RES	Receives estimates or related information via interphone from sectors or positions within the facility
RHF	Receives handoff via interphone from another facility
RHM	Receives handoff manually from adjacent sector or position with the facility
RHS	Receives handoff via interphone from adjacent sector or position within the facility
RRF	Receives revisions via interphone from another facility
RRS	Receives revisions via interphone from another sector or position within the facility
SB	All activities associated with plastic shrimp boats
SC	Counts strips
SK	Checks strips
SS	Sequences strips

A-2.2 Communications

100 AIR TRAFFIC CONTROL INSTRUCTIONS

110 A/C VECTORING/HEADING MESSAGE

A control instruction informing the pilot to modify his heading. This category also includes air-initiated requests related to heading changes.

120 HOLDING

Applies only to those control commands issued by local or ground control instructing pilots to hold somewhere on the ground.

130 ALTITUDE CONTROL

A control message directing the pilot to modify his present aircraft altitude. This category includes air-initiated requests for changes to aircraft altitude.

140 SPEED CONTROL

A control message directing the pilot to alter his air-speed. This category also includes air-initiated requests for changes to aircraft speed.

150 CLEARANCE CONTROL WITHOUT HOLDING INFORMATION

A control message containing the pilot's clearance limit. It may or may not contain details of his routing and altitude. This category also includes air-initiated requests for changes to or information relating to aircraft clearance. It also covers take-off, landing, and other clearances given in a terminal area. Clearances containing altitude, speed, or beacon code information are also coded to the appropriate category.

160 CLEARANCE CONTROL WITH HOLDING INFORMATION

A control message containing aircraft holding instructions. It pertains to airborne aircraft only, and includes all ground- or air-initiated messages relating to holding.

170 AIR FILES

Filing or refiling of flight plans by the aircraft in flight will be classified 170 in addition to any other appropriate category. Includes all messages pertaining to air filing as well as actual air filing of a flight plan.

180 FLIGHT PLAN DELIVERY

Filing of flight plans by the aircraft on the ground will be classified 180 in addition to any other appropriate category.

200 ELECTRONIC COMMUNICATION SUPPORT MESSAGE

210 CALL-UP MESSAGE

This message is defined as a simple, acknowledged, radio contact from either the controller or the aircraft. This class is not used if transmission includes any other type message.

220 BEACON CONTROL

Beacon control messages are those involving transponder checks, beacon code changes, or any control action modifying the transponder operation. It is mutually exclusive with 240 or 250.

230 HAND-OFF/FREQUENCY CHANGE

It may be identified by noting the instructions given to the pilot to switch to another frequency and/or ATC facility. This message type includes those cases where an aircraft leaves the controller frequency for such reasons as calcellation of IFR flight plans.

240 BEACON DISCRETE CODE

This classification includes all transmissions involving the use of the 4096 discrete beacon codes. A discrete code is one in which the last two digits are not zeros. 240 messages may also be type 340 messages. It is mutually exclusive with 220.

250 MODE C AUTOMATIC ALTITUDE REPORTING

Messages relating to Mode C altitude readout information or the automatic altitude reporting equipment associated with a beacon transponder.

300 AIR TRAFFIC CONTROL SUPPORT

310 POSITION REPORT

The pilot reports his present or future position in terms of a ground fix or distance therefrom. This includes ground-initiated reporting of, or requests for, present or future aircraft position.

320 ALTITUDE REPORT

This message type includes present altitude reports or requests for reports of future altitude by the controller. It does not include messages pertaining to altitude information provided by Mode C automatic reporting equipment.

330 HEADING AND SPEED REPORTS

This message type also includes ground-initiated requests for information relative to aircraft heading or speed.

340 AIRCRAFT IDENTIFICATION

All messages concerned with the process of identification of the occupant of particular airspace whether it is a visual sighting or a radar target. 340 messages may also be 220 messages. Messages requesting or reporting position and altitude solely or primarily for identification purposes will be classified as 340 in addition to any other appropriate category.

350 FACILITY SUPPORT

This category involves messages concerning the capability of a ground facility to furnish specific operational support of coverage. These messages supply the aircraft with advisories such as: radar service terminated; expect radar contact at (fix), (altitude); par service not available; etc. It does not include messages related to outages or breakdowns of equipment. These are covered in sections 440 or 470.

400 <u>ADVISORY MESSAGES</u>

410 AIRCRAFT TRAFFIC ADVISORY

These messages advise the pilot and/or controller of air traffic in the vicinity of the aircraft. This category also includes surface traffic advisories or information on any other ground situation not sufficiently general and/or enduring as to warrant broadcasting (on ATIS). This rule applies regardless of whether or not ATIS is actually operating in the area.

420 AIRCRAFT STATUS

These messages cover the status of all aircraft and air frame equipment with the exception of radio and/or communications equipment checks.

430 GENERAL WEATHER

This message type includes forecasts or current weather information closely related to the area of operation. It covers those weather items general or enduring enough to be handled by automatic voice or digital data communications links. Altimeter settings are not included in this class.

440 AIRPORT STATUS

This message category will include only information sufficiently general and/or durable as to warrant broadcast (on ATIS). This rule applies regardless of whether or not ATIS is actually operating in the area. Altimeter settings are excluded from this category. Includes all landing aids associated with an airport except VOR's and DME's.

450 SPECIFIC WEATHER

This classification covers pilot reports of observed weather and specific weather information supplied to the pilot which is not sufficiently general or enduring to be broadcast. It includes items of weather at locations too remote to be of interest to aircraft operating within the sector/terminal area. Altimeter settings are excluded from this category.

460 ALTIMETER SETTINGS

Any messages concerned with pressure reference setting for the altimeter. Unless aircraft altitude is actually requested or reported, messages in this category will not be classified also as 320 type messages.

470 FACILITY STATUS

Any message pertaining to the operating status of a facility not sufficiently general or enduring to be broadcast. Includes all radars except PAR's and ASDE's.

480 GENERAL APPROACH INFORMATION

This class covers advisory information about types of approaches in use. It does not include the type or approach issued in an approach clearance -- these are type 150.

490 FLIGHT CONDITIONS

Any message by the pilot or controller pertaining to general flight conditions. This type covers words or phrases such as: "VFR conditions," "Special VFR conditions," "IFR conditions," "In-the-clear," "On top," "On instruments," "Ground contact," "Airport in sight," and similar messages. It does not apply to general or specific weather items containing visibility values, cloud heights or ceilings, or precipitation conditions either actual or forecast.

500 <u>COMMUNICATION INCIDENTS</u>

510 NO CONTACT

This classification is applied to the <u>transmission</u> which requires a response but to which no response is received. It also applied to cases where the caller is heard and not understood but the "called" replies with a request for repeat and the repeat is not eventually successful. In this case the transmission not understood is classified as type 511 and the request for repeat is classified as type 514. It might also be a type 560.

520 REQUEST FOR REPEAT

A transmission in which the pilot or controller requested a repeat of a previous transmission, usually identified by the words, "say again." This type is not used if any other message types are included in the request for repeat.

530 BLANK

540 COMMUNICATION EQUIPMENT CHECK

This category is applied to those messages generated to check channel performance. It includes those messages requesting a change of frequency due to transmission or reception difficulties.

550 COMMUNICATION INCIDENTS

Any transmission in shich the meaning of all or part of the text cannot be understood due to any type of communication incident will be classified as message type 550, in addition to any other message types which can be determined.

560 RELAYED MESSAGES

Any transmission which is relayed or which concerns the relaying of a message will be classified as type 560 as well as any other appropriate type.

600 UNCLASSIFIABLE

610 MISCELLANEOUS MESSAGE

Any transmission in which the starting time and duration is determinable and the contents of the text do not apply to any other message type definition will be classified message type 610.

620 UNCLASSIFIABLE

A transmission in which the starting time and duration is determinable but part or all of the text cannot be understood due to data reduction difficulties is classified as a message type 620 in addition to any other message types which can be determined. It also includes all transmissions containing more than six message types.

630 AIRCRAFT-TO-AIRCRAFT MESSAGE

This type is applied to non-ATC communications between two or more aircraft (whether on the ground or in the air). If the messages are relayed in support of air traffic control they are classified as 560 and any other appropriate type.

640 PAUSE

Any pause between transmissions which exceeds two seconds in duration will be treated as a separate transmission, and will be classified 640. Pause will be considered to be "originated" by the originator of the transmission being awaited. If pause exceeds ten (10) seconds it is treated as a separate interval between transactions.

700 INCOMPLETE COMMUNICATION TRANSACTIONS

710 FIRST PORTION OF TEXT MISSING

A transmission in which the start time and the duration cannot be determined will be classified as message type 710.

720 LAST PORTION OF TEXT MISSION

A contact in which the finish time and the duration cannot be determined will be classified as message type 720.

800 INTERPHONE COMMUNICATIONS

810 AIR TRAFFIC CONTROL TRANSACTIONS

This category covers any interphone transaction containing information relative to air traffic control operations.

820 MISCELLANEOUS TRANSACTIONS

This type is assigned to all interphone transactions not associated with the ATC function.

A-3 FLIGHT SERVICE STATION STUDY, FAA

PBW (Pilot Briefing with Weather)
PBN (Pilot Briefing, No Weather)
FPW (Flight Plan Data with Weather)
FPN (Flight Plan Data, No Weather)
AC (Aircraft Contacted)
AA (Aircraft Assisted)
PBW and FPW
Current weather conditions
Weather forecast
Current weather and weather forecast
Winds aloft report
Forecast and winds aloft
Landing communication
Touch and go landing approach
IFR practice approach
Taxiing for departure
T.O. (take off) and ATC clearance
Activating flight plan
Opened flight plan
Filed flight plan
Weather, forecast, flight plan
Closed flight plan
Cancel flight plan
Cancel F.P. and frequency request
No F.P. -- no go
Request ATC clearance
Request IFR clearance
Request VFR
Request VFR FP clearance
Request frequency
PIREPS
PIREPS, weather, forecast

NOTAM (Notice to Airmen)
Facsimile
CIFR (Cancel IFR)
VFR report
NOTAM, WALF and weather or PBW
Miscellaneous messages
PBW-FPN

APPENDIX B TO VOLUME IV

ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM
PLAN FOR
RESEARCH, DEVELOPMENT, TEST, EVALUATION

4.2 PROGRAM ELEMENT 222 - AUTOMATION

The National Aviation System Plan[1] provides for continuing improvements and expansions of the national aviation system (NAS) so as to correct current deficiencies and to meet projected demands over the next decade. The plan as published in 1972 identifies 21 major engineering and development programs which have been established in collaboration with the aviation community and are consistent with the related plans and programs. The plan is to be revised to include an Advanced Air Traffic Management System AATMS RDT&E plan as Program Element 22. It is proposed that Program Element 22 consist of seven sub-elements, as illustrated on Figure 4.2.1, AATMS RDT&E Program Structure. The proposed organization and direction of Program Element 222, Automation, is described in the following paragraphs.

4.2.1 Definition of Program Element 222

Automation, as applied to AATMS, is a design concept that integrates the most acceptable, efficient, and effective roles of man and machine into an efficient and safe air traffic system. The objective is to realize the potentially sizable and necessary cost savings for system operation and maintenance that may be obtained by automating manual tasks. The specific activities are oriented to providing direction for the evolution of a machine intensive system from the current labor intensive system.

4.2.2 Technical and Management Approach

Underlying the development of the AATMS is the thesis that men, as users, will depend upon the AATMS for safe efficient management of air travel and men, as managers, will be responsible for its operation. Underlying the pursuit of a specific AATMS concept is the philosophy that an adequate cost effective aviation system is sought which men, with respect to their capabilities and responsibilities, may use comfortably and with a high degree of confidence in both normal and failure modes of operation. Underlying the overall approach to develop the AATMS is the need to fully integrate the user's needs and preferences and to coordinate the development

[1] "The National Aviation System Plan - Ten Year Plan 1973-1982," Department of Transportation, Federal Aviation Admin., 1000.27 Appendix 2, March 1972.

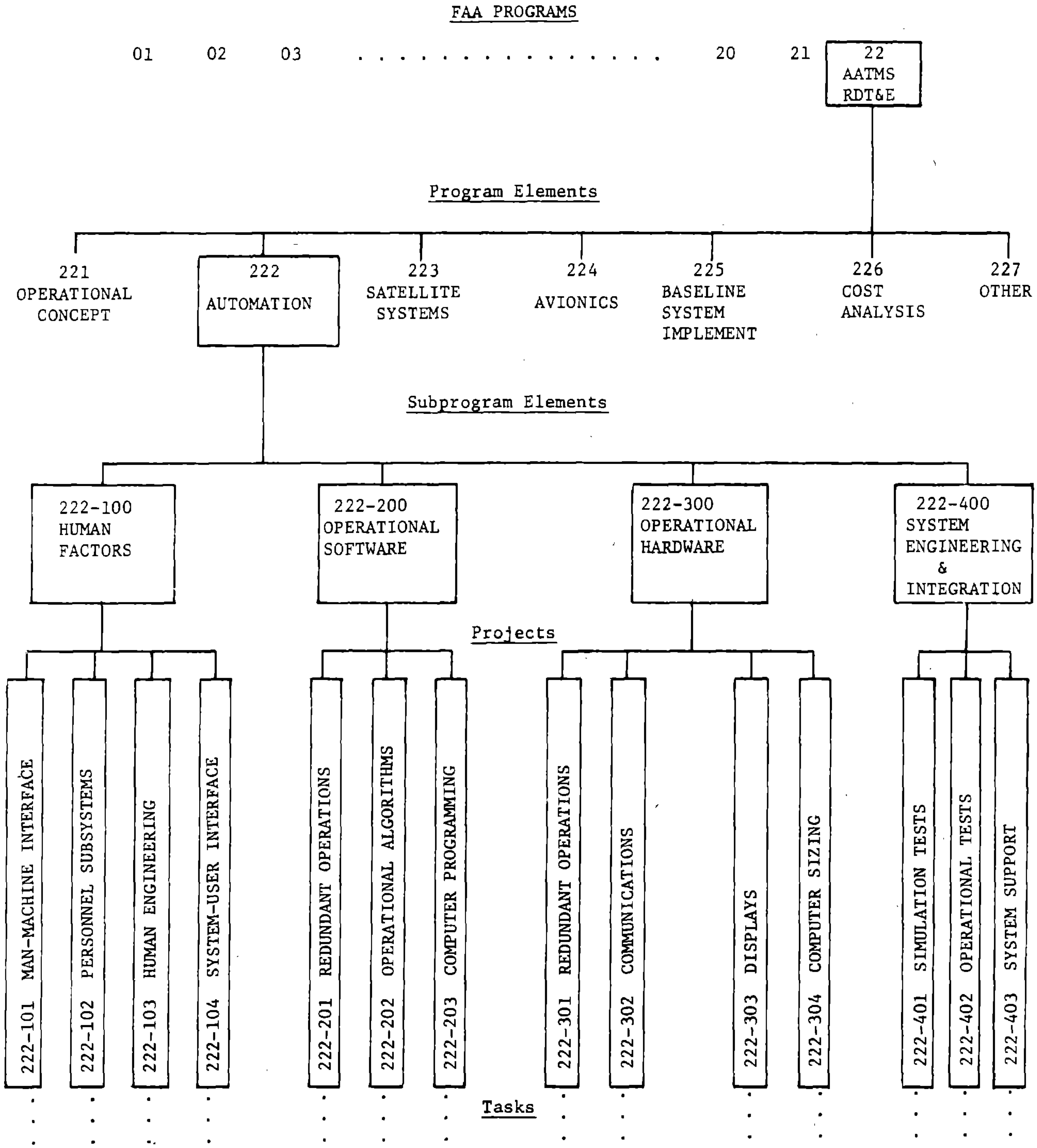


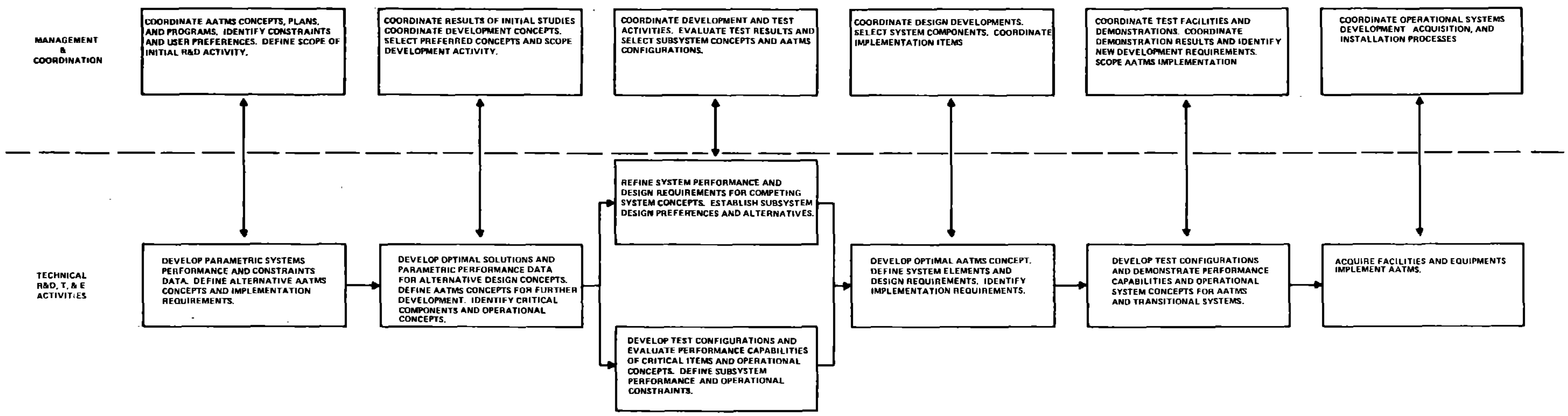
FIGURE 4.2.1 AATMS RDT&E PROGRAM STRUCTURE

processes with the aviation community so as to assure an orderly transition from current systems to the advanced systems.

In the last few years, programs for the development of the NAS and ARTS facilities together with programs for improving communications, surveillance, and navigation systems have led to incremental progressions toward a machine assisted system. Ongoing programs provide for the continuing enhancement and acquisitions of new facilities and equipments and R&D for the development of new equipments for potential use in advanced system concepts. These programs have been driven, in part, by the studies that have repeatedly emphasized that reductions in operations and maintenance cost should be possible thru increased levels of automation. These same studies have also indicated that it will be necessary to evolve an air traffic management concept from the current air traffic control concept if the full cost saving potentials are to be realized.

The general approach for evolving the AATMS designs is illustrated on Figure 4.2.2, AATMS RDT&E Approach. The AATMS must necessarily evolve from the projected en route, terminal, and central system control concepts, facilities, and equipments, and will likely utilize much of the improved navigation, surveillance, landing, and communications systems currently in process of development. As such, the AATMS RDT&E program should serve to influence the enhancement and design processes so as to facilitate the transition process and to minimize the total facility and equipment cost for achieving the AATMS. Such AATMS RDT&E coordination activities are considered inherent in the overall processes.

Considering the complexity of the AATMS, a fully integrated systems approach will be required to effectively manage the AATMS RDT&E activities. The activities must necessarily be integrated with other DOT/FAA programs and be compatible with the plans and programs of the general aviation community, including the international aspects. A sound systems engineering approach must be also used to manage the individual activities of the AATMS subprogram elements. Within the automation area, Program Element 222, the activities would not only define automation limits and constraints which may be used in formulating operational concepts, Program Element 221, or

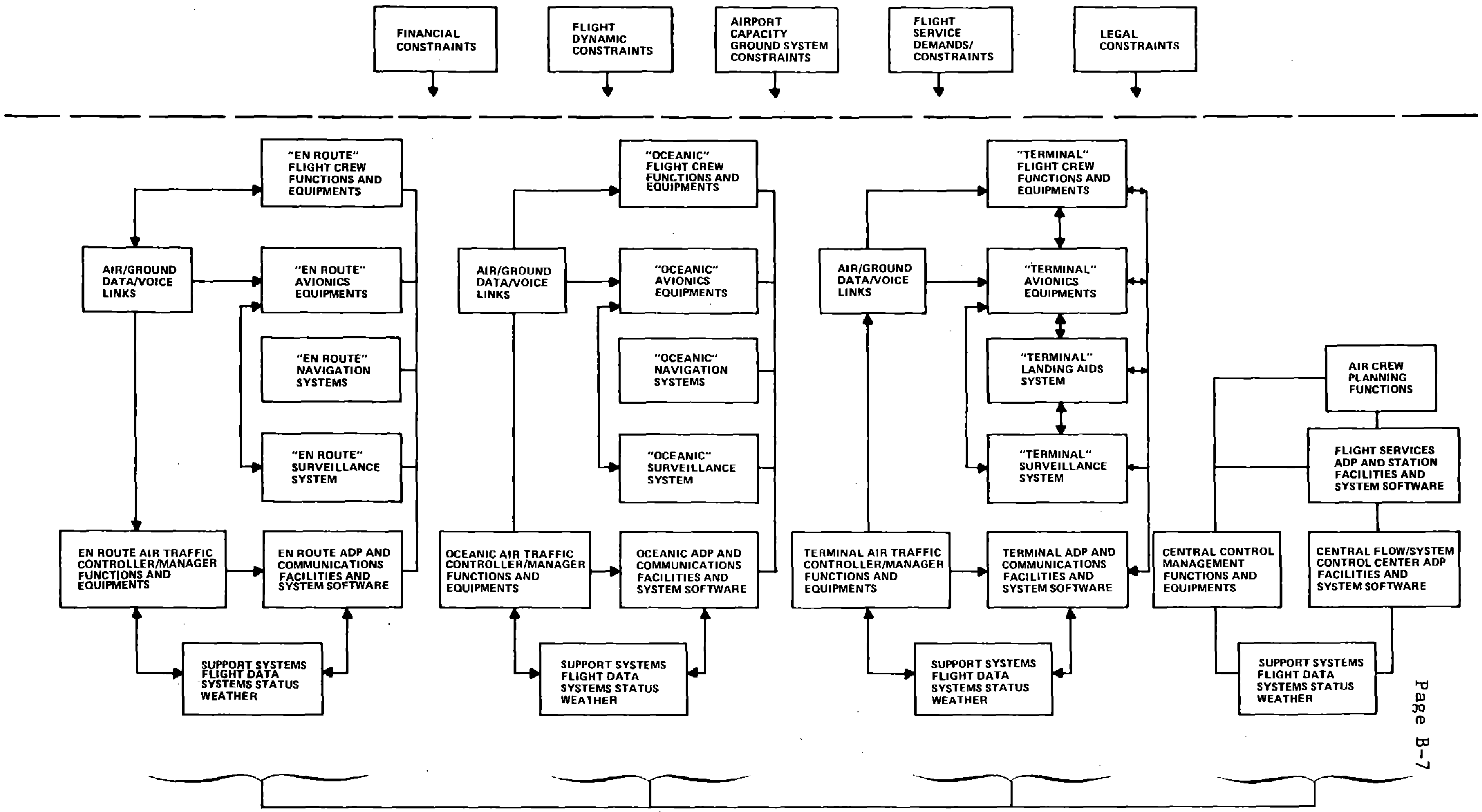

MANAGEMENT & COORDINATION
COORDINATE AATMS CONCEPTS, PLANS, AND PROGRAMS. IDENTIFY CONSTRAINTS AND USER PREFERENCES. DEFINE SCOPE OF INITIAL R&D ACTIVITY.
COORDINATE RESULTS OF INITIAL STUDIES COORDINATE DEVELOPMENT CONCEPTS. SELECT PREFERRED CONCEPTS AND SCOPE DEVELOPMENT ACTIVITY.
COORDINATE DEVELOPMENT AND TEST ACTIVITIES. EVALUATE TEST RESULTS AND SELECT SUBSYSTEM CONCEPTS AND AATMS CONFIGURATIONS.
COORDINATE DESIGN DEVELOPMENTS. SELECT SYSTEM COMPONENTS. COORDINATE IMPLEMENTATION ITEMS
COORDINATE TEST FACILITIES AND DEMONSTRATIONS. COORDINATE DEMONSTRATION RESULTS AND IDENTIFY NEW DEVELOPMENT REQUIREMENTS. SCOPE AATMS IMPLEMENTATION
COORDINATE OPERATIONAL SYSTEMS DEVELOPMENT ACQUISITION, AND INSTALLATION PROCESSES
TECHNICAL R&D, T, & E ACTIVITIES
DEVELOP PARAMETRIC SYSTEMS PERFORMANCE AND CONSTRAINTS DATA. DEFINE ALTERNATIVE AATMS CONCEPTS AND IMPLEMENTATION REQUIREMENTS.
DEVELOP OPTIMAL SOLUTIONS AND PARAMETRIC PERFORMANCE DATA FOR ALTERNATIVE DESIGN CONCEPTS. DEFINE AATMS CONCEPTS FOR FURTHER DEVELOPMENT. IDENTIFY CRITICAL COMPONENTS AND OPERATIONAL CONCEPTS.
REFINE SYSTEM PERFORMANCE AND DESIGN REQUIREMENTS FOR COMPETING SYSTEM CONCEPTS. ESTABLISH SUBSYSTEM DESIGN PREFERENCES AND ALTERNATIVES.
DEVELOP TEST CONFIGURATIONS AND EVALUATE PERFORMANCE CAPABILITIES OF CRITICAL ITEMS AND OPERATIONAL CONCEPTS. DEFINE SUBSYSTEM PERFORMANCE AND OPERATIONAL CONSTRAINTS.
DEVELOP OPTIMAL AATMS CONCEPT. DEFINE SYSTEM ELEMENTS AND DESIGN REQUIREMENTS. IDENTIFY IMPLEMENTATION REQUIREMENTS.
DEVELOP TEST CONFIGURATIONS AND DEMONSTRATE PERFORMANCE CAPABILITIES AND OPERATIONAL SYSTEM CONCEPTS FOR AATMS AND TRANSITIONAL SYSTEMS.
ACQUIRE FACILITIES AND EQUIPMENTS IMPLEMENT AATMS.

establishing automation requirements which may be used in developing cost projections, Program Element 226, but would also develop the processes for transitioning from the current systems to the advanced more machine-intensive systems of the future.

To facilitate the R&D processes, it is recommended that the automation area be subdivided into functional areas as illustrated on Figure 4.2.1. The proposed organization facilitates conducting independent analyses as well as developing the systems related trade-off data required for concepts developments and systems definitions. Further, it is recommended that the initial activities be oriented to developing the systems parametric and constraint information required for the development of systems concepts and that following activities be directed to developing specific concepts and system requirements as the overall AATMS concepts and designs evolve. The underlying approach of effecting an orderly transition from the current systems to the advanced systems in collaboration with the general aviation community should be adopted as a policy. The inter dependencies of the AATMS RDT&E tasks as associated with the transition from current systems is illustrated on Figure 4.2.3.

4.2.3 Subprogram Element Descriptions

The descriptions of the subprogram elements are based on the premise that the future AATMS operators will continue to make basic decisions, but will be given the means to formulate such decisions at a higher level than currently allowed. A basic premise that the current air traffic controllers will evolve to air traffic managers, but that the most effective roles of man and machine in the AATMS remain to be developed, underlies the development activity concept. The necessities to ensure continuity of operations of the AATMS under conditions of system failures, the need to transition from current systems to AATMS, and the need to integrate and coordinate the automation tasks with the related programs and the aviation community are included in the approach and task descriptions. The Automation Program Element (222) described herein discusses these tasks in four subprogram areas: Human Factors, Operational Software, Operational Hardware, and Systems Engineering and Integration.



4.2.3 R&D INTERDEPENDENCIES; ATC SYSTEMS

4.2.3.1 Human Factors

The human factors activities (222-100) associated with the AATMS program are divided into four broad categories, each related to a major aspect of system design and development. First there is the definition of the man-machine interface. This work is already in progress and will continue throughout the AATMS program. As the specific characteristics of the man-machine interface take shape during the RDT&E process, attention will be directed along two parallel channels of concern. One will be human engineering of system components and individual equipment items; the other will be the design of the personnel subsystem itself, which entails delineation of the manning structure, specification of the numbers and types of personnel needed, and definition of training requirements. The fourth area of human factors involvement will be in studies of the interface between the AATMS and the users of the airspace. This will include primarily specification of interface requirements and evaluation of air-crew interactions with the AATMS. This area represents the counterpart of RDT&E in the Avionics program element (224). In the later stages of system development, human factors studies will be needed in the areas of system integration and operation. The concerns here will be the contributions of man to the performance of the AATMS and the "fine tuning" of the system with respect to human participation. This work is conducted under subprogram 222-400.

4.2.3.2 Operational Software

The operational software area (222-200) is concerned with the development of appropriate data processing algorithms, the need for failure protection redundancy, man-machine interfaces, and the experimental verification of the AATMS automation. The activities consist of system requirements definition, software requirements definition, analysis and preliminary design, and detailed program design, coding, and testing. Current and complete documentation is a must and should include software requirements documents, preliminary design specifications, interface design specifications, final design specifications, and test plans. Product assurance techniques, including the use of autonomous and detached test groups, must be used. Strict adherence to configuration control and extensive use of test standards, procedures, and tools must be guaranteed.

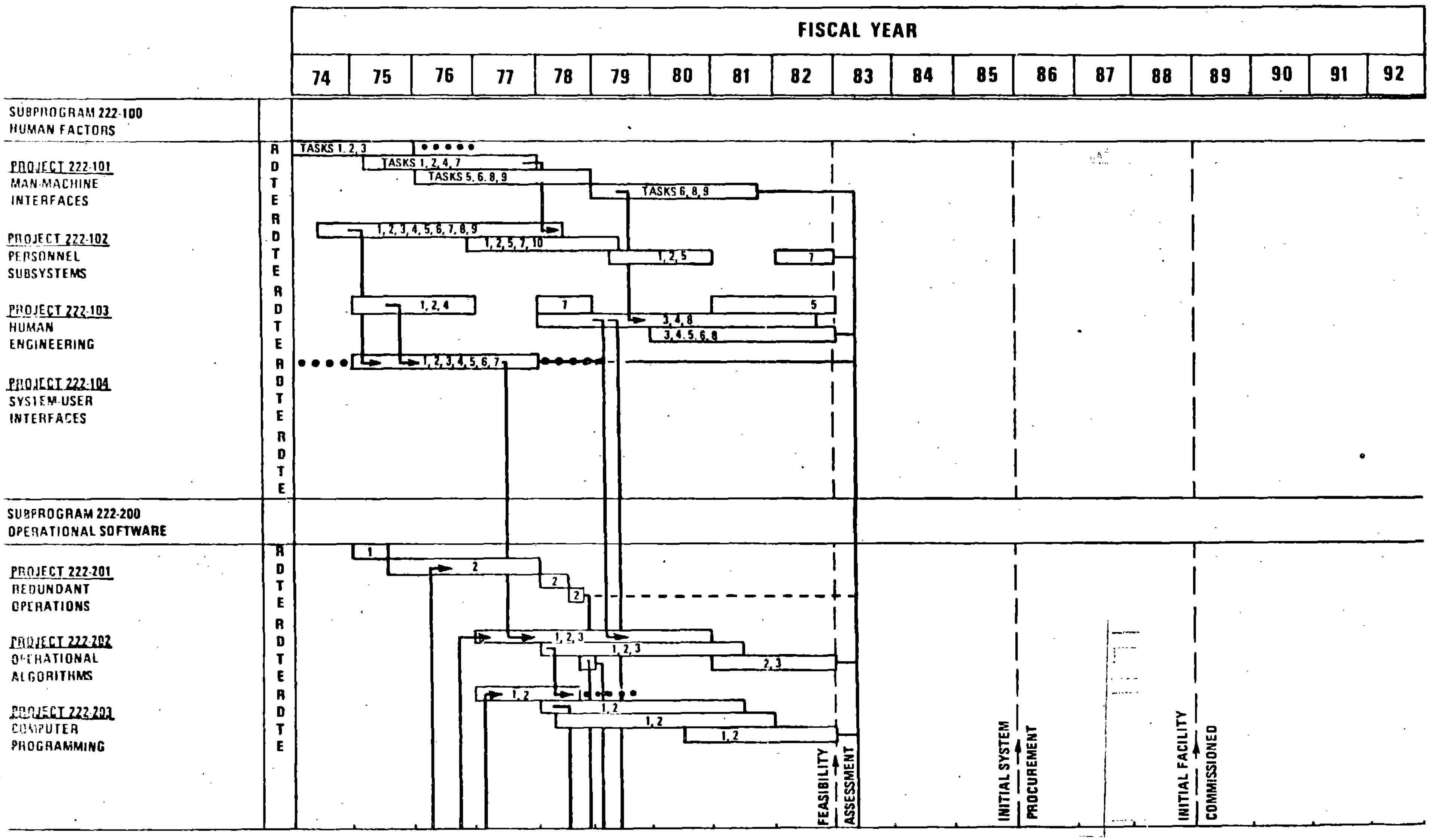


FIGURE 4.2.4 AUTOMATION RDT&E RELATIONSHIPS, SCHEDULES, & INTERFACES

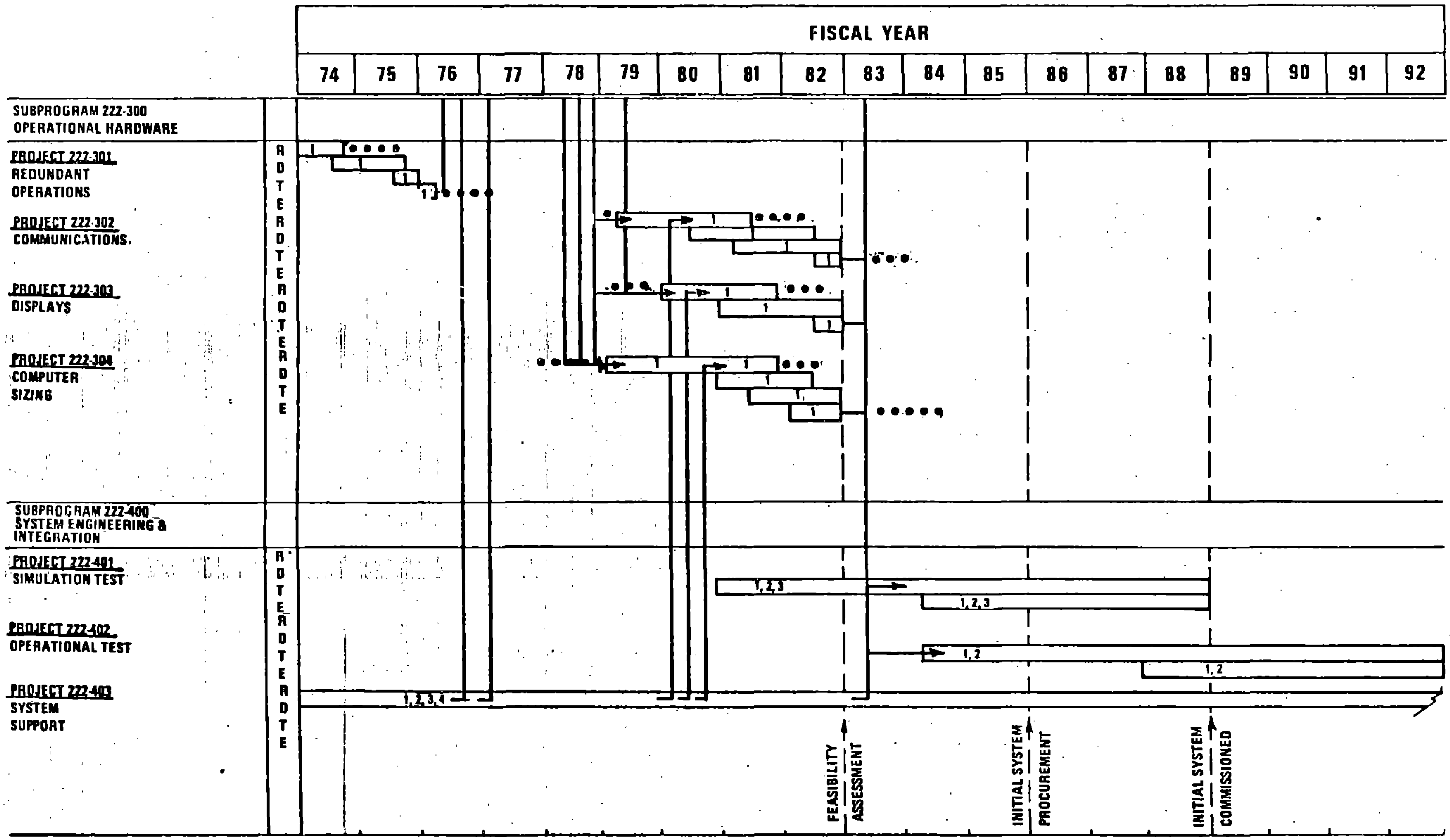


FIGURE 4.2.4 AUTOMATION RDT&E RELATIONSHIPS, SCHEDULES, & INTERFACES (CONTINUED)

4.2.3.3 Operational Hardware

The operational hardware area (222-300) is concerned with the need for redundancy, the ability of computers to communicate with each other, the determination of the requirements and the ultimate development of display equipment, mass storage devices, computer architecture, and computer sizing requirements when considering centralized vs. dispersed facilities. Study and experimental contracts must be let with hardware and software firms to fulfill these requirements.

4.2.3.4 Systems Engineering and Integration

The systems engineering and integration area is concerned with tying together the human factors, the software, and the hardware areas of automation research. It is concerned with developing and using such tools as systems analysis, mathematical modeling, and simulation and operational testing. Simulation testing will be used where feasible to save costs and maintain safety. Operational testing will be conducted where simulation cannot give sufficient assurance or where simulation is impractical. Test and evaluation is aprt of each subprogram's activities but this subprogram (222-400) is concerned with interface relationships at the subsystem and system level.

4.2.3.5 Relationships, Schedules and Interfaces

Figure 4.2.4 is a plot of the subprogram and project relationships that exist and a tentative schedule for their accomplishment. Tasks within each project are assigned to the R, D, T, or E phases. Task numbers are identified in the paragraphs to follow. Information presented is based on our present best estimate of what is required. It is expected that tasks and projects will be added, deleted, and/or modified as the AATMS program progresses.

4.2.4 Subprogram 222-100 Human Factors

The human factors area recognizes the requirement to achieve a distribution of responsibilities that permits the man to perform as an operational element of the system. Philosophically, man must retain management responsibility for the system -- it cannot be delegated to computers. Further, wherever man is responsible, he must be able to keep himself informed and to influence the situation with regard to that responsibility. These requirements dictate an operational role for man. Work accomplished to date has identified the responsibilities involved but much additional is needed to produce precise definitions of each man-system interface. Specific projects proposed in this area are discussed below.

4.2.4.1 Project 222-101 - Man-Machine Interface

Statement of the Problem

The high level of automation which characterizes the AATMS will, in many respects, change the role of man in air traffic control. Although job options will differ and man will relinquish to computers many of the tasks which he now performs, there will remain an essential and undelegatable core of human involvement and responsibility. The Automation Application Study has produced a first approximation to this problem's solution but in a generic context. The kinds of things that man should do and the responsibilities that man should have are now, in general, known. What remains to be done in this area, is to make the connection between generic requirements and specific system requirements. The connection can only be made through extensive study of the specifically evolving AATMS structure and careful application and testing of the principles developed to this point.

Technical Approach

The precise nature and role of man as an operator, as a manager, and as a back-up component must be determined. Information necessary to permit the optimization of the distribution of authority and responsibility between man and machine will be made available through direct studies of the problem and the characteristics of the specific AATMS structure.

Statement of Work

RDT&E tasks in this area are required over the span of FY74 to FY81 as the total system feasibility is developed. Specific tasks are listed:

222-101-1 Definitions of human intervention in AATMS equipment failure modes (information requirements, take-over and warm-up times, error rates)

222-101-2	Tradeoff studies of manual vs. automatic back-up
222-101-3	Studies of man-computer interaction
222-101-4	Definition of the controller's role and response requirements in contingency operations.
222-101-5	Confirmation of the allocation of critical tasks
222-101-6	Refinement of manual task time estimates
222-101-7	Definition of optimal modes of man-machine interaction for data flow, control actions, and traffic planning
222-101-8	Workload studies and validation of workload distribution
222-101-9	Optimization of the distribution of authority and responsibility between man and machine

Resources Required

Approximately 25 man-years are required.

Responsibilities

Contractor support to TSC.

4.2.4.2 Project 222-102 - Personnel Subsystem

Statement of the Problem

The personnel subsystem is a vital element in a man-managed system. During the AATMS operational testing and phasein period, there will be a need to build up a personnel subsystem to support its operation. At the same time, the predecessor system will be servicing ever increasing traffic demands and utilizing a population of ATC experts trained in that system's structure. Extensive planning is necessary to effect the smooth transition of those ATC experts into attractive careers in the AATMS and to utilize the extant expertise to the fullest in the AATMS implementation. A continuing effort, starting with the base of knowledge established in the initial Automation Applications study, will be necessary to expand that base as more detail of the AATMS is developed and to evolve a personnel subsystem design.

Technical Approach

Constant review of personnel requirements as they are changed with the advent of the automated system will be required. In effect, there will have to be a personnel subsystem design effort carried out in parallel with the hardware and software RDT&E programs.

Statement of Work

Personnel subsystem RDT&E tasks are:

222-102-1 Validation of qualitative manning requirements (job categories, occupational specialities, controller position and options, support personnel types, etc.)

222-102-2 Validation of quantitative manning requirements (number of personnel by job category, occupational speciality, type of facility, and level)

222-102-3 Development of job descriptions (duties and tasks by position, career options and occupational specialities, levels of advancement)

222-102-4 Design of job and career patterns (concentration and distribution of manpower, advancement opportunities, transfers within and across occupational specialties)

222-102-5 Definition of controller team composition and division of duties and responsibilities

222-102-6 Formulation of selection criteria for controllers and support personnel

222-102-7 Establishment of controller performance standards and proficiency measures

222-102-8 Specification of training requirements, including:

- Course and syllabus design
- Classroom and on the job training
- Individual and team training
- Cross training between positions/options
- Transition training

222-102-9 Specification of training equipment requirements, including:

- Part and whole task trainers
- Simulators
- Use of operational equipment for training
- Job aid design

222-102-10 Studies of factors influencing controller acceptance of the AATMS, including:

- Job design
- Man/machine interface characteristics
- Socio-economic factors
- Duties, authority and responsibility
- Equipment characteristics

Resources Required

Approximately 35 man-years are required.

Responsibilities

Contractor support to TSC.

4.2.4.3 Project 222-103 - Human Engineering

Statement of the Problem

Synchronized with the RDT&E cycle for AATMS equipment will be a human engineering effort to assure the compatibility of displays, controls, and consoles with human operator requirements. Human factors attention is also required regarding the design of AATMS from the point of view of maintainability and maintenance activities. This problem area directly relates to the needs of managers for interactions with the system to support their responsibilities. The information needed by the managers must be readily accessible, in sufficient detail, and in clear and concise form. Likewise, the means for the managers to take necessary actions must be provided that are most suitable for human manipulation.

Technical Approach

Human engineering personnel will be integrated with the hardware designers. They will help set design requirements, participate in detailed equipment design, and evaluate equipment features influencing operator performance.

Statement of Work

Human engineering tasks include:

222-103-1	Development of display requirements (information content, modes, format, symbology, visual and auditory characteristics)
222-103-2	Development of control and input device requirements (type, operating characteristics, force and dexterity, and feedback features)
222-103-3	Review and evaluation of specific control and display designs
222-103-4	Design of consoles and work stations
222-103-5	Human factors support of facilities design
222-103-6	Evaluation of work environment and operational sites
222-103-7	Specification of maintainability features and maintenance operations
222-103-8	Evaluation of individual equipment designs with respect to maintenance operations and compatibility with human performance capabilities

Resources Required

Approximately 35 man-years are required plus operational systems hardware.

Responsibilities

TSC plus contractor support

4.2.4.4 Project 222-104 - System User Interface

Statement of the Problem

Automation in the AATMS will have major implications for the airspace user, particularly the aircrew, both in planning and conducting flights. Conversely, aircrew performance will affect operation of the AATMS and some automation details. This effect is closely related to Avionics RDT&E (Program Element 224) and should be coordinated with work in that area. The thrust of Project 222-104 is toward the implications of ATC automation for system users. Such implications touch nearly all aspects of system operation as indicated by the proliferation of tasks for this project.

Technical Approaches

Flight simulators plus operational equipment and aircraft will be used to collect data and otherwise gain experience in the relationship of the user to the system proposed.

Statement of Work

222-104-1 Delineation of flight service station requirements, specifically:

- information requirements (input and output)
- user access and input devices
- output devices and output characteristics

222-104-2 Investigation of aircrew work load changes resulting from AATMS design features, in terms of:

- user class differences
- airspace
- flight phase
- contingency and failure modes

222-104-3 Determination of the influence of pilot performance on system operation:

- variations in pilot competence
- reliability of performance (man and equipment)
- backlash of airborne failure on pilot and/or controller work load

222-104-4 Cockpit information requirements and display/control requirements for:

- flight data (status, command, management planning)
- ATC - related information

222-104-5 Specification of pilot qualifications and training requirements

222-104-6 Determination of general aviation requirements in the areas of:

- information requirements
- instrumentation
- procedures
- training
- airman certification and proficiency maintenance

222-104-7 Investigation of pilot/user acceptance factors, including:

- freedom of airspace user
- required avionics and instrumentation
- performance requirements and standards
- flexibility of AATMS to meet user demands
- procedures and rules

Resources Required

Approximately 15 man-years are required plus simulators and operational flight equipment.

Responsibilities

FAA and TSC plus contractor support.

4.2.5 Subprogram 222-200 - Operational Software

This subprogram provides for the investigation, design, development, and test of computer software required for en route control of aircraft.

Included are the study and possible design, implementation and test of redundant software and the development, test and evaluation of control algorithms. Consideration is to be given to language requirements for the operational design as well as training software requirements.

4.2.5.1 Project 222-201 - Redundant Operations

Statement of the Problem

The important role of software in maintaining system safety and capacity is well recognized. An investigation is necessary to ensure that the AATMS will be able to successfully meet its various failure states.

Technical Approach

Redundant software is a candidate solution to fail-operational design. A literature search, and possibly interviews, will be conducted to ascertain the potential of redundant software programs in ensuring system performance. An analysis of the AATMS functions is to be supplied to help determine which functions warrant a backup. New software will likely be developed, tested and evaluated.

Statement of Work

RDT&E tasks in this area are:

- 222-201-1 Evaluate results of past experience in redundant programming
- 222-201-2 Develop and test redundant software

Resources Required

Approximately 30 man-years, plus approximately $5 million computer cost.

Responsibilities

Contractor support to TSC.

4.2.5.2 Project 222-202 - Operational Algorithms

Statement of the Problem

Increases in efficiency, capacity, and safety, and reduction in airborne delays are required in serving the projected traffic demand. A comprehensive approach to ATC algorithm development, which takes every advantage of the design freedom inherent in a new system, is required to produce the necessary algorithmic capabilities.

Technical Approach

An automated system for checking flight plans and monitoring progress is proposed. Develop an algorithm which utilizes a data base of flight plans, weather status, terminal status, jurisdiction workloads and delays to recommend the most efficient use of airspace and runways. An automated system for detecting potential airborne conflicts will be developed. The detection algorithm would utilize a risk determination along with a scanning filter. A conflict resolution algorithm would choose from possible solutions by comparing the relative desirability of a maneuver, the aircraft types, and the risks associated. Data bases will be developed to support algorithm construction and pre-operational testing.

Statement of Work

222-202-1	Develop, test and evaluate a flow control algorithm
222-202-2	Develop, test and evaluate a conflict detection algorithm
222-202-3	Develop, test and evaluate a conflict resolution algorithm

Resources Required

Approximately 45 man-years, plus a high speed digital computer and an ATC simulator.

Responsibilities

Contractor support to TSC.

4.2.5.3 Project 222-203 - Computer Programming

Statement of the Problem

A data management system (DMS) and an executive operating system (OS) will be required to support the automated functions of the AATMS. The Automation Applications study has produced an estimate of the scope of data processing requirements but further study is needed to determine the optimum configuration for data processing facilities (i.e., centralized or distributed). This configuration is, in turn, necessary as a basis for the design and implementation of a suitable DMS and a capable, efficient OS.

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Technical Approach

Conduct a detailed requirements analysis and compare the results with specifications of currently available data management systems. Determine the consequences of developing a specialized (AATMS-tailored) system. If deemed desirable, develop a specialized data management system. Conduct the same type of study of general purpose vs. specialized executive and possibly develop a special purpose executive. Considerations of communications reliability, costs of data transfer, reaction time and access time will be important elements of the work.

Statement of Work

222-203-1	Analyze requirements, evaluate alternatives and develop a DMS
222-203-2	Analyze requirements, evaluate alternatives and develop an OS
222-203-3	Test and evaluate the DMS and the OS

Resources Required

Approximately 90 man-years are required, plus computer useage.

Responsibilities

Contractor support to TSC.

4.2.6 Subprogram 222-300 - Operational Hardware

This subprogram provides for the investigation, design, development, and test of computer hardware required for en route control of aircraft. Included are the study and possible design, implementation of redundant hardware, computer to computer communication networks, and display requirements. In addition, computer sizing for the AATMS concept will be evaluated considering centralized vs. dispersed placement.

4.2.6.1 Project 222-301 - Redundant Operations

Statement of the Problem

The importance of maintaining system safety in a high capacity environment is well recognized. An investigation is necessary to ensure that the AATMS will be able to successfully meet its various failure states.

Technical Approach

Redundant operation is a candidate solution in fail-operational design. A study is to be conducted to determine the appropriate role for hardware redundancy. An examination of applicability of double or triple redundancy of the same or different systems and determination of requirements for new hardware will be performed. Develop, test, and evaluate new hardware, if necessary.

Statement of Work

222-301-1 Design, test and evaluate redundant hardware operations

Resources Required

Approximately 30 man-years, plus computer useage.

Responsibilities

Contractor support to TSC.

4.2.6.2 Project 222-302 - Communications

Statement of the Problem

The AATMS design will place a major demand upon the ability of computers to communicate effectively and economically with each other. Major difficulties arise in handling incompatible data streams and rates.

Technical Approach

The proposed solution is to develop a protocol for a computer communications network. To be considered are the practicalities, standardization, formalization of rules and definitions of data transforms to permit compatability. The approach would include an investigation of available research, development of several approaches to a protocol which would involve data link formats, message distribution and switching software, and the use of small communications processors and finally, testing and evaluation of the protocol and prototype communications processors, if indicated.

Statement of Work

RDT&E tasks in this area are:

222-302-1 Develop and test a computer communications network involving diverse computers.

Resources Required

Approximately 20 man-years, plus computer useage.

Responsibilities

Contractor support to TSC.

4.2.6.3 Project 222-303 - Displays

Statement of the Problem

The types of displays appropriate for supporting enroute control of aircraft must be determined prior to the development of an operational system. Once determinations have been made about the desired level of automation, studies must be conducted to determine the types of displays which will meet the required levels of interaction, reliability and other technical constraints. Test display hardware must be evaluated as well as the software to drive them in prototype form.

Technical Approach

Test hardware will be selected to meet the required display categories. Several candidate systems from each category will be tested by exercising them in a real time environment by a general purpose display software package on a computer.

Statement of Work

RDT&E tasks in this area are:

222-303-1	Selection of candidate displays for required categories
222-303-2	Development of software test and simulation software
222-303-3	Test and Evaluation of display hardware

Resources Required

Approximately 20 man-years, plus computer useage.

Responsibilities

Contractor support to TSC

4.2.6.4 Project 222-304 - Computer Sizing

Statement of the Problem

The extent to which data processing resources are concentrated, dispersed, and/or internetted is a fundamental decision which affects hardware, as well as software and communications requirements. It likewise affects the cost/benefits and the failure modes analysis of the system.

Technical Approach

The AATMS preliminary software designs are to be used for the purpose of sizing the data processing required for their implementation. Consideration will be given to the frequency and time for execution. An analysis will be conducted of the computer architecture available and the extent to which the tasks could be performed in dispersed and/or centralized configurations. Trade-offs between communications, data processing, and storage resources will be identified and quantified.

Statement of Work

RDT&E tasks in this area are:

222-304-1 Refined computer sizing for advanced automation concepts

Resources Required

Approximately 45 man-years, plus computer useage.

Responsibilities

Contractor support to TSC.

4.2.7 Subprogram 222-400 - System Engineering and Integration

The System Engineering and Integration (SE/I) segment of the AATMS Automation RDT&E Plan is concerned with projects which will support the test and evaluation efforts in system development. As personnel and data processing subsystems are developed in the previously discussed automation areas, program managers will require the means to test and evaluate interacting subsystems. Simulation models, specifically tailored for the purpose, operational tests, and a whole battery of supporting studies are to be provided under this subprogram title. In addition, this subprogram area covers base housing and experimental facilities support.

4.2.7.1 Project 222-401 - Simulation Test

Statement of the Problem

During the conduct of the AATMS research and development program, subsystem concepts may be modified and/or hardware characteristics may be found to differ from early projections. The impact of such changes must be evaluated quickly and economically within the context of operations with interfacing subsystems or, in some cases, with the complete system.

Technical Approach

The basis for making decisions concerning the course of validating and/or modifying RDT&E activities can be considerably enhanced if program managers have computer (fast-time) simulation models available to them to complement other evaluative tools. The approach is to develop a family of AATMS concept-oriented models of varying scope, resolution, and complexity. The models are to produce performance data for system evaluation in accordance with initially determined criteria.

Statement of Work

RDT&E tasks in this area are:

222-401-1 Analysis of evaluation criteria
222-401-2 Design of simulation model set
222-401-3 Model development and test

Resources Required

Approximately 120 man-years plus computer useage.

Responsibilities

Contractor support to TSC.

4.2.7.2 Project 222-402 - Operational Test

Statement of the Problem

During the conduct of the AATMS research and development program, subsystem concepts may be modified and/or hardware characteristics may be found to differ from early projections. Evaluating the impact of such changes by simulation methods does not always result in sufficient assurance to proceed. Other types of testing must be considered.

Technical Approach

A performance assurance program is proposed to encompass all phases of the flight and ground inspection system, ground calibration, pre-flight testing procedures, and radio frequency measurements. Efforts are to be made to ensure that equipment continues to perform in accordance with initial design objectives or are modified to meet performance requirements. It will be concerned with subsystem and system performance.

Statement of Work

RDT&E tasks in this area are:

222-402-1	Subsystem test program
222-402-2	System test program

Resources Required

Cannot be identified now

Responsibilities

FAA facility(s) to be selected.

4.2.7.3 Project 222-403 - System Support

Statement of the Problem

There are several categories of work to be accomplished during the RDT&E phase in support of projects such as AATMS. Support is required in this area of facilities and equipment as well as in a series of miscellaneous study areas.

Technical Approach

Detailed support facilities and equipment requirements will be specified later in the evolution of AATMS. These will include housing, aircraft, flight inspection, training, and logistics performance. Currently, a series of studies have been identified to support the subprograms of human factors, operational software, and operational hardware, primarily as they interface.

Statement of Work

RDT&E tasks in this area are:

222-403-1	Distribution of hazards in current & future air traffic management systems
222-403-2	Ultimate theoretical limits to airport capacity
222-403-3	Evolution paths to future air traffic management systems
222-403-4	Impact of collision avoidance logics on air traffic management systems

Resources Required

Approximately 15 man-years

Responsibilities

FAA, TSC, and contractor support.

APPENDIX C

RESULTS OF TREND ANALYSIS UTILIZING THE DELTA SIMULATION

This appendix details the results of utilizing the DELTA (Determine Effective Level of Task Automation) simulation for the establishment of trends in the AATMS manpower and data processing system requirements.

C-1 PURPOSE

The exercising in this study of the DELTA simulation was oriented to the establishment of trends in manpower and data processing requirement for changes in the automation levels. Due to the limited exercising of the simulation the absolute level of manpower and data processing requirements was established through utilization of the hand calculations detailed in Chapter 3 of this volume. While the small sample size provided by the exercising of the simulation is not sufficiently extensive to provide absolute levels, the exercise was designed to provide sufficient data to substantiate the validity of the trends calculated by procedures detailed in Chapter 3.

C-2 INPUT DATA

Since the DELTA simulation runs input data provided for the SRI DELTA Simulation Validation Study simulated the SFO BAY TRACON, it was elected to utilize as much as possible of the same scenario for the 1995 AATMS trend runs. While the complete details of the scenario are contained in Reference 1, the remainder of this section does address some of the more significant input variables.

C-2.1 System Structure

A portion of the San Francisco Bay TRACON was used as the location to be simulated in the trends study.

In addition to the Menlo Final and South Feeder sectors it was necessary to create two artificial en route sectors to serve as program "sources" and a runway complex to serve as a program "sink" for aircraft. However, the resources from these three sectors were deliberately not included in the results. The South Feeder and Menlo Final sectors geography was defined in terms of handoff locations on the Standard Terminal Arrival Routes (STARs) as provided by SRI in Reference 1. Four STARs were modelled and three non-standard routes were developed to handle other flights into San Francisco. Pop-ups, itinerants and local traffic were also included in the study.

C-2.2 Aircraft Classes

Twenty-eight different aircraft types were defined in Reference 1. Examination of the aircraft characteristics of these types indicated that they could be grouped into six classes for purposes of the model. The six classes are summarized in Table C-1, along with the key characteristics. The mix of aircraft on the various routes was as specified in Reference 1.

C-2.3 Runway Occupancy Times

An important difference between current terminals and those projected for the 1995 time frame is the time an aircraft will spend on a runway. These times will vary with aircraft type and, therefore, have been developed for each of the six aircraft classes previously defined. It was assumed that the San Francisco terminal will have high speed (i.e., 30 knots), continuous runway exits and that the deceleration rate will be 6 ft/sec^2 for all aircraft classes. The resulting runway occupancy times for the six classes were supplied by the Transporation Systems Center in Reference 2. They are as follows:

Aircraft Class	Occupancy Time (in seconds)
AC01	43.4
AC02	39.7
AC03	39.7
AC04	37.3
AC05	20.6
AC06	23.5

TABLE C-1 AIRCRAFT CHARACTERISTICS

AIRCRAFT TYPE	GENERAL DESCRIPTION	TAKEOFF SPEED (KTS)	APPROACH SPEED (KTS)	CRUISE SPEED (KTS)	CRUISE ALTITUDE (10^3 FT)
AC01	Jumbo Jet	250.	165.	523.	30-39
AC02	4-Engine Heavyweight Jet	220.	150.	478.	30
AC03	2/3-Engine Lightweight Jet	220.	150.	496.	25
AC04	2/4-Engine Turbo-Prop	120.	140.	235.	25
AC05	Small GA Piston	70.	75.	160.	10
AC06	Multi-Engine Piston	100.	90.	185.	12

C-3 RESULTS

Three different automation levels were studied under two different demand conditions. The high demand level approximates a flow rate of 60 aircraft per hour through the sectors of interest. This level represents the nominal projected SFO busy hour operations for 1995 as defined by SRI. A lower demand level of 40 aircraft per hour was also used and represents the lowest estimate of projected SFO busy hour operations for 1995.

In addition to these six runs designed to study the variation of resource requirements with changes in the automation levels as originally defined, a simple special excursion case was run with man/machine allocation designed to maximize the manual performance of tasks having any element of decision making capability required. This excursion was designed to provide insight into the impact of alternative allocation of tasks requiring decision making.

C-3.1 Results for Three Automation Levels

The results of the DELTA model run for the three automation levels and 2 demands are presented in Figure C-1 and C-2. The resources required to accomplish the automated tasks, measured in thousands of instructions per second, are shown in Figure C-2. The resources required to perform the manual tasks, measured in equivalent men, are shown in Figure C-1. Equivalent men were found by taking each man available in a particular configuration, multiplying by the percent of the time each man was busy, and summing these products.

The three automation levels were studied. Briefly, the lowest level was the least automated, relying heavily upon manual resources; level R is a fairly highly automated mixture of resources, being recommended as the most economical mix of men and computers; level IV is still more highly automated. A detailed discussion of automation levels can be found in Chapter 3 of Volume IV.

As expected, the number of men required decreases with increased automation, but at a decreasing rate at higher automation levels (as seen on the 60 aircraft per hour curve) in Figure C-1. On the other hand, as can be seen in Figure C-2, the computer requirements climb steeply with increased automation levels.

R

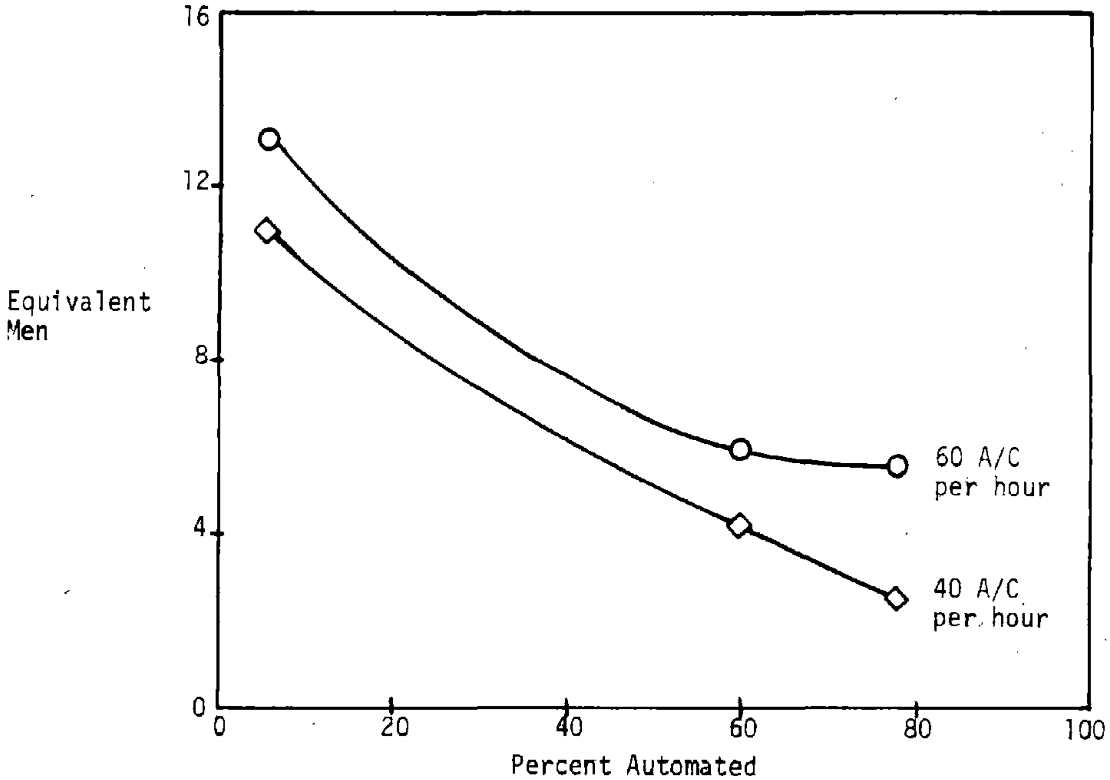

FIGURE C-1 MANPOWER RESOURCE REQUIREMENTS

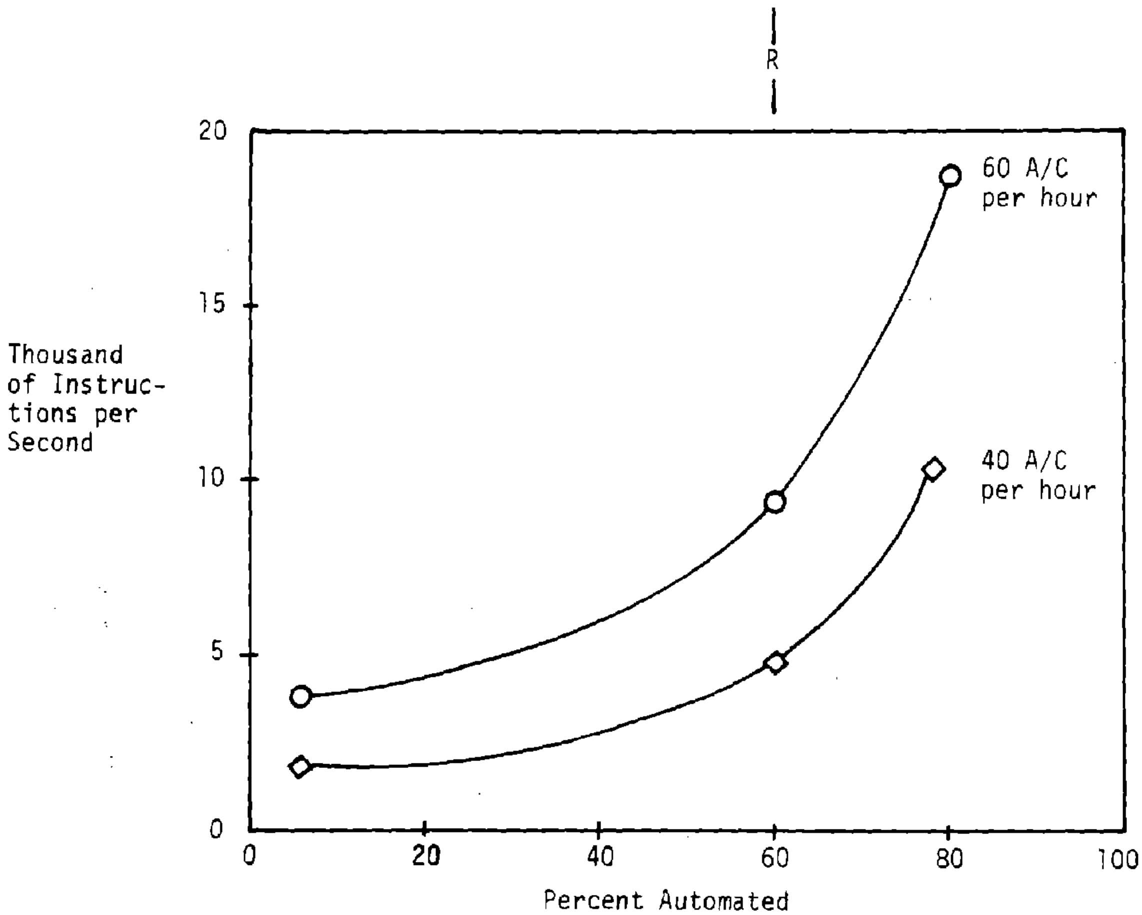

FIGURE C-2 DATA PROCESSING RESOURCE REQUIREMENTS

The primary utility of the DELTA simulation for the SFO case lies in the substantiation of the selection of an automation level using the methodology discussed in Chapter III of Volume IV. This methodology determined variation in resources with automation level for all of CONUS. The recommended level as derived in Chapter III resulted in approximately 70% of the tasks being automated. For the SFO case examined using the DELTA simulation, automating of the same set of tasks resulted in approximately a 60% level of automation. This apparent anamoly resulted from the fact even though the task allocation is the same for a task whether performed in SFO or CONUS, the SFO case only examined a subset of the total set of manual and automated tasks performed in CONUS.

However, an examination of the curves in Figure C-1 and C-2 suggest that the recommended level is near a "knee" in the curves, illustrating the variation in manual and automated resources with percentage of automation. Such a location is normally near optimum.

Thus the use of the more sophisticated DELTA simulation for the SFO case resulted in conclusions which are consistent with the recommendation based on the less sophisticated methodology used for aggregation of all of CONUS resource requirements.

C-3.2 Results for Special Excursion Run

Since one of the characteristics of the recommended automation level is that many of the routine decision making tasks were automated, there was some interest in exploring the impact of such automation on the manpower levels. A computer simulation run was thus structured to examine the case where routine decision making tasks were allocated to men. The run was identical to the recommended case with the exception that tasks were allocated as follows:

1. All tasks currently automated (as of 1972) were automated (as per SRI input)
2. Of the remaining tasks, all tasks which were manual in the recommended automation level remained manual
3. Of the remaining tasks, any which involved a decision making performance capability were made manual
4. All remaining tasks were automated

The results are plotted in Figure C-3 and C-4. Since the demand used as input for the excursion case was 40 aircraft per hour, the curve previously established for the variation of resource with automation level (originally as shown in Figure C-1 and C-2) is included for comparison. As expected the manual resource requirements are higher for the excursion case than for the recommended level since the percentage of the automated tasks are lower. However, the increase is higher than would be anticipated by interpolating between levels to obtain resources for the percentage of automation associated with the excursion case. This greater than anticipated increase in manpower requirements results from the manpower required for induced tasks. Thus the results of the excursion suggest that following the normal man/machine allocation methodology developed in the study has potential for minimizing induced tasks.

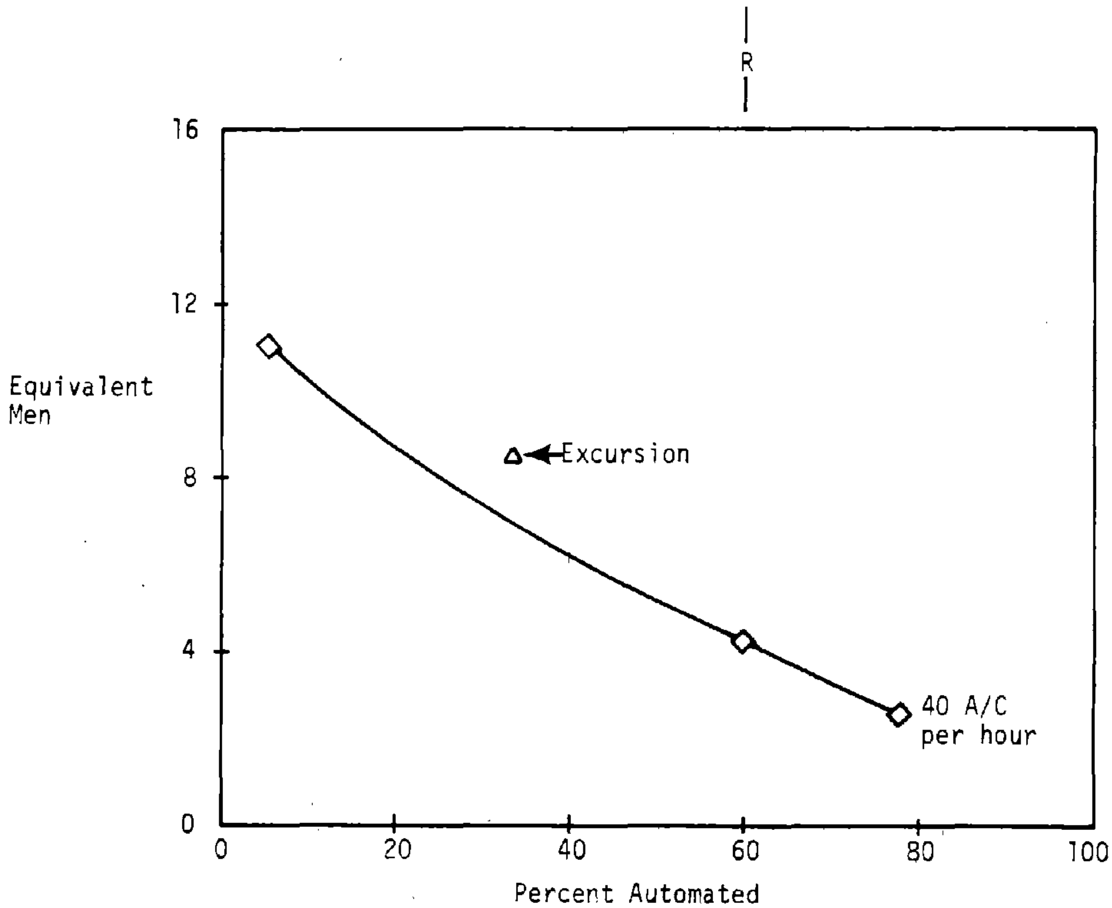

FIGURE C-3 MANPOWER RESOURCE REQUIREMENTS

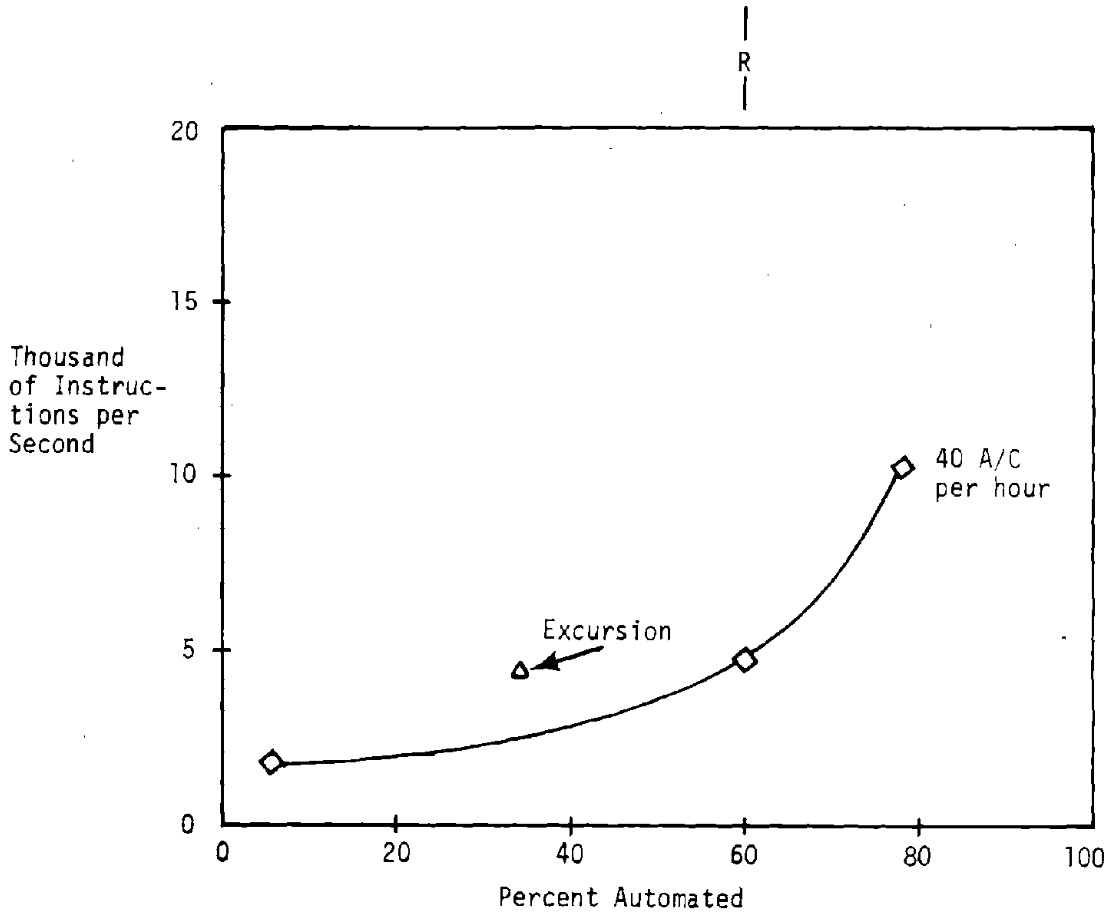

FIGURE C-4 DATA PROCESSING RESOURCE REQUIREMENTS

REFERENCES

1. "Revised Test Plan for the TRW DELTA Model", Williams, J. O. et al., Stanford Research Institute Project 2332, Technical Note 8, 29 June 1973, with additions on 13 August 1973 and 10 October 1973.

2. "Runway Occupancy Times for 1995 Trend Cases", Robert S. Ow, Transportation Systems Center Memorandum, 29 October 1973.

REFERENCES

1. Air Traffic Control Advisory Committee, Report of the Department of Transportation Air Traffic Control Advisory Committee, (ATCAC), 2 Volumes, December 1969.

2. Autonetics Division (North American Rockwell Corp.), Fourth Generation Air Traffic Control Study, Report No. DOT-TSC-304-1, June 1972.

3. Boeing Company, Study and Concept Formulation of a Fourth Generation Air Traffic Control System, 5 Volumes, Report No. DOT-TSC-306-1, April 1972.

4. Corson, J. J. et al., Air Traffic Controller Career Committee Report, Department of Transportation, January 1970.

5. Davis, C. G., and Wallace, W. H., The Controller in Positive and Traditional Control, Report No. FAA/BRD-301, Federal Aviation Agency, September 1961.

6. Davis, C. G., et al., Influence of Selected Sector Characteristics Upon ARTCC Controller Activities. Final Report, Contract FAA/BRD-301, The Matrix Corporation, June 1963.

7. DOT, Transportation Systems Center, Advanced Air Traffic Management System Study Report, Report No. DOT-TSC-OST-73-20, June 1973.

8. Federal Aviation Administration, National Aviation System Plan 1973-1982, Document No. 1000.27, Appendix 2, Department of Transportation, March 1973.

9. Holland, F. C., Flight Service Station Weather Briefing Content Ananlysis, The MITRE Corporation, Report No. MTR-6424, June 1973.

10. The MITRE Corporation, Advanced Air Traffic Management System B: Summary Report, Federal Aviation Administration, Report No. FAA-EM-73-10, June 1973.

11. National Aviation Facilities Experimental Center, Data Report on the Manual Operations at Jacksonville ARTCC. Project 167-641-01X, April 1970.

12. National Aviation Facilities Experimental Center, Data Report on the Before and After ARTS II Automation at Knoxville. Project 151-515-05X, November 1970.

13. Rockwell International Corp., Advanced Air Traffic Management System Final Report, April 1973.

14. Rucker, R. A., Parlow, R. D., Sternfels, P. R. and Mayer, D. S., Controller Productivity Study, The MITRE Corporation, Report No. MTR-6110, November 1971.