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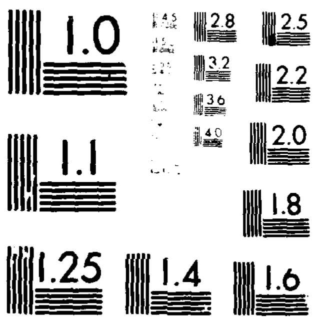

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LEVEL II

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ANALYSIS OF EXPANDABILITY AND MODIFIABILITY OF COMPUTER CONFIGURATION CONCEPTS FOR ATC

Volume I: Distributed Concept

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FINAL REPORT

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16. Abstract

The questions of expandability and modifiability of a 1990-era Air Traffic Control (ATC) system are addressed. Two strawman systems are described at the functional level: a Baseline System, which represents the ATC system as it might be just after the replacement of the current National Airspace System (NAS) en route computers, and a Future System, which represents what might be derived ten years later under an appropriate scenario for ATC development. A distributed processing computer configuration is postulated for the Baseline System, and processing and communications loads are calculated on the basis of traffic and parameter estimates for 1985. Expansion and modification of the Baseline System to produce the Future System designed to meet estimated 1995 loads under the supplied scenario are examined. The distributed processing concept, as considered here, was deemed generally suitable for use in the ATC system of the future.

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PREFACE

This report was prepared under Project Plan Agreement FA-958, "Future ATC Computer Systems", sponsored by the Federal Aviation Administration, Office of Systems Engineering Management.

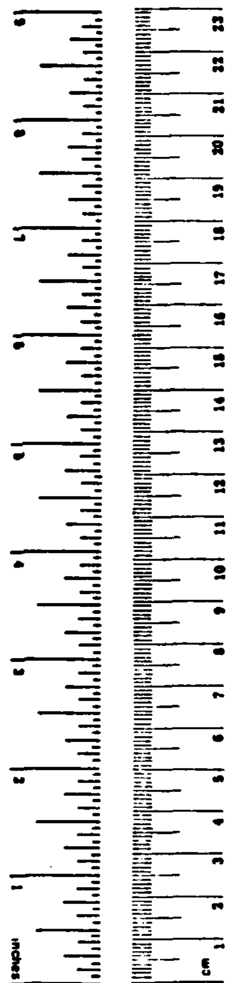
The authors wish to acknowledge the contribution by A.G. Zellweger of the FAA of the Scenario for 1995 included in this report as Appendix A. In addition, they wish to acknowledge the contributions and leadership of Vivian Hobbs, who was project leader during the first 15 months of the project and who originated many of the ideas embodied in the report.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

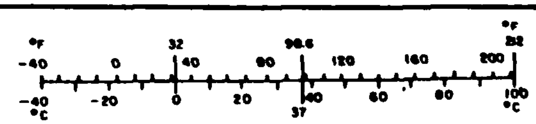
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ABBREVIATIONS AND ACRONYMS

A/C	Aircraft
ATC	Air Traffic Control
ATCRBS	Air Traffic Radar Beacon System
AERA	Automatic En Route ATC
AID	Aircraft Identification
ARTS	Automated Radar Terminal System
ATIS	Automatic Terminal Information System
BCAS	Beacon Collision Avoidance System
C	Conflict Processor
CCC	Central Computer Complex
CDC	Channel Display Controller
CDTI	Cockpit Display Traffic Indicator
CE	Computer Elements
CID	Computer Identification
CONUS	Continental United States
CPN	Comparative Processing Number
CPU	Central Processing Unit
DABS	Discrete Address Beacon System
DARC	Direct Access Radar Channel
DBM	Data Base Management
DCC	Display Channel Controller
D_d	D-position Display Processor
DL	Data Link
DP	Data Processing
D_r	R-position Display Processor
DRG	Data Receiving Group
ER	Engineering Requirements
ETABS	Electronic Tabular Display System
ETD	Estimated Time of Departure
ETF	Estimated Time Over Fix
F_c	Clearance Generation Processor
FAA	Federal Aviation Administration
F_b	Bulk Flight Data Processor
F_d	Display Flight Data Processor
FEDSIM	Federal Computer Performance Evaluation and Simulation Center
FLAT	Flight Plan - Aided Tracking
FSS	Flight Service Station
HOL	High Order Language

ABBREVIATIONS AND ACRONYMS (CONT.)

ICS	Interprocessor Communications Subsystem
I_e	External Interface Processor
IFR	Instrument Flight Rules
I/O	Input/Output
IOCE	Input-Output Control Elments
LAX	Los Angeles Airport
M	Million
Ms	Multisecond
MSAW	Minimum Safe Altitude Warning
MX	Multiplexer Channel
NADIN	National Aviation Data Interchange Network
NAFEC	National Aviation Facilities Experimental Center
NAS	National Airspace System
NWS	National Weather Service
O&E	Operational and Environmental
OS	Operating System
OSEM	Office of Systems Engineering Management
PAM	Peripheral Adapter Modules
PVD	Plan View Display
R	Radar Processor
RMMS	Remote Maintenance Monitoring System
S	Selector Channels
S	Supervisory Processor
SE	Storage Elements
SLT	Solid Logic Technology
SPAR	System Performance Analysis Report
SPI	Special Purpose Indicator
T	Track Processor
T_p	Terminal Processor
TDMA	Time Division Multiple Access
TIPS	Terminal Information Processing
TPC	Terminal Path Control
TSC	Transportation Systems Center
μ/sec	Micro Seconds
VFR	Visual Flight Rules

1. INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

In replacing the existing National Airspace System (NAS) computer complex, the Federal Aviation Administration (FAA) will choose one concept for computer architecture from among many possible competitive proposals. The system, as installed by the mid-1980's, will be expected to have a useful life of about twenty years and to meet all requirements put on it during that time. However, requirements change with time, therefore, it cannot be expected that the 1985 system will be completely satisfactory in 1995 and beyond because of possible increasing traffic loads and of additional funtions to be performed. It is, then, incumbent on the FAA to choose their replacement system wisely, so that in the 1980's they will have a system which can be expanded and changed enough to continue to serve throughout its expected lifetime.

At the same time, computer technology, both in hardware and software, is changing rapidly so that a system designed today may be obsolete by the time it is installed. A bigger problem is the requirement to make design decisions of far ranging implications, without benefit of practical experience, with the available alternatives. This is the problem addressed in this study.

Specifically, what will be the effect in the 1990's of a choice made now of a computer architectural concept for installation in the 1980's? In other words, the attempt is made to assess not how well each computer configuration would serve as a replacement for the system, meeting the requirements of 1985, but rather how well it might perform over the following twenty years or so.

1.2 METHOD OF ANALYSIS

Before this analysis can begin, the proposed computer architectural concepts for the Air Traffic Control (ATC) computer complex must be obtained, and the future ATC system described. The first of these was postulated by the study team, and the second was provided by the sponsor.

Four generic computer configurations were identified based roughly on concepts already suggested as possible candidates. Each configuration was abstracted to a set of processors with local memory connected by an interprocessor communications subsystem whose form was not specified. The configurations were then differentiated by the way functions were assigned to processors and the possible specialization of processors to perform in different ways. The four configurations selected to this point cover a wide range of possibilities but could be supplemented by others as appropriate.

1) "Distributed" System

Processing takes place either at the source of the data to be processed or at the location where the output is used. The functions are partitioned into sets which are as small as practicable. Each set is assigned to a single processor which can then be specialized for that set of tasks.

2) "Federated" System

The system is made up of a number of identical processors; each is assigned a set of functions to perform. The functions are grouped according to the way they share data, and groups are assigned to processors in a way which balances the load among them. The assignment of functions and data to processors does not vary with time.

3) "Multi-Processor" System

The system is similar to the present NAS computer complex, as it is made up of identical processors and memory modules arranged so that any processor can access any memory. The processing is scheduled dynamically with functions assigned to any free processor. This configuration specializes to the uniprocessor by eliminating redundant processors.

4) "String-oriented" System

The processing is organized into sequences or strings of related tasks; each of which is assigned to a set of processors arranged in pipeline fashion. Processors can be specialized for the tasks assigned them.

The scenario supplied by the FAA [see Appendix A] describes the structure of the airspace, the distribution of traffic, the surveillance and communications modes, and the new and improved services to be rendered by the ATC system from the mid-1990's on. This view of the world is only one of many possible views, but it has the advantages of being quite general, allowing a range of independent parameters to be postulated, and of being quite demanding of the ATC system, allowing near worst-case conditions to be studied.

The methodology followed in this study consisted of three steps for each configuration type.

a) A "Baseline" System was developed, which is or was a version of the candidate configuration sized, with functions assigned to processors and data to memories, to serve as the en route computer complex in 1985. It is what the system would look like if this configuration were chosen for implementation as the en route computer system replacement.

b) Using the same configuration, the "Future" System is developed. New traffic loads and functions, taken from the scenario, are postulated, and the system is resized and reconfigured, where necessary, to carry out the new functions.

c) The analysis of the implications of the system choice is carried out. The results of this analysis supply the answer to the question posed above.

1.3 DESCRIPTION OF THIS REPORT

The body of this report contains the material from each of the three steps of the methodology for the first of the four configuration types, the "distributed" system. (It is expected that the remaining types will be the subjects of later volumes.) Section 2 contains the functional description of the Baseline System, and Section 3 describes the Future System. The analysis of the implications of configuration choice is given in Section 4. Three appendices follow: Appendix A is the scenario for the Future System as supplied by the FAA, Appendix B describes the methods used to get traffic estimates for 1985 and 1995, and Appendix C gives the results of a related background study on the limitations of, and possible extensions to, the current IBM 9020® system.

2. THE BASELINE SYSTEM

2.1 ENVIRONMENT OF THE BASELINE SYSTEM

The "Baseline" System is a hypothetical implementation of the ATC en route system as it might appear in 1985. It is assumed that an IBM 9020® replacement computer will have been procured and installed, and that the system will meet the 1985 functional requirements.

2.1.1 Surveillance

It is assumed that by 1985 some Discrete Address Beacon System (DABS) sensors will be operational, but that most FAA sensors will still be combined primary and Air Traffic Control Radar Beacon System (ATCRBS) radars. This means that the computer system will have to handle both types of data, DABS and ATCRBS, in a mixed environment. It is assumed that data coming from DABS equipped aircraft will have an additional DABS identification associated with them.

2.1.2 Communications

It is assumed that the National Aviation Data Interchange Network (NADIN) system will be used for inter-facility and remote communications with enough bandwidth available so that there is essentially no limit on communications of this type. This means that a single communications interface can service all external sources and destinations, since there will be a common interface standard and communications protocol.

Wherever DABS is implemented, the DABS data link will be available, hence the system must be ready to use it. There is the implicit assumption that some aircraft will have DABS data-link equipment and can make use of it.

2.1.3 Interfaces

The NAS computer will exchange data with the Central Flow Control Facility, a Weather Services facility, and a Flight Service facility in addition to adjacent ATC facilities. Flow Control messages from the en route center to the facility will convey information about non-scheduled flight plans, changes to flight plans, actual departures and conditions at terminals; messages flowing in the other direction will contain delays to be imposed on scheduled flights and other flow controlling directives. The Weather Services will provide both map and textual data describing existing and predicted weather patterns and events; weather information derived locally and from pilot observations will be transmitted to the Weather facility. Finally, flight plans, filed through the Flight Service Station (FSS), will be received by the en route computer, which will, in turn, transmit status and control information to the Flight Service facility.

2.1.4 Air Activity

Estimates of processing and communications loads on the 1985 system will depend on the number and types of aircraft being serviced then, as well as the particular services being rendered. In order to derive estimates of the required parameter, the traffic figures for 1975 (the latest available as this study was initiated) were assembled, converted to required measures, and projected to 1985. The process is described in detail in Appendix B.

It was decided to carry out the analysis of the Baseline System for three centers: small, medium, and large. To do this, 1975 data from three actual centers, Denver, Memphis, and Chicago, were used as the bases for projection to 1985. (Note: We do not claim to be predicting the traffic at those actual centers in 1985, but rather what the traffic at typical small, medium, and large centers might be in 1985.)

The parameters chosen to describe the operation of the en route ATC system in 1985 are given in Table 2.1-1 together with the values assumed to hold, at that time, for the small, medium, and large centers.

2.1.5 Airspace Structure

It is assumed that the structure of the airspace in 1985 is basically what it is today; i.e., there will be terminal-control, positive-control, and no-control airspace. It is assumed that everything above 12,500 feet is in positive control airspace.

2.1.6 En Route System Functions

The set of functions performed by the Baseline System will include those performed by the current NAS as well as a set now under development, and likely to be developed by 1985.

The current NAS functions are:

a. Bulk Store Processing,
b. Flight Plan Activation,
c. Route Conversion,
d. Posting Determination,
e. Flight Plan Position Extrapolation,
f. Fix-time Calculation,
g. Associated Checking,
h. Beacon Code Allocation,
i. Radar Data Preliminary Processing,
j. Target/Track Correlation,
k. Track Acquisition,
l. Tracking [Flight Plan-Aided Tracking (FLAT) and Free]
m. Conflict Alert,

TABLE 2.1-1 PARAMETERS DESCRIBING ATC OPERATION - BASELINE YEAR, 1985

NO.	PARAMETER		SMALL	CENTER MEDIUM	LARGE
1	Number of Radar Targets From the CDs (Peak)	$[\rho]$	339	533	787
2	Number of Radars	$[\eta]$	9	5	5
3	Number of Tracks in the System (Peak)	$[\tau]$	254	400	590
4	Number of Correlated Targets (Peak) 0.95 (#3)	$[\tau_o]$	229	361	548
5	Number of Flight Plans Entered From Bulk Store (Busy Hour)	$[\phi_B]$	85	42	227
6	Number of Flight Plans in Two-Minute Interval From Bulk Store	$[\phi_2]$	3	1	7
7	Number of Flight Plans Entered Through FSSs (Busy Hour)	$[\phi_F]$	42	175	137
8	Number of Active Flight Plans in the System (Peak)	$[\phi_A]$	430	668	984
9	Number of Displays (Sectors)	$[\sigma]$	34	36	43
10	Number of Controller Operations (Per Minute Per Position)	$[\delta_{CR}]$	4	4	4
11	Number of Uncorrelated Radar Returns (Peak) 0.01 (#3)	$[\rho_\mu]$	2	4	6
12	Number of Conflicts Predicted per Hour	$[\gamma]$	58	144	333
13	Number of Departures/ Arrivals (Busy Hour)	$[\phi_{AD}]$	126	216	364
14	Number of Overflights (Busy Hour)	$[\phi_o]$	130	152	87
15	Number of D Controller Operations (Per Minute Per Position)	$[\delta_{CD}]$	6	6	6
16	Number of MSAW Conflicts Detected per Hour	$[\mu]$	6	12	30
17	Number of Flight Plan Amendments Entered per Hour	$[\ell_H]$	2040	2160	2580
18	Number of Flight Plans Activated per Hour	$[\phi_H]$	254	434	728
19	Number of Flight Plan Entries per Display	$[\phi_{DI}]$	24	36	46

n. Display Generation,
o. Display Control,
p. Message Processing,
q. Data Base Management,
r. Real-time Quality Control of Radar Data,
s. System Data Recoding,
t. Dynamic Simulation,
u. Critical Data Recording, and
v. Supervisory Functions.

Functions which are currently under development and which could be expected to be in place by the late 1980's include:

1) En Route Metering,
2) Flight Plan Probe,
3) Minimum Safe Altitude Warning (MSAW), and
4) Conflict Resolution (First Stage).

Certain subsystems interface with the IBM 9020® now, or will in the future. These are:

a) Display Channel,
b) Direct Access Radar Channel (DARC),
c) Electronic Tabular Display System (ETABS),
d) Weather Processing, and
e) FSS.

Of these, it is assumed that the Display Channel functions are carried out by the new system itself and that the Display Channel equipment has been moved out with the Central Computer Complex (CCC) equipment. The DARC equipment will not be needed and will also be moved out. The ETABS equipment will be retained; it is assumed that it can be incorporated into the Baseline System easily. It is assumed the the FSS and Weather Processing systems interface as described above. (Section 2.1.3).

It is also assumed that the Baseline System will support the Central Flow Control function and will make use of its outputs where appropriate (Section 2.1.3.)

2.2 FUNCTIONAL DESCRIPTION OF THE BASELINE SYSTEM

The first step in what is essentially a preliminary system design process is the preparation of a functional description of the system. The description should be implementation-independent, showing neither hardware nor operating-system dependencies.

2.2.1 Functional Organization of the Baseline System

The functional organization of the Baseline System is described here in a block diagram and a set of accompanying tables. The diagram, Figure 2.2-1, shows the static relationship among the functions and the flow of information through the system. The tables, Tables 2.2-1 through 2.2-4, describe the processing in a few words and list information received and produced along with source and destination.

In the diagram, functions are represented as rectangular boxes. Each function accepts one or more message or data files as input and produces one or more as output; these are represented as boxes with curved bottoms. System inputs and outputs are represented by octagonal boxes. The inputs enter from the left, and outputs leave at the right. There is a tendency for information to flow, therefore, from left to right, although locally the four data bases--Flight Data, Operational and Environmental Data, Track Data and Display Data--serve as points of accumulation.

In preparing the tables, the functions were grouped under three primary and three support headings. The primary category consists of radar data processing, track data processing, and flight data processing, while the support group consists of display processing, message processing, and data base management. No tables were prepared for the last two groups since the activities of these functions seem too straightforward to warrant explanation.

2.2.2 Characteristics of Functions

A set of operational characteristics with which the system may be described has been compiled and is listed below. An attempt has been made to define characteristics that are implementation-free, that depend on the properties of the functions and their roles in system operation. Characteristics such as response time and operational role of the function are virtually independent of the implementation because they are derived from the functional requirements. Others, such as amount of storage requirement and amount of processing per operation, depend to a greater or lesser degree on how the functions are implemented. Without knowledge of the implementation, the values of these characteristics cannot be stated precisely, and therefore they are measured in order-of-magnitude terms only.

There are two points to be made. First, for the purpose of this study, the values of the characteristics as derived are sufficient. There is no attempt being made to fix on any one implementation or group of implementations, or even a particular level of technology, but rather to evaluate concepts. Second, the attempt to derive more exact expressions is both fruitless and unwise. More precision is not available without assumptions which would limit the extent of the study.

2.2.2.1 Amount of Storage Required - This includes space for the program, incidental data and work space but, specifically, does not include the relevant data base. It is expressed as small, medium, large, or very large, where:

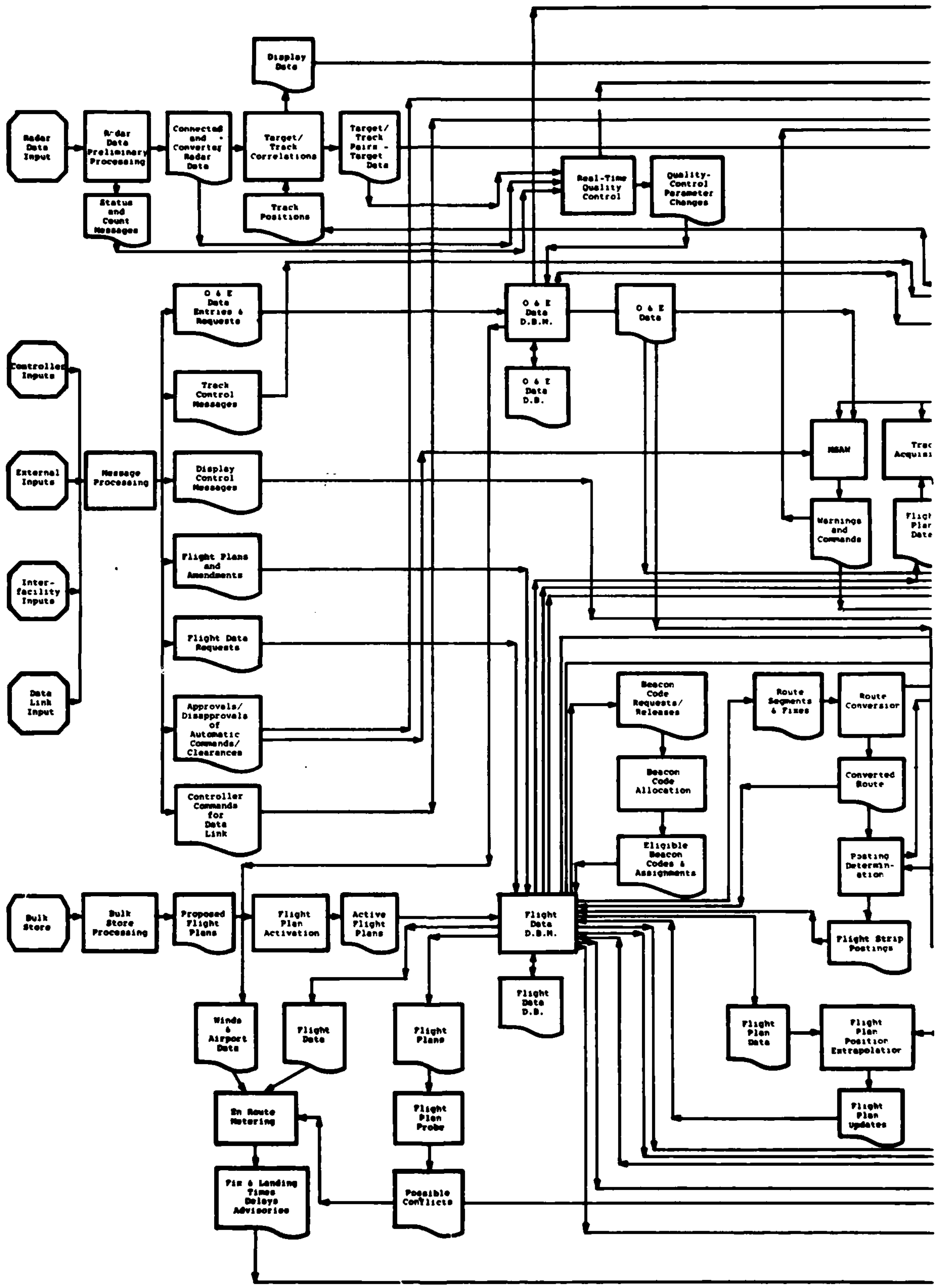

FIGURE 2.2-1. BASELINE SYSTEM FUNCTIONAL BLOCK DIAGRAM

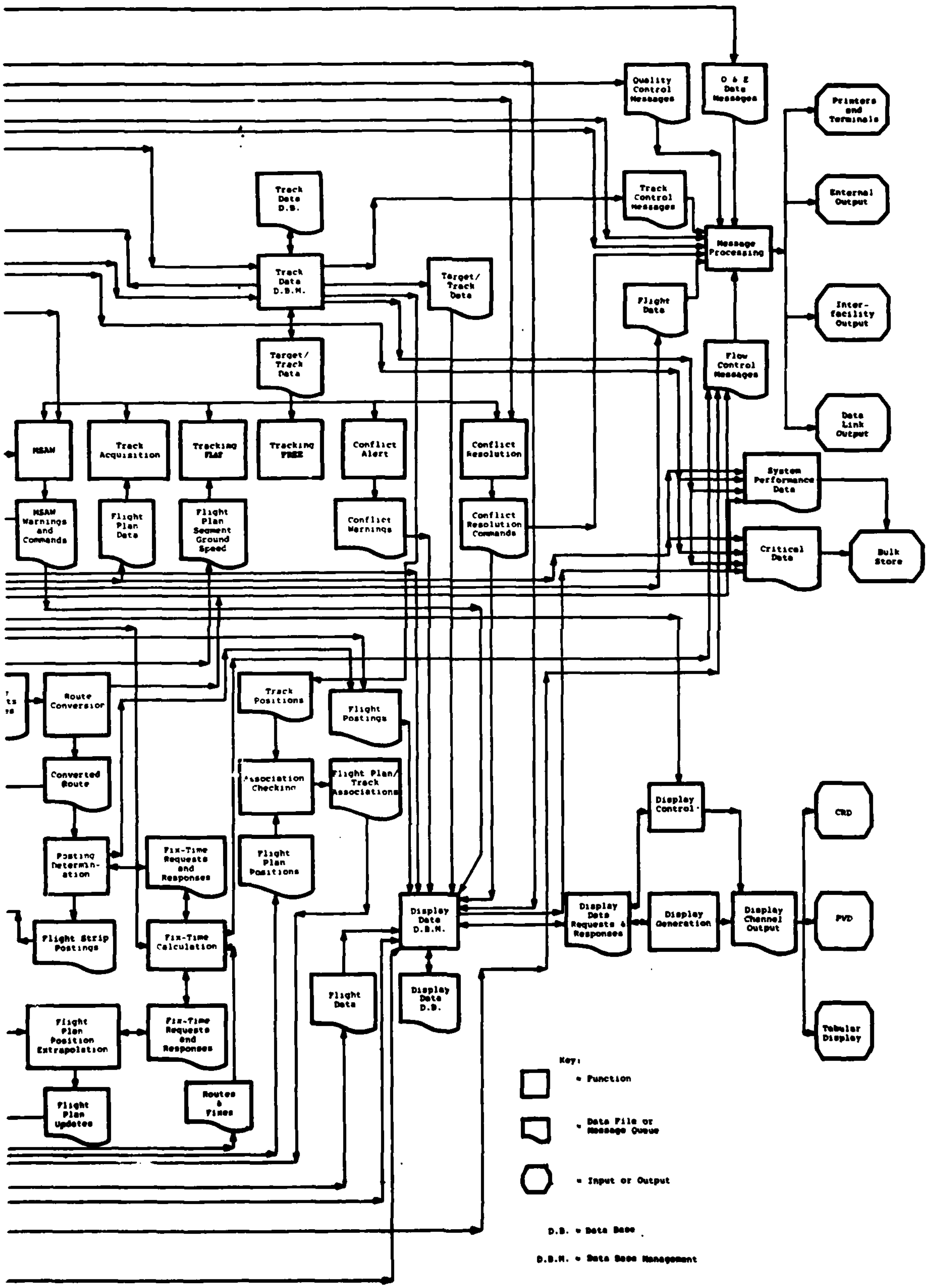

FIGURE 2.2-1. (Continued)

TABLE 2.2-1 RADAR DATA PROCESSING

INPUTS	SOURCE	PROCESSING	OUTPUTS	DESTINATION
Digitized Radar Returns (Primary: range, azimuth Secondary: range, azimuth, beacon code, altitude	Radar Digitizer (DABS)	Preliminary Processing (Slant range correction Coordinate conversion Selective rejection of redundant returns Altitude conversion) (Triggered by availability of data from digitizer)	Corrected and Converted Radar Data (X,Y in system coordinates, beacon code, altitude in feet)	Target/Track Correlation
Barometric Pressure	Operational & Environmental Data D.B.			
Corrected and Converted Radar Data	Preliminary Processing	Target/Track Correlation	Target/Track List (ID, position, altitude, beacon code)	Track Data D.B.
Track Data (Position, altitude, ID)	Track Data D.B.		Uncorrelated Radar Returns	Display Data D.B.
Status and Test Messages Corrected and Converted Data Target/Track Pairs	Preliminary Processing Target Track Correlation	Real-time Quality Control (Status message monitoring, Test message monitoring, Radar data count check, Registration and Collimation Analysis, Permanent Echo Verification	Quality Control Parameter Changes Quality Control Messages	O&E D.B. Message Processing
Simulation Control Messages	Controller Input	Dynamic Simulation	Simulated Radar Data (x, y, beacon code, altitude	Target/Track Correlation

*D.B. = Data Base

TABLE 2.2-2 FLIGHT DATA PROCESSING

INPUTS	SOURCE	PROCESSING	OUTPUTS	DESTINATION
Prefiled Flight Plans	Bulk Store	Bulk Store Processing (Select flight plans expected to be valid in N minutes (N~30))	Proposed Flight Plans	Flight Plan Activation
Proposed Flight Plans	Bulk Store Processing	Flight Plan Activation (Select flight plans expected to be valid in N seconds (N~60))	Active Flight Plans	Flight Data D.B.
Beacon Code Assignment Requests Release of Beacon Codes	Flight Data D.B.	Beacon Code Allocation (Assign beacon codes according to preset classifications) (Operates on demand-e.g., when a flight changes to a new altitude regime)	Beacon Code Assignments Updated List of Eligible Beacon Codes	Flight Data D.B.
Route Segments and Fixes	Flight Data D.B.	Route Conversion (Convert flight plan as filed to standard form) (Operates whenever flight plan is activated or modified)	Converted Routes	Flight Plan D.B. Posting Determination
Fix-Times	Fix-Time Calculation	Posting Determination (Trigger printing of flight strips)	Fix-Time Requests Flight Strip Postings	Fix-Time Calculation Flight Plan D.B. Flight Strip Output

TABLE 2.2-2 (CONTINUED)

INPUTS	SOURCE	PROCESSING	OUTPUTS	DESTINATION
Flight Data (Route segments, fixes, expected times over fixes)	Flight Data D.B.	Flight Plan Position Extrapolation (Compute present location of a/c along flight plan)	Flight Data Updates	Flight Data D.B.
Fix-Times (Updated times over fixes)	Fix-Time Calculation		Fix-Time Requests	Fix-Time Calculation
Fix-Time-Requests	Route Conversion & Posting Flight Plan Position Extrapolation	Fix-Time Calculation (Calculate expected time over next fix)	Fix-Times	Route Conversion & Posting Flight Plan Position Extrapolation
Routes and Fixes	Flight Data D.B.			
Flight Plan Positions	Flight Data D.B.	Association Checking (Compare track position with flight plan expected position to see if flight is following its plan)	Flight Plan/Track Associations	Flight Data D.B.
Track Positions	Track Data D.B.			

TABLE 2.2-3 DISPLAY PROCESSING

INPUTS	SOURCE	PROCESSING	OUTPUTS	DESTINATION
Display Control Messages Display Data Responses	Message Processing Display Data D.B.	Display Control (Respond to display control & change commands)	Display Channel Output (Display commands) Display Data Requests (Descriptors of needed data)	Output Devices Display Data D.B.
Display Data Responses	Display Data D.B.	Display Generation (Generate display tables for each position)	Display Data Requests (Descriptors of needed data)	Display Data D.B.

TABLE 2.2-4 TRACK DATA PROCESSING

INPUTS	SOURCE	PROCESSING	OUTPUTS	DESTINATION
Target Data (Position, beacon code, altitude) Flight Plan Data (ETA, position, altitude, beacon code, ID)	Track Data D.B. Flight Data D.B.	Track Acquisition (Match target with expected a/c flight position)	Track Data (Target/Track association)	Track Data D.B.
Target Data (Position, beacon code, altitude) Track Data (Position, velocity, beacon code, altitude)	Track Data D.B.	Tracking (Free)	Track Data (Position, velocity)	Track Data D.B.
Target Data (Position, beacon code, altitude) Track Data (Position, beacon code, altitude) Flight Plan Data (Ground speed, heading status (straight, turn, hold))	Track Data D.B. Flight Data D.B.	Tracking (FLAT)	Track Data (Position, velocity)	Track Data D.B.
Target/Track Data (Position, velocity, altitude, ID)	Track Data D.B.	Conflict Alert	Conflict Warnings	Display Data D.B.

TABLE 2.2-4 CONTINUED)

INPUTS	SOURCE	PROCESSING	OUTPUTS	DESTINATION
Target/Track Data (Position, velocity, altitude, ID) Approvals/Disapprovals (Controller input)	Track Data D.B. Message Processing	(*) Conflict Resolution	Conflict Resolution Commands	Display Data D.B. Message Processing
Target/Track Data (Position, velocity, altitude, ID) Environmental Data (Terrain grid) Approvals/Disapprovals (Controller input)	Track Data D.B. O & E Data D.B. Message Processing	(*) MSAW	MSAW Warnings and Commands	Display Data D.B. Message Processing

small < 5,000 bytes,
5,000 < medium < 20,000 bytes,
20,000 < large < 100,000 bytes,
100,000 < very large.

2.2.2.2 Amount of Processing per Program Operation - "Amount of Processing" represents both the number of instructions executed and the complexity of the instruction mix. "Program Operation" must be defined for each function and may depend on implementation.

Two types are distinguished:

Type 1: The program operates on whatever data is available.

(The amount depends on the system load). The amount of processing is expressed as a function of the system load components with coefficients depending on type of processing. For example,

$$P = K_1 + K_2 L + K_3 M$$

where L, M are components of the system load.

Type 2: The program operates on a constant amount of data independent of system load. The amount of processing is expressed as a constant.

$$P = K.$$

The coefficients, K, K_1, K_2, and K_3, are expressed as small, medium, and large according to the type of processing:

small - e.g. simple request for data

medium - e.g. flight plan position calculation

large - e.g. tracking.

As a rule of thumb, the amount of processing for each level is ten times the preceding; i.e., if small = x, then medium = 10x, large = 100x, reflecting the order-of-magnitude sizing discussed earlier.

2.2.2.3 Frequency of Operation (Duty Cycle) - This is an expression of how often the program operates and of how regular the operation is. If the function is operated periodically, the frequency is expressed as:

once/30 minutes (e.g., bulk storage processing)

once/minute (e.g., flight plan activation) once/10seconds (e.g., surveillance)

once/second (e.g., display processing)

once/millisecond (e.g., data base management)

Other rates are also possible.

If the frequency is not constant, we assume it is aperiodic; (i.e., we disregard the possibility that the function is periodic, but some load-sensing mechanism changes the frequency so that it is step-wise variable). The average rate is, therefore, given as a function of load,

$$\phi = f(L)$$

and an indication is given of the variability:

nearly uniform

fluctuating

erratic.

Other possibilities, such as response to either a buffer-full condition or interval time-out, will be considered as special cases depending on implementation.

The frequency of operation may be dictated by considerations external to the function itself, such as the need to respond to another function or to provide a timely input to another function. The rationale used in estimating frequency should be explained.

2.2.2.4 Type of Processing - Estimates are made of the percentages of the processing in each of the classes:

I/O

Calculation

Logical

Character (String) Processing

Matching or Sorting

2.2.2.5 Amount of Data in and/or Out per Program Operation - Program operation should be defined as in 2.2.2.2. The amounts of data are expressed as functions of the load components as was done there. The coefficients are expressed as small though very large according to the ranges:

small < 20 bytes,
20 < medium < 200 bytes,
200 < large < 2,000 bytes,
2,000 < very large.

2.2.2.6 Response Time - This is an estimate of the response requirement on this function as imbedded in the system, taking into account the overall system performance requirements. It is expressed as, for instance:

< 1 second
< 10 seconds
> 10 seconds

These estimates are based on performance requirements which may not remain fixed; i.e., they may depend on a particular set of functions being included.

2.2.2.7 Operational Role of the Function - This is the basic role the function plays in system operation. Suggested categories are:

processes primary input,

produces primary output,

produces supplementary output,

develops basic data, and

provides support service.

2.2.2.8 Dependence on Other Functions - This should be a short description of how this function is related to the other functions. Suggested categories are:

Independent - asynchronous, uses no special derived data,

Runs only when called by another function,

Requires data developed by another function.

Other categories are needed. A function may fit into many categories simultaneously.

2.2.3 Characteristics of the Baseline Functions

The characteristics developed above have been compiled for the functions which make up the Baseline System. These are listed in Table 2.2-5.

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS

	RADAR DATA--PRELIMINARY PROCESSING
	Program operates once for each buffer load from each sensor.
I Storage	Medium (Buffer space for data in and out is largest factor.)
II Processing per Operation	$P = K_1 + K_2R$ Where R is the number of radar targets from the CD. K_1 = small, K_2 = medium
III Frequency of Operation	Program must service all CDs within space of about 1 second. It probably would operate periodically then, ~ once/sec/radar.
IV Types of Processing	I/O 20% Calc. 60% Log. 10% Char. 0 Match. 10%
V Amount of Data	In: $D = K_1 + K_2R$ R is the number of radar targets K_1 = medium, K_2 = small Out: $D = K_1 + K_2R$ R is the number of radar targets K_1 = medium, K_2 = small
VI Response Time	< 1 second Dictated by requirement to deliver radar data to the display within time limit prescribed by performance requirements (plus need to service the sensors)
VII Operational Role	Processes primary input
VIII Dependence	Independent, asynchronous of other functions

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	REAL-TIME QUALITY CONTROL
	Operates periodically (function of radar scan rates) and on demand
I Storage	Small
II Processing per Operation	$P = K_1 + K_2 N$, where N is the number of radars in the system K_1 = small, K_2 = medium
III Frequency of Operation	Once per radar scan ~ 10 sec.
IV Types of Processing	I/O 0 Calc. 80% Char. 0 Log. 20% Match. 0
V Amount of Data	In: $D = K_1 N$ where K_1 = medium, N = number of radars Out: $D = K$ where K = small
VI Response Time	~ 1 second Dictated by the need to compute and apply correction factors to the data from the next scan
VII Operational Role	Provides support service
VIII Dependence	Requires data from Preliminary Processing and Target/Track Correlation

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	TARGET/TRACK CORRELATION
	Once for each operation of that program, or perhaps once once per n operations where n is small
I Storage	Small (could be medium if buffer space needed)
II Processing per Operation	$P = K_1 + K_2R + K_3R \log_2 T$ where R = no. of radar returns, T = no. of tracks in system K_1 = small, K_2 = small, K_3 = small
III Frequency of Operation	Program must handle all the data from Preliminary Processing periodically, ~ once/sec/radar or ~ once/sec/n radars
IV Types of Processing	I/O 0 Calc. 10% Log. 20% Char. 0 Match. 70%
V Amount of Data	In: $D = K_1 + K_2R + K_3T$ R= no. of radar targets, T = no. of tracks K_1= medium, K_2=small, K_3=small Out: $D = K_1 + K_2R$ R = no. of radar targets K_1 = medium, K_2 = small
VI Response Time	< 1 second Program must meet same response requirment as Preliminary Processing
VII Operational Role	Processes primary input Develops basic data (part of Track Data D.B.)
VIII Dependence	Processes data-stream from Preliminary Processing

TABLE 2.2.5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	DYNAMIC SIMULATION
	Operates only when specifically requested, then operates cyclically, synchronized with radar data input
I Storage	Small
II Processing per Operation	$P = K_1 + K_2 T_s$, where T_s is the number of simulated targets, K_1 = small, K_2 = large
III Frequency of Operation	Operates about once per second.
IV Types of Processing	I/o 0 Calc 60% Log 40% Char. 0 Match. 0
V Amount of Data	In: D = K where K is small Out: $D = KT_s$ where T_s is the number of simulated targets K = medium
VI Response Time	∿1 second
VII Operational Role	Provides supplementary service
VIII Dependence	Operates independently of the rest of the system

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	BULK STORE PROCESSING
	Each operation reads in a number of flight plans, such that the start times span about 30 minutes.
I Storage	Medium (mostly buffer space)
II Processing per Operation	$P = K_1$ where K_1 = small
III Frequency of Operation	Periodic ~ once/10 minutes
IV Types of Processing	I/O 80% Calc. 0 Log. 5% Char. 15% Match. 0
V Amount of Data	In: $D = K_1 + K_2F$ F = number of flight plans K_1 = small, K_2 = medium Out: $D = K_1 + D_2F$ (Din = Dout)
VI Response Time	No particular response time requirement
VII Operational Role	Processes primary input
VIII Dependence	Independent, asynchronons of other functions

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	FLIGHT PLAN ACTIVATION
	Operates on all flight plans due in next two minutes, then sets timer for trigger when next flight plan is due.
I Storage	Small
II Processing per Operation	$P = K_1 + K_2F$ where F is the number of flight plans due in the next 2 minutes K_1 = small, K_2 = medium
III Frequency of Operation	Aperiodic, ~ once/2 minutes, nearly uniform under high load Depends on number of flight plans
IV Types of Processing	I/O 0 Char. 75% Calc. 0 Match. 0 Log. 25%
V Amount of Data	In: $D = K_1 + K_2F$ where F = number of flight plans K_1 = small, K_2 = medium Out: D = K where K = medium
VI Response Time	No particular response time requirement
VII Operational Role	Processes primary input to Flight Data D.B.
VIII Dependence	Processes data-stream from Bulk Store Processing

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	BEACON CODE ALLOCATION
	Operates once for each request for beacon code or release of beacon code
I Storage	Small
II Processing per Operation	$P = K_1$ where K_1 = small
III Frequency of Operation	Aperiodic, ~ once/second, depending on the number of active fluctuating flight plans
IV Types of Processing	I/O 0 Char. 0 Calc. 0 Match. 0 Log. 100%
V Amount of Data	In: D = K Out: D=K where K = small where K = small
VI Response Time	< 1 second
VII Operational Role	Develops basic data
VIII Dependence	Runs when called by request

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	ROUTE CONVERSION	
	Operates once for each flight plan activation or flight plan change	
I Storage	Large	
II Processing per Operation	$P_1 = K_1$ where K_1 = large (for flight plan activation)	$P_2 = K_2$ where K_2 = medium (for flight plan amendment)
III Frequency of Operation	Aperiodic, ~ once/second, nearly uniform depends on number of flight plans	
IV Types of Processing	I/O 0 Cal. 20% Log. 40%	Char. 40% Match. 0
V Amount of Data	In: D = K K = large	Out: D = K K = medium
VI Response Time	< 10 seconds Mostly response to flight plan change message.	
VII Operational Role	Develops basic data	
VIII Dependence	Processes input stream from Flight Plan Activation Also operates independently upon external request	

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	POSTING DETERMINATION
	Each operation either processes whole converted flight plans or changes as produced by Route Conversion, or it posts the fixes due in the next interval.
I **Storage**	Small
II **Processing per Operation**	$P_1 = K_1$ where K_1 = large (for whole flight plans) $P_2 = K_2$ where K_2 = medium (for single interval)
III **Frequency of Operation**	Operates after each run of Route Conversion plus when triggered by the interval timer aperiodically ~ once/sec depending on number of flight plans fluctuating
IV **Types of Processing**	I/O 40% Calc. 0 Log. 10% Char. 30% Match. 20%
V **Amount of Data**	In: D = K, K = medium Out: D = K, K = small
VI **Response Time**	< 10 second
VII **Operational Role**	Develops basic data Produces and triggers primary output
VIII **Dependence**	Processes input stream from Route Conversion Responds to interval timer

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	FLIGHT PLAN POSITION EXTRAPOLATION
	Operates on all flight plans periodically
I **Storage**	Small
II **Processing per Operation**	P = K where K = medium
III **Frequency of Operations**	Periodic ~ once/30 sec. Operates on fraction of active flight plans such that each flight plan is processed once/5 minutes
IV **Types of Processing**	I/O 0 Char. 0 Calc. 60% Match. 0 Log. 40%
V **Amount of Data**	In: $D = K_1F$ Out: $D = K_2F$ where F is the number of flight plans K_1 = medium, K_2 = small
VI **Response Time**	< 10 seconds
VII **Operational Role**	Develops basic data
VIII **Dependence**	Asynchronous with other functions Processes data as available

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	FIX-TIME CALCULATION
	Operates when called by Posting Determination or Flight Plan Position Extrapolation
I Storage	Small
II Processing per Operation	$P = K_1$ where K_1 = medium
III Frequency of Operation	Aperiodic, ~ once/.1 second, fluctuating depending on the number of flight plans
IV Types of Processing	I/O 0; Calc. 60%; Log. 40%; Char. 0; Match. 0
V Amount of Data	In: $D = K_1$ Out: $D = K_2$ where K_1 = medium, K_2 = small
VI Response Time	<.1 second, in order to maintain system operation
VII Operational Role	Develops basic data Operates as subfunction, supplies specialized service
VIII Dependence	Operates when called

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	ASSOCIATION CHECKING	
	Operates on all matched flight plans periodically	
I Storage	Small	
II Processing per Operation	$P = K_1 + K_2F$ where F is the number of flight plans K_1 = small, K_2 = medium	
III Frequency of Operation	Periodic, ~ once/30 seconds	
IV Types of Processing	I/O 0 Calc. 60% Log. 40%	Char. 0 Match. 0
V Amount of Data	In: $D = K_1F$ where F = the number of flight plans K_1 = medium, k_2 = small	Out: $D_2 = K_2F$
VI Response Time	<10 seconds	
VII Operational Role	Develops basic data Produces control information	
VIII Dependence	Asynchronous with other data Processes data as available	

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	FLIGHT PLAN PROBE
	Operates on all flight plans periodically
I Storage	Medium
II Processing per Operation	$P = K_1 + K_2F \log_2 F$ where F is the number of flight plans K_1 = small, K_2 = medium
III Frequency of Operation	~ once/10 minutes periodic
IV Types of Processing	I/O 0; Char. 0 Calc. 20%; Match. 70% Log. 10%
V Amount of Data	In: $D = K_1F$; Out: $D = K_2F$ where F = number of flight plans K_1 = medium, K_2 = small
VI Response Time	>10 sec.
VII Operational Role	Develops secondary output
VIII Dependence	Asynchronous, timing independent of other functions Uses available data.

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS
(CONTINUED)

	EN ROUTE METERING	
	Operates on each flight at prescribed fixed and/or times	
I **Storage**	Medium	
II **Processing per Operation**	$P = K_1$ where K_1 = medium	
III **Frequency of Operation**	Aperiodic, ~ once/five minutes for each flight in the system	
IV **Types of Processing**	I/O 0 Calc. 40% Log. 50%	Char. 10% Match. 0
V **Amount of Data**	In: $D = K_1$ where K_1 = medium	Out: $D = K_2$ K_2 = medium
VI **Response Time**	< 10 seconds, to ensure timeliness of results	
VII **Operational Role**	Develops secondary output	
VIII **Dependence**	Depends on data from Association Checking and Flight Plan Extrapolation functions Responds to internal timer	

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	DISPLAY GENERATION
	Each operation processes the data for all displays.
I Storage	Large
II Processing per Operation	$P = K_1+K_2F + K_3F D_i$ where F = number of flight plans, D_i = number of displays K_1 = medium, K_2 = medium, K_3 = medium
III Frequency of Operation	Periodically, ~ once/10 sec Synchronized with radar scan
IV Types of Processing	I/O 0 Calc. 30% Log. 20% Char. 30% Match. 20%
V Amount of Data	In: $D = K_1 + K_2F$ Out: $D = (K_3 + K_1F)D_i$ where F = number of flight plans, D_i = number of displays K_1 = large, K_2 = medium, K_3 = large, K_4 = medium
VI Response Time	<10 sec,
VII Operational Role	Produces primary output
VIII Dependence	Independent, asynchronous Uses available data

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS
(CONTINUED)

	DISPLAY CONTROL	
	Operates once for each control message received	
I **Storage**	Small	
II **Processing per Operation**	$P = K_1$ where K_1 = medium	
III **Frequency of Operation**	Aperiodic, ~ once/30 sec/display fluctuating	
IV **Types of Processing**	I/O 50% Calc. 10% Log. 0	Char. 30% Match. 10%
V **Amount of Data**	In: $D = K_1$ where K_1 = small, K_2 = small	Out: $D = K_2$
VI **Response Time**	< 1 second	
VII **Operational Role**	Controls primary output	
VIII **Dependence**	Independent, asynchronous	

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	TRACK ACQUISITION
	Operates once per basic system cycle, ~ twice per radar scan
I **Storage**	Small
II **Processing per Operation**	$P = K_1 + K_2R$ where R = number of uncorrelated radar returns K_1 = small, K_2 = medium
III **Frequency of Operation**	Periodic, ~ once/5 sec.
IV **Types of Processing**	I/O 0 · Char. 0 Calc. 20% · Match. 60% Log. 20%
V **Amount of Data**	In: $D = K_1R$ · Out: $D = K_2R$ where R = number of uncorrelated radar returns K_1 = medium, K_2 = small
VI **Response Time**	< 10 sec.
VII **Operational Role**	Processes primary input
VIII **Dependence**	Synchronized with Target/Track Correlation Uses data from Target/Track Correlation

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	TRACKING (Free)
	Operates once per basic system cycle on all available data
I **Storage**	Small
II **Processing per Operation**	$P = K_1 + K_2 T_{FR}$ where T_{FR} is the number of tracks being free-tracked K_1 = small, K_2 = large
III **Frequency of Operation**	Periodic, ~ once/5 sec.
IV **Types of Processing**	I/O 0 Calc. 60% Log. 40% Char. 0 Match. 0
V **Amount of Data**	In: $D = K_1 T_{FR}$ Out: $D = K_2 T_{FR}$ where T_{FR} = number of tracks being free-tracked K_1 = medium, K_2 = medium
VI **Response Time**	< 1 second
VII **Operational Role**	Processes basic data
VIII **Dependence**	Synchronized with Target/Track Correlation Uses data from Target/Track Correlation

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	TRACKING (FLAT)
	Operates once per basic system cycle on all available data
I **Storage**	Small
II **Processing per Operation**	$P = K_1 + K_2 T_{FL}$ where T_{FL} = number of tracks being FLAT-tracked K_1 = small, K_2 = large
III **Frequency of Operation**	Periodic, ~ once 5/sec
IV **Types of Processing**	I/O 0 Char. 0 Calc. 60% Match. 0 Log. 40%
V **Amount of Data**	In: $D = K_1 T_{FL}$ Out: $D = K_2 T_{FL}$ where T_{FL} = number of tracks being FLAT-tracked
VI **Response Time**	< 1 second
VII **Operational Role**	Processes basic data
VIII **Dependence**	Synchronized with Target/Track Correlation Uses data from Target/Track Correlation, Association Checking and Flight Plan Position Determination

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS
(CONTINUED)

	CONFLICT ALERT
	Each operation processes all tracks
I **Storage**	Medium
II **Processing per Operation**	$P = K_1 + K_2 T \log_2 T$ where T is number of tracks K_1 = small, K_2 = medium
III **Frequency of Operation**	Periodic, ~ once/minute
IV **Types of Processing**	I/O 0 Char. 0 Calc. 20% Match. 70% Log. 10%
V **Amount of Data**	In: $D = K_1 T$ Out: $D = K_2 T$ where T = number of tracks K_1 = medium, K_2 = small
VI **Response Time**	~ 10 sec.
VII **Operational Role**	Produces supplementary output
VIII **Dependence**	Asynchronous, independent Uses available data

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	CONFLICT RESOLUTION
	Each operation processes all conflicts
I Storage	Medium
II Processing per Operation	$P = K_1 + K_2 C$ where C = number of conflicts K_1 = small, K_2 = large
III Frequency of Operation	Periodic, ~ once/minute
IV Types of Processing	I/O 0 Calc. 60% Log. 40% Char. 0 Match. 0
V Amount of Data	In: $D = K_1C$ Out: $D = K_2C$ where C = number of conflicts K_1 = medium, K_2 = medium
VI Response Time	<10 sec.
VII Operational Role	Produces supplementary output
VIII Dependence	Synchronized with Conflict Alert Uses data from Conflict Alert

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS
(CONTINUED)

	MSAW
	Operates on all tracks in system
I Storage	Medium
II Processing per Operation	$P = K_1 + K_2T$ where T = number of tracks K_1 = small, K_2 = medium
III Frequency of Operation	Periodic, ~ once/30 seconds
IV Types of Processing	I/O 0 Calc. 60% Log. 40% Char. 0 Match. 0
V Amount of Data	In: $D = K_1T$ Out: $D = K_2T$ where T is the number of tracks K_1 = medium, K_2 = small
VI Response Time	<10 sec.
VII Operational Role	Produces supplementary output
VIII Dependence	Asynchronous, independent Uses available data

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	MESSAGE PROCESSING
	Operates once per message processed
I **Storage**	Medium
II **Processing per Operation**	$P = K_1$ where K_1 = medium
III **Frequency of Operation**	Aperiodic, ~ once/10 msec. fluctuating
IV **Types of Processing**	I/O 40% Char. 40% Calc. 0 Match. 0 Log. 20%
V **Amount of Data**	In: $D = K_1$ Out: $D = K_2$ where K_1 = small, K_2 = small
VI **Response Time**	<1 second
VII **Operational Role**	Processes basic data Controls distribution of data and control information Provides fundamental service
VIII **Dependence**	Asynchronous, independent

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	O&E D.B.M.
	Operates once per data request or response
I **Storage**	Small
II **Processing per Operation**	$P = K_1$ where K_1 = small
III **Frequency of Operation**	Aperiodic, ~ once/millisecond fluctuating
IV **Types of Processing**	I/O 0 Calc. 10% Log. 40% Char. 50% Match. 0
V **Amount of Data**	In: $D = K_1$ Out: $D = K_2$ where K_1 = small/medium, K_2 = medium/small
VI **Response Time**	<10 sec.
VII **Operational Role**	Processes basic data Provides fundamental service
VIII **Dependence**	Asynchronous, independent

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	CRITICAL DATA D.B.M.
	Operates cyclically as data is collected and (rarely) during recovery and restart operations
I Storage	Small
II Processing per Operation	$P = K_1$ where K_1 = small during normal operations = large during recovery
III Frequency of Operation	~ once/millisecond during normal operations
IV Types of Processing	I/O 0 Calc. 10% Log. 40% Char. 50% Match. 0
V Amount of Data	In: $D = K_1$ K_1 = small (normal) Out: $D = K_2$ K_2 = very large (recovery)
VI Response Time	< 10 sec (normal) < 1 sec (recovery)
VII Operational Role	Supports recovery and restart only
VIII Dependence	Asynchronous, independent

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	SYSTEM PERFORMANCE D.B.M.
	Operates cyclically as data is collected
I Storage	Small
II Processing per Operation	$P = K_1$ where K_1 is small
III Frequency of Operation	~ once/millisecond
IV Types of Processing	I/O 0 Char. 50% Calc. 10% Match. 0 Log. 40%
V Amount of Data	In: $D = K_1$ K_1 = small Out:
VI Response Time	<10 sec.
VII Operational Role	Support function
VIII Dependence	Asynchronous, independent

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	FLIGHT DATA D.B.M.
	Operates once per data request or response
I Storage	Small
II Processing per Operation	$P = K_1$ where K_1 = small
III Frequency of Operation	Aperiodic, ~ once millisecond fluctuating
IV Types of Processing	I/O 0 Calc. 10% Log. 40% Char. 50% Match. 0
V Amount of Data	In: $D = K_1$ Out: $D = K_2$ where K_1 = small/medium, K_2 = medium/small
VI Response Time	<10 sec.
VII Operational Role	Processes basic data Provides fundamental service
VIII Dependence	Asynchronous, independent

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	TRACK DATA D.B.M.
	Operates once per data request or response
I Storage	Small
II Processing per Operation	$P = K_1$ where K_1 = small
III Frequency of Operation	Aperiodic, ~ once/millisecond fluctuating
IV Types of Processing	I/O 0 Char. 50% Calc. 10% Match. 0 Log. 40%
V Amount of Data	In: $D = K_1$ Out: $D = K_2$ where K_1 = small/medium, K_2 = medium/small
VI Response Time	<10 sec.
VII Operational Role	Processes basic data Provides fundamental serivce
VIII Dependence	Asynchronous, independent

TABLE 2.2-5 OPERATIONAL CHARACTERISTICS OF BASELINE FUNCTIONS (CONTINUED)

	DISPLAY DATA D.B.M.
	Operates once per data request or response
I Storage	Small
II Processing per Operation	$P = K_1$ where K_1 = small
III Frequency of Operation	Aperiodic, ~ once/millisecond fluctuating
IV Types of Processing	I/O 0 Calc. 10% Log. 40% Cnar. 50% Match. 0
V Amount of Data	In: $D = K_1$ Out: $D = K_2$ where K_1 = small/medium, K_2 = medium/small
VI Response Time	<10 sec.
VII Operational Role	Processes basic data Provides fundamental service
VIII Dependence	Asynchronous, independent

2.2.4 Characteristics of Data Base

There are two characteristics which may be used to describe the NAS data base: size and complexity. Size has been expressed as small, medium, large and very large, using the same limits as for amount of storage required for functions (Section 2.2.2.1):

small < 5,000 bytes,
5,000 < medium < 20,000
20,000 < large < 100,000
100,000 < very large.

Complexity is not as easy to deal with in a general way. In this case, however, the files used are relatively simple, so that their structure can be shown directly.

Each data base is considered to be made up of files, each being made up of items, and each item (possibly) made up of sub-items. The complexity of the data bases may then be shown by listing the files, items, and sub-items explicitly.

In Table 2.2-6, the major elements of the four Baseline System data bases are listed: Track Data, Flight Data, Operational and Environmental Data, and Display Data. An estimate of file size and a description of the item and sub-item structure are given. The form in which each item or sub-item appears is given, using the common computer programming terminology, integer, real, logical, or alphanumeric. An indication of the functions which supply and use each item is also given.

2.3 ARCHITECTURE OF THE BASELINE SYSTEM

Once the operation of the system from a functional viewpoint is well understood, the preliminary design of the computer system may go forward. During the design process, the computer configuration would be developed in conjunction with both the allocation of functions and the sizing of the system. In this section, however, the three aspects will be described in turn.

2.3.1 Description of the Configuration

The configuration covered in this report was earlier described as a "distributed" system, with processing taking place at the source of the data to be processed or at the location where the output is used. A configuration of that type designed to carry out the Baseline Functions is shown in Figure 2.3-1.

The system consists of a set of independent processors connected to each other by an Interprocessor Communications Subsystem (ICS) whose nature is not disclosed in the diagram. The ICS could be implemented in a number of ways; e.g., a global,

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES

DATA BASE: TRACK DATA-I
FILE NAME: TRACKS-(1) FILE SIZE: LARGE

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
CID	Computer Identification--Unique ID Used for Reference Throughout the System			Integer	System	Nearly All Referers
AID	Aircraft Identification--Flight Number			Alpha-numeric	Track Acquisition	Display Data DBM
Reported Position	Correlated Target Position	X,Y	System Plane Coordinates	Real	Target/Track Correlation	Tracking (Free or FLAT)
Smoothed Position	Smoothed Target Position	X,Y	System Plane Coordinates	Real	Tracking (Free or FLAT)	Tracking (Free or FLAT)
Predicted Position	Predicted Track Position	X,Y (old, new)	System Plane Coordinates	Real	Tracking (Free or FLAT)	Tracking (Free or FLAT) Conflict Alert Conflict Resolution MSAW Display DBM Association Checking Target/Track Correlations
Reported Altitude	Model C Altitude, Corrected			Integer	Target/Track Correlation	Tracking (Free or FLAT) Display DBM

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: FLIGHT DATA-II
FILE NAME: ACTIVE FLIGHT PLANS (CONVERTED) FILE SIZE: LARGE

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
CID	Unique ID Used For Reference Throughout the System			Integer	Track Data DBM	Most Referers
AID	Aircraft Identification Flight Number			Alpha-numeric	Route Conversion	Posting Determination Display Data DBM
Route	Series of Fixes Describing Path	Fixes ETF Fix-Posting Time Altitude	Fixes to be Posted Expected Time Over Fix Time at Which Fix Should be Posted Assigned Altitutude Over Fix	Alpha-numeric Integer Integer Integer	Route Conversion	Flight Position Extrapolation Fix-Time Calculation
Flight Position		X,Y	System Plane Coordinates	Real	Flight Plan Position Extrapolation	Association Checking En Route Metering Fix-Time Calculation Flight Plan Position Extrapolation
Flight Velocity		X,Y	System Plane Coordinates	Real	Flight Plan Position Extrapolation	Tracking (FLAT) En Route Metering Fix-Time Calculation Flight Plan Position Extrapolation

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: TRACK DATA II
FILE NAME: TRACKS (2) FILE SIZE:

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Predicted Altitude				Real	Tracking (Free or FLAT)	MSAW Tracking (Free or FLAT) Conflict Alert Conflict Resolution
Predicted Velocity		$\dot{X},\dot{Y}$	System Plane Coordinates	Real	Tracking (Free or FLAT)	Tracking (Free)
Predicted Altitude Rate				Real	Tracking (Free or FLAT)	Tracking (Free or FLAT) MSAW Conflict Alert Conflict Resolution
Reported Beacon Code				Integer	Target/Track Correlation	Display DBM
Assigned Beacon Code				Integer	Flight Data DBM Message Processing	Target/Track Correlation
Target Status		Special Beacon Codes SPI Equipment Indications		Logical	Target/Track Correlation	Tracking (Free and FLAT) Display DBM

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: FLIGHT DATA-III
FILE NAME: ACTIVE FLIGHT PLANS (CONVERTED)-(2) FILE SIZE:

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Assigned Altitude				Integer	Route Conversion	En Route Metering
Status	Straight, Turn, Hold			Logical	Route Conversion Flight Plan Position Extrapolation	Tracking (FLAT)

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: TRACK DATA-III
FILE NAME: TRACKS - (3) FILE SIZE:

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Track Status	Free/FLAT Straight, Turn, Hold			Logical	Tracking (Free or FLAT) Association Checking	Tracking (Free or FLAT)

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: FLIGHT DATA-IV
FILE NAME: AIRSPACE ROUTE INFORMATION   FILE SIZE: LARGE

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Routes		Route Name Segments Altitudes	Fix Pairs Upper, Lower Limits	Alphanumeric Alphanumeric Integer	Adaptation	Route Conversion
Fixes		Fix Name X,Y	Latitude, Longitude System Plane Coordinates	Alphanumeric Real	Adaptation	Route Conversion Fix-Time Calculation Flight Plan Position Extrapolation
Fix Posting Areas		ID Preferred Fix Boundary Vertices	Fix Name System Plane Coordinates	Integer Alphanumeric Real	Adaptation	Route Conversion Posting Determination
Sectors		ID Boundary Vertices Altitude Limits	System Plane Coordinates	Alphanumeric Real Real	Adaptation	Posting Determination

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: TRACK DATA--IV
FILE NAME: UNCORRELATED TARGETS FILE SIZE: SMALL

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Position		X,Y	System Plane Coordinates	Real	Target/Track Correlation	Track Acquisition Display Data DBM
Beacon Code				Integer	Target/Track Correlation	Track Acquisition Display Data DBM
History		Run Length Code Changes		Integer	Target/Track Correlation	Track Acquisition Display Data DBM
Altitude				Integer	Target/Track Correlation	Track Acquisition Display Data DBM

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: FLIGHT DATA-V
FILE NAME: BEACON CODES FILE SIZE: MEDIUM
AIRCRAFT CHARACTERISTICS
AIR CARRIERS

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Eligible Codes				Iteger	Adaptation Beacon Code Allocation	Beacon Code Allocation
Classi-fication	Altitude, Type, Arrival/Depar-ture, etc.			Alpha-numeric	Adaptation	Beacon Code Allocation
A/C Type				Alpha-numeric	Adaptation	
Speed				Integer		
Weight Class	H,L			Alpha-numeric		
Air Carrier ID's				Alpha-numeric	Adaptation	

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: TRACK DATA--V
FILE NAME: TRACK CONTROL FILE SIZE: SMALL

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Hand Off Points		X,Y	System Plane Coordinators	Real	System	Tracking (Free or FLAT)

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: OPERATIONAL AND ENVIRONMENTAL DATA--I
FILE NAME: WEATHER FILE SIZE: LARGE

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Barometric Pressure		Pressure Time Reporting Station Correction Factors		Real Integer Alpha-numeric Decimal Fractions	O&E Data DBM (from weather system)	O&E Data DBM (for data link message)
Winds Aloft		Altitude Level Grid Co-ordinators Wind Speed Wind Directions		Integer Real Real Integer	O&E Data DBM (from weather system)	Fix-Time Calculation En Route Metering
Weather Observations				Alpha-numeric	O&E Data DBM (from weather system)	Display Generation (D-position)
Weather Contours		Type Intensity Boundary Points		Integer Integer Real	Reader Data Preliminary Processing	Display Generation (R-position)

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: FLIGHT DATA—I
FILE NAME: ACTIVE FLIGHT PLANS (UNCONVERTED) FILE SIZE: SMALL

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Time	ETF First Fix or ETD			Integer	Flight Plan Activation	Route Conversion
Flight Plan	One of Standard Formats			Alpha-numeric	Flight Plan Activation	Route Conversion

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: OPERATIONAL & ENVIRONMENTAL DATA-II

FILE NAME: SENSORS FILE SIZE: SMALL

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
ID				Alpha-numeric	Adaptation	
Location	Registration	X,Y	System Co-ordinates	Real	Adaptation	
Coverage	Radar Sort Boxes	Preferred, Supple-mentary		Integer	Adaptation	
Short Range Correc-tion Factors		Range Factor		Real	Adaptation	Radar Data--Preliminary Processing
Weather Filter Table		WADA R Limit	Weather Azimuth Division Area Limiting Range	Integer Real	Adaptation	Radar Data--Preliminary Processing
Rho-Theta Filter		ADA, R min, R max	Azimuth Division Area	Integer Real	Adaptation	Radar Data--Preliminary Processing
Registra-tion Collima-tion Correction Factors		ΔR, ΔB		Real	RTQC	Radar Data--Preliminary Processing

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: OPERATIONAL & ENVIRONMENTAL DATA-III FILE SIZE: MEDIUM, SMALL

FILE NAME: MSAW, AIRPORT

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
X,Y	MSAW Terrain Grid			Integer	Adaptation	MSAW
Minimum Safe Altitude				Integer	Adaptation	MSAW
ID	Airport Data			Alpha-numeric	Adaptation	
X,Y	Center Field Coordinates			Real	Adaptation	
Runways		ID X,Y In Use Meter Fix Handoff points	Threshold Coordinates	Alphanumeric Real Logical Alphanumeric Real	Adaptation Adaptation Operator Input Adaptation Adaptation	En Route Metering En Route Metering Track Acquisition

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: OPERATIONAL & ENVIRONMENTAL DATA-III FILE SIZE: SMALL
FILE NAME: COMMUNICATIONS

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Routing		Message Type Destinations		Alphanumeric Integers	Adaptation	Message Processing
External Sources/ Destinations		ID Communications Type		Alphanumeric	Adaptation	Message Processing

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: DISPLAY DATA--I
FILE NAME: TARGET/TRACK, DATA BLOCK FILE SIZE: LARGE

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Tracks		ID X,Y	Display Coordinates	Alphanumeric Integer	Display Generation	Display Control
Uncorrelated Targets		X,Y Beacon Code Altitude		Integer Alphanumeric Alphanumeric	Display Generation	Display Control
Fixed Data	Appears in All Data Blocks	ACID Velocity Altitude Type	Computed Ground Speed H or L	Alphanumeric Integer Integer Alphanumeric	Display Generation	Display Control
Variable Data	Appears Only Where Appropriate	Conflict Warnings MSAW Warnings		Alphanumeric Alphanumeric	Display Generation	Display Control
Control Data		Altitude Filters Code Filters		Integer Integer	Operator Action	Display Generation

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: DISPLAY DATA-II
FILE NAME: WEATHER, TABULAR, CONTROL   FILE SIZE: MEDIUM, SMALL, SMALL

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Severe Weather Outlines		X,Y Pairs		Integer Pairs	Display Generation	Display Control
Weather Messages				Alpha-numeric	Display Generation	Display Control
List ID & Heading				Alpha-numeric	Display Generation	Display Control
List Location				Integer	Display Generation	Display Control
Entries				Alpha-numeric	Display Generation	Display Control
Devices		Types Addresses Status		Integer Integer Logical	Adaptation	Display Control
Sector Assign-ments	Display Number			Integer	Adaptation	Display Control

TABLE 2.2-6 MAJOR ELEMENTS OF BASELINE DATA BASES (CONTINUED)

DATA BASE: CRITICAL DATA AND SYSTEM PERFORMANCE DATA
FILE NAME: (NONE) FILE SIZE: MEDIUM, LARGE

ITEM	DESCRIPTION	SUB-ITEM	DESCRIPTION	FORM	WRITTEN BY	USED BY
Track Data	Position, Altitude, Velocity, Altitude Rate			Various	Tracking	Recovery
Flight Plan Data	Position, Speed Time-to-Next Fix			Various	Flight Plan Position Extrapolation Fix-Time Calc.	Recovery
Postings	Current Postings			Various	Posting Determination	Recovery
Status	Sensor and System Parameter Values			Various	Various	Recovery
Track Flight System Data	Virtually Any Variable or Parameter in the System, When Requested			Various	Various	Off-Line

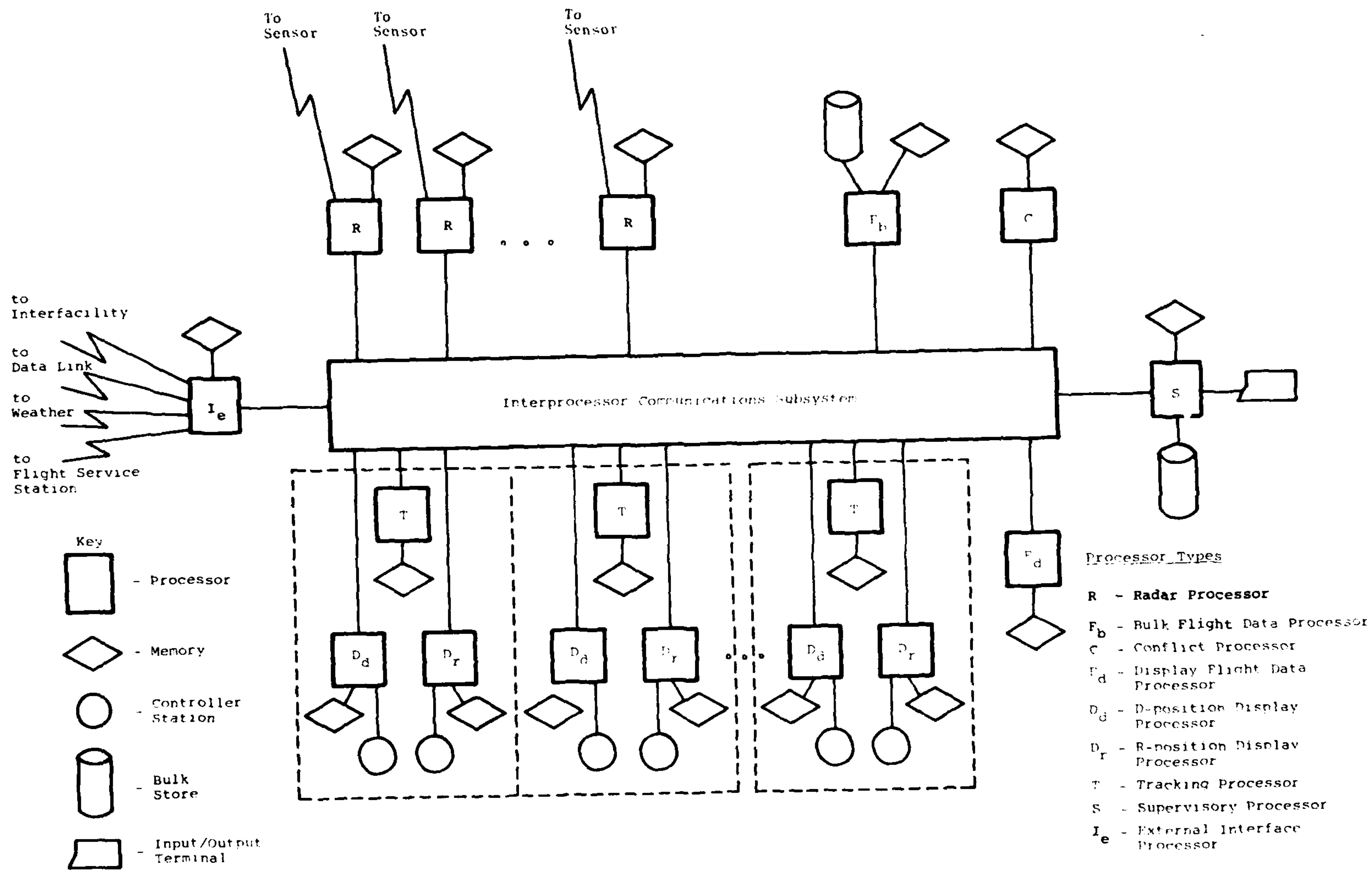

FIGURE 2.3-1 BASELINE SYSTEM HARDWARE CONFIGURATION

time-division-multiplexed bus, a hierarchy of local buses, or a switched network of some kind. It is felt that this aspect of the design has only a secondary effect on the performance of the system as a whole; therefore, given that the ICS has sufficient capacity to meet the demands placed on it, the choice of implementation may be made independently of the rest of the system.

The "distributed" Baseline System contains nine types of processors, as shown in Figure 2.3-1. There is one Radar Processor (R) for each sensor in the system. Its job is to accept the input stream of radar data from the sensor (DABS or ATCRBS), process the data where necessary and route it to the appropriate sector processor. The Bulk Flight Data Processor (F_b) reads in prestored flight plans and processes them for later use, the Conflict Processor (C) looks for conflicts in the flight paths of aircraft in the system and issues warnings when they occur, and the Display Flight Data Processor (F_d) distributes the flight data to the sector processors as it is needed.

Each sector work-station is manned by two controllers, preserving the current R and D positions. The sector is served by three processors with attendent displays and data entry devices. The R controller uses displays driven by the R-position Display Processor (D_r) which receives data from the corresponding Tracking Processor (T). The D controller's station is driven by the D-position Display Processor (D_d) which receives data from processor F_d. There are as many work-stations as there are sectors, plus a few spares for training, maintenance, and backup.

The External Interface Processor (I_e) serves as a message processor, linking the Center computer to the DABS data-link, the Weather Processing system, and the Flight Service Station system. Finally, the Supervisory Processor (S) exercises control over the whole system, collects critical and performance measurement data, and initiates startup, restart, and start-over procedures.

Each processor has sufficient private memory to hold all of its programs and data, including appropriate data bases; there is no global memory. Bulk storage devices are attached to the Bulk Flight Data Processor, F_b, and to the Supervisory Processor, S. The latter is also equipped with an I/O Terminal for operator interface.

2.3.2 Allocation of Functions and Data Bases

The functions to be performed and the data bases to be used by the Baseline System have been described in the preceding section. The allocation of processing functions and the associated data bases to processors is shown in Table 2.3-1 and 2.3-2, respectively. The rationale for allocating functions was based on the following considerations:

TABLE 2.3-1 ALLOCATION OF FUNCTIONS IN THE BASELINE SYSTEM

PROCESSOR	FUNCTION
R	Radar Data Preliminary Processing Real-time Quality Control* Dynamic Simulation* Data Routing
F_b	Bulk Store Processing Flight Plan Activation Route Conversion Flight Plan Position Extrapolation Fix-Time Calculation En Route Metering Flight Plan Probe Message Routing Flight Data DBM O&E Data DBM
C	Conflict Alert Conflict Resolution MSAW Message Routing O&E Data DBM Track Data DBM
F_d	Beacon Code Allocation Fix-Time Calculation Posting Determination Message Routing Flight Data DBM
D_d, D_r	Display Generation Display Control Message Processing
T	Target/Track Correlation Track Acquisition Tracking (FLAT & Free) Association Checking
S	Supervisory Functions Message Processing System Performance Data DBM Critical Data DBM
I_e	Message Processing

*Actually running in only one or a small number of the set of processors.

TABLE 2.3-2 ALLOCATION OF DATA BASES IN THE BASELINE SYSTEM

PROCESSOR	DATA BASE	REMARKS
F_b	Flight Data O&E Data	 Weather, Airport
C	Track Data O&E Data	 Sensors, MSAW, Airport
F_d	Flight Data	
T	Track Data	One sector per processor
D_d, D_r	Display Data	One sector per processor
S	System Performance Data Critical Data	

a) The independence of the function with respect to other functions and to data bases in the system,

b) The nearness of the function in terms of processing sequence to the source of the data or the user of the processed data,

c) The place of the function in the expected sequence of operation.

Since the configuration to be studied was a "distributed" system, the first thought in each case was to assign the function to a separate processor. This view was then modified as necessary to account for strong functional and data dependencies and to ensure that the various processing sequences required of the system were supported.

There is no simple, direct way to explain how the system is expected to operate. The account which follows describes in roughly chronological order the processing which takes place when an aircraft departs from a terminal in the Center's area and then the processing which accompanies an arrival. (This could be thought of as the same aircraft entering the adjacent Center's area and arriving at a terminal there). During the course of the description, the operation of various functions which could take place are described in terms of the processing, the data accesses, and the communications. Not every flight will require all of the processing described, but, for illustrative purposes, as many features as possible are included.

At some time, say 30 minutes, before Flight XY555 is scheduled to depart from terminal TER in the area served by the Center being described, the prestored flight plan is read from the bulk store by the Bulk Store Processing function operating in the Bulk Flight Data Processor, F_b. Within the next few minutes, the flight plan is activated by Flight Plan Activation and the route is converted to the standard internal form by Route Conversion. This information is stored in the Flight Data Data Base by the Flight Data Data Base Management function, and, at the same time, a copy is sent to the Display Flight Data Processor (F_d) to be stored in its Flight Data Data Base by its Flight Data Data Base Management function. At this point, the information stored in the two data bases is the same, but, as the flight advances through the ATC system, the different functions in the two Flight Data processors will develop different data. Care will have to be taken to insure that the two data bases remain consistent and synchronized with each other.

In F_d, the Posting Determination function prepares to transmit to the Terminal and to the en route sector containing the departure fix, flight data concerning XY555 and its time of departure. At an approximate time, say ten minutes prior to departure, the information is posted. That is, F_d transmits a message to the terminal via the ICS and the External Interface

Processor, I_e, and, at the same time, selects the proper D-position Display Processor, D_d, to which to post the departure.

Eventually, Flight XY555 departs TER and becomes visible to a sensor connected to the Center. Target returns are received by the corresponding Radar Processor, R, and are subjected to Preliminary Processing and routed to the appropriate Tracking Processor, T, (obviously, the one servicing the sector where the departure fix is located). The data may be sent to one or more other sectors if the aircraft is near a boundary. Each Tracking Processor will do Target/Track Correlation, Track Acquisition and Tracking (FLAT and Free) for tracks and targets within its sector and will transmit data to the R-position Display Processor, D_r, for output to the controller on the usual Plan View Display (PVD). In the case of Flight XY555, position and velocity data, cross-tell data, is sent from the Terminal to the Center for some time prior to handoff of control so that the Center can be sure it is acquiring the correct target. This data is received at the External Interface Processor and routed by prior arrangement to the correct T processor; i.e., to the correct sector.

Note that two different data-routing situations have been described: radar data from sensors being routed to appropriate sectors and cross-tell data from an adjoining facility being routed to an approximate sector. In the first case, a mapping is required from one position of the center area - the coverage by the sensors - to another - the set of sectors. This should be a simple, but non-trivial, task for the Radar Processors. In the second case, what is needed is merely a knowledge of which sectors correspond to the handoff fixes being approached by the aircraft in question. The trivial matching process will not extend the External Interface Processor.

The flight will pass through sector after sector, being handed off from one to the next at the appropriate hand-off fixes, being preceded by postings along the way. As the flight approaches the exit fix from the center area, its flight plan is passed to the adjacent center, then the cross-tell data and then control itself, through the hand-off message. The responsibility for the flight plan passing is given to F_d and for the cross-tell and hand-off is given to T.

On the arriving side of this transfer, the I_e processor receives the flight plan, which it passes to F_b, and the cross-tell and handoff messages, which is passes to T. The flight plan is activated, and its route converted to standard form in F_b; this information is then stored in the Flight Data Base and also passed to processor F_d, in the same way as pre-filed flight plans, described above, are passed. While the flight is being tracked across each sector in the T processors and being passed from one sector to the next, the Flight Plan Position Extrapolation and En Route Metering functions in the F_b processor monitor its progress. The Position Extrapolation function sends position updates for each flight to the T processors for use by the Association Checking and Flight Plan Aided Tracking functions; the En Route Metering function sends advisories and commands to the F_d processor for conveyance to the appropriate D_d processor.

Note that in this implementation, flight plan data displayed through the D_d processor, principally as flight postings, come from the F_d processor for the most part, while flight plan data used in the T processor or displayed through the D_r processor come from the F_b processor. Clearly there is a need for careful design at this point so that contradictory information can never appear in the D- and R- position displays.

The T processors send tracking information to the Conflict, or C, processor which maintains a Track Data Data Base for all tracks in the system and is responsible for the Conflict Alert and Conflict Resolution functions which transcend sector boundaries. The related MSAW function is also assigned to the C processor. Warnings and commands (or recommendations) are transmitted to the F_d processor for retransmission to the appropriate D_d processor and subsequent display to the controller. They are also sent to the I_e processor when DABS data link or interfacility communication is indicated. It is assumed that controller approval is required for transmission from the center; these approvals (or disapprovals) are routed from the D_d processor to both the C and I_e processors.

The controller, or sector, work-station consists of two displays and related data-entry devices, driven by the D_d and D_r processors. The station is self-contained in that it can, once it has been loaded with a set of data, operate without reference to the rest of the system. The controller can modify the display and enter queries and commands to the system through the display processors. Data used to generate displays are passed to D_r from the corresponding T processor and to D_d from F_d.

The principal avenue for requests for data from the various data bases in the system is through the D_d processor, where the requests are formatted and then transmitted to the F_d processor. These requests which can be satisfied from the data bases in F_d will be answered; the rest will be forwarded to the appropriate processor. A Flight Plan Probe request or a request for weather information would be sent to F_b; a request for information about a conflict situation would be sent to the C processor.

The radar input processor, R, will be assigned two other functions: Real-Time Quality and Dynamic Simulation. The former need be actually running in only one of the R processors at any time, although each will have the capability if assigned the task for backup purposes. Dynamic Simulation can be run on one R processor for each training sector in use.

All of the processors will collect critical and system performance data and send them to the S processor for storage.

The S processor will use the critical data to restart the system in case of a failure, or part of the system in case of a partial failure.

2.3.3 System Sizing

It must be assumed that the Baseline System will be capable of carrying out all of the functions of the ATC system at the traffic levels expected in the baseline year, 1985. These traffic levels have been discussed in Section 2.1.4, and factors germane to the operation of the system have been derived and listed in Table 2.1-1. The operational characteristics of each of the functions of the Baseline are given in Table 2.2-5, and the evaluation of these characteristics, with the appropriate load factors, gives a measure of the system size.

Two assumptions underline many of the processing estimates. The first is that sectors are sized and configured so that each one handles approximately the same traffic load. The second is that all of the targets in a sector may be scanned by the sensors in one second. Since there is a response time requirement on all target and track related processing, all such processing may be required to take place in that second rather than spread over the whole scan time.

To illustrate the analysis that has been carried out, the operations of two functions are described below in detail.

2.3.3.1 Analysis of Fix-Time Calculation - This is a routine which is called, in the F_b processor, by the Flight Plan Position Extrapolation and Route Conversion functions and, in the F_d processor, by the Posting Determination function. According to Table 2.2-5, the amount of processing for each operation of the program is given by:

$$P = K_1$$

where K_1 = medium. An estimate of the average amount of processing per second in the F_b processor is then

$$P_s = \left(\frac{\phi_A}{300} + \frac{\phi_H + \alpha_H}{3600}\right) K_M$$

where ϕ_A = number of active flight plans in the system,

ϕ_H = number of flight plans activated per hour, and

α_H = number of flight plan amendments per hour.

The coefficient gives the number of times per second the function is called: once each five minutes (300 seconds) for each active flight plan by Flight Plan Position Extrapolation and once for each flight plan activated or flight plan amendment entered.

The values of ϕ_A, ϕ_H and α_H for the small, medium, and large centers taken from Table 2.1-1 are:

	Small	Medium	Large
ϕ_A	430	668	984
ϕ_H	254	434	728
α_H	2,040	2,160	2,580

Therefore, the values of P_s are 2.07 K_M, 2.95 K_M, and 4.20 K_M for the small, medium, and large centers, respectively.

In a similar way, in the F_d processor, the amount of processing is given by:

$$P_s = \left(\frac{\phi_A}{300} + \frac{\phi_H}{3600}\right) K_M$$

resulting in values of 1.50 K_M, 2.35 K_M and 3.48 K_M.

2.3.3.2 Analysis of Target/Track Correlation - This function operates in the T processor, handling the target data transmitted from the radar processor and the tracks assigned to the particular sector. The average processing per second is:

$$P_s = K_s + K_s \rho_s + K_s \rho_s \log_2 T_s$$

where ρ_s = number of radar targets per sector,

T_s = number of tracks per sector.

Using the numbers from Table 2.2-1, the processing per second for small, medium, and large centers is $27.65K_s$, $50.05K_s$, and $68.30K_s$, respectively.

2.3.3.3 Comparative Processing Loads - It is desirable to have a single number as a measure of processing load on each processor, and, for the purposes of this study, that number need have no absolute interpretation. Such a number which is here called the Comparative Processing Number (CPN), can be derived for each processor in the system by summing the expressions for amounts of processing in each processor and then applying the relation.

$$100\ K_S = 10K_M = K_L = 1. \quad \text{(Section 2.2.2.2)}$$

As an example, the evaluation of the processing expressions for the C processor is given in Table 2.3-3. This evaluation for each of the processors results in the set of Comparative Processing Numbers for the Baseline System processors for small, medium, and large centers given in Table 2.3-4.

2.3.3.4 Comparative Communications Requirements - The communications among the functions, and hence among the processors, is the next matter of concern. Given the allocation

TABLE 2.3-3 EVALUATION OF PROCESSING - C PROCESSOR

FUNCTION	PROCESSING		
	SMALL	MEDIUM	LARGE
Conflict Alert	$0.02K_S+33.82K_M$	$0.02K_S+57.63K_M$	$0.02K_S+90.51K_M$
Conflict Resolution	$0.02K_S+0.016K_L$	$0.02K_S+0.040K_L$	$0.02K_S+0.093K_L$
MSAW	$0.03K_S+8.47K_M$	$0.03K_S+13.33K_M$	$0.03K_S+19.67K_L$
Message Routing	$0.02K_S$	$0.04K_S$	$0.10K_S$
Track Data DBM	$50.80K_S$	$80.00K_S$	$118.00K_S$
O&E Data DBM	$25.48K_S$	$36.23K_S$	$54.20K_S$
Sum	$(76.37K_S$ $+42.29K_M$ $+0.016K_L)$	$(116.34K_S$ $+70.96K_M$ $+0.040K_L)$	$(172.37K_S$ $+110.18K_M$ $+0.093K_L)$
Comparative Processing Number	5.01	8.30	12.83

TABLE 2.3-4 COMPARATIVE PROCESSING NUMBERS - BASELINE SYSTEM

PROCESSOR	CPN			REMARKS
	Small	Medium	Large	
R (ATCRBS)	1.22	3.02	4.31	
R (DABS)	1.02	2.82	4.12	
F_b	1.38	2.16	3.28	
C	5.01	8.30	12.83	
F_d	0.47	0.73	1.10	
D_d	0.07	0.08	0.09	
T	7.33	11.57	14.77	
D_r	2.22	2.82	3.32	
I_e	1.70	2.50	3.60	
S	4.83	5.05	5.84	

of functions to the processors, the traffic and other load factors, it is possible to estimate the number of messages generated in the processors and their lengths, and thus to calculate the average communications traffic into and out of each processor.

As an example, consider the message traffic occuring as the result of the discovery by the Conflict Alert function of an impending problem and the generation of commands to the aircraft involved by the Conflict Resolution function. The message flow is illustrated in Figure 2.3-2. The C processor sends the advisory/command message simultaneously to T processor for relay to D_r; to the F_d processor for relay to D_d; and to I_e for data-link if the aircraft are equipped, and for inter-facility if the conflict is near the center boundary. The D-controller approves or disapproves the commands, thereby generating a message to F_d which will be relayed to I_e, to initiate transmission of the Advisory Command message, and to C, for action by the Conflict functions. All of these message transactions and the others like them have been counted and tabulated; their frequencies and lengths estimated.

In calculating the required channel capacities into and out of each processor, it was assumed that message lengths would be doubled by the redundancy needed for error detection and correction, and that the capacity provided should be three times the required average to account for peaks in the demand. It was found on examination of the data that the communications requirements seemed to clump together in three ranges. Therefore, three types of channel were postulatd to cover these ranges. The slow speed channel, called Type A, has a capacity of 9,600 bits per second. The medium speed, Type B, has a capacity of 33,600 bits per second, and the high speed, Type C, has a capacity of 300,000 bits per second. The channel types into and out of each processor for the small, medium, and large centers are given in Table 2.3-5.

The requirements for redistribution of critical data in the event of a restart are given parenthetically in the table. These requirements were calculated by assuming that all such data is transmitted over a period of four seconds. For instance, in the T processor, it was assumed that 36 bytes were recorded for each track during each scan. This amounts to 27, 40, and 50 bytes/second for the small, medium, and large centers, respectively. On restart, data for a whole 10 second scan will have to be transmitted over a four second interval, giving 68, 100 and 125 bytes/second. These values are multiplied by 16 to get the bit rates, including redundancy of 1,100, 1,600, and 2,000 bits/second. Note that this is a peak rate requirement, which can be satisfied in each case by a slow speed, or Type A, channel.

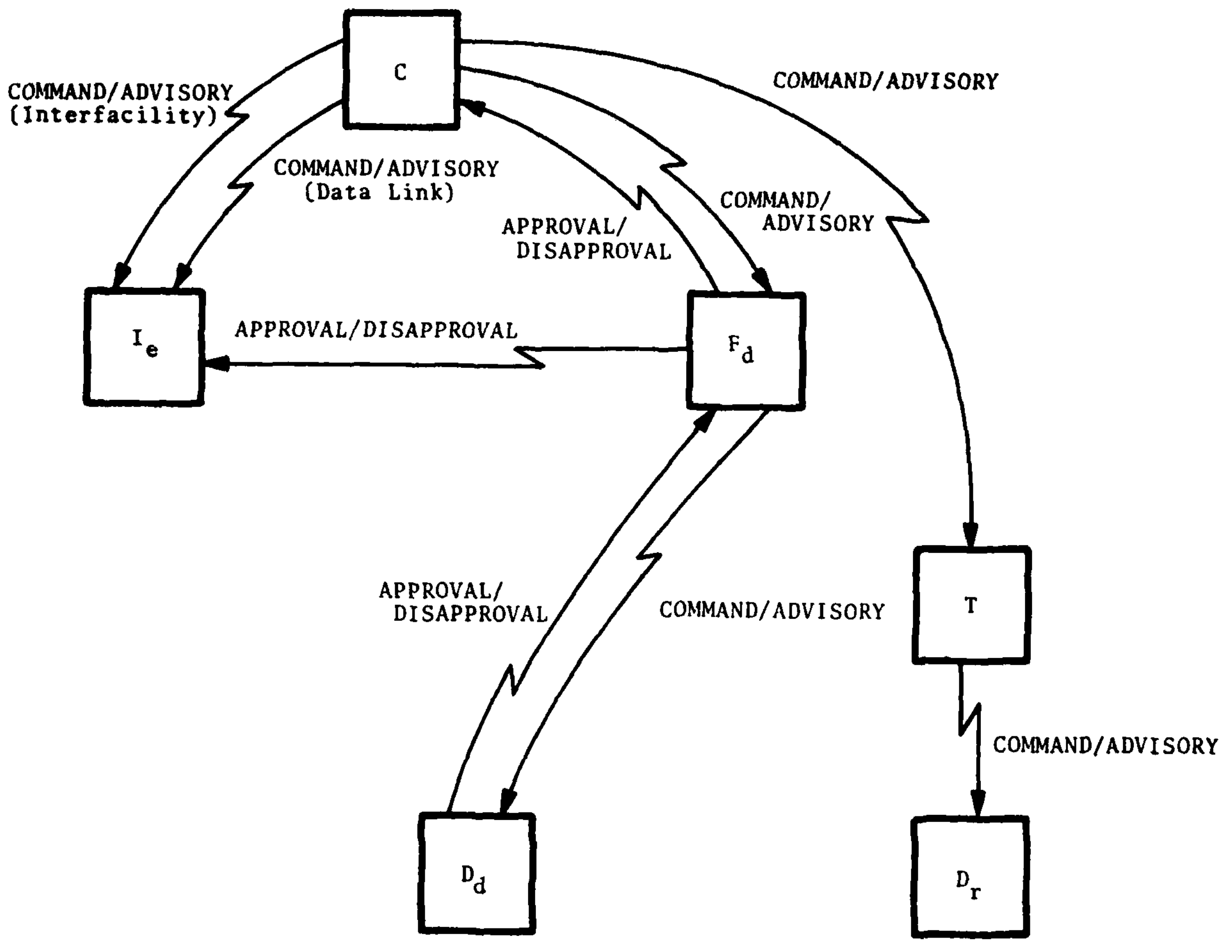

FIGURE 2.3-2. MESSAGE TRAFFIC RESULTING FROM DETECTION OF A CONFLICT

TABLE 2.3-5 COMMUNICATIONS CHANNEL REQUIREMENTS - BASELINE SYSTEM

PROCESSOR	COMMUNICATIONS CHANNEL TYPE					
	SMALL		MEDIUM		LARGE	
	IN	OUT	IN	OUT	IN	OUT
R(ATCRBS)	A (A)*	B	A (A)	B	A (A)	C
R(DABS)	A (A)	B	A (A)	B	A (A)	C
F_b	A (C)	B	A (C)	C	A (C)	C
C	C (B)	B	C (B)	B	C (B)	B
F_d	A (C)	B	B (C)	C	B (C)	C
D_d	A (A)	A	A (A)	A	A (A)	A
T	B (A)	B	B (A)	C	B (A)	C
D_r	A (A)	A	A (A)	A	A (A)	A
I_e	B (A)	B	B (A)	B	B (A)	B
S	2C	A (2C)	3C	A (3C)	3C	A (3C)

*Figures in parentheses are for redistribution of critical data for restart.

Type A capacity = 9,600 bits per second

Type B capacity = 33,600 bits per second

Type C capacity = 300,000 bits per second

3. THE FUTURE SYSTEM

3.1 ENVIRONMENT OF THE FUTURE SYSTEM

The Future System is a hypothetical ATC Central Computer Complex for 1995 that might evolve from the "Baseline" System of 1985-1995. It is assumed that the "Future" System is, in effect, the "Baseline" System modified and enhanced to meet functional requirements beyond 1995.

3.1.1 Surveillance

By 1995, surveillance will be based wholly on the DABS network rather than the mixed DABS-ATCRBS system that prevailed during the lifetime of the supplanted "Baseline" System. All aircraft are assumed to be equipped with DABS transponders; additionally, those aircraft utilizing Level 1 service will be suitably equipped for DABS data link. Each ATC facility's computer complex will be connected to the DABS network, thus assuring coverage continuity. Target/track correlation and, in fact, automatic tracking will no longer be required functions at the facility computer because of the uniqueness of DABS target ID and position data.

3.1.2 Communications

It is assumed that ground based interfacility and remote communications will continue to be provided by the NADIN system with its common interface standard and communications protocol. The principal medium for ground/air communications will be the DABS data link.

3.1.3 Interfaces

The "Future" System's interfaces with other facilities are assumed to be substantially the same as those previously described for the "Baseline" System; i.e., the Central Flow Control Facility, Weather Services Facility, Flight Service Facility, and adjacent ATC facilities.

3.1.4 Air Activity

The 1995 traffic forecast was estimated in a manner similar to that of 1985, which is described in Appendix B.

The parameters describing the en route system in 1995, as well as the values assumed to be reasonable for the small, medium, and large centers (projected data from three actual centers, Denver, Memphis and Chicago), are presented in Table 3.1-1.

TABLE 3.1-1 PARAMETERS DESCRIBING ATC OPERATION - 1995

NO.	PARAMETER		CENTER SMALL	MEDIUM	LARGE
1	Number of Radar Targets From the Sensors	$[\rho]$	N/A	N/A	N/A
2	Number of Sensors	$[n]$	9	5	5
3	Number of Tracks in the System (Peak)				
	En Route, Level 1	$[\tau_{E1}]$	230	361	558
	En Route, Level 2	$[\tau_{E2}]$	98	155	240
	Terminal	$[\tau_T]$	0	82	164
4	Number of Correlated Targets	$[\tau_C]$	N/A	N/A	N/A
5	Number of Flight Plans Entered from Bulk Store (Busy Hour)	$[\phi_B]$	114	57	313
6	Number of Flight Plans Entered in Two Minute Intervals from Bulk Store	$[\phi_2]$	4	2	10
7	Number of Flight Plans Entered Through FSSs (Busy Hour)	$[\phi_F]$	62	245	194
8	Number of Active Flight Plans in the System (Peak)	$[\phi_A]$	572	882	1342
9	Number of Displays (Sectors)				
	En Route, Level 1	$[\sigma_{E1}]$	16	24	37
	En Route, Level 2	$[\sigma_{E2}]$	12	16	24
	Terminal	$[\sigma_T]$	0	10	20
10	Number of R-controller Operations (Per Minute Per Position)				
	En Route, Level 1	$[\sigma_{CR1}]$	1	1	1
	En Route, Level 2	$[\sigma_{CR2}]$	4	4	4
	Terminal	$[\sigma_{CRT}]$	2	2	2
11	Number of Uncorrelated Radar Returns (Peak)	$[\rho_u]$	N/A	N/A	N/A
12	Number of Conflicts Predicted per Hour	$[\gamma]$	10	24	58
13	Number of Departures/ Arrivals (Busy Hour)	$[\phi_{AD}]$	166	300	507
14	Number of Overflights (Busy Hour)	$[\phi_O]$	157	132	75
15	Number of D-controller Operations (Per Minute Per Position)				
	En Route, Level 1	$[\sigma_{CD1}]$	3	3	3
	En Route, Level 2	$[\sigma_{CD2}]$	6	6	6
	Terminal	$[\sigma_{CDT}]$	6	6	6
16	Number of MSAW Conflicts Detected per Hour	$[\mu]$	2	7	21
17	Number of Flight Plan Amendments Entered per Hour	$[\psi_H]$	1680	2400	3660
18	Number of Flight Plans Activated per Hour	$[\phi_H]$	352	604	1014
19	Number of Flight Plan Entries per Display				
	En Route	$[\phi_{DIE}]$	24	44	45
	Terminal	$[\phi_{DIT}]$	0	15	13

N/A - Not Applicable

3.1.5 Airspace Structure

In 1995, airspace structure will be such that positive control will be exercised where traffic is heavy, while maximum freedom will be allowed where traffic is light. The assumed structure provides for several levels of service in essentially four categories of airspace; the levels of service range from highly automated, central ground-controlled separation in positive control airspace to ground-independent, air-derived separation in uncontrolled airspace. It is assumed that the traffic in each center area is distributed so that 43% is under Level 1 control, 19% under Level 2 control, and 38% not under positive control. The airspace structure and levels of service are depicted in Figure 3.1-1.

3.1.6 Future System Functions

The set of functions performed by the Future System will include most of those performed by the Baseline System plus three new functions:

Coordinate Conversion,

Clearance Generation, and

Terminal Path Control.

Table 3.1-2 contains a list of Baseline functions indicating those carried over and added to the new functions of the Future System.

ATC service provided in Level 2 (see Figure 3.1-1) will be based primarily on the following functions:

MSAW,

Conflict Detection and Resolution, and

En Route Metering.

Each of these functions generates warnings, commands, or advisories which are voice-linked or data-linked to aircraft, (but only if approved by the air traffic controller), in what might be characterized as a semi-automatic mode similar to the present ATC system.

Of the three new functions, only Clearance Generation is a Level 1 function. Coordinate Conversion is an internal function and Terminal Path Control, a terminal service function. Unlike the warnings, commands, and advisories from the Level 2 service functions, the messages from Clearance Generation are automatically data-linked to aircraft in the Level 1 service area. Since conflict-free flight paths are assured by Clearance

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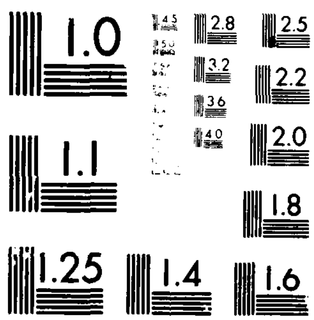

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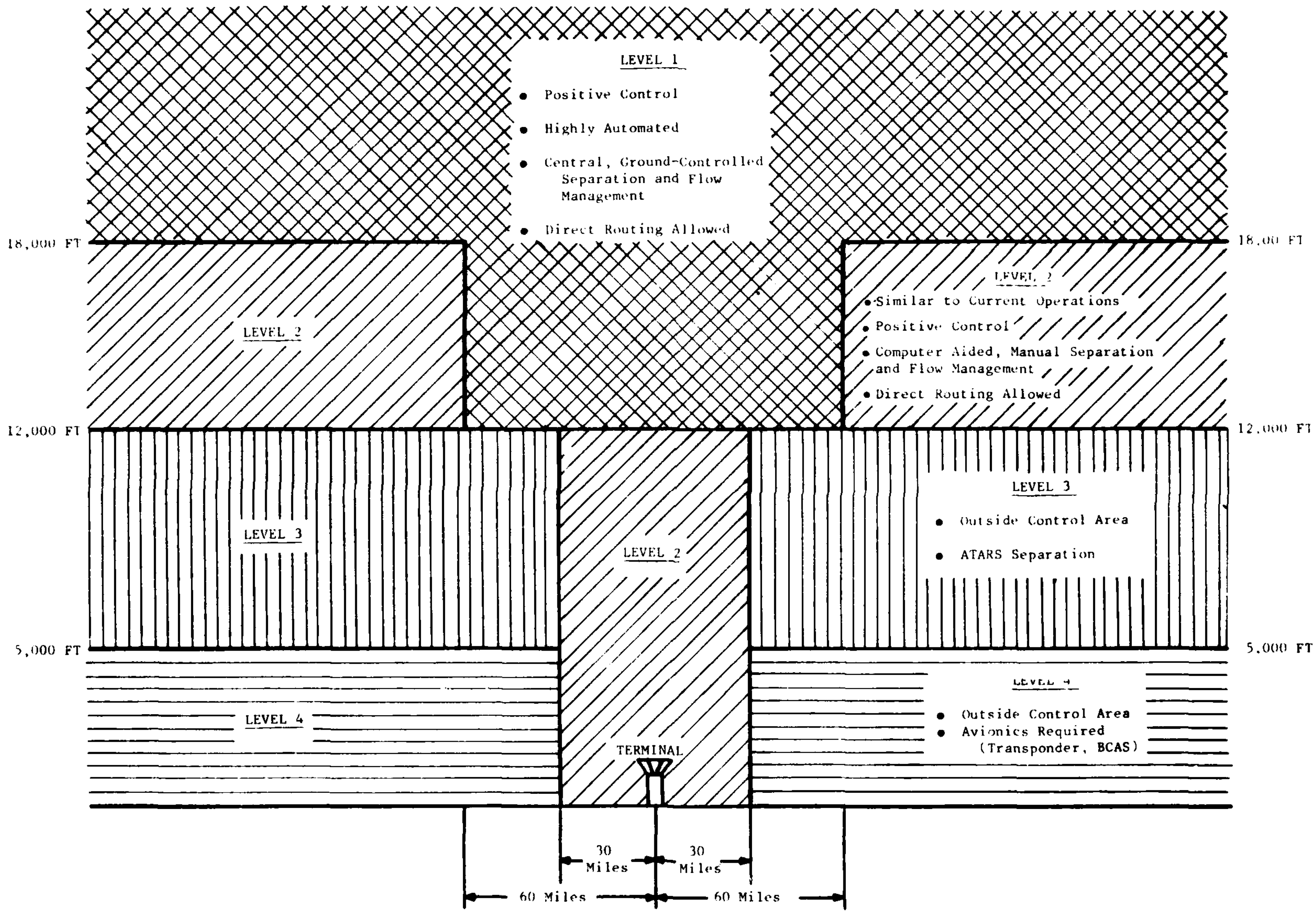

FIGURE 3.1-1 1995 AIRSPACE STRUCTURE AND LEVELS OF SERVICE

TABLE 3.1-2. COMPARISON OF BASELINE AND FUTURE SYSTEM FUNCTIONS

BASELINE SYSTEM	FUTURE SYSTEM	COMMENTS
Bulk Store Processing	Bulk Store Processing	
Flight Plan Activation	Flight Plan Activation	
Route Converstion	Route Converstion	
Posting Determination	Posting Determination	
Flight Plan Position Extrapolation	Flight Plan Position Extrapolation	
Fix-Time Calculation	Fix-Time Calculation	
Flight Plan Probe	Flight Plan Probe	
MSAW	MSAW	
Dynamic Simulation	Dynamic Simulation	
Critical Data Recording	Critical Data Recording	
Supervisory Function	Supervisory Function	
Display Generation	Display Generation	
Display Control	Display Control	
Enroute Metering	En Route Metering	Augmented in Future System
Conflict Alert	Conflict Detection and Resolution	Modified and Combined in Future System
Conflict Resolution		These functions are not included in the Future System because of the radar processing and tracking performed by DABS.
Association Checking		
Beacon Code Allocation		
Radar Data Preliminary Processing		
Real-Time Quality Control of Radar Data		
Target-Track Correlation		
Track Acquisition		
Tracking (FLAT and Free)		
	Coordinate Conversion	New Function
	Clearance Generation (AERA)	New Function
	Terminal Path Control	New Function

Generation, the clearances are automatically dispatched unless disapproved by the air traffic controller.

3.2 FUNCTIONAL DESCRIPTION OF THE FUTURE SYSTEM

The functional description of the Future System reveals both its similarities with and differences from the Baseline System. In the case of the Baseline System the description is implementation-independent, showing neither hardware nor operating system dependencies.

3.2.1 Functional Organization of the Future System

The functional organization of the Future System is illustratd in a block diagram, Figure 3.2-1, and its processing functions described in Tables 3.2-1 through 3.2-4. The principal differences between the Baseline and Future Systems as detailed in Figure 3.2-1 are attributable to:

a) All radar processing and tracking functions being performed by processors at DABS sensor sites,

b) Incorporation of Terminal Approach/Control functions at the en route facility, and

c) Introduction of a Clearance Generation function similar to, and possibly derived from, the Automatic En Route ATC (AERA) concept.

As a result of (a) above, the unique target ID and position data received from the DABS network need only be subjected to a coordinate conversion process which transforms DABS sensor site coordinates to the en route system's stereographic plane. The converted target data is then sent to the Track Data Base Management System for subsequent distribution to other functions requiring track data. Note that there are no tracking functions in the Future System because they would be unnecessarily redundant. In fact, even if a DABS site should fail, another site or sites in the DABS network would provide the required data.

The integration of terminal Approach/Control functions in the en route center is provided by a new function shown in the block diagram as Terminal Path Control. The latter generates approach/departure profiles and the metering and spacing commands that are automatically dispatched to the aircraft via the DABS data link unless the terminal controllers intervene and override the messages.

The introduction of the Clearance Generation function assures that aircraft receiving Level 1 service are provided conflict-free flight paths through the continous monitoring of all aircraft in the airspace and the automatic generation of essential clearances for transmission via DABS data link.

3.2.2 Characteristics of Functions

The set of characteristics with which the functions can be described is unchanged from those discussed in Section 2.2.2. The operational characteristics of the new functions, as well as those Baseline System functions which will be modified, are described in Table 3.2-5. To avoid duplication, the retained Baseline System functions which remain unchanged are not included in Table 3.2-5.

3.2.3 Characteristics of Data Bases

The data bases in the Future System are essentially the same as those of the Baseline System as described in Section 2.2.4 and Table 2.2-6, and are, therefore, not repeated herein.

3.3 ARCHITECTURE OF THE FUTURE SYSTEM

The "Future" System is derived from the "Baseline" System by the addition (or deletion) of resources processors, memories, displays, etc. The choice of what to add or delete is made on the basis of functional or capacity requirement as in the Baseline System. The following sections will describe the configuration which resulted from this design process as well as the functional allocations and sizing that led to the configuration.

3.3.1 Description of the Configuration

The configuration of the Future System is shown in Figure 3.3-1. As in the Baseline System, the Inter-processor Communications Subsystem connects those processors which have need to exchange messages. The configuration is made up of eleven types of processors, each of which has its own memory. Two new processors, the Clearance Generation Processor, F_c and the Terminal Processor, T_p, have been added, and all but one of the Radar Processors, R, have been deleted. The only other obvious difference is the addition of a DABS input to External Interface Processor I_e.

3.3.2 Allocations of Functional and Data Bases

The allocation of the functions to the processors is given in Table 3.3-1 and of data bases to processors in Table 3.3-2. Functions, data bases, and processors that are new, or drastically changed, are marked with an asterisk.

As shown in Figure 3.3-1, the Future System consists of ten types of processors, each having its own memory for programs and data rather than global memory. Bulk or secondary storage is attached to the Bulk Flight Data Processor F_b and the Supervisory Processor, S. Unlike the Baseline System which has a Radar Processor, R, directly connected to each ATCRBS/DABS Sensor, the Future System has only one Radar Processor with no direct

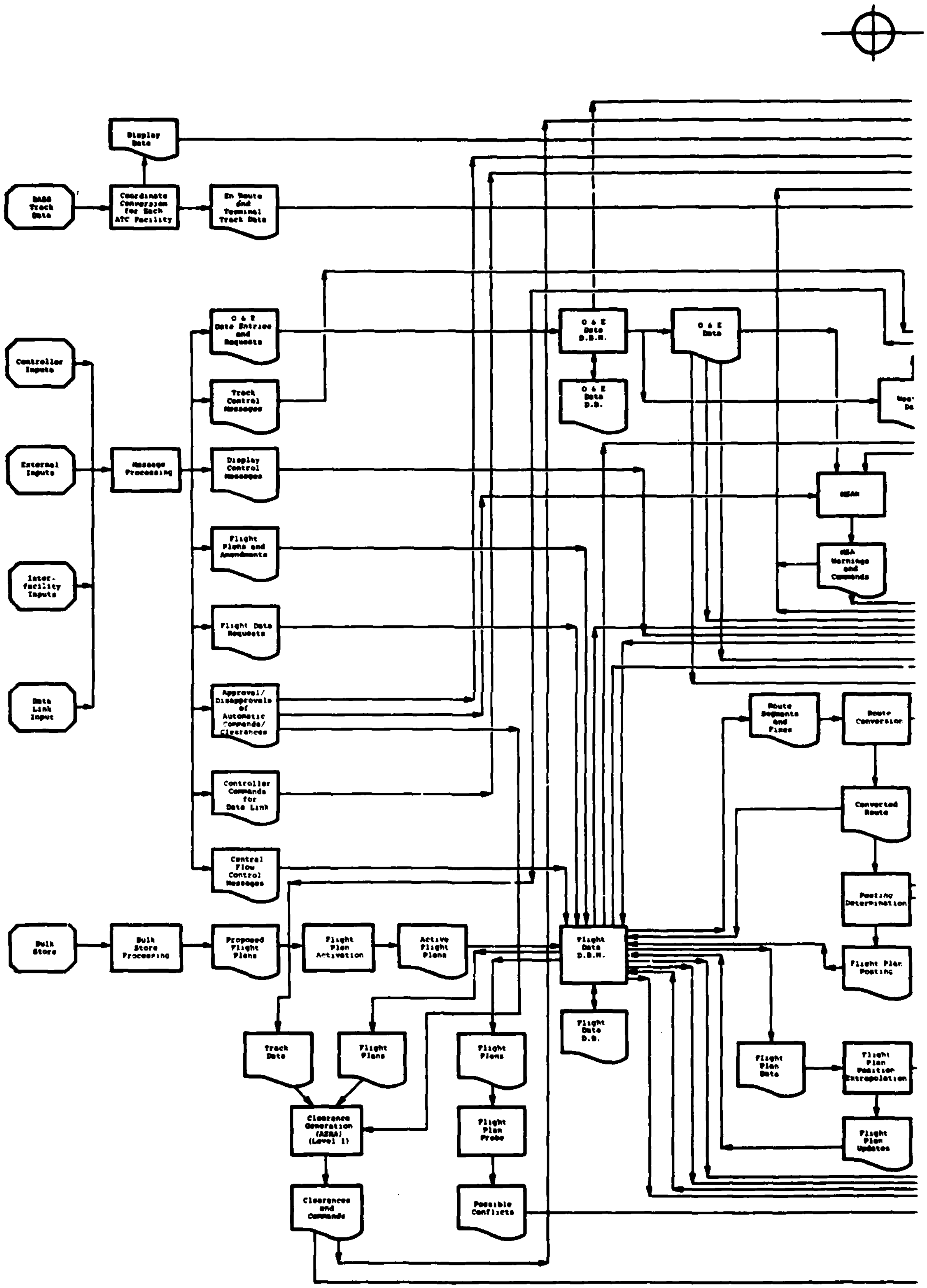

FIGURE 3.2-1. FUTURE SYSTEM FUNCTIONAL BLOCK DIAGRAM

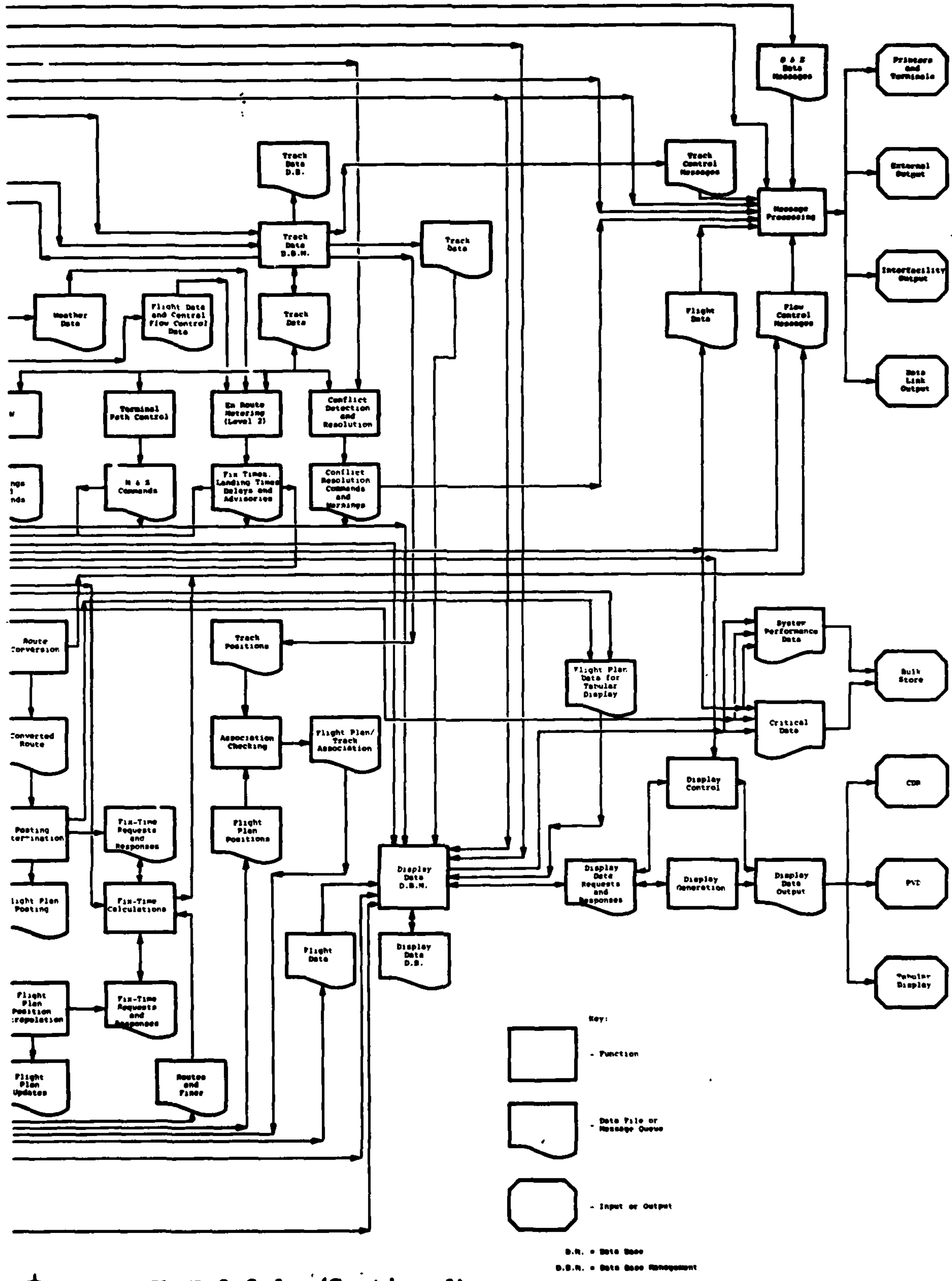

FIGURE 3.2-1. (Continued)

TABLE 3.2-1. RADAR DATA PROCESSING

INPUT	SOURCE	PROCESSING	OUTPUT	DESTINATION
DABS Track Data (ID, Altitude, Position, Velocity)	DABS Sensor Site	Coordinate Conversion	Converted Track Data (X,Y in System Coordinates, ID, Altitude Velocity)	Track Data D.B.
Simulation Control Messages	Controller Input	Dynamic Simulation	Simulated Track Data (ID, X-Y, Altitude, Velocity)	Track Data D.B.

TABLE 3.2-2. FLIGHT DATA PROCESSING

INPUT	SOURCE	PROCESSING	OUTPUT	DESTINATION
Prefiled Flight Plans	Bulk Store	Bulk Store Processing (Select flight plans expected to be valid in N minutes (N~30)	Proposed Flight Plans	Flight Plan Activation
Proposed Flight Plans	Bulk Store Processing	Flight Plan Activation (Select flight plans expected to be valid in N seconds (N~60)	Active Flight Plans	Flight Data D.B.
Route Segments and Fixes	Flight Data D.B.	Route Conversion (Convert flight plan as filed to standard form. Operates whenever flight plan is activated or modified)	Converted Routes	Flight Plan D.B. Posting Determination
Fix-Times	Fix-Time Calculation	Posting Determination (Triggers display of data on D-controller tabular display)	Fix-Time Requests Flight Data Postings	Fix-Time Calculation Flight Plan D.B. D-Controller Tabular Display
Flight Data (Route segments, fixes expected times over fixes)	Flight Data D.B.	Flight Plan Position Extrapolation (Compute present location of a/c along flight plan)	Flight Data Updates	Flight Data D.B.
Fix-Times (Updated times over fixes)	Fix-Time Calculation		Fix-Time Requests	Fix-Time Calculation

TABLE 3.2-2. FLIGHT DATA PROCESSING (CONTINUED)

INPUT	SOURCE	PROCESSING	OUTPUT	DESTINATION
Flight Plan Data (Route segments, fixes, expected times over fixes, assigned altitudes)	Flight Data D.B.	Flight Plan Probe (Extrapolates flight plans to find possible conflicts)	Conflict Warnings	Display Data D.B.
Winds and Airport Data Flight Plan Data (Route segments, fixes, expected times over fixes, assigned altitudes)	O&E D.B. Flight Data D.B.	En Route Metering (Compute expected landing times, times over fixes, required delays and speed and heading advisories)	Fix-Times Landing times Delays Advisories	Display Data D.B.
Fix-Time Requests Routes and Fixes	Route Conversion & Posting Flight Plan Position Extrapolation Flight Data D.B.	Fix-Time Calculation (Calculate expected time over next fix)	Fix-Times	Route Conversion & Posting Flight Plan Position Extrapolation

TABLE 3.2-3. DISPLAY PROCESSING

INPUT	SOURCE	PROCESSING	OUTPUT	DESTINATION
Display Control Messages	Message Processing	Display Control (Responds to display control & charge commands)	Display Commands	Output Devices
Display Data Responses	Display Data D.B.		Display Data Requests (Descriptors of needed data)	Display Data D.B.
Display Data Responses	Display Data D.B.	Display Generation (Generate display tables for each position)	Display Data Requests (Descriptors of needed data)	Display D.B.

TABLE 3.2-4. TRACK DATA PROCESSING

INPUT	SOURCE	PROCESSING	OUTPUT	DESTINATION
Target/Track Data (Position, velocity, altitude, ID)	Track Data D.B.	MSAW	MSAW Warnings and Commands	Display Data D.B.
Environmental Data (Terrain Grid)	O&E Data D.B.			Message Processing
Approvals/Disapprovals (Controller input)	Message Processing			
Target/Track Data (Position, velocity, altitude, ID)	Track Data D.B.	Terminal Path Control	Heading, Altitude, and Speed Commands	Display Data D.B.
Environmental Data (Terminal Area Geometry and Georgraphy)	O&E Data D.B.			Message Processing
Approvals/Disapprovals (Controller Input)	Message Processing			
Target/Track Data (Position, velocity, altitude, ID)	Track Data D.B.	Conflict Detection and Resolution	Conflict Warnings and/or Resolution Commands	Display Data D.B.
Approvals/Disapprovals (Controller Input)	Message Processing			Message Processing

TABLE 3.2-5 OPERATIONAL CHARACTERISTICS OF FUTURE FUNCTIONS

	EN ROUTE METERING
	Operates on each Level 2 flight at prescribed fixes and/or times
I Storage	Medium
II Processing per Operation	$P = K_1$ where K_1 = medium
III Frequency of Operation	Aperiodic, ~once/five minutes for each Level 2 flight
IV Types of Processing	I/O 0 Char. 10% Calc. 40% Match. 0 Log. 50%
V Amount of Data	In: $D = K_1$ Out: $D = K_2$ where K_1 = medium K_2 = medium
VI Response Time	<10 seconds
VII Operational Role	Produces traffic management directives for use by controller
VIII Dependence	Depends on properly processed Flight Data

TABLE 3.2-5 OPERATIONAL CHARACTERISTICS OF FUTURE FUNCTIONS

(CONTINUED)

	CONFLICT DETECTION AND RESOLUTION
	Processes all Level 2 tracks periodically
I Storage	Medium
II Processing per Operation	$P = K_1 + K_2 T \log T + K_3 C$ where T = number of Level 2 tracks, C = number of conflicts detected K_1 = small, K_2 = medium, K_3 = large
III Frequency of Operation	Periodic, ∿ once/minute
IV Types of Processing	I/0 0 Char. 0 Calc. 40% Match. 35% Log. 25%
V Amount of Data	In: $D = K_1 T$ Out: $D = K_2 C$ where T = number of tracks, C = number of conflicts detected K_1 = medium, K_2 = medium
VI Response Time	< 10 seconds
VII Operational Role	Produces traffic control commands under emergency conditions
VIII Dependence	Uses tracking data from DABS

TABLE 3.2-5 OPERATIONAL CHARACTERISTICS OF FUTURE FUNCTIONS (CONTINUED)

	COORDINATE CONVERSION
	Operates once per buffer load per sensor
I Storage	Medium (including buffer space in and out)
II Processing per Operation	$P = K_1 + K_2 T$, where T is the number of tracks K_1 = small, K_2 = small
III Frequency of Operation	∿ once/second/sensor
IV Types of Processing	I/O 20% Calc. 70% Log. 40% Char. 0 Match. 0
V Amount of Data	In: $D = K_1 + K_2 T$ K_1 = small, K_2 = medium Out: $D = K_1 + K_2 T$ K_1 = small, K_2 = medium
VI Response Time	<1 second
VII Operational Role	Processes primary input
VIII Dependence	Independent, asynchonous of other functions

TABLE 3.2-5 OPERATIONAL CHARACTERISTICS OF FUTURE FUNCTIONS (CONTINUED)

	CLEARANCE GENERATION (AERA)
	Operates periodically on each Level 1 flight
I Storage	Large
II Processing per Operation	$P = K_1 + K_2 T$, T = number of Level 1 tracks K_1 = medium, K_2 = large
III Frequency of Operation	~once per 5 minutes on each Level 1 flight
IV Types of Processing	I/O 0 Char. 0 Calc. Match 40% Log.
V Amount of Data	In: $D \approx K_1$ Out: $D = K_2$ K_1 = medium, K_2 = medium
VI Response Time	~10 seconds
VII Operational Role	Produces automatically delivered flight clearances to Level 1 flights
VIII Dependence	Depends on properly processed flight and track data

TABLE 3.2-5 OPERATIONAL CHARACTERISTICS OF FUTURE FUNCTIONS (CONTINUED)

	TERMINAL PATH CONTROL
	Operates periodically on all flights in the Terminal Control Area
I Storage	Large
II Processing per Operation	$P = K_1$ where K_1 = large
III Frequency of Operation	once/5 seconds/track
IV Types of Processing	I/O 0 Calc. 50% Log. 40% Char. 0 Match. 10%
V Amount of Data	In: $D = K_k$ K_1 = medium Out: $D = K_2$ K_2 = small
VI Response Time	~1 second
VII Operational Role	Produces traffic control directives for use by controller in the terminal area
VIII Dependence	Depends on track data from DABS

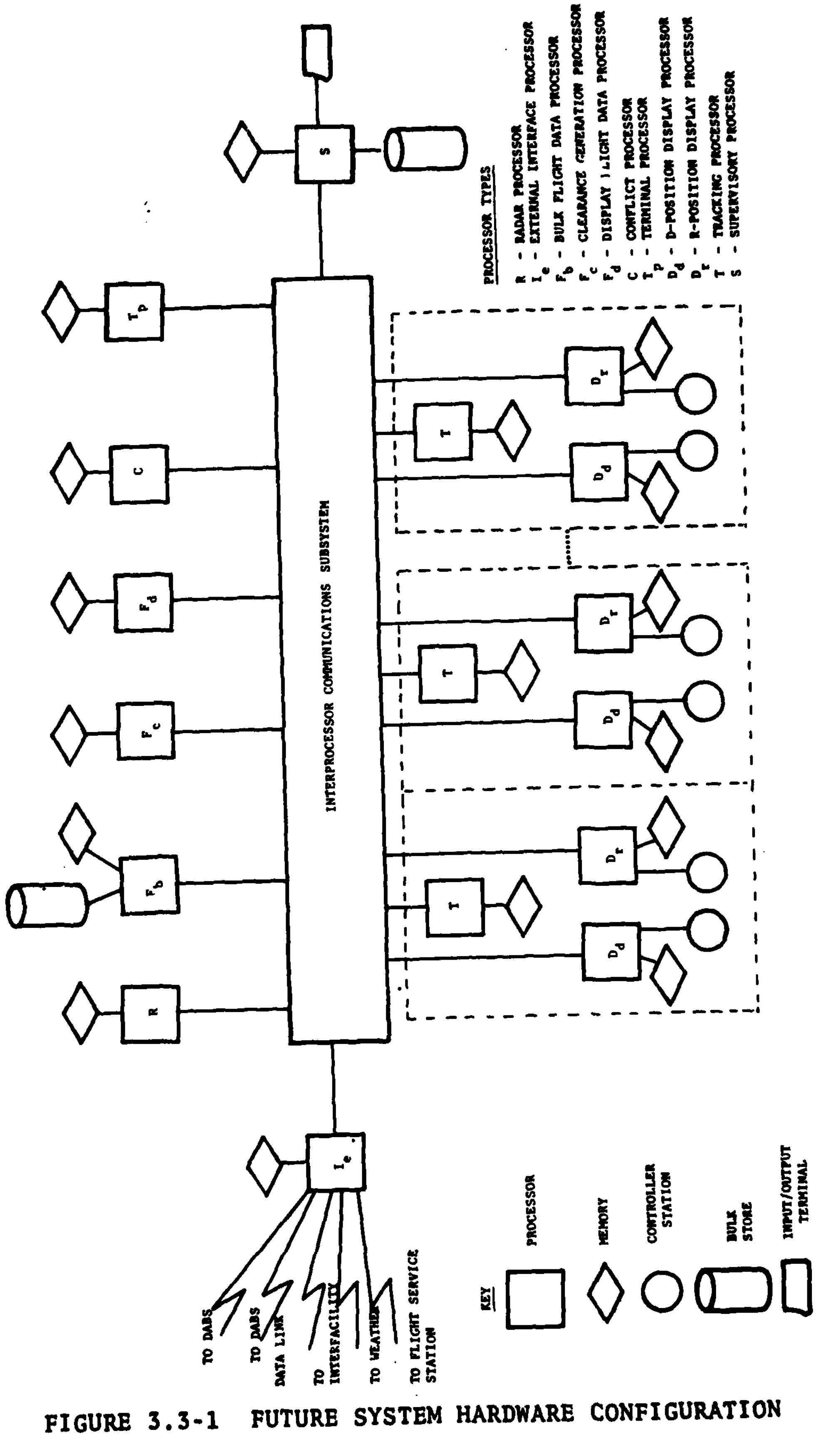

FIGURE 3.3-1 FUTURE SYSTEM HARDWARE CONFIGURATION

TABLE 3.3-1. ALLOCATION OF FUNCTIONS IN THE FUTURE SYSTEM

PROCESSOR	Function
R	*Coordinate Conversion Dynamic Simulation Data Routing
F_b	Bulk Store Processing Flight Plan Activation Route Conversion Flight Plan Position Extrapolation (Level 2) Fix-Time Calculation (Level 2) En Route Metering (Level 2) Flight Plan Probe (Level 2) Message Routing Flight Data DBM O&E Data DBM
C	Conflict Detection and Resolution (Level 2) MSAW (Level 2) Track Data DBM O&E Data DBM
$*T_p$	*Terminal Path Control Track Data DBM
F_d	Fix-Time Calculation (Level 2) Posting Determination (Level 2) Message Routing Flight Data DBM
D_d, D_r	Display Generation Display Control Message Processing
$*F_c$	*Clearance Generation (AERA) (Level 1) Flight Data DBM Track Data DBM
T	Track Data Format Maintenance Association Checking Flight Plan Modification to Tracking Track Data DBM
S	Supervisory Functions Message Processing System Performance Data DBM Critical Data DBM
I_e	Message Processing
S	Supervisory Functions Message Processing System Performance Data DBM Critical Data DBM
I_e	Message Processing

TABLE 3.3-2. ALLOCATION OF DATA BASES IN THE BASELINE SYSTEM

PROCESSOR	DATA BASE	REMARKS
F_b	Flight Data	
	O&E Data	Weather, Airport
C	Track Data	
	O&E Data	Sensors, MSAW, Airport
*T_p	*Track Data	Terminal Area
F_d	Flight Data	
D_d, D_r	Display Data	One Sector per Processor
S	System Performance Data	
	Critical Data	
*F_c	*Flight Data	
T	Track Data	

connection to the sensors. The input stream of radar data from the DABS sensor network is fed into the External Interface Processor (I_e) and then to the ICS before entering the Radar Processor. The role of the Radar Processor diminishes, being limited to coordinate conversion (sensor site to facility), dynamic simulation, and data routing. The External Interface Processor (I_e) serves as the principal link with the outside world; i.e., the DABS Sensor network, DABS data link, the Weather Processing System, Flight Service Station, Central Flow Control Facility, and other facilities. The roles of both the Bulk Flight Data Processor (F_b) and the Conflict Processor (C) remain unchanged, except that much of the processing in F_b and all in C are restricted to level 2 service only. The Display Flight Data Processor (F_d) performs all of its previously designated functions with the exception of Beacon Code Allocation. This is no longer required because the DABS System uses permanently assigned beacon codes; it, too, deals mainly with level 2 operations.

Two new processors, F_c and T_p, have been incorporated. F_c generates conflict-free clearances for level 1 service; T_p provides the means for consolidating terminal functions with en route functions and performing terminal path control in the center.

The Supervisory Processor, S, is the means by which control over the entire system is maintained. It collects critical and performance measurement data and initiates startup, restart, startover, and configuration/reconfiguration procedures.

The controller work-station in the Future System, while retaining the same processing elements, an R-position Display Processor (D_r), a D-position Display Processor (D_d), and a Tracking Processor (T), differs in function from the Baseline System in that the Tracking Processor no longer does tracking, per se. Track data is supplied from DABS via the R processor to the appropriate T processor for the en route sectors; flight plan position data is supplied by the F_b processor. The T processor in the en route work-station does association checking between the two and, under the appropriate circumstances, uses flight plan data to modify or supplement the track data.

The controller work-stations are identical with respect to processors, displays, and data entry devices and may be adapted by software (or firmware) to En Route level 1 or level 2, or to Terminal Approach/Departure Control.

3.3.3 System Sizing

The Future System was analyzed in the same way as the Baseline System to obtain the comparative processing numbers for each of the processors and the comparative channel requirements into and out of each of them. The CPN's are shown in Table 3.3-3 and the channel requirements in Table 3.3-4.

TABLE 3.3-3. Comparative Processing Numbers - Future System

Processor	CPN		
	Small	Medium	Large
R	1.74	2.82	4.27
F_b	0.65	0.93	1.44
F_c	5.13	8.06	17.00
C	2.17	3.57	5.70
T_p	-	6.38	12.76
F_d	0.19	0.29	0.46
D_d	0.11	0.12	0.14
T	2.05	2.05	2.05
D_r	1.36	1.40	1.40
I_e	4.96	8.62	13.61
S	5.28	5.92	7.16

TABLE 3.3-4 COMMUNICATIONS CHANNEL REQUIREMENTS - FUTURE SYSTEM

PROCESSOR	COMMUNICATIONS CHANNEL TYPE					
	SMALL		MEDIUM		LARGE	
	IN	OUT	IN	OUT	IN	OUT
R	C (A)*	C	C (A)	C	2C (A)	2C
F_b	A (C)	B	A (C)	C	A (C)	C
F_c	C (C)	B	C (C)	B	C (2C)	C
C	B (B)	B	B (B)	B	C (B)	B
T_p	C (B)	B	C (B)	B	C (B)	B
F_d	A (C)	C	B (C)	C	B (C)	C
D_d	A (A)	A	A	A	A (A)	A
T	B (A)	B	B (A)	C	B (A)	C
D_r	B (A)	A	A (A)	A	A (A)	A
I_e	B (A)	C	C (A)	C	C (A)	2C
S	3C	A (3C)	4C	A (4C)	5C	A (4C)

*Figures in Parentheses are for Redistribution of Critical Data for Retart.

Type A capacity = 9600 bits per second
Type B capacity = 33600 bits per second
Type C capacity = 300000 bits per second

4. ANALYSIS OF ISSUES

The question addressed throughout this study has been, "What will be the effect in the 1990's of having chosen a distributed processing concept for the 9020® replacement?" The answer is derived in two ways: 1) by discussing certain basic issues which are likely to arise in conjunction with changes and improvements to the system, and 2) by examining the effects of a sample scenario on a strawman model of a future ATC system. In the first case, reasoning is from the general to the specific, from knowledge of general system behavior to the more specific ATC application. In the second, reasoning goes from the specific, somewhat fanciful implementation to the more general ATC application. The two lines of reasoning meet at the ATC application, for what is specific to the one is general to the other.

As general background to this discussion, it may be useful to consider the level of technology of the system that might be procured to replace the 9020. It can be assumed that it will be equivalent to what might be commercially available in about 1984. Since the results of this study are not particulary sensitive to the level of the technology assumed, a broad statement of what might be expected will suffice. A quick survey of some current literature [1-4] leads to the following assertions about the 1984 computer systems:

1) Great amounts of processing capability will be available in the form of microprocessors, e.g. a 32 bit computer on a single chip. [4]

2) Random-access memory with one megabit on a single chip will be available and the price will approach .02 cents per bit. [4]

3) Electronic mass-storage devices such as bubble memories and charge-coupled devices will be available and cost-effective in the range of 4-40 megabits. [3]

4) Communications links such as fiber optics will allow wide-band (400 Mbps) communications over distances of ten kilometers. [1]

A distributed system built with this kind of technology would be extremely powerful compared to today's NAS system, leading one to consider factors other than raw processing power and memory capacity as the more important.

4.1 BASIC ISSUES

From the myriad of issues that have to be faced in the 1990's with respect to the ATC computer subsystem, four seem to be of primary importance: The effect of functional modification on the system, the effect of increasing load, the influence of new technology, and the general area of software design, implementation, and maintenance.

With regard to distributed processing systems, it has become clear during this study that, the key to the success of any particular design is the efficacy of the interprocessor communications subsystem, and that the critical performance measurement criteria involve synchronization of the system and response time of the processes. The other aspects, such as amounts of processing power and memory at each node, seem straight-forward by comparison. Therefore, most of the discussion which follows will be concentrated on the dynamic behavior of the system and its interaction with the issues.

4.1.1 Functional Modification

A fundamental, but generally unwritten, requirement which every system design is expected to meet is that it be amenable to changes in the remaining requirements. Among other things, these changes could involve adding a new function, or modifying one or more of the existing functions. How amenable, then, is a system implemented under a distributed concept to functional modification?

The structure of the software of a system has been recognized as the quality that can lead to designs which are easy to modify in the ways being discussed here. Well-structured programs have the property of being composed of loosely-coupled, independent modules, where "loosely-coupled" means, essentially, related only through information passed as a part of the calling operation (as opposed to sharing global variables, for instance).

A problem in the system design process is the need to match the structure of the software to the structure of the requirements and specifications, while also matching the structure of the hardware. It is not always easy to maintain this two-level matching, even with the aid of sophisticated high-level languages and their compilers and complex operating systems, when the hardware is specified first and the software is then designed to fit it. On the other hand, it would seem that if the software structure were matched to the requirement/specification, and then the hardware structure were designed to match the software, the process could become nearly optimal.*

In practice,a certain amount of give and take in the design process between hardware and software structures cannot be avoided because the hardware is not, after all, continuously variable in structure and cannot be matched exactly to an

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*An excellent example of this process is the DABS system, where the concept of the hardware being matched to the design was enunciated in the Request for Proposals.

arbitrary software structure. Because of its inherent modularity, a distributed processing architecture is very flexible and could be matched more easily than most to a predefined software structure.

It may then be assumed that a 9020® replacement system based on the distributed processing concept would attain the matching of the software structure to the requirement/specification structure and the hardware structure to the software structure. The question then becomes: how easily is the change in requirement passed through the software structure, accomodated by the hardware structure?

There will be a range of possible functional modifications, some of which have little or no effect on the software structure, others which seriously perturb it. A new function added to the system, which needs only modest amounts of input data at low frequency, produces only modest amounts of output and has virtually no effect on other processing, can be treated in a trivial way, possibly by assigning it to a new independent processor added to the system just for this purpose. The more important cases occur when the functional modifications require large amounts of data not previously available produce new and/or large amounts of output or strongly effect the operating of the other functions.

It is possible to infer the structure of a possible 1980's ATC system from Figure 2.2-1, Baseline System Functional Block Diagram; A possible 1990's system is presented in Figure 3.2-1, Future System Functional Block Diagram. Suppose that the 1980's structure was mapped onto a distributed processing system in some reasonable way. Then the question would be whether that processing system, hardware and software, could be modified so that it would accept a mapping of the 1990's structure.

If the system were built with current technology, one would examine first-order effects, such as processing capacity and memory size requirements, and be able to detect possible problem areas. With the technology assumed for the 9020 replacement system, one can envision a system composed of a large number of microcomputers, each of which is equivalent in processing to an IBM 4341® or a DEC VAX-11/780®. This is the "hardware overkill" assumption, that every node has all the processing and memory capacity that it will ever need.

There are other factors, however, which will affect the feasibility of the structural mapping: communications, control, response, reliability, and recovery, among others. The initial system design presumably accounts for each of these factors in an acceptable fashion; the changes in the design which produce the future System must not be allowed to compromise system performance in those areas.

The key to the performance of a distributed processing system in the ATC application will be the suitability and adaptability of the Interprocessor Communications Subsystem (ICS). Figure 2.2-1 shows two main streams of information, Target/Track Data and Flight Data, flowing through the system. As they flow from Sensors to Display and from Bulk Store or other source to Display, they interact at Association Checking and Flight Plan Aided Tracking. There are also streams of data flowing to the Critical Data and System Performance Data recording functions. Super-imposed on these streams is a constant circulation of messages which flow into the system from controller and remote inputs and leave the system at controller displays and remote outputs. Other message traffic is absorbed or generated by the system itself.

The system diagrammed in Figure 3.2-1 is the same in many respects. However, Automatic Clearance Generation and Terminal Path Control have been added, and Track Data rather than Target Data is supplied by the sensor. These differences will cause a large change in the way Track Data is handled. For instance, in the Baseline System the Track Data supplied to the Conflict Alert and Conflict Resolution functions comes from the individual sector Track processors, while in the Future System, Track Data would come from the DABS sensor through the Coordinate Conversion function in the R processor. Furthermore, the Automatic Clearance Generation and Terminal Path Control functions in the Future System will be users of Track Data, requiring additional data paths not found in the Baseline System.

It can be assumed that the communications system for the 1980's system will be designed both statically and dynamically, i.e., the amount of traffic between processors will be calculated, and links of the proper bandwidth will be provided. Furthermore, the proper message handling software and hardware will be provided at each processor so that transmission delays will be kept within specified limits. Conversion to the 1990's system will require a recalculation of link requirements and a re-evaluation of message handling capabilities in view of new communications needs.

It may be that one or more interprocessor links will be found to have too little capacity for the amount of data to be transferred in the new system. Because of its very nature, one would expect that a distributed processing configuration could be modified or adapted relatively easily to meet the new requirement; a higher-speed channel could be substituted, an additional parallel link could be supplied, or a dedicated direct link could be added.

A more subtle problem, with a less clear solution, occurs when the patterns of the message traffic shifts in such a way that it starts to overload one or more of the nodes. That is, the well-known phenomenon occurs where queue lengths begin to grow and delays to get longer as the capacity of the queue server is approached. Even without overflow, the performance of the system may be severely degraded by the delays which are inherent in the physical as well as logical transfer of messages between processes.

These delays contribute also to possible problems in control and synchronization of processes. Without a close coupling, such as global memory between processors, the control programs in each have no way of synchronizing operations other than by the same communications link by which messages are sent. A breakdown in the message traffic then causes, or at least contributes to, a breakdown in control. With a distributed system the modification of a working system requires much greater care in this area than for a more closely coupled type.

The response exhibited by a system is, of course, dependent on the delays which occur, so that what has already been said applies. For the purpose of control and synchronization, it is enough to know what the delays are; for the purpose of maintaining response time within requirements, it is necessary to be able to limit delays at each step of a chain of processes. One way to make this easier is to reduce the number of steps in the chain by keeping the data near the place where they are used. This, however, leads to maintaining multiple copies of data which are used by a number of distributed functions, which in turn leads to the possibility of synchronization problems. A tradeoff must then be made between ease of access to a distributed data base and ease of control of the integrity of a centralized data base. The modification of the system must include judicious consideration of this tradeoff.

The matters of system reliability (hardware and software), error detection, recovery, and restart will greatly influence the design of the 1980's ATC system; the particular nature of the distributed processing configuration will require special attention. The difficulties that must be faced in producing a system of this type which can detect and recover from faults are being faced [5] but are not well understood at this time. By 1984, our assumed year for design freeze, there should be a better understanding of the questions being raised now, and by the 1990's, there may well be a number of new techniques developed. These techniques would, if available, make the modification and further development of the ATC system in a distributed configuration quite reasonable. Lack of progress in this area during the next few years, however, would tend to make this concept less attractive. In fact, of all aspects to be considered, this matter of reliable operation should be the pacing one, and the one on which any decision to adopt distributed processing should depend.

4.1.2 Increasing Traffic Load

It is axiomatic that the load on the system will increase over the years, and that the system must be planned to accomodate the increase. Though one can assume very large memory sizes and processing capacities, there are limits; the processors and memories are finite. Given that the ATC system is implemented as a distributed system and that additional traffic load must be accomodated, what are the problems, or advantages, to be encountered?

The impact of increased traffic load will be felt over the whole system, though not uniformly, in the requirement for increased processing capability, increased memory and increased communications capacity. This is essentially a hardware problem, assuming the software has been properly parameterized. One obvious problematical characteristic of the distributed system, as defined here, is the fact that memory and processing are not shareable between functions except by functional redesign. That is, excess capacity at processor A which carries out function M cannot easily be used to relieve a shortage at processor B doing function N. The implication is that each component of the system must be sized separately and provided with capacity to meet peak demands plus provision for growth. Furthermore, there is no way to average out uncertainties in the estimates, compensating for an underestimation in one part with a possible overestimation in another.

There are a number of ways in which the increased capabilities could be provided: first, it may be possible to estimate what the future load will be and to size the system correspondingly. Essentially, one would be buying the 1995 capacity in advance. This is the riskiest method as well as being somewhat wasteful of resources.

Secondly, if the hardware/software system is designed properly, the capacity could be expanded by adding modules. Increasing storage capacity this way is relatively easy, but increasing processing capability by adding modules is probably not feasible in a system of this type.

A third way might be to adopt the policy of expanding system capacity continually and regularly by replacing, in a systematic way, some fraction of the system each year with new, faster or larger components. If one-tenth of the system were replaced every year, then at the end of ten years, the whole system would be renewed. The initial system could be designed with capacity to handle traffic at a level predicted for some number of years, say n, in the future. The new hardware being incorporated into the system each year would be sized to handle traffic (n+10) years in the future. At the end of the ten years, the system would be renewed and sized for n years into the future and the cycle could repeat.

This kind of piecemeal expansion would be relatively easy to schedule with a distributed system both from a hardware and a software viewpoint. (See also Section 4.1.3).

4.1.3 Introduction of New Technology

Computer technology will continue to advance after the replacement ATC system has been put into service. The question that remains is will the FAA will find it easy to take advantage of such developments if the ATC system is built as a distributed processing system?

Why would it be advantageous to introduce non-standard equipment into an already well-designed, smoothly operating system? There are three obvious reasons: to improve the performance of the system, to improve the reliability of the system, or to provide a new service with the system. In each case, the new hardware could be a better version of equipment already in use or be a new type of equipment.

At first glance, it seems clear that a distributed system would be most conducive to this kind of equipment substitution or addition because of the inherent modularity of the design. This will be true as long as the proper provisions have been made for this future expansion, and the provisions have been based upon real standards. Unfortunately, requirements tend to develop in ways different from predictions and, as technology develops, standards change to keep pace. Thus, the problems of matching unlike equipment, or of introducing equipment whose use requires significant change to existing hardware or software are not automatically solved.

However, if that kind of problem is discounted as unlikely, or manageable at worst, then the modularity and loose-coupling of the distributed system should make it relatively easy to add the newer technologies from a functional viewpoint.

Consider an extreme case: suppose a new solid-state mass-storage device was offered which incorporated data-base management functions and that the Track Data were to be stored on the device. Access to data on any track could then be in terms of any attribute of the track. The conflict detection program could then not maintain its own data base but could instead inquire of the Track Data manager for all tracks within certain areas. In other words, the course filter part of the algorithm would be implemented in the data management processor as part of the data access software. This would require a rather extensive reworking of the conflict functions, but other functions could continue to operate as before, accessing the data in the usual fashion by track number or whatever, until it was necessary or convenient to change them. Note, however, that a redesign of this type would require careful analysis of the implications to inter-process communications (Section 4.1.1).

4.1.4 Software (Design, Implementation, Maintenance)

As emphasized previously, the structure of the software should match the structure of the hardware. Indeed, the software should be designed first, and the hardware assembled to match it. If the software is designed in a nicely structured way, with loosely-coupled, so-called information-hiding modules, then a distributed processing system of loosely-coupled, independent processors can be assembled to match the software structure.

It can be assumed that the 1980's system will be reasonably designed, implemented, and tested, so that it may exhibit, with a high degree of confidence, those general properties that any viable system should possess. These are (as paraphrased from a slightly different context [6]):

1) Freedom from deadlock,

2) Completeness (the ability to handle all conditions that might arise),

3) Stability (the ability to return to "normal" behavior after an initial or temporary perturbation),

4) Progress (the absence of cyclic behavior where no useful activity takes place),

5) Freedom from overflow, and

6) Termination (arrival at the desired final situation).

An important question is the extent to which the system can be modified to fulfill its new functional requirements as well as the still-relevant older functional requirements, while still maintaining its integrity as represented by the above listed general requirements.

Since the software will be composed of loosely-coupled, single-entry modules, each module can be modified, or even replaced by a different module, as long as the interface requirements, in and out, do not change and all timing constraints are satisfied. This, of course, makes the software maintenance process relatively simple because interactions with other modules are constrained to those through the interface. This is true of many modular systems, but in the distributed processing system it is enforced by the physical structure.

A change in system design, however, is not the same; here it is a matter of changing the inputs and outputs of modules to accomplish new purposes. The changes being suggested for the ATC system are quite extensive, and each one will require changes in many modules. These changes are no more difficult in principle to design, code, and implement in a distributed system than any other type; in fact, the structure discussed above may make it easier than others.

In practice, the ease with which these changes can be coded and implemented will depend to a large degree on the extent and the completeness of the software support available. Ideally, a high order language (HOL) should be provided which would support the distributed system, with built in process-level message protocols, process synchronization primitives, and the like. If the processors of the system are dissimilar, this fact should be transparent to the programmer, who should be able to write a process for, and assign it to, any processor (capable of performing the process) in exactly the same way. One possibility which should be seriously considered is ADA, the new Department of Defense standard language.

Furthermore, there should exist a distributed operating system (OS) which can implement the language constructs in software or hardware to ensure process synchronization and system integrity. The relationship of the HOL and OS to the detection of, and recovery from, hardware and software faults should be well understood.

There are other areas of distributed processing which need investigating [7], but not all of them apply to the particular type of configuration being considered here. Progress is being made in the language and operating system areas [e.g., 8, 9] and it may be assumed that, with the interest being shown in distributed processing, it will continue. Note in particular that the nature of the distributed processing system defined here does not demand an OS which solves the really difficult problem of resource-sharing among processes. In this system, each process is permanently assigned a particular processor rather than being temporarily assigned any processor which happens to be available.

Any assessment of the viability of design concept for the ATC system should place great emphasis on software development and maintenance facilities because this is where the greatest payoff is to be found. In assessing a distributed processing concept, the scrutiny should be even more careful since the development state of software support is at the moment so uncertain. At the very least, the compiler should support all of the processors, as mentioned above; linkers, loaders and run-time facilities should support the configuration in a uniform manner; and debugging and test aids should allow controlled testing of all or part of the system. The whole package should support and enforce structured design and programming practices.

4.2 SPECIFIC ISSUES

In developing the model ATC system used in this analysis, a certain number of assumptions were made over and above the specific provisions of the scenario. One of these, in particular, had a large effect on the form of the Future System, and on the way the Baseline System might evolve into the Future System. This assumption was that track data, rather than target data, would be transmitted from the DABS network to the ATC system. The reason for assuming this is not that it is a likely thing to happen, although the suggestion has been made that this is the way the ATC system should operate. The real reason is that it would be an example of a really major change in the way the Future System would operate as compared to the Baseline System, requiring a major modification for the Baseline System to accomodate the changes, thereby furthering the purpose of this study, to examine the effects of change on the system.

4.2.1 All-DABS Environment

The DABS will provide the ATC system with extremely high-quality surveillance data, as well as a digital data-link not now available. Each of these will have an effect on the functioning of the future en route system.

The surveillance data may be so good that track data smoothed and predicted track positions and calculated velocities and accelerations, produced by the DABS tracker may be of such high quality that it may be used by the ATC system in lieu of similar quantities calculated by the surveillance data user. It is assumed in this analysis that this is the case.

It may also be that the DABS data link may be so useful and be available so inexpensively (because of developments in electronics) that it is very widely or even universally, adopted by users of the ATC system, commercial, military, and general aviation. It is assumed that this is also the case.

A third assumption, based on all DABS environment, is that data is collected in a network of DABS sensors which transmit the data to the en route center through a (logically) single interface. The ATC system receives track data from multiple sites which have among themselves selected and transmitted the best of the available data on each track under surveillance. Track positions are given with respect to the originating sensors, and coordinate conversion takes place in the center processor.

These three assumed characteristics of the DABS environment have a great effect on the form of the Future System and the way it is derived from the Baseline System.

The first and most obvious change from Baseline to Future is in the requirement for External Interface processing. All of the sensor data in coming into the center and all of the data link messages both into and out of the center are added to the Baseline System load in this area. Comparison of the comparative processing numbers for the External Interface Processor (I_e) for the Baseline and Future System show that the processing requirement is increased by a factor of 3 to 4 from the small to the large center. The communications load into the processor from the rest of the system (to be transmitted to the external world) is increased, except for the small center, so that the channel requirement moves up one notch, from medium speed to high speed. The load out of the processor (from the external world) to the rest of the system is also increased so much that for the large center, two high-speed channels are needed to replace a medium-speed channel.

It is an implicit assumption in all of this analysis that the same hardware is to be used in the centers regardless of size. That is, if a processor, memory or communications link is not naturally modular, or if a function cannot be divided among parallel processors, then the unit will be sized to handle the center with the largest requirement.

The message processing function, assigned to the External Interface Processor, can obviously be divided among as many parallel processors as is practicable. In fact, this would probably be done in any implementation for reasons other than the size of the processor, such as redundancy for failure protection. In a distributed processing system the messages received from the outside world would be routed by the I_e processor through the Interprocessor Communication Subsystem addressed to a processor, rather than being addressed to a process and forwarded through some operating system function which would handle the physical addressing. This is an example of the kind of simplicity which is attained through the matching of the functional/software structure and the hardware structure in a distributed system.

All of the sensor data goes in the Future System to a single Radar Processor (R) which now has the tasks of coordinate conversion from sensor to center coordinates and routing of the data to the proper recipients. A comparison of Comparative Processing Numbers (CPNs) shows that the R processor used to process ATCRBS data in the Baseline System is about the right size to handle the tasks in the Future System. If one accepts that a single size processor can be used for small, medium, and large centers in the Baseline System, a size range of about four, then that same size processor would be appropriate for the R processor in the Future System.

The difficulty in changing the major functions of the R processor is, once again, the communications requirements. The amount of data moved into and out of each processor will be increased dramatically; instead of data from a single sensor entering from the external environment and leaving via the ICS, data from all of the sensors must enter and leave via the ICS. If the bandwidth in and out is a problem, then an obvious solution is to replicate the R processor and split the task among them. From a functional point of view this would be easy to do since the processing of each track report is essentially independent of any other. It is also reasonable to do this from the reliability point of view since a failure of one processor would have no effect on the others except to make their share of the load somewhat larger.

The communications aspect also includes the addressing and access schemes. Compare the flow of surveillance data in the two systems. In the Future System, the sensor data are transmitted from the I_e processor and destined for any one of the R processors, a kind of single queue, multiple server discipline not used in the Baseline System. In the next stage, the processed track data are transmitted from the R processor with each message addressed to some subset of the other processors: the messages containing track data for level 1 flights are sent to the Clearance Generation Processor (F_c) and the Tracking Processor (T) at the level 1 workstations, track data for level 2 flights are sent to the Conflict Processor (C) and the T processors at the level 2 workstations, and track data for terminal flights are sent to the Terminal Processor (T_p) and the T processors at the Terminal Workstations. These are either multiple messages, or messages with multiple addresses. In the Baseline System, radar data were sent from each R processor to the appropriate T processor, and track data were sent from the T processors to the C processor.

The point of all this is that the surveillance data distribution scheme is completely changed, both in the pattern of distribution and in the protocol of distribution. The flexibility and/or modularity of the Interprocessor Communications Subsystem will determine the feasibility of modifying the system.

Finally, the use of track data from DABS will relieve the T processors in the workstations of most of their processing load. This should be of no real consequence, although it could be looked upon as "wasted" capability.

4.2.2 Addition of Level 1/Level 2 Service

The scenario for the Future System describes a new type of ATC service, level 1 service, to be provided to part of the airspace in the 1990's. Level 2 service, which is similar to today's positive control, will be provided in the rest of the controlled space, outside of the Terminal Control Areas (discussed in the next section). The new service is described as highly automated, positive control with central, ground-controlled separation and flow management.

It was perceived during the development of the functional diagram of the Future System that the level 1 function, Automatic Clearance Generation, was essentially independent of the parts of the system which provide the level 2 service; Automatic Clearance Generation is shown in Figure 3.2-1 as accepting Flight and Track Data from the respective data bases and producing clearances and commands for transmission to aircraft via the data link. Interaction with the controllers is provided by message input and display output.

It seemed reasonable to add a processor to the system dedicated to the level 1 control function. Track Data would be supplied, as described in Section 4.2.1, from the R processors, while Flight Data would come from the Bulk Flight Data Processor (F_b). Outputs would go to the I_e processor for transmission on the DABS Data Link and to the T processors in the level 1 workstations. It also seemed reasonable to process all flight plans through the route conversion process in the F_b processor, as in the Baseline System, and to transmit the converted data to level 1 processing in F_c, level 2 processing in F_b and the Display Flight Data Processor (F_d), or terminal processing in T_p. The processing and communication pattern for the level 2 service, then, is exactly preserved though reduced somewhat in scope; the level 1 service is an add-on with a minor change in the output of the Route Conversion Function to send level 1 Flight Data to the Automatic Clearance Generation function in the F_c processor.

The addition of Automatic Clearance Generation to the system results in a reduction in the amount of processing to be done in the F_b and C processors despite the increase in traffic from the 80's to the 90's. The extent of this change depended, of course, on the assumption that more than two-thirds of controlled traffic used level 1 service (see Section 3.1.5). Regardless of the reason for the relative loads, it is an example of how the flexibility of the distributed processing configuration can be used to adopt hardware structure to an evolving function/ software structure.

The controller, working the level 1 sectors in the Future System, will operate differently than he would while working a level 2 sector. He will use "management-by-exception", or some other acceptable technique. Whatever the details of procedures to be used, he will require different presentations of information on his displays. If the controller workstation in the Baseline System were properly designed, (i.e., if the system designer had correctly foreseen the requirement), conversion of the workstation from the Baseline to the level 1 capability would be simply a matter of software changes. (This subject is also discussed in the next two sections).

The importance of the ICS to the performance of the system has been stressed repeatedly up to this point, it is not amiss to dwell on it one more time. The controller workstations have two displays, each driven by a display processor, the D-position Display Processor (D_d) and the R-position Display Processor (D_r). The D_r processor is supplied with data to be displayed from an integral associated processor, the T processor. One can envision D_r being connected to the outside world only through the T processor (though this is not necessary, nor necessarily desirable). On the other hand, the D_d processors are all supplied with data to be displayed from a common, F_d processor, which is not part of any of the workstations. The D_d processors are connected to the ICS, then, in order to communicate with F_d. There were two reasons why a single F_d processor was provided in the Baseline System: 1) the duty cycle/response time requirements for the Flight Data processing were of the order of once per five minutes per track, hence a single processor could handle nearly any conceivable load easily, and 2) the inclusion of the ETABS equipment, which had this connectivity in the Baseline System, was to be considered.

One would hope that the ICS which forms the core of the Baseline System would be flexible and modular enough to allow the level 1 workstations to be driven from the F_c processors in the same way that the level 2 workstations are driven by the F_d processor.

4.2.3 Terminal Consolidation

One provision of the scenario for the Future System is that the functions of the twenty to thirty largest terminal areas would be consolidated with the functions of the en route centers within whose jurisdiction they lie. Given the number of centers and the geographical distributions of the large terminals, it is reasonable to suppose that a small center might have no terminals which qualify for consolidation, a typical medium center might have one, and a large center might have two or more. For illustrative purposes, it will be assumed that this is the case.

The Functional Block Diagram of the Future System, Figure 3.2-1, shows that the function, Terminal Path Control (TPC), inputs are Track Data from the Track Data Data Base and Arrival and Departure Flight Plans from the Flight Data Data Base. It has outputs in the form of Advisories and Commands which are sent to the Display Data Data Base for display to the controllers and the Message Processing for output to aircraft via data link if and when approved by the controllers. These are, of course, only the major inputs and outputs; for there are numerous control, query, and response messages going back and forth between the controllers and the Terminal Path Control function.

There is little, if any, interaction between the TPC function and the en route functions. This is not surprising since the terminals are controlled now by functions whose only interaction is via the set of interfacility messages (and controller inputs transmitted by voice link). In the Future System, the same kind of interaction will take place via an analogous set of messages; the real new interaction is between the TPC function and Track Data and Flight Data Data Bases, which are now common to the en route and terminal functions.

The implementation of the TPC processing in the Future System may be seen in Figure 3.3-1. Since terminal processing is so nearly independent of the other functions, it makes sense to assign it to a separate processor, operating as independently as possible. Furthermore, since the terminal areas are geographically separated, even when within the same center area, they are functionally almost completely independent of one another, so each one could be assigned its own processor, operating independently of the others.

The terminal controllers, like the level 1 and 2 controllers, can benefit from the development of data presentations which are specialized to their own particular needs. If the controller workstations are properly configured, these special displays can be provided by changes in the software (or firmware) in the T, D_r and D_d processors. Note that, as with the level 1 workstations, data to be displayed at the D-positions through the D_d processors will come from a different source than in the Baseline System, in this case, from the T_p processor rather than F_d. Again, the connecting of the ICS and its flexibility and modularity will be crucial.

4.2.4 Sizing and Capacity

Ideally, the distributed processing system would consist of a set of similar sized tasks with clearly defined, moderate, inter-task communications requirements. These tasks could then be assigned to a set of identical processors, each capable of performing one of the tasks; and the processors could be connected by a communications system, capable of handling the interprocessor message load.

Under the "hardware overkill" hypothesis, the standard processor would be chosen to be so capable and with so much memory that no indivisible task would be too big for it. If, then, each processor were connected to every other by a very high bandwidth link, the hardware aspects of the design problems would simply disappear. Even if this turns out to be a valid procedure, investigating the processing requirements of the ATC would be worthwhile, if only to understand its operation better.

The numbers used in the computations of the processing requirements for the Baseline System and the Future System were based on estimates of peak traffic loads in 1985 and 1995. The formulas were based on estimates of relative computational complexity of the various functions performed by the system. The final outputs of Comparitive Processing Numbers and Communications Channel Requirements for the Baseline and Future Systems are given in Tables 2.3-2, 2.3-3, 3.3-2 and 3.3-3. They are not meant to be used to select a processor for a particular task; obviously they are not suited to that. They are to be used to compare 1) the ranges of requirements within a center and among small, medium, and large centers, and to compare 2) the changes in requirements in going from the Baseline to the Future System.

There are three ways in which the variation in CPNs may be viewed: within a center, from center-to-center and across time, from Baseline to Future System. The following observations may be made:

a) The widest variation in Comparative Processing Number occurs when comparing numbers for different processors within a center of a given size and a given timeframe. The ratios of the largest CPN to the smallest range from nearly 50 to over 150. There is a wide variation in the communications requirements of various processors within a given center as well.

b) The variation of CPNs within either the Baseline or Future System in going from a small to a large center for the same processor is much smaller. In both systems, the ratio of the CPN for any one processor in a large center to the CPN of the same processor in a small center ranges from 1 to less than 4.5 in both the Baseline and the Future Systems. The communications requirements show the same kind of moderate increase, either no change in channel type or a move to the next larger type.

c) The ratios between CPNs of processors of the same kind at similarly sized centers in going from the Baseline to the Future Systems show no such trend; some of them are less than one third and some greater than three. The communications channel requirements also fail to show a trend; some of them increase and others decrease.

The within center variation in the CPN is obviously a function of the design of the system, in particular, the partitioning of the functions and their assignment to the various processors. The lower bound on the size of the most capable processor is given by the size of the largest indivisible task; the size of the least capable processor might approach zero. In the Baseline System, the largest processors are the C and T processors, the former because it has a large number of computations to do in a moderate amount of time, and the latter because it has a modest number of computations in a very short time.

If the D_d processor is dismissed as a trivial driver of an alphanumeric display, then the ratio of processing requirements within each Baseline center is about 15. If all processors, except perhaps D_d were identical, then more than half of them would be oversized by a factor of four or more, not including factors for peaking and expansion. (That is, for comparison purposes only, the processing requirements have been considered. In order to actually size the processors, one would have to account for the fact that the processors should run at less than 50% of capacity in order to be able to handle peaks in non-uniform demands. One would also want to provide additional capacity to allow for increase in traffic over the life of the system. Since these factors would be applied to all of the processors, they may be, and have been, suppressed in this study).

Furthermore, if identical processors are to be used in all of the centers, large and small, then an additional factor of two would be introduced at the small centers. Half of the processors in the small center would have an order of magnitude more capacity than required.

Suppose then that this imbalance was acceptable, that the hardware costs could be shown to be such a small part of the life cycle costs that the advantages of having a single type of processor far outweigh the possible extra cost. How much change will be necessary in going from the Baseline to the Future System? A comparison of the CPNs of the two systems shows that there is surprisingly little increase given and that the traffic load on which the calculations were based is larger. As a matter of fact, many processors have much lower CPNs. The answer, of course, is that the processing load has been redistributed. Tracking has been moved to the DABS processors, processing of level 1 traffic has been concentrated in the new Automatic Clearance Delivery processors, and sensor data processing has been moved to the External Interface processor. New processing load in the form of Terminal Path Control is assigned to new T_p processors. There seems to be no problem of processing power. Of the three places in the Future System which have large requirements, two, F_c and T_p are new processors which could be implemented with new technology in the 1990's, while the third, I_e, is assigned a function that is easily divided among a number of processors.

As far as interprocessor communications is concerned, a simple summation of the peak rates into or out of all of the processors of the largest center in the Future System gives a maximum required capacity of approximately 100K bytes/sec. In other words, the ATC system is not particularly demanding as far as interprocessor communications rate is concerned, although other factors, such as synchronization and reliability remain as initial design issues.

In summary, the distributed processing configuration studied here seems 1) to be a reasonably flexible way of providing the processing capability in an ATC system, and 2) to be a system which can be easily modified to meet new requirements.

4.3 SUMMARY AND CONCLUSIONS

This study attempted to find the answer to the question, "What will be the effect in the 1990's of having chosen a distributed processing concept to replace the current en route ATC computers?" Subject to certain qualifications and caveats, the answer determined here is that the distributed processing concept is ideally suited for the ATC system of the 1980's, and, when the system is to be modified in the 1990's, it will provide a reasonable basis on which to build a new system.

The following statements summarize the conclusions drawn from this study:

1) The structure of the hardware of a system should be matched closely to the structure of the software of the system, which should have been matched to the structure of the functional requirements of the system. A distributed processing configuration may be designed which matches closely the structure of the software of the ATC system. Furthermore, the configuration may be easily modified to match changes in the software structure as functional requirements change.

2) The state of support software for distributed systems is at present, somewhat uncertain, but there is a great deal of research underway in such areas as high-order languages for distributed processing and distributed operating systems.

3) Many ATC system changes will consist of new, virtually independent, functions to be added to the system. The form of the distributed processing configuration will make it especially convenient to add functions of this type by implementing them on new independent processors.

4) While memory and processors, already part of the system, might be difficult to reassign to new functions in some cases because of their size, new components of higher capacity and/or new technology could be substituted or added. A systematic program of upgrading the system for added capacity could be worked out, replacing 1/nth of the system each year for n years.

5) A standard controller workstation could be developed which would contain displays, display drivers, input devices, and enough processing and memory capacity to make it capable of serving a variety of controller positions.

6) The variations in the sizes of processors needed in a distributed ATC system seem to be caused more by design decisions in the assignment of functions to processors than by load variations from center to center or with time. The flexibility of the distributed concept should make relatively easy the balancing of the system load as new requirements cause the system to be modified.

7) The real key to the performance of a distributed processing system is the capability of the Interprocessor Communications Subsystem. Although bandwidth requirements will be quite modest, the

synchronization of the component processes and the attainment of various system response time requirements will depend on how well the ICS is conceived and implemented.

8) The feasibility of any particular system modification will depend on the flexibility and modularity of the ICS and on whether it can be modified to handle the new pattern of message traffic. If the addressing/access scheme is not suitable, a serious problem could arise in making the modification.

9) The dynamic behavior of the modified system should be of concern; there is no certainty that a well behaved system will retain its good qualities when modified.

10) The reliability and error tolerance of distributed systems is not yet understood. Many ad hoc solutions exist, but this is an area in which much work needs to be done.

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APPENDIX A

SCENARIO FOR 1995

A.1 INTRODUCTION

FAA is in the process of establishing and analyzing the ATC computer requirements for the 1980's and 1990's. It is evident the the en route computers need replacement if the projected traffic and functional growth is to be accommodated. While the transition and acquisition strategies for a new system have not been selected, it is reasonable to assume that deployment of a new en route computer will begin in the late 1980's. That computer system, when first installed, will perform the functions being performed today; e.g., DARC, ETABS, and those new functions that are currently being developed for the 9020® computers. This new baseline ARTCC computer system, once in place, will provide the vehicle for evolution to the much more highly automated ATC system.

In FY-79 and FY-80 the Transportation Systems Center (TSC) is examining how well different computer architectures can handle such ATC evolution. The approach taken was to map a Baseline System onto different architectures and to analyze the extension of each of these mappings to a fairly optimistic future (1995) scenario.

The following scenario was prepared jointly by the Office of Systems Engineering Management (OSEM) and TSC for this analysis. It incorporates many of the ideas discussed within the AED and ATF complexes, but should, in no way, be interpreted as a statement of FAA long term requirements.

This strawman does reflect the general direction in which the ATC system is expected to evolve and thus is well suited to the TSC analysis.

The scenario represents a significant functional step forward from the baseline rather than a realistic projection for the specific year 1995. Furthermore, there is no implication that the scenario is to be implemented as a single upgrade from the baseline.

A.2 AIRSPACE STRUCTURE

A.2.1 Levels of Service

There will be five levels of en route ATC service and/or airspace regulation. Note that ATC is imposed only on the top two levels and that surveillance is maintained only over the top three.

Level 1 Highly automated, positive control; central, ground-controlled separation and flow management; direct routing allowed.

Level 2 Similar to current operations --computer-aided, manual separation and flow management; positive control; direct routing allowed.

Level 3 Outside of control area but within the DABS surveillance; ATARS provides separation.

Level 4 Avionics required (transponder, BCAS).

Level 5 No services, no requirements.

A.2.2 Description of Structure

The airspace will be structured so that positive control will be exerted where traffic is heavy, while maximum freedom will be allowed where traffic is light. Specifically:

a. Level 1 service will be supplied in all airspace over 18,000 ft and airspace over 12,000 ft within 60 miles of designated terminals.

b. Level 2 service will be supplied in the remaining airspace over 12,000 ft and en route airspace below 12,000 ft that is within 30 miles of the designated terminals.

c. Level 3 service will be supplied over the remaining en route area between 5,000 ft and 12,000 ft where there is significant traffic.

d. Level 4 and 5 en route service will be supplied elsewhere.

A.2.3 Terminal Areas

Radar control (arrival, departure, and transition) for all terminal radar facilities within the 20-30 largest terminal regions will be integrated into the en route facility within whose jurisdiction the terminal region lies. Other terminal radar facilities will remain relatively unchanged. The basic terminal control philosophy in these integrated facilities will not change. Pilots will notice a difference, because integration of control will permit a suitable sectorization within the affected regions.

A.3 SURVEILLANCE AND COMMUNICATIONS

A.3.1 Aircraft Surveillance and Data Dissemination

A.3.1.1 En Route Surveillance - All secondary radars are DABS with 4 to 6-second update rates, and all areas under levels 1, 2, and 3 will be covered.

A.3.1.2 Terminal Surveillance - There will be some terminal primary radar. All terminal secondary radars will be DABS.

A.3.1.3 General

All surveillance systems will be netted with adjacent sensor sites backing up one another. Each ATC facility will be connected to this surveillance network and will, therefore, be able to obtain surveillance information from any sensor. The DABS sensors, through the surveillance network, will assure coverage continuity. Each sensor site will be responsible for a fixed geographic region and will provide target reports for distribution over the network for all aircraft in the region. The sites will, when necessary, make use of information from adjacent centers to improve the quality of the target reports. Target reports will contain unique DABS ID codes, thereby eliminating the need for the target/track correlation function at the user ATC facilities (except for primary returns with no beacon information). Slant-range correction and $R\theta$/XY coordinate conversion will be performed by the DABS site processors. Target reports will be in the sensor coordinate system.

A.3.2 Weather Surveillance and Data Dissemination

FAA will get weather data from the National Weather Service (NWS) network in the form of contours and flow patterns. This will be augmented by winds aloft data provided by aircraft via the data link. There will be a weather controller (meteorologist) at each center who reviews the information and annotates it. The information will be distributed to the controller (selectively) and to AERA. In the high density terminal areas, FAA radars will be modified to have Doppler processing systems to provide data to the ATC computers.

A.3.3 Avionics

A.3.3.1 General - The avionics for 1995 will be configured to operate with the DABS and its associated Data Link (DL). The avionics is to provide both uplink reception and downlink transmission of surveillance and communication messages in a digital Time Division Multiple Access (TDMA) format as described in the DABS Engineering Requirements (ER) report. The transition capacity of the data link is structured around the 600 DABS periods (of 4.2 ms) per scan, resulting in 16,800 transactions of about 170 bits each (2.8 million bits) per scan.*

A.3.3.2 Services Provided (Future) - Surveillance is provided to all aircraft. ATC services (tactical) are provided to Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) A/C (about 45% of fleet). DL requirement is about 0.03 Comm-A message (5 bits) per A/C per scan.

ATARS and Cockpit Display Traffic Indicator (CDTI) are provided to an undetermined number of IFR and other A/C (20-40% of fleet). DL requirement is between 1-14 messages (170-2700 bits) per A/C per scan.

Real-time automatic weather delivery is provided to all aircraft. DL requirement is about .03 Comm-A message (5 bits) per A/C per scan.

Record messages (less time critical, e.g. flight plan revision, ATIS, weather) are provided to all aircraft. The DL requirement is 0.10 Comm-A message (17 bits) per GA A/C and 0.42 Comm-A message (71 bits) per air carrier A/C per scan.

Ground data is uplinked to all aircraft. The DL requirement is 0.5 Comm-A message (84 bits) per A/C per scan.

Downlink of airborne data is provided from all aircraft. The DL requirement is the same as for uplink (84 bits).

A.3.3.3 Adequacy and Projected Performance - Provision of services indicated represents a demand equivalent of four transactions (640 bits) per aircraft per scan (LAX 1995 model). Accounting for an estimated round reliability of 90% results in a requirement for 4.4 transactions per A/C per scan. This 4.4 transactions per A/C demand is about 80% of the capacity (5.4) for an eight sensor configuration operating in the LA basin 1995 model.

The estimates may be conservatively high since DABS round reliability should be much better than 90%. Not all A/C in 1995 may be equipped with DABS or with cockpit devices which allow the use of DL services. Traffic growth may be less than the LA basin 1995 model estimates.

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*If the DABS sensor services 400 aircraft (a/c), it has a theoretical capacity of 42 Comm-A transactions per aircraft per scan. Under projected conditions, (i.e. Los Angeles International Airport (LAX) 1995 model), this may be reduced to between 5-10 Comm-A transactions per A/C per scan because of the distribution, or bunching of A/C in the sensor beam width. The most severe azimuth bunching would be 14 aircraft in a 2.4 degree beam width, all within 48 n. mi. of the sensor serving them.

The DABS Data Link can handle all services postulated, while limiting interference with ATCRBS to an acceptable level. Much more use of ATC automation services than indicated could be provided with little impact on capacity.

A.4 CONTROL STRUCTURE

A.4.1 Facility Hierarchy

There will be a single, central traffic management facility, similar to the present Central Flow Control Facility, which will exchange control information with the en route centers. There will be 20 en route centers as there are now, but the number of terminal approach/departure control facilities will be drastically reduced by the absorption of the busiest 20-30 into the corresponding en route facilities. Tower facilities will remain as at present.

A.4.1.1 Central Facility - The central facility will communicate with all of the centers via a common data communications network.

A.4.1.2 En Route Centers - Each of the centers will be able to communicate with all others via the common data network (although they would normally communicate only with adjacent centers). The centers will be alike functionally, differing only with respect to capacity.

The consolidation of terminal and en route control, where it is accomplished, will be complete; all approach and departure control within a terminal area will be included, and a common radar data base will be used for both en route and terminal control.

A.4.1.3 Terminal Facilities - Those terminal facilities not absorbed into the en route centers will continue to operate much as they do now. Terminal facilities will communicate with en route centers via the common data network.

A.4.1.4 Tower Facilities - Within the integrated terminal regions:

a. Towers will be supplied with remotely driven displays using digital information from the en route centers.

b. Tower automation systems will exchange information with the centers via the common data communications network.

A.4.2 Integrated Flow Management

There will be a three-level integrated flow management system incorporating Central Flow Control, En Route Flow Control, and Terminal Flow Control.

A.4.2.1 Central Flow Control - The Central Flow Control function will manage the flow of traffic on a nationwide basis, attempting to eliminate airborne delays for flights into high-density terminals.

Central Flow Control will be connected to the ARTCCs so that it can receive messages concerning current operations (actual departure, flight plan amendments, etc.) and transmit flow control messages (departure delays, etc.).

A.4.2.2 En Route Flow Control - The En Route Flow Control Function will attempt to minimize airborne delays and inefficient flight profiles, such as low-altitude holding, by speed and path control over the center area and, over the areas of adjacent centers (with their cooperation).

Information gathered in the terminal areas (acceptance rates, weather) will be collected in the ARTCC for use there and for transmittal to the Central Facility.

This function, in coordination with the AERA function, will act to restructure the traffic flow over the center area when required by weather changes or changes in airport capacities.

A.4.2.3 Terminal Flow Control - Terminal Flow Control will be composed of two parts:

a. The planning function and the flow function (see also, Section A.4.3.4).

b. The planning function will derive information about the operation of the terminal and supply it to the central and en route flow control functions as needed.

c. The flow function will act as an automatic metering and spacing mechanism to ensure the arrival of traffic at the runway threshold at the correct times.

A.4.3 New Functions

A.4.3.1 AERA and Traffic Management - The present separate functions and/or concepts of conflict detection and resolution, MSAW, en route metering, terminal metering and spacing, flight plan probe, and AERA will be integrated into a single functional subsystem which will generate conflict free profiles and clearances for traffic operating in positive control airspace.

This function will hand off traffic either to the local controller at the busy terminals, or to the approach controller at the terminals which retain approach/departure control.

A.4.3.2 FSS Flight Plan Preprocessing - Flight plans submitted through FSS will be transmitted to the ARTCC (over a direct data line or data communications network). Format, syntax, and legality checks will already have been performed.

A.4.3.3 Weather Services - Weather information will be available to the system from two sources: the NWS computer and from Doppler weather radars (see Section A.3.2).

The en route computer complex will process both kinds of weather information, making them available to both automated and non-automated parts of the system. That is, data such as winds aloft and contours of severe weather will be available to the AERA and Integrated Flow Management function (see Section A.4.3.1) for path prediction and hazard warnings. Weather contours and selectable data read-outs will be available as well on the displays of the ATC Specialists.

A.4.3.4 Terminal Functions - Approach and departure control functions for the 20-30 busiest terminals areas will be integrated into the en route system. Control functions in these terminal areas will be similar to today's with the addition of automated metering and spacing (see Section A.4.3.1). These functions will be combined with the en route functions to produce a unified control system (as opposed to being a mere translation of the present terminal system onto the en route computer.) Since the system will be integrated, a common radar data base will be available for use throughout the center's area, including the terminal areas. The Terminal Information Processing System (TIPS) functions will be fully supported, including services in the major and remote satellite towers.

A.4.4 Backups

Automated functions in the en route system will be fully backed up at other centers. A failed center will be divided geographically so that each adjacent center can take over responsibility for a portion of the failed center's airspace. The specific mechanism for carrying out the back-up function has not yet been determined.

(For purposes of studying the capability for evolution of different replacement computer architectures, the above characterization is adequate to account for additional communication loads, processing requirements, and memory requirements.)

A.4.5 Controller/Automation Interface

Clearly the role of the ATC specialist will change considerably as automated decision making is introduced. As a result, the physical man/machine interface and the type data and data flow between man and machine will likely be different from what it is today. Because of the great uncertainty about what this interface should be, no postulation will be made in this scenario. For purposes of the analysis, it will be assumed that automated decision making will be introduced.

A.5 LOADING

Loading figures for representative centers (small, medium, and large for 1975 have been obtained from published FAA sources (Ref. 1, 2). Estimates for 1985 have been obtained from an additional source (Ref. 3). These numbers have been used to develop sizing estimates for the so-called *"Baseline" System*.

It will be assumed that traffic will increase during the 1985-1995 period linearly at the same rate as for 1985-1990 given in Reference 3.

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APPENDIX B

METHODOLOGY FOR ESTIMATING ARTCC LOADING DATA

FOR FORECAST YEARS 1985 AND 1995

B.1 INTRODUCTION

The basic objective in developing center loading data was to estimate the range of loads that the 1985 Baseline CCC must be designed to operate under and the increased loads that the enhanced Baseline CCC can be expected to encounter in 1995. 1975 was chosen as the base year from which these projections were made because of the availability of historical data and because it seemed reasonable to work with 10-year intervals preceding and following the 1985 Baseline System date. Loads representative of high, medium, and low density en route centers were developed on the basis of the rankings of 20 Continental United States (CONUS) centers with respect to total IFR flights handled annually. Chicago, Memphis, and Denver were the centers that proved to be representative of high, medium, and low density, respectively.

This appendix first describes how the available 1975 air traffic activity data was analyzed to develop proportionalities, peaking factors, peak instantaneous aircraft, and flight plan counts. It then describes how the latter were used to review FAA aviation forecasts and thereby estimate loading data for 1985 and 1995.

B.2 ANALYSIS OF 1975 AIR TRAFFIC ACTIVITY DATA

B.2.1 Flights Handled

The process of analyzing 1975 data begins with an examination of Table B-1. The first step was to deduce from Table B-1 the non-CONUS center "departures" and "overs" from the totals as shown below.

TABLE B-1 RANK ORDER OF FAA ARTCCs BY IFR AIRCRAFT HANDLED AND BY IFR DEPARTURES AND OVERS: FISCAL YEAR 1975

CENTER	AIRCRAFT HANDLED		DEPARTURE		OVER	
	RANK	NUMBER	RANK	NUMBER	RANK	NUMBER
Total	--	23,585,999	--	9,258,198	--	5,069,603
Chicago, Illinois ..	1	1,724,441	1	757,296	13	209,849
Cleveland, Ohio	2	1,655,816	3	606,716	1	442,384
New York, New York .	3	1,533,078	2	649,095	10	234,888
Atlanta, Georgia ...	4	1,383,014	4	562,586	7	257,842
Washington, D.C. ...	5	1,378,370	6	534,795	5	308,780
Indanapolis, Ind. ..	6	1,316,443	9	445,977	3	424,489
Fort Worth, Texas ..	7	1,305,953	5	546,726	12	212,501
Memphis, Tenn.	8	1,138,534	12	404,315	4	329,904
Los Angeles, Calif..	9	1,092,133	7	507,793	21	76,547
Jacksonville, Calif.	10	1,089,248	16	328,584	2	432,080
Kansas City, Mo. ...	11	1,079,663	11	411,301	8	257,061
Houston, Texas	12	1,046,545	8	455,481	17	135,583
Miami, Florida	13	1,024,853	10	430,270	16	164,313
Minneapolis, Minn. .	14	1,011,297	14	391,147	11	229,003
Boston, Mass.	15	917,781	15	368,406	14	180,969
Oakland, Calif.	16	890,893	13	392,834	18	105,225
Albuquerque, N. Mex.	17	875,362	18	311,105	9	253,152
Denver, Colorado ...	18	696,778	19	217,390	6	261,998
Seattle, Wash.	19	670,501	17	317,792	24	34,917
Salt Lake City, Utah	20	448,918	21	136,984	15	174,950
Honolulu, Hawaii ...	21	386,585	20	150,923	20	84,739
Anchorage, Alaska ..	22	279,714	22	121,665	23	36,384
San Juan, P.R.	23	251,230	23	76,939	19	97,352
Great Falls, Mont. .	24	193,999	24	67,210	22	59,579
Balboa, Canal Zone .	25	79,861	25	24,045	25	31,771
Guam	26	71,884	26	21,326	26	29,232
Fairbanks, Alaska ..	27	43,105	27	19,497	27	4,111

Source: "FAA Air Traffic Activity, Fiscal Year 1975" U.S. DOT FAA, Information and Statistics Division, Office of Management Systems.

Non-CONUS Center	Aircraft Handled	Departures	Overs
Honolulu	386,585	150,923	84,739
Anchorage	279,714	121,665	36,384
San Juan	251,230	76,939	97,352
Balboa	79,861	24,045	31,771
Guam	71,884	21,326	29,232
Fairbanks	43,105	19,497	4,111
	1,112,379	414,395	283,589
Percent of Total	4.7	4.5	5.6

The numbers for the now extinct Great Falls center were added to those of the Salt Lake City center (which subsequently absorbed it a year or so later), and a new table, Table B-2, was prepared with Conus center numbers only. Each center's percentage of departures and overs was calculated; annual counts of flights, departures, and overs were converted to average day counts by dividing by 365.

Peak day 1975 counts were then obtained from "En Route IFR Air Traffic Survey Peak Day - Fiscal Year 1975," published by the FAA's Office of Management Systems. The busy hour and total departures on the peak day for each center were extracted from the survey and entered in Table B-2 along with their average day counterparts. For each center, the peaking factors for peak day were derived by calculating the ratio of total departures-peak day to total departures-average day; the peaking factor for busy hour-peak day was obtained by calculating the ratio of busy hour departures-peak day to total departures-peak day. The use of these factors is described later during the procedure for estimating 1985 and 1995 data.

B.2.2 Flight Plans Filed

Since "FAA Air Traffic Activity Fiscal Year 1975" provides a breakout (Table 15) of flight plans originating from flight service stations grouped by state rather than by center, it was necessary to reorganize the data by assigning flight service stations to their associated centers. Table B-3 contains the data resulting from this effort. The number of flight plans on an average day was obtained by dividing by 365. Busy hour-average day, peak day, and busy hour-peak day were obtained by multiplying average day counts by the busy hour and peak day factors.

TABLE B-2 1975 AIR TRAFFIC ACTIVITY DATA AT CONUS CENTERS

CENTER	ANNUAL FLIGHTS	FLIGHTS ON AVERAGE DAY	ANNUAL DEPARTURES: PERCENT OF TOTAL DEP.	ANNUAL DEPARTURES: DEPARTURES	DEPARTURES ON AVERAGE DAY	ANNUAL OVERFLIGHTS: PERCENT OF TOTAL OVERS	ANNUAL OVERFLIGHTS: OVERFLIGHTS	OVERFLIGHTS ON AVERAGE DAY	BUSY HOUR DEPARTURES PEAK DAY	TOTAL DEPARTURES PEAK DAY	BUSY HOUR PEAK DAY FACTOR	PEAK DAY FACTOR
Chicago	1,724,441	4,725	8.6	757,296	2,075	4.4	209,849	575	220	3,069	0.071	1.479
Cleveland	1,655,816	4,536	6.9	606,716	1,662	9.2	442,384	1,212	211	2,418	0.087	1.455
New York	1,533,078	4,200	7.3	649,095	1,778	5.0	234,888	544	173	2,365	0.073	1.33
Atlanta	1,383,014	3,789	6.4	562,586	1,541	5.4	257,842	706	183	2,147	0.085	1.393
Washington	1,378,370	3,776	6.1	534,795	1,465	6.4	308,780	846	157	1,948	0.08	1.33
Indianapolis	1,316,443	3,607	5.0	445,977	1,222	8.8	424,489	1,163	140	1,770	0.079	1.448
Ft. Worth	1,305,953	3,578	6.2	546,726	1,498	4.4	212,501	582	177	2,219	0.08	1.481
Memphis	1,138,534	3,119	4.6	404,315	1,108	6.9	329,904	904	130	1,618	0.08	1.46
Los Angeles	1,092,133	2,992	5.7	507,793	1,391	1.6	76,547	210	164	1,930	0.085	1.387
Jacksonville	1,089,248	2,984	3.7	328,584	900	9.0	432,080	1,184	151	1,345	0.112	1.494
Kansas City	1,079,663	2,958	4.7	411,301	1,127	5.4	257,061	704	139	1,795	0.077	1.592
Houston	1,046,545	2,867	5.2	455,481	1,248	2.8	135,583	372	172	1,992	0.086	1.596
Miami	1,024,853	2,808	4.9	430,270	1,179	3.4	164,313	450	137	1,744	0.079	1.479
Minneapolis	1,011,297	2,771	4.4	391,147	1,072	4.8	229,003	627	129	1,728	0.975	1.612
Boston	917,781	2,515	4.2	368,406	1,009	3.8	180,969	496	123	1,511	0.081	1.498
Oakland	890,893	2,441	4.4	392,834	1,076	2.2	105,225	288	122	1,398	0.087	1.3
Albuquerque	875,362	2,398	3.5	311,105	852	5.3	253,152	694	132	1,445	0.091	1.7
Denver	696,778	1,909	2.5	217,390	596	5.5	261,998	718	75	787	0.095	1.32
Seattle	670,501	1,837	3.6	317,792	871	0.7	34,917	96	106	1,403	0.076	1.61
Salt Lake	642,917	1,761	2.3	204,194	559	4.9	234,529	643	84	919	0.091	1.64
	22,473,620			8,843,803			4,786,014					

TABLE B-3 FLIGHT PLANS ORIGINATING AT FLIGHT SERVICE STATIONS IN 1975

CENTER	ANNUAL FLIGHT PLANS FROM FSSs	AVERAGE DAY	BUSY HOUR AVERAGE DAY	PEAK DAY	BUSY HOUR PEAK DAY
Chicago	277,647	761	54	1,126	80
Cleveland	547,260	1,499	130	2,181	190
New York	546,248	1,497	109	1,991	145
Atlanta	273,811	750	64	1,045	89
Washington, D.C.	287,821	789	63	1,049	84
Indianapolis	308,777	846	67	1,225	97
Ft. Worth	270,707	742	59	1,099	88
Memphis	323,141	885	71	1,292	103
Los Angeles	219,335	601	51	836	71
Jacksonville	260,087	713	80	1,065	119
Kansas City	279,138	765	59	1,218	94
Houston	378,642	1,037	89	1,655	142
Miami	224,692	616	49	911	72
Minneapolis	212,137	581	44	937	70
Boston	318,875	874	71	1,309	106
Oakland	129,175	354	31	460	40
Albuquerque	165,394	453	41	770	70
Denver	64,323	176	17	232	22
Seattle	128,208	351	27	565	43
Salt Lake City	71,362	196	16	329	33
	5,286,770				

In order to obtain a measure of how many flight plans are filed through the centers, the annual number of flight plans filed through the FSS were deducted from the annual departures from each center - the assumption being that every departure constitutes a flight plan. These numbers are presented in Table B-4 again with a conversion to average day. Table B-4 also includes the number of annual flights per center and the ratio of flight plans filed through each center to annual flights. This factor is used later in the derivation of 1985 and 1995 data.

B.3 PROCEDURE FOR ESTIMATING 1985 ACTIVITY DATA FOR REPRESENTATIVE HIGH, MEDIUM, AND LOW DENSITY CENTERS

B.3.1 Estimation of Traffic Shares in 1985

The first step in developing 1985 activity data representative of high (Chicago), medium (Memphis), and low (Denver) density centers was to obtain the 1985 forecast figures of 15.5 million departures and 7.4 million overs. (See Table B-5). The non-CONUS shares, 4.5% of departures and 5.6% of overs in 1975, as derived in Section B.2.1, were then deducted to obtain the following 1985 totals, representative of the 20 CONUS centers:

Departures	14.7	
Overs	6.9	
Flights	36.3	(twice the departures plus the overs).

Separate shares of the above 1985 totals for each of the three subject centers were obtained by using the 1975 percentages included in Table B-2 for departures and overs. These figures are listed below.

CENTER	DEPARTURES	OVERS	FLIGHTS
Chicago	1,264,200 (8.6%)	303,600 (4.4%)	2,832,000
Memphis	676,200 (4.6%)	476,100 (6.9%)	1,828,500
Denver	367,500 (2.5%)	379,500 (5.5%)	1,114,500

Using the counts for departures, overs, and flights developed above, 1985 air activity data for the three centers was calculated and compiled in Table B-6. The peak day and busy hour-peak day factors were those generated from the 1975 activity data. Table B-7 contains busy hour flights and flight plans for average and peak days. Refer to Table B-8 for the equations used to generate the data in both Tables B-6 and B-7.

B.4 ESTIMATES OF 1995 ACTIVITY DATA

B.4.1 Derivation of 1995 Traffic Shares

TABLE B-4 FLIGHT PLAN FILED THROUGH CENTERS IN 1975

CENTER	ANNUAL DEPARTURES (A)	FLIGHT PLANS FROM FSSs (B)	NUMBER (A-B)	FLIGHT PLANS FILED THROUGH CENTERS				
				PERCENT OF ANNUAL FLIGHTS	AVERAGE DAY	BUSY HOUR AVERAGE DAY	PEAK DAY	BUSY HOUR PEAK DAY
Chicago	757,296	277,647	479,649	27.8	1,314	93	1,943	138
Cleveland	606,716	547,260	59,456	3.6	163	12	237	21
New York	649,095	546,248	102,847	6.7	282	24	393	33
Atlanta	562,586	273,811	288,775	20.9	791	67	1,102	94
Washington, D.C.	534,795	287,821	246,974	17.9	677	54	900	72
Indianapolis	445,977	308,777	137,200	10.4	376	30	544	43
Ft. Worth	546,726	270,707	276,019	21.1	756	60	1,120	90
Memphis	404,315	323,141	81,174	7.1	222	18	325	26
Los Angeles	507,793	219,335	288,458	26.4	790	67	1,096	93
Jacksonville	328,584	260,087	68,497	6.3	188	21	280	31
Kansas City	411,301	279,138	132,163	12.2	363	28	578	45
Houston	455,481	378,642	76,839	7.3	211	18	336	29
Miami	430,270	224,692	205,578	20.1	563	44	833	66
Minneapolis	391,147	212,137	179,010	17.7	490	37	790	59
Boston	368,406	318,875	49,531	5.4	136	11	204	17
Oakland	392,834	129,175	263,659	5.6	722	63	939	82
Albuquerque	311,105	165,394	145,711	16.6	399	36	678	62
Denver	217,390	64,323	153,067	22.0	419	40	533	53
Seattle	317,792	128,208	189,584	28.3	519	39	836	64
Salt Lake	136,984	71,362	65,622	14.6	180	18	302	30

TABLE B-5. IFR AIRCRAFT HANDLED FAA AIR ROUTE TRAFFIC CONTROL CENTERS

(In millions)

Fiscal Year	Total: Aircraft Handled	Total: IFR Departures	Total: Overs	Aircraft Handled: Air Carrier	Aircraft Handled: Air Taxi	Aircraft Handled: General Aviation	Aircraft Handled: Military
Historical*							
1973	22.8	8.9	5.1	12.6	.9	4.6	4.7
1974	22.9	9.0	4.9	12.4	1.1	5.1	4.3
1975	23.6	9.3	5.1	12.4	1.3	5.5	4.4
1976	23.9	9.4	5.1	12.4	1.4	6.0	4.2
1977	26.0	10.2	5.6	13.0	1.6	6.9	4.5
1978E	28.1	11.1	5.9	13.6	1.9	8.2	4.4
Forecast							
1979	29.7	11.8	6.1	14.1	2.3	8.9	4.4
1980	31.1	12.4	6.3	14.3	2.7	9.7	4.4
1981	32.5	13.0	6.5	14.6	2.9	10.6	4.4
1982	34.0	13.6	6.8	14.9	3.3	11.4	4.4
1983	35.4	14.2	7.0	15.2	3.7	12.1	4.4
1984	36.9	14.9	7.1	15.4	4.1	13.0	4.4
1985	38.4	15.5	7.4	15.7	4.3	14.0	4.4
1986	39.7	16.1	7.5	16.0	4.5	14.8	4.4
1987	41.4	16.8	7.8	16.5	5.0	15.5	4.4
1988	42.8	17.4	8.0	16.8	5.4	16.2	4.4
1989	44.2	18.0	8.2	17.1	5.6	17.1	4.4
1990	45.6	18.6	8.4	17.4	5.8	18.0	4.4

E Estimate *Source: FAA Air Traffic Activity.
Prior to 1977, the fiscal year ended June 30.
Detail may not add to total due to independent rounding.
The aircraft handled count consists of the number of IFR departures multiplied by two plus the number of overs. This concept recognizes that for each departure there is a landing. An IFR departure is defined as an original IFR flight plan filed either prior to departure or after becoming airborne. An overflight originates outside the ARTCC area and passes through the area without landing. The forecast data assume present operating rules and procedures. Air taxi includes commuter.

Source: "FAA Aviation Forecasts Fiscal Years 1979-1990," Published in 1978 by FAA Office of Aviation Policy.

TABLE B-6 1985 AIR TRAFFIC ACTIVITY DATA FOR CHICAGO, MEMPHIS, AND DENVER

CENTER	ANNUAL FLIGHTS	FLIGHTS ON AVERAGE DAY	ANNUAL DEPARTURES	DEPARTURES ON AVERAGE DAY	ANNUAL OVERFLIGHTS	OVER-FLIGHTS ON AVERAGE DAY	OVER-FLIGHTS ON PEAK DAY	BUSY HOUR OVER-FLIGHTS ON PEAK DAY	BUSY HOUR DEPARTURES ON PEAK DAY	TOTAL DEPARTURES ON PEAK DAY	BUSY HOUR PEAK DAY FACTOR	PEAK DAY FACTOR
Chicago	2,832,000	7,759	1,264,200	3,464	303,600	832	1,231	87	364	5,123	0.071	1.479
Memphis	1,828,500	5,010	676,700	1,853	476,100	1,304	1,904	152	216	2,705	0.080	1.46
Denver	1,114,500	3,053	367,500	1,007	379,500	1,040	1,373	130	126	1,329	0.095	1.32

TABLE B-7 BUSY HOUR FLIGHTS AND FLIGHT PLANS FOR AVERAGE AND PEAK DAY 1985

CENTER	IFR FLIGHTS HANDLED			IFR FLIGHT PLANS FILED THROUGH CENTERS			IFR FLIGHT PLANS FILED THROUGH FSSs		
	ANNUAL TOTAL	BUSY HOUR AVERAGE DAY	BUSY HOUR PEAK DAY	ANNUAL TOTAL*	BUSY HOUR AVERAGE DAY	BUSY HOUR PEAK DAY	ANNUAL** TOTAL	BUSY HOUR AVERAGE DAY	BUSY HOUR PEAK DAY
Chicago	2,832,000	551	815	787,296	153	227	476,904	93	138
Memphis	1,825,500	401	584	129,611	28	42	546,589	120	175
Denver	1,114,500	290	383	245,190	64	85	122,310	32	42

* (Annual Flights Handled 1985) X $\frac{\text{(FPs Filed Through Center 1975)}}{\text{(Annual Flights Handled 1975)}}$

** (Annual Departures (1985) - (Annual FPs Filed Through Center)

TABLE B-8 FORMULAS FOR DERIVING VARIOUS TYPES OF ACTIVITY DATA

1. $\text{Busy Hour Flights on Average Day} = \frac{\text{Annual Flights}}{365} \times \frac{\text{Busy Hour Departures on Peak Day}}{\text{Total Departures on Peak Day}}$

2. $\text{Busy Hour Flights on Peak Day} = 2\ (\text{Busy Hour Departures on Peak Day}) + \frac{\text{Annual Overflights}}{365} \times \frac{\text{Busy Hour Departures on Peak Day}}{\text{Total Departures on Peak Day}}$

3. $\text{Busy Hour Flight Plans Filed through Center on Average Day} = \left(\frac{\text{Annual Departures}}{365} - \frac{\text{Annual Flight Plans from FSSs}}{365}\right) \times \frac{\text{Busy Hour Departures on Peak Day}}{\text{Total Departures on Peak Day}}$

4. $\text{Busy Hour Flight Plans Filed through Center on Peak Day} = (\text{Busy Hour Peak Day Departures}) - \left(\frac{\text{Annual Flight Plans from FSSs}}{365} \times \frac{\text{Peak Day Departures}}{\text{Average Day Departures}} \times \frac{\text{Busy Hour Departures on Peak Day}}{\text{Total Departures on Peak Day}}\right)$

5. $\text{Busy Hour Flight Plans filed through FSSs on Average Day} = (\text{Average Daily FPs from FSSs}) \times \frac{(\text{Busy Hour Departures on Peak Day})}{(\text{Total Departures on Peak Day})}$

6. $\text{Busy Hour Flight Plans Filed through FSSs on Peak Day} = (\text{Busy Hour Average Day FPs from FSSs}) \times \frac{(\text{Busy Hour Peak Day FPs Filed Through Centers})}{(\text{Busy Hour Average Day FPs Filed Through Centers})}$

7. $\text{Annual FPs filed through Centers} = (\text{Annual Flights 19\_\_}) \times \frac{(\text{FPs through Centers 1975})}{(\text{Annual Flights 1975})}$

8. Annual FPs filed through FSSs = (Annual Departures 19_) - (Annual FPs filed through Centers) for 19_

9. $\text{Busy Hour Average Day FPs through Centers} = \frac{\text{Annual FPs through Centers}}{365} \times \frac{\text{Busy Hour Departures Peak Day}}{\text{Total Departures Peak Days}}$

10. $\text{Busy Hour Peak Day FPs through Centers} = (\text{Busy Hour Average Day FPs through Centers}) \times \frac{\text{Total Departures Peak Days}}{\text{Total Departures Average Day}}$

11. $\text{Busy Hour Average Day FPs through FSSs} = \frac{\text{Annual FPs through FSSs}}{365} \times \frac{\text{Busy Hour Departures Peak Day}}{\text{Total Departures Peak Day}}$

12. $\text{Busy Hour Peak Day FPs through FSSs} = (\text{Busy Hour Average Day FPs through FSSs}) \times \frac{\text{Total Departures Peak Day}}{\text{Total Departures Average Day}}$

13. $\text{PIAC} = 2\ (\text{Busy Hour Departures Peak Day}) \times \left(\frac{\text{Center Transit Distance} \div 2}{\text{Speed of Departures/Arrivals}}\right) + \left(\text{Busy Hour Overs Peak Day} \times \frac{\text{Center Transit Distance}}{\text{Speed of Overflights}}\right)$

14. $\text{PIFPC} = \text{PIAC} + \frac{\text{Busy Hour Peak Day Flights}}{2}$

Between 1985 and 1990, the annual increase in departures and overs was 0.6 and 0.2 million, respectively. Assuming that these annual increments are sustained through 1995, one can then add 3.0 (5 x 0.6) million to the 1990 forecast departures of 18.6 million and 1.0 (5 x 0.2) million to the 1990 forecast overs of 8.4 million to obtain 21.6 and 9.4 million, respectively, for 1995.

Assuming that the non-CONUS radar shares of departures and overs continues as in 1975 to be 5.2% and in 1995 to be 6.8%, and deducting these shares from the 1995 projected estimates, 20.5 million departures and 8.8 million overs are obtained as indicated below.

$21.6 \times 0.052 = 1.1232$ 21.6000 − 1.1232 = 20.4768 million departures

$9.4 \times 0.068 = 0.6392$ 9.4000 − 0.6392 = 8.7608 million overs

Separate shares of the estimated 1995 forecast departures and overs for each of the three subject centers were obtained by using each center's percentage of 1975 departures and overs. These Figures are included in Table B-9.

TABLE B-9 CHICAGO, MEMPHIS, AND DENVER SHARES OF 1995 FORECAST TRAFFIC

CENTER	FLIGHTS*	DEPARTURES	OVERS
CONUS	49,714,400	20,476,800	8,760,800
Chicago	3,907,475	1,761,000 (8.6%)	385,475 (4.4%)
Memphis	2,488,355	941,930 (4.6%)	604,495 (6.9%)
Denver	1,505,685	511,920 (2.5%)	481,845 (5.5%)

*Twice the departures plus the overs.

B.4.2 Peak Day Departure Estimates

In Table B-10, the figures from Table B-9 were converted to average daily figures as part of the process of estimating busy hour and peak day figures using the peaking factors developed from the 1975 data. The procedure used to derive "Total Departures-Peak Day 1995" and "Busy Hour Departures Peak Day 1995" is shown below.

Chicago 1995

Since the estimated forecast of Total Departures-Average Day 1995 is 4,825, then

Total Departures-Peak Day ÷ 4825 = 1.479

Total Departures-Peak Day 1995 = 7,136.

Since Total Departures-Peak Day 1995 is 7,136, then,

Busy Hour Departures-Peak Day 1995 ÷ 7136 = 0.071

Busy Hour Departures-Peak Day 1995 = 507

Memphis 1995

Since the estimated forecast of Total Departures-Average Day 1995 is 2,581, then

TABLE B-10 1995 AIR TRAFFIC ACTIVITY AT CHICAGO, MEMPHIS AND DENVER ARTCCs

CENTER	ANNUAL FLIGHTS	FLIGHTS ON AVERAGE DAY	% OF TOTAL DEP.	ANNUAL DEPARTURES	DEPARTURES ON AVERAGE DAY	% OF TOTAL OVERS	ANNUAL OVERFLIGHTS	OVER-FLIGHTS ON AVERAGE DAY	BUSY HOUR DEPARTURES PEAK DAY	TOTAL DEPARTURES PEAK DAY	BUSY HOUR PEAK DAY FACTOR	PEAK DAY FACTOR
Chicago	3,907,745	10,706	8.6	1,761,000	4,825	4.4	385,475	1,056	507	7,136	0.071	1.479
Memphis	2,488,355	6,817	4.6	941,930	2,581	6.9	604,495	1,656	300	3,755	0.08	1.46
Denver	1,505,685	4,125	2.5	511,920	1,403	5.5	481,845	1,320	176	1,852	0.095	1.32

Total Departures-Peak Day 1995 ÷ 2,581 = 1.455

Total Departures-Peak Day 1995 = 3,755

Since Total Departures-Peak Day 1995 is 3,768, then

Busy Hour Departures-Peak Day 1995 ÷ 3755 = 0.080

Busy Hour Departures-Peak Day 1995 = 300

Denver 1995

Since the estimated forecast of Total Departures-Average Day 1995 is 1,403, then

Total Departures-Peak Day 1995 ÷ 1403 = 1.32

Total Departures-Peak Day 1995 = 1,852

Since Total Departures-Peak Day 1995 is 1,852, then

Busy Hour Departures-Peak Day 1995 ÷ 1852 = 0.095

Busy Hour Departures-Peak Day 1995 = 176.

B.4.3 Flight Plans Handled

In order to calculate the number of flight plans filed through the three subject centers and the FSSs associated with each, the following equations were used:

FPs filed through Centers 1995 = (Annual Flights 1995) x (FPs filed through Centers 1975 ÷ Annual Flights 1975)

FPs filed through FSSs 1995 = (Annual Departures 1995) - (Annual FPs filed through Centers 1995)

In Table B-4 the percentage of annual flights representative of the flight plans filed through each center in 1975 was calculated for each center. The percentages for Chicago, Memphis, and Denver (27.8, 0.071, and 0.22, respectively) were then taken off the annual flights for each center in 1995 and entered in Table B-11. By subtracting the flight plans filed through each center in 1995 from the annual departures from each center, the number of flight plans filed through each center's associated set of flight service stations was obtained.

Data in Table B-11 was then used to develop busy hour counts and peak instantaneous counts presented in Table B-12.

TABLE B-11 1995 AIR TRAFFIC ACTIVITY ON AVERAGE DAY AT CHICAGO, MEMPHIS, DENVER

CENTER	ANNUAL FLIGHTS	FLIGHTS ON AVERAGE DAY	ANNUAL DEPARTURES	DEPARTURES ON AVERAGE DAY	ANNUAL OVERS	OVERS ON AVERAGE DAY	ANNUAL FLIGHT PLANS FILED THROUGH CENTERS	FLIGHT PLANS FILED THROUGH CENTERS ON AVERAGE DAY	ANNUAL FLIGHT PLANS FILED THROUGH FLIGHT SERVICE STATIONS	FLIGHT PLANS FILED THROUGH FSSs ON AVERAGE DAY
Chicago	3,907,745	10,706	1,761,000	4,825	385,475	1,056	1,086,353	2,976	674,647	1,848
Memphis	2,488,355	6,817	941,930	2,581	604,495	1,656	176,673	484	765,257	2,097
Denver	1,505,685	4,125	511,920	1,403	481,845	1,320	331,251	908	180,669	495

TABLE B-12 1995 BUSY HOUR AND PEAK INSTANTANEOUS COUNTS FOR CHICAGO, MEMPHIS, AND DENVER

CENTER	BUSY HOUR FLIGHTS ON PEAK DAY	BUSY HOUR DEPARTURES ON PEAK DAY	BUSY HOUR OVERS ON PEAK DAY	PEAK INSTANTANEOUS AIRBORNE COUNT*	PEAK INSTANTANEOUS FLIGHT PLAN COUNT**
Chicago	1,089	507	75	798	1,342
Memphis	732	300	132	516	882
Denver	489	166	157	328	572

*Based on assumed Chicago center transit distance of 300
Memphis center transit distance of 300
Denver center transit distance of 400

Assumed aircraft speeds of 600 knots for overs
200 knots for departures/arrivals

Additional assumptions: Overs travel full transit distance at 600 knots
Departures/arrivals travel half transit distance at 200 knots

Thus, PIAC = 2 (Busy Hour Departures Peak Day) x $\frac{150}{200}$ + (Busy Hour Overs Peak Day) x $\frac{300}{600}$

e.g., Chicago PIAC $= 2\left(507 \times \frac{150}{200}\right) + \left(75 \times \frac{300}{600}\right)$
$= 798$

**PIFPC = PIAC + $\frac{\text{Busy Hour Peak Day Flights}}{2}$

e.g., Chicago PIFPC $= 798 + \frac{1089}{2}$
$= 1,342$

APPENDIX C

SURVEY OF NAS EN ROUTE SYSTEM PERFORMANCE

C.1 INTRODUCTION

Existing studies of the NAS En Route System were reviewed to correlate the considerations of the replacement system with respect to processing load estimates and determining feasible transition paths. The foremost objective was the verification of the replacement system functional load estimates with measurement data of the current system.

The replacement system is expected to be implemented by the late 1980's. Projections of how the current system would evolve during this time frame were made. This allows consideration of the feasibility of possible transition paths to the replacement system. These projections entailed developing an understanding of the current system's performance and limitations. Air traffic loads on the computer systems were estimated. Various alternatives for extending the capacity to meet these estimated loads were reviewed.

This work represents an overview approach for developing a global comprehension and identifying areas that warrant further investigation. The readily available literature was surveyed, liberal reasonable assumptions were employed, and varying levels of detail were considered. The reader is assumed to have general familiarity with ATC, the NAS En Route System, computer performance, and computer architecture.

C.2 VERIFICATION OF FUNCTION PROCESSING LOAD ESTIMATES

The methodology of the functional processing load estimates in Sections 2.2.2.2 and 2.2.2.3 was verified by examining the possible correlations with measurement data of the current system. Limiting the estimates to an order of magnitude accuracy permitted the use of readily available measurement data on release NAS En Route 3d2.1 System. These data were the same as those used for the basis of Kelley's study "Distributed Processing Techniques for En Route Air Traffic Control."* The use of common data may facilitate future comparisons.

The original measurement data is from the System Performance Analysis Report-48 (SPAR) and SPAR-55 studies of release 3d2.1. The 26 program elements with highest processor utilization were considered. These account for over 90% of the total processor utilization.

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*Kelley, James P. "Distributed Processing Techniques for En Route Air Traffic Control," The MITRE Corporation, METREK Division, Mc Lean VA., MITRE Technical Report 7589, July 1977.

The correlation between the program element of 3d2.1 and the functional description of the replacement system is complex and incomplete. However, five disjoint groupings with reasonable correlations exist and are illustrated in Figures C-1 and C-2. These five groupings allowed the verification of the load estimation method. Of the functions not correlated in these groupings, conflict alert is among the most notable.

The relationship between program elements and the functions are depicted by the straight lines between the two listings. A straight line between a program element of 3d2.1 and a function of the replacement system indicates significant commonality of the work performed. As graphically portrayed in Figures C-1 and C-2, correlation among groups 1, 2, and 3 is much simpler than among groups 4 and 5.

An approximation of each function's load processing estimate for 110 tracks, 40 displays and 5 radars is calculated. Each approximation is reduced to a function of one processing rate constant, K_{small}, using the rule of thumb, $K_{large} = 10\ K_{medium} = 100\ K_{small}$, in section 2.2.2.2. Thus the processing estimate for the functions in Table 2.2-5 are reduced to the quantities in Table C-1. The first column gives the approximation used for load estimation verification. The sums of reduced function load estimates are given in column 3 of Table C-2 for each group.

The measured processing load for each program element is totalled for all program elements in each group. These sums in terms of sec/sec of a 9020A® cpu are given in column 1 of Table C-2.

The relationship between the processing proportionality K_{small} and the 9020A cpu is not known. Assuming the load estimates are exact for each group, a value of K_{small} for each group is determined and given in column 4 of Table C-2. In column 5, the K_{small} values are normalized to the group 3 value.

Thus, column 5 has the range of variation of the K_{small} values found by assuming equalities between the measured and estimated group loads. The range of variation is within the order of magnitude accuracy of the estimation method. The agreement is better in the first three groups which have simpler relationships. The order of magnitude accuracy of the processing load estimates for the functions in the five groups have been verified indirectly by the observed variation in column 5 of the normalized K_{small} values.

C.3 DESCRIPTION OF THE CURRENT NAS EN ROUTE SYSTEMS

The NAS En Route Systems hardware in the ARTCCs has three different configurations Each has two major components, a computational subsystem, the CCC, and a display subsystem. There are twenty operational ARTCCs covering the U.S. airspace. Ten of these have the complex composed of the IBM 9020A CCC

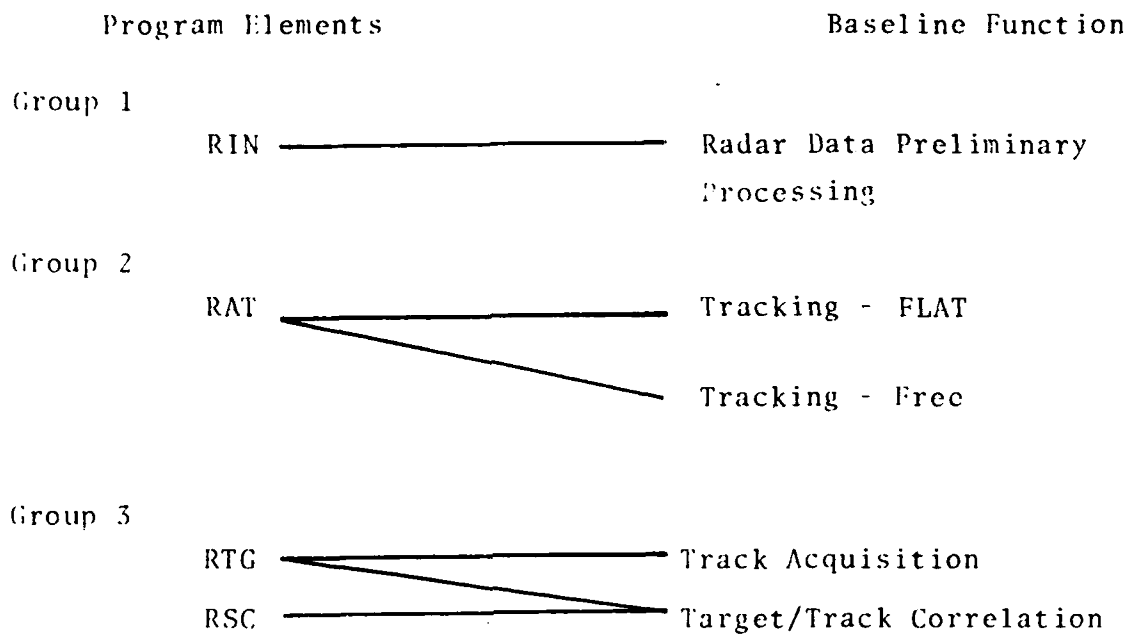

FIGURE C-1 RELATIONSHIPS OF CURRENT PROGRAM ELEMENTS AND BASELINE FUNCTIONS

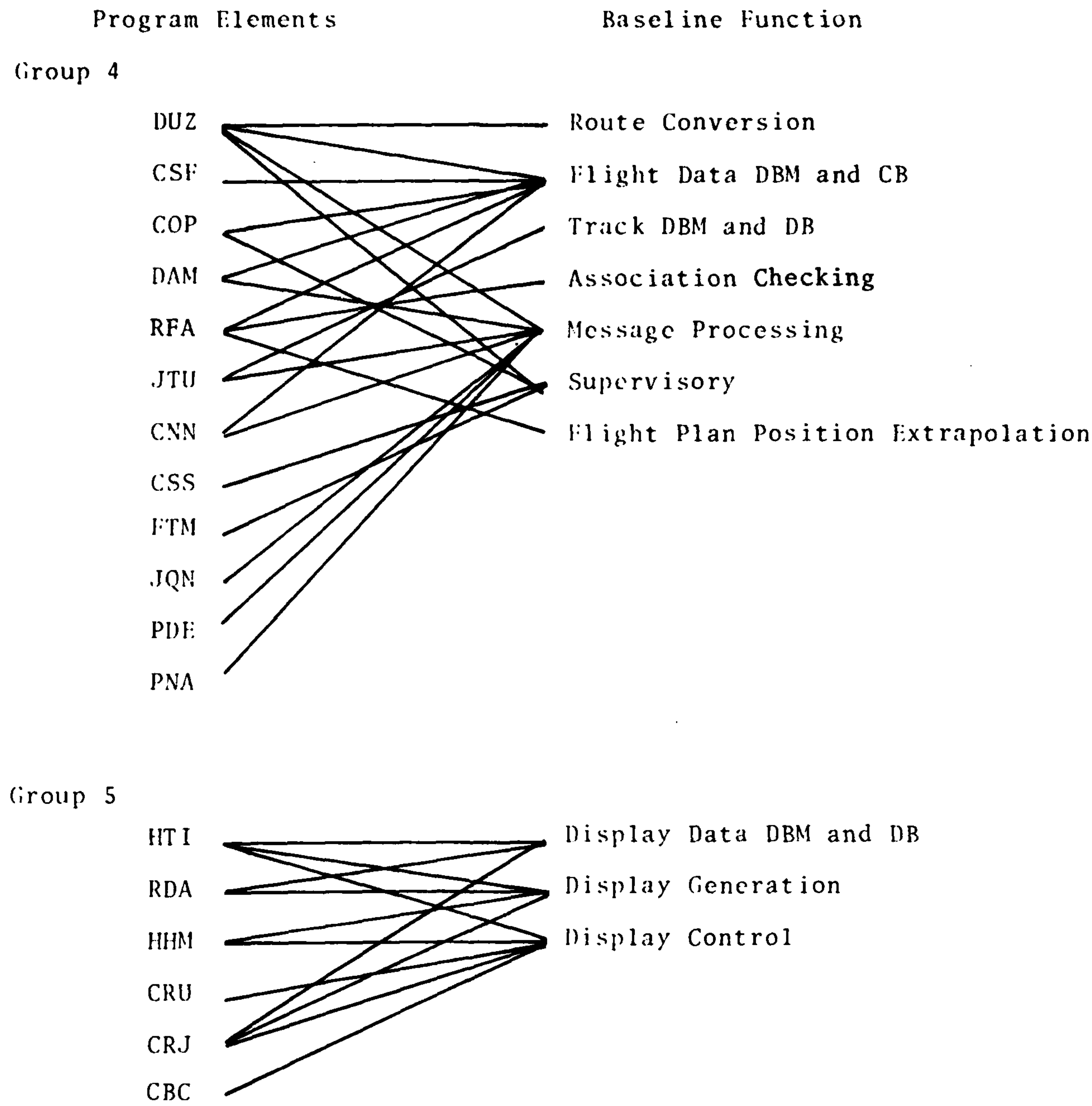

FIGURE C-2 RELATIONSHIPS OF CURRENT PROGRAM ELEMENTS AND BASELINE FUNCTIONS

TABLE C-1 PROCESSING ESTIMATES FOR EN ROUTE FUNCTIONS FOR: $N_{FP} = 2N_T$, $N_D = 40$, $N_R = 5$,

FUNCTION		P in K_s for T = 100	200	400
Radar Data Preliminary Processing	$\alpha N_T.N_R$	$5x10^3$	$1x10^4$	$2x10^4$
Tracking (FLAT and Free)	αN_T	$2x10^3$	$4x10^3$	$8x10^3$
Track Acquisition	αN_T	$2x10^1$	$4x10^1$	$8x10^1$
Target/Track Correlation	$\alpha N_T \ln N_T.N_R$	$2.5x10^3$	$3x10^3$	$3.3x10^3$
Display Data DBM	αC	10^3	10^3	10^3
Display Generation	$\alpha N_T.N_D$	$2x10^3$	$4x10^3$	$8x10^3$
Display Control	αN_D	10^1	10^1	10^1
Route Conversion	αC	10^2	10^2	10^2
Track DBM	αC	10^3	10^3	10^3
Flight DBM	αC	10^3	10^3	10^3
Association Checking	αN_T	$5x10^1$	$1x10^2$	$2x10^2$
Message Processing	αC	10^3	10^3	10^3
Flight Plan Position Determination	αN_T	$5x10^1$	10^2	$2x10^2$
Fix Time Calculation	αC	10^2	10^2	10^2
Posting Determination	αC	$5x10^1$	$5x10^1$	$5x10^1$
Flight Plan Activation	αN_T	$5x10^{-1}$	1	2
Bulk Store Processing	αC	$2x10^{-3}$	$2x10^{-3}$	$2x10^{-3}$
Beacon Code Allocation	αC	1	1	1
O. and E. DBM	αC	10^3	10^3	10^3
Conflict Alert	$\alpha N_T.\ln N_T$	76	88	10^2

TABLE C-2 LOAD ESTIMATES AND THEIR RATIOS

Program Element Groups	Sum of Program Element Load in sec/sec of IBM 9020A® cpu	Sum of Function Load Estimates K_{small}	Calculated Values K_{small}	Normalized Values K_{small} (to Group 3 value)
1	0.40	5500	$7.3x10^{-5}$	2.6
2	0.18	2500	$7.2x10^{-5}$	2.6
3	0.056	2000	$2.8x10^{-5}$	1.0
4	0.71	3200	$22.x10^{-5}$	7.9
5	0.45	2000	$23.x10^{-5}$	8.2

computational subsystem and the Raytheon 730® Channel Display Controller (CDC) display system. Five consist of the IBM 9020D® (DCC) computational subsystem and the IBM 9020E® DCC. These systems complexes are depicted in Figure C-3.

The display subsystems appear adequate for the future. The Raytheon 730 CDC can drive up to 60 display positions, while the triplex IBM 9020E DCC can drive up to 90. These limitations are within the projected load requirements through the late 1980's. The available literature gives no indication of serious limitations in either the CDC or DCC.

The focus of this survey is, therefore, on the computing subsystem, the CCC. Both the IBM 9020A® and the 9020D have limitations which may become operational performance issues by the late 1980's. The computing subsystem encompasses the major areas of interest for the replacement system design, as most of the replacement baseline functions are performed in the current computing subsystem.

The IBM 9020A and 9020D CCCs have a distributed asynchronous bus structure very similar to the General Electric (GE) MULTICS®, Burroughs 5000®, and Digital Equipment Corporation (DEC) PDP-10® architectures. The three main components are the computer elements (CE), the input-output control elements (IOCE), and the storage elements (SE). The component technology is the IBM solid logic technology® (SLT). The engineering is standard IBM 360/50® and IBM 360/65® except for the distributed bus and its interfaces.

The 9020A and 9020D differ in the CEs and SEs. The CEs and SEs of the 9020A are modified versions of IBM 360/50 design. The 9020D has IBM 360/65 engineering in its CE and SE . The IOCEs employ IBM 360/50 engineering and are identical for both the 9020A and the 9020D CCCs.

The major peripherals of interest are the disks, IBM 2314®, the tapes, IBM 2401®, and the peripheral adapter modules (PAM), which are heavily customized IBM 2701®. The PAMs control all communications for the computing system except for the link to the CDC or DCC. A comparison of the 9020A and 9020D characteristics is given in Table C-3.

As indicated in Table C-3 and Figure C-4 the 9020A is a four processor CE system. Normally one of each major element is kept on standby, redundant, in case of an element failure. The 9020D diagrammed in Figure C-5 is a three processor system that normally operates with two processors on-line.

The IOCEs each have two selector channels (S), one multiplexer channel (MX) and 131k bytes of local memory. One selector channel for each IOCE normally communicates with the CDC or DCC. The second selector channel is used for disk and tape activity. The multiplexer channel handles the PAM. Redundant

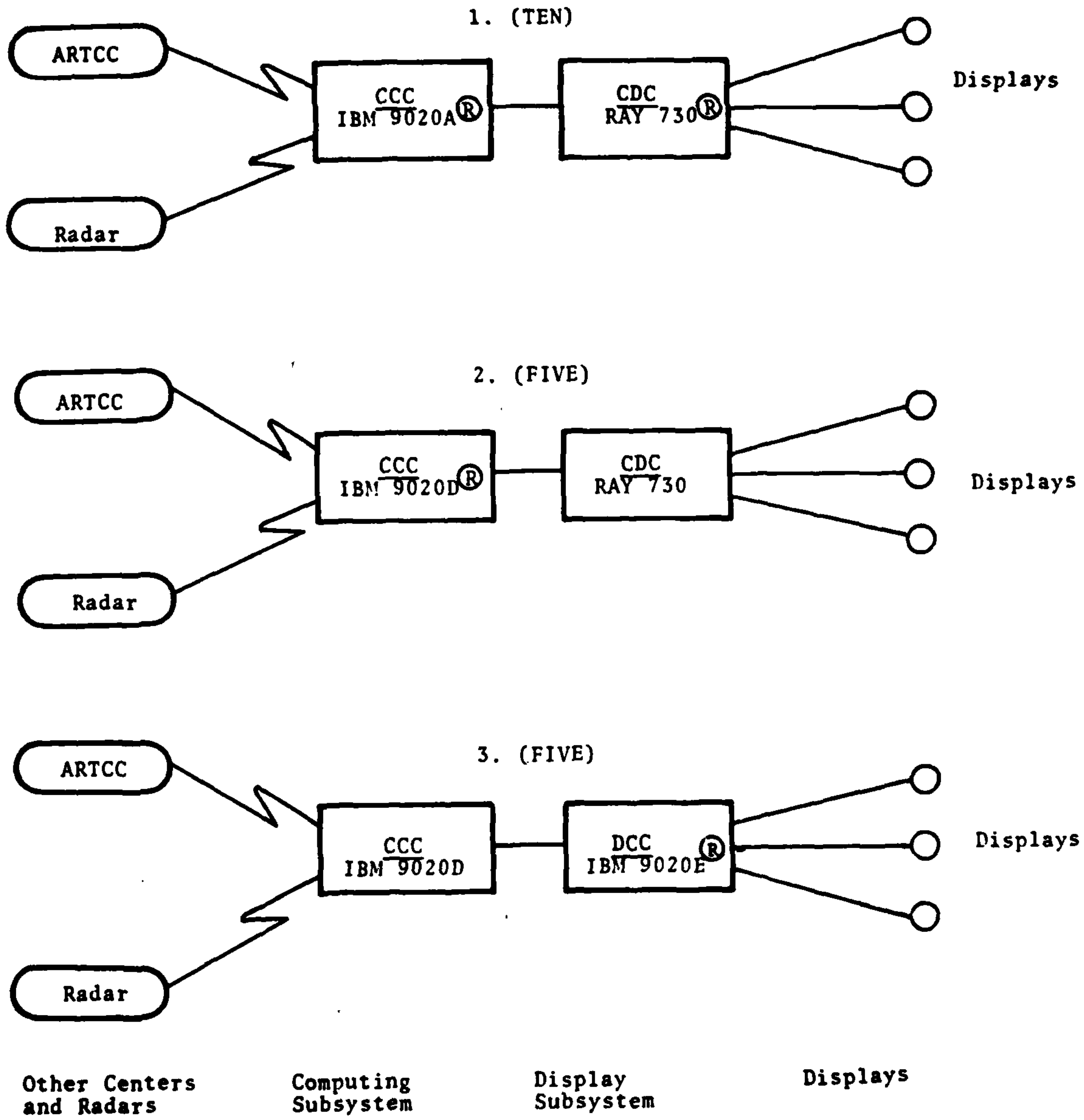

FIGURE C-3 TYPES OF EN ROUTE SYSTEMS

TABLE C-3 IBM 9020A® AND 9020D® CHARACTERISTICS

Characteristic	9020A	9020D
CE cycle time	0.5 μsec	0.2 μsec
SE cycle time	2.5 μsec/4 bytes	0.8 μsec/8 bytes
SE capacity/unit	0.25 megabyte	0.5 megabyte

Number or Capacity	9020A On-line	9020A Total	9020D On-line	9020D Total
CE	3	4	2	3
SE	9	11	5	6
Total memory	2 1/4 mb	2 3/4 mb	2 1/2 mb	3 mb
PAM	2	3	2	3
Tape Controller	2	3	2	3
Disk Controller	2	3	2	3
Disk Drive	2	6	2	6

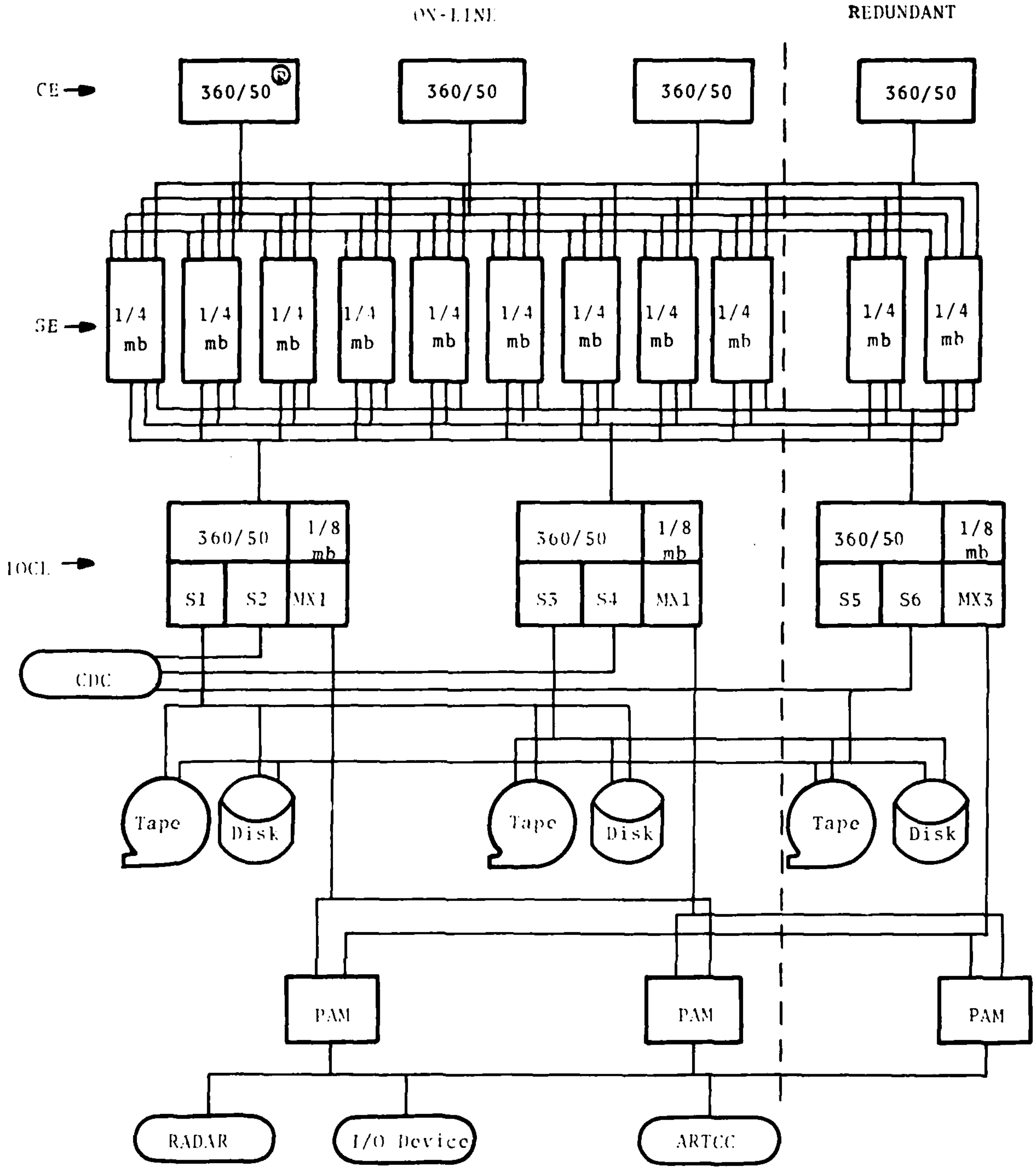

FIGURE C-4 'SIMPLIFIED' 9020A® CONFIGURATION DIAGRAM

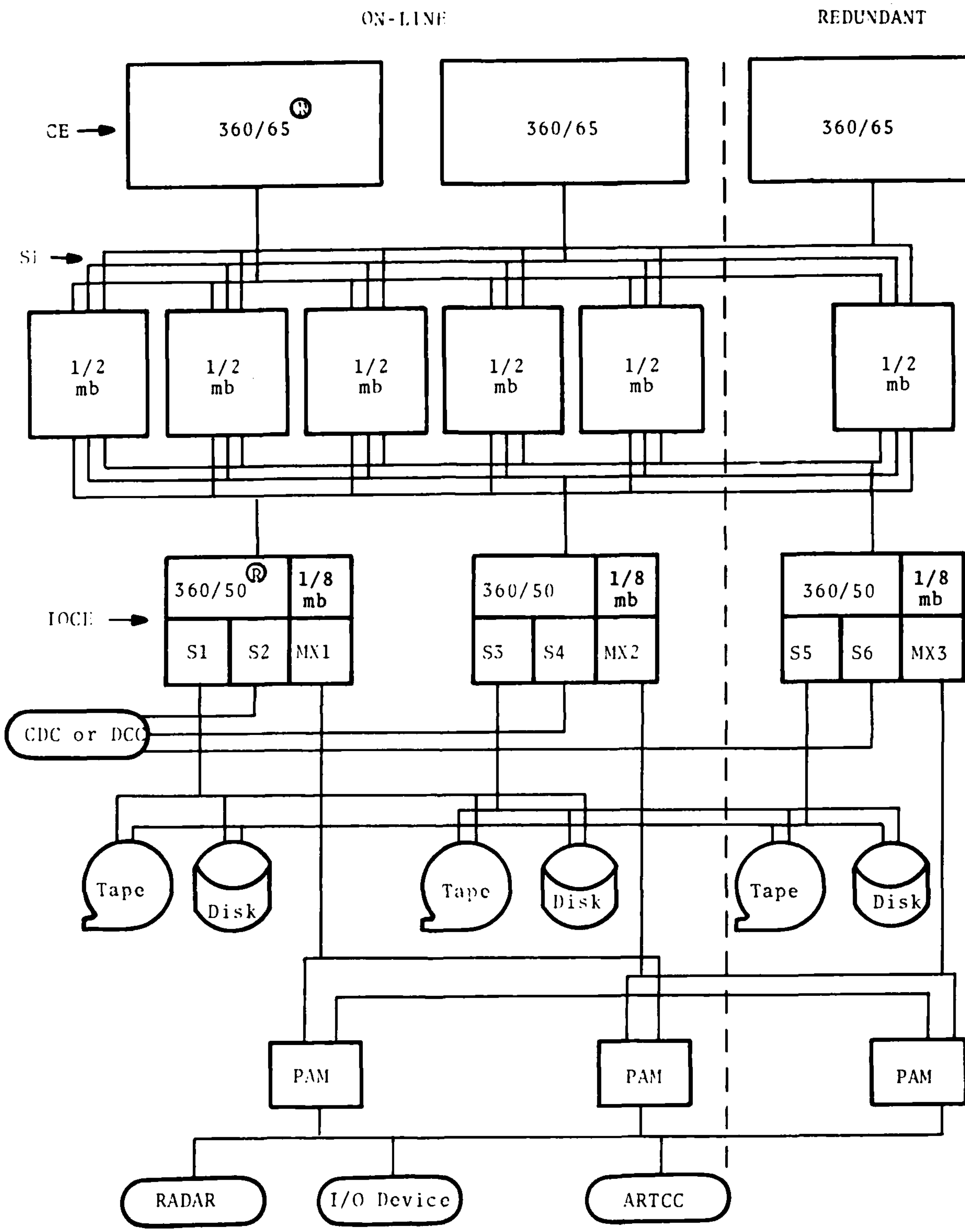

FIGURE C-5 'SIMPLIFIED' 9020D® CONFIGURATION DIAGRAM paths are supplied by use of dual channel controllers for the disks, tapes, and multiple connections.

The centers with the 9020A® CCC routinely keep two SEs off-line. This allows use of the off-line redundant elements for performing required data processing (DP) operations. The minimum useful core needed is 1/2 megabyte for the DP functions. Thus, two 9020A SEs are used, while one 9020D® SE is used for DP functions. The 9020A CCC typically has 2-1/4 megabytes on-line storage; and the 9020D CCC has 2-1/2. The memory for both the 9020A and 9020D is not interleaved. This facilitates reconfiguration if an SE should fail. The usual on-line configurations are depicted to the left side of the dashed lines in Figures C-1 through C-3.

C.4 PROJECTED PEAK AIR TRAFFIC LOADS IN THE LATE 1980's

Estimates were made of peak track counts for 1977. As stated in the Federal Computer Performance Evaluation and Simulation Center (FEDSIM) study,* the track count is the best single load metric and is an adequate load parameter for this survey. The heavy peak track counts observed in the 1977 Logicon Study of the Fort Worth ARTCC** were used as the basis for estimating other ARTCC peak track counts. Estimates of 1975 IFR flights were assumed to be proportional to 1977 peak track counts. The estimates are given in Table C-4.

Table C-4 also gives the ARTCC configurations and the number of sectors. With the exception of Houston, the larger peak track counts are 9020D configurations. Peak track count is the best single metric, but other factors should be considered when better than ±10% accuracy is desired.

The air traffic growth estimates range between 2% and 6% per year with 4.4% as the best estimate. Figure C-6 shows the estimated peak track growth of the 9020A and 9020D maximum peak counts. The 9020A maximum peak count in 1977 was assumed to be 200, and the 9020D maximum in 1977 is 300. The growth curve of the 9020A maximum peak count also shows the range limits of 2% and 6% per year growth.

Thus in 1985 the estimated maximum peak track count for a 9020A center is between 233 and 318, with the best estimate at 280. The maximum peak count for the 9020D ARTCC in 1985 is 425, assuming a 4.4% per year growth rate.

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*"NAS Capacity Study," FEDSIM, Washington D.C., Contract Number AY-409-008-TSC, November 1975.
** Kandler, W.D., et. al., "Response Time Analysis Study Fort Worth ARTCC Measurements" Logicon, Inc. Atlantic City NJ, Contract Number: DOD-RATQWA-3881, Logican Report Number: R4940-107, August 1977 (NAS Doc. 78-0211).

TABLE C-4 ESTIMATED TRAFFIC AND HARDWARE ARTC CONFIGURATIONS

CENTER	ESTIMATED PEAK TRACK COUNT (1977)	ESTIMATED IFR FLIGHTS (1975)			CONFIGURATION (COMPUTING)/ (DISPLAY)	NUMBER OF SECTORS
		PEAK DAY BUSY HOUR	AVG. DAY BUSY HOUR	ANNUAL TOTAL		
Cleveland	301	527	395	1,655,816	IBM9020D®/9020E®	47
Chicago	275	481	336	1,724,441	9020D/9020E	43
Jacksonville	246	435	254	1,092,133	9020D/RAY730®	37
Atlanta	243	426	322	1,383,014	9020D/730	41
Fort Worth	229	401	286	1,305,953	9020D/IBM9020E	39
New York City	220	385	307	1,533,014	9020D/9020E	39
Washington DC	218	382	302	1,378,370	9020D/9020E	36
Houston	215	376	247	1,046,545	9020A®/RAY730	41
Indianapolis	213	372	285	1,316.443	9020D/730	34
Los Angeles	198	346	254	1,092,133	9020D/730	37
Kansas City	190	332	230	1,079,663	9020D/730	36
Memphis	190	332	250	1,138,534	9020A/730	36
Albuquerque	189	327	218	875,362	9020A/730	34
Miami	177	310	222	1,024,853	9020A/730	28
Minneapolis	174	305	208	1,011,297	9020A/730	34
Boston	163	286	204	917,781	9020A/730	32
Oakland	154	269	212	890,893	9020A/730	39
Seattle	125	219	140	670,501	9020A/730	22
Denver	125	218	181	696,778	9020A/730	34
Salt Lake City	98	172	123	448,918	9020A/730	21

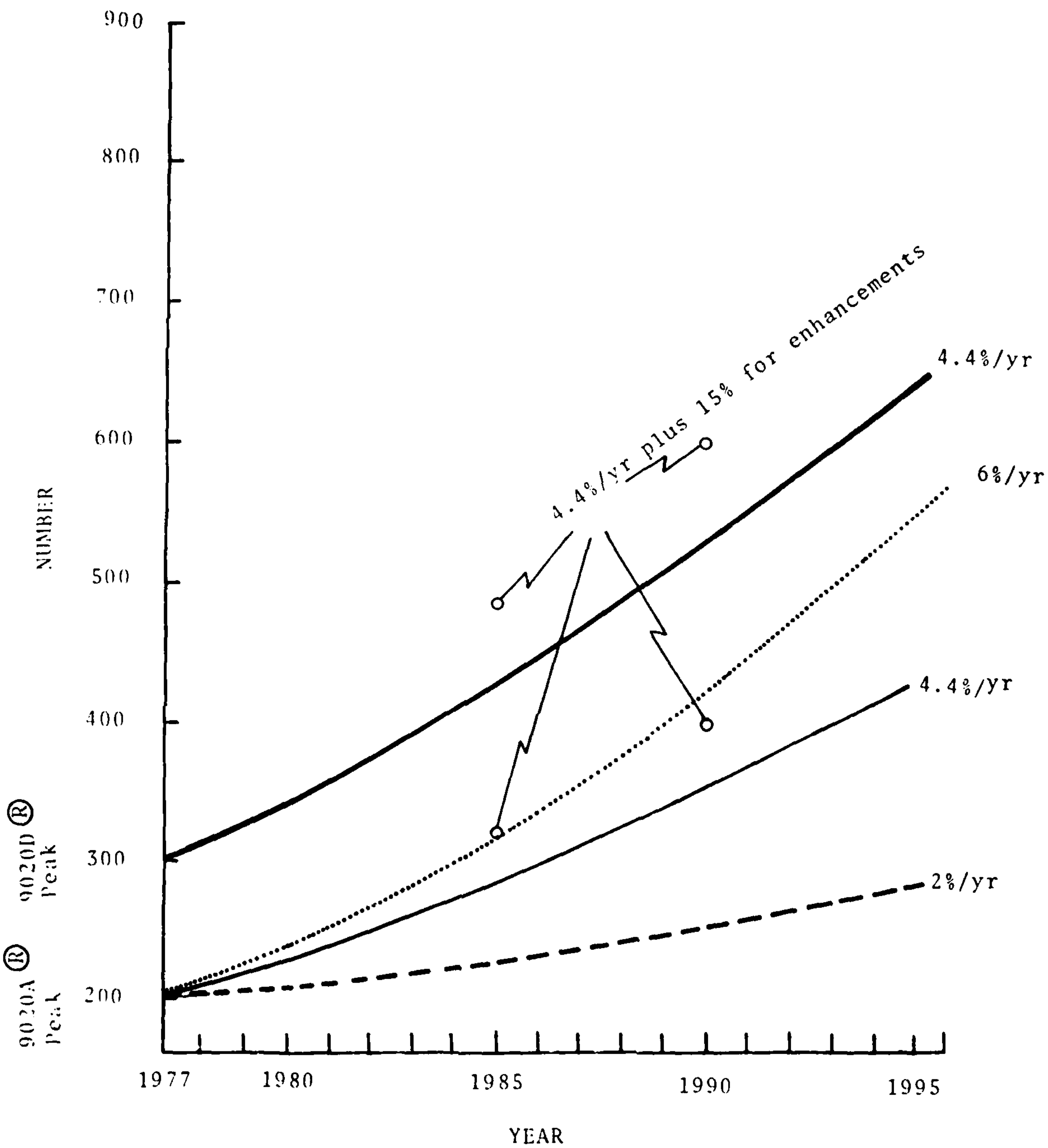

FIGURE C-6 ESTIMATED PEAK TRACK COUNTS

In addition to anticipated traffic growth, planned enhancements to be implemented by the late 1980's will increase the resource requirements of the CCC. Table C-5 gives the estimated memory and Central Processing Unit (CPU) requirements for each enhancement. If all the enhancements listed are implemented, an additional 730 kbytes of memory and 0.39 sec per sec of a 9020A® CPU equivalent will be required. These estimates are for a track count of 225 and the 1978 base, version 3d2.8.

The additional CPU requirement of 0.4 sec per sec of a 9020A CPU is roughly equivalent to 30 tracks at a total track count of 200 or about a 15% CPU increase. Thus all these enhancements would add an equivalent 15% load to the traffic growth curves in Figure C-6. With all enhancements, the equivalent maximum peak track counts in 1985 for 4.4% per year growth are 488 for the busiest 9020D® center and 322 for the busiest 9020A center. This is a possible 60% increase in the total CPU requirement. The memory storage requirements for all enhancements is equivalent to a 25% increase.

The enhancement estimates and the implementation schedule is subject to question in detail, but, nevertheless, give rough estimates of the requirements increase in addition to the traffic growth. For this survey, an annual traffic increase of 4.4% per year with an additional 15% CPU and 25% memory requirement by the late 1980's was assumed. Input/Output (I/O) requirements for the enhancements were not estimated.

These assumptions give equivalent peak track counts of approximately 488 for the busiest 9020D center and 325 for the busiest 9020A center in 1985. This is a 60% increase over 1977. In 1990 the nominal growths with enhancements give maximum peak counts of 402 tracks for the busiest 9020A center and 607 tracks for the busiest 9020D center.

Estimated peak counts, without enhancements and nominal traffic growth for the busiest 9020A centers, is 280 tracks in 1985 and 350 tracks in 1990. For the busiest 9020D centers, the corresponding counts are 422 tracks in 1985 and 527 tracks in 1990.

C.5 LIMITATIONS OF CURRENT NAS EN ROUTE SYSTEM

The 9020A and 9020D CCC were reviewed with respect to their current air traffic capacity versus the estimated air traffic load in the late 1980's. The data indicates that the 9020A CCC has serious limitations with respect to maximum peak track counts. By 1985 the maximum peak track count for the busiest 9020A center may exceed the capacity of the current 9020A configuration. In the late 1980's, this capacity will most likely not be adequate for peak loads.

The CCC is a real time system in many of its performance requirements and must meet these real time requirements under

TABLE C-5 ENHANCEMENT ESTIMATES FOR CPU AND MEMORY
(by MITRE, 1978 Base, 225 Tracks)

	Storage kilobytes	CPU sec/sec ® IBM 9020A CE
Major Enhancements		
Conflict Predict	220	0.15
En Route MSAW	120	0.10
Conflict Alert	80	0.07
DABS Interface	50	0.04
Conflict Resolution	30	0.01
Metering	40	0.01
Subtotal	540	0.38
Secondary Enhancement		
ETABS	40	0.15 → 0
FSS Auto	0	0
Weather	0	0
NADIN	+80 → -20	0
DARC	12	0.004
TIPS	30	0
ATARS	4	0
ARTS III & II	0	0
ATCSCC	0	0
CMA	120	0.005
Oceanic Auto	4	0
Subtotal	190	0.009
TOTAL	730	0.39

SOURCE: Dodge, P.O., "9020 Sizing Estimates for SRDS Planned Automation Enhancements," MITRE Corporation/METREK Division, McLean, VA, Briefing Viewgraphs, January 25, 1979.

peak loading conditions. Originally, the CCC program elements and active data were to be resident in primary memory, and no disks were to be used. The computing capacity of the 9020A® was to be more than adequate. The latter use of disks for swapping program elements was employed without increasing the original I/O capacity. Where the 9020A processing capacity was inadequate, an enhanced version, designated the 9020D®, was employed.

The upgrade to the 9020D, with computer elements more than 3-1/2 times the processing capacity of the 9020A CE, gives a duplex 9020D 2.4 times the CPU capacity of a triplex 9020A. The I/O composition of the 9020A and 9020D configurations are identical. The operational capacity of the primary memory of the 9020A and 9020D are very similar as seen in Table C-3. The most significant difference between the 9020A and the 9020D is CPU capacity.

Rough estimates give a routine peak count capacity of the 9020A to be about 175 tracks and the 9020D about 235 tracks. In actual operation, the capacity is extended by reducing or eliminating data recording, bringing redundant elements on-line, and reducing capabilities.

Crude estimates of the effect of employing these non-routine means of increasing capacity give a peak track count capacity of 300 tracks for the 9020A CCC and 500 tracks for the 9020D CCC. These estimates should be explored further. They indicate a possible shortfall of capacity during peak traffic loads for the busiest 9020A centers by 1985.

The means of reducing or eliminating data recording does not seriously affect operational capabilities. Failure of an SE or CE during a mode of operations, where all elements of the type to fail were on-line in order to meet peak load demands, is a situation whose remedies should be carefully explored.

An abundance of very good measurement studies has been made of the NAS En Route State System. Each new version is tested at National Aviation Facilities Experimental Center (NAFEC) and many field studies have been performed. These studies give a good overall performance understanding of the NAS En Route System. For a more detailed (accuracy better than +10%) understanding, more work is needed to better correlate the NAFEC tests with field measurements. The additional studies are in progress, or in planning, and, when finished, an accurate, comprehensive performance assessment of the En Route System can be made.

The needed measurement work is ably covered in the FEDSIM and Logicon studies.* This work would also allow the limitations

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*Kandler, W.D., "NAS En Route Response Time Analysis Study, Composite Analysis of Indianapolis, Memphis, Forth Worth, and (Continued) of the current 9020A® and 9020D® systems to be determined within the accuracy needed for detailed planning. The limitations estimated by this survey are rough (greater than ±10%) but give an indication of where further accuracy should be pursued.

The major items in the NAFEC test that reduce accuracy are: the limited number of different traffic loads (two) for each configuration, conflict alert being off, very little change of the data recording variable, and no variation in the amount of memory used. The field measurements are mainly of hardware resource utilization and do not readily relate to the detailed NAFEC software module utilization. Since the field measurements are made during actual operation, many changes in the data recording variable occur.

Estimates were made of the peak track counts where the response times of the NAS performance criteria would begin to exceed the established goals noticeably. The range of the load from the first notice of exceeding response time until the response time has increased to an unacceptable limit is typically 10-20%. The accuracy of these estimates, given in Table C-6, is probably not better than 20%.

Comparison of these peak load limits to the peak load estimate of Section C.4 indicates that the busiest 9020A center may have performance difficulties under peak loads during the middle 1980's. The busiest 9020D centers would not have peak load problems until the late 1980's, assuming nominal traffic growth only. Additional NAS enhancements could advance these time frames.

A simple view of where resource limitations occur for peak traffic loads in the 9020® system is given in Table C-7. The overall limits are complex functions of all these resources. A classic case is the trade-off between memory capacity and processing capacity by different computational algorithms. Some of the many interrelated factors are given in Table C-8.

As seen in Table C-7, the 9020A system has limitations in all the primary resources, if the full data recording levels are occurring. If recording was completely eliminated, more than 10% of processing capacity is recovered, and about 50% of the I/O bandwidth is recovered. At about a 200 track load, a triplex 2-1/2 megabyte 9020A uses about 50% of the I/O bandwidth for program element swapping.

If a 9020A system had the memory capacity to keep all program elements resident in primary memory, and data recording

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(Continued)
NAFEC Measurements, Final Report, Vol. 1," Logican Inc., Rosslyn VA, Contract Number DOT-FATQWA-3881, Logican Report Number R494D-110/NAS Doc. 78-0206, March 1978.

TABLE C-6 ESTIMATED PEAK TRACK COUNT LIMITS

IBM 9020A®		
Full Data	Reduced Data	Reduced Data
3CE, 9SE 175	3CE, 10SE 250	4CE, 11SE 300
IBM 9020D®		
Full Data	Reduced Data	Reduced Data
2CE, 5SE 235	2CE, 5SE 450	3CE, 6SE 550

TABLE C-7 PRIMARY RESOURCE LIMITATIONS

(Normal Operation at Current Traffic Peaks)		
Resource	IBM 9020A®	IBM 9020D®
I/O Bandwidth	Yes	Yes
I/O Device Speed	Yes	Yes
Memory Capacity	Yes	Yes
Memory Bandwidth	Yes	No
Processing Capacity	Yes	No

TABLE C-8 DIRECT AND INDIRECT PERFORMANCE ISSUES

DIRECT		
Memory Capacity	⟷	Swapping Rate
Memory Bandwidth	⟷	Storage Interference
Storage Interference	⟷	Processing Capacity
I/O Device Speed	⟷	I/O Bandwidth
Memory Bandwidth	⟷	I/O Bandwidth
INDIRECT		
Memory Capacity	⟷	Processing Capacity
Swapping Rate	⟷	Processing Capacity
Memory Capacity	⟷	I/O Bandwidth
Data Recording	⟷	Processing Capacity

was eliminated, the system would still be limited by processing capacity and memory bandwidth. The processing capacity of the current triplex 9020A® system is about 200 tracks. The two on-line IOCEs are utilized, approximately 20%, for radar processing. A potential 40% increase in capacity by IOCE offloading is limited by the memory bandwidth of the 9020A SEs.

The storage interference of the 9020A with a 200 track load is estimated to be 10-20% of its utilized processing capacity. Typically, at this level of storage interference, increased processor utilization incurs a marked increase in storage interference. This effect can go beyond the point of diminishing returns. The effect of increased processor utilization in storage interference in the current 9020A system is not accurately known.

Simulation of the 9020A system to measure the interrelationship of processor utilization and storage interference is feasible and would be simpler and cheaper than actual measurements. This would allow determination of the actual potential of IOCE off-loading.

Depending on the local adaption data and expected load, the NAS En Route software requires between 3 and 3.5 megabytes of primary memory. This would allow all program elements to be resident in primary memory and eliminate swapping of program elements. The 9020A and 9020D® centers can have 2.5 megabytes on-line with one redundant storage element available.

The minimum buffer size is slightly less than 0.5 megabytes. Thus the maximum swap ratio is slightly less than 3. An old rule of thumb for time sharing systems with 9020® I/O technology was an upper bound ratio of 3 for acceptable time sharing response. The real-time response required of the 9020 system requires larger than minimum buffer in order to reduce the swap ratio. Increasing the buffer size increases the swapping activity. Thus delicate tuning is required due to the I/O limitations of the 9020 system. Under these circumstances the memory capacity of the 9020A and 9020D is considered significantly limited at peak traffic loads.

The load limit estimates in Table C-6 are rough, and many complex factors must be considered. The data does indicate that the 9020A system limitations are significant with respect to peak traffic loads anticipated in the late 1980's. More accurate and detailed study is needed to explore this potential problem.

C.6 ALTERNATIVES FOR INCREASING 9020 CAPACITY

The alternatives for enhancing the 9020 system's performance cover I/O, processing and memory capacities. The Logicon Study (March 1978) extensively covered I/O channel utilization. Table C-9 lists the enhancements suggested in the Logicon work. The

TABLE C-9 RANKING OF CHANNEL UTILIZATION IMPROVEMENTS

RECOMMEN-DATION	LABOR HOURS (Months)	HARDWARE COST ($1000)	TOTAL COST ($1000)	TRACK CAPACITY INCREMENT	FIGURE OF MERIT
SAR Improvements	18	-	75	50	0.70
New Disk I/O Method	12	-	50	20	0.40
Disk Remap	4	-	16	5	0.30
Smoothed Disk and Tape I/O	12	-	50	10	0.20
Third Selector Channel and Added Disks	36	1500	1650	200+	0.12
Partial Cross-Barred Channels	24	-	100	10	0.10
1600 BPI Tape Drives	24	1100	1200	80	0.07
Third Selector Channel	24	1500	1600	80	0.05
Disk Shuttle Access Method	24	-	100	5	0.05
ITEL Disks	120	7900	8500	110	0.01
Small SAR Records	2	-	8	-40	-5.00

SOURCE: Kandler, W.D., "NAS En Route Response Time Analysis Study, Analysis of Channel Utilization Improvement Methods, Final Report, Vol. II, "Logican Inc., Rosslyn VA, Contract Number DOT-FAT-QWA-3881, Logican Report Number: R4940-110, March 1978, NAS DOC.78-0207.

track increments are with respect to full data recording and swapping of a 200 track load.

Processing capacity may be increased by further utilization of the IOCEs. Current work is addressing this. However, as discussed in Section C-4, the storage interference in the 9020A® system may significantly impair this approach. More investigation is needed to determine the limit of IOCE utilization in the 9020A.

Potential memory capacity for the 9020A system was increased with the Model 08A® storage element, but the 08A SE was not implemented in the field. Part of the issue was diagnostics for field operations. Two 08A SE are used at NAFEC without any difficulties. The 08A SE doubled the 0.25 megabyte capacity of the currently used Model 08® SE. The 08 SE memory speed was not increased and storage interference would not be reduced directly by the 08A SE.

Advances in memory technology since the 08A design offer three distinct advantages: a) cost, b)speed, and c) reliability.

a) Cost: current memory costs per unit capacity are a fraction of the 08A costs. Estimates of memory cost would include a one time engineering and programming cost of $200K; $20K for each storage element cabinet, back plane, and power supply; and memory at $10K for each megabyte.

b) Speed: speed would be about 400 nanoseconds per 8 bytes or faster. This is more than six times faster than the current 9020A Model 08 SE memory. The greatly increased speed would not improve single processor performance but would markedly reduce storage interference. The full potential of IOCE off-loading of 40% processing capacity for the 9020A could be realized. The reduction of the current estimate of 10 to 20% for 200 track load storage interference would be added to the IOCE off-loading capacity.

c) Reliability: error correcting circuits and built-in diagnostics are extremely reliable. Diagnostics for the multiport switch could be built-in, or possibly existing diagnostics could be used.

Processing capacity would also become greater by increased memory capacity which could eliminate swapping and allow algorithmic trade-offs of processing capacity for memory capacity. Eliminating swapping of the program should give more than a 10% improvement at a 200 track load. Algorithmic trade-off would have to be studied carefully, but 20% or greater improvement would not be unusual.

Eliminating program element swapping and existing storage element interference might give a 30% processing capacity improvement. This would be without extensive software changes as might be incurred in IOCE off-loading. Simulations could be employed to further investigate the potential of faster and increased memory for the 9020A®.

Another possible product of recent technology is the use of primary memory technology for secondary memory devices such as disks. This would be a pseudo disk with zero rotation latency and microsecond access time. Data transfer would be from memory to memory. No overruns would occur. Transfer could be interrupted. Transfer would be at the maximum speed determined by the IOCE. Thus disk accesses would be reduced from almost a tenth of a second to microseconds.

The estimated cost of the memory extendor approach would be a one-time $100K engineering and programming cost; $10K for each pseudo device for cabinet, rack, and power supply; and $10K per megabyte of capacity. Typically, an eight megabyte capacity per device is the limit of current off the shelf products.

This last approach should work well with the 9020D® system to reduce swapping response time without increasing memory capacity. The 9020A system would possibly not be improved due to its other limitations. Simulation could also explore the benefits of the memory extendor enhancement.

Many alternatives are available to enhance the capacity of the 9020® Systems. If needed these alternatives could increase the capacity to meet the increased traffic growth and NAS software improvements until 1990. None of the alternative enhancements would change the basic architecture of the current NAS En Route Systems. Thus baseline transition possibilities will not be significantly impacted by possible enhancements.

C.7 PROJECTED NAS EN ROUTE CONFIGURATIONS FOR THE LATE 1980's

To validate baseline assumptions, projections were made of current planning to determine how the NAS En Route System would evolve by 1985. These projections included system performance and peak traffic loads. Figure C-7 illustrates the expected evolution of current plans. The PAM designates the replacement of the current PAM.

Examination of the configuration in Figure C-7 suggests the possible incorporation of the NADIN processor, the data receiving group, and the PAM replacement into a single communications processor. A possible configuration is illustrated in Figure C-8. This configuration would consolidate the communications functions. Additionally DARC has ready communication paths to the 9020 and ETABS.

A more difficult and significant change of current plans would be to replace the CDCs and DCCs with an upgraded DARC system and use a central communications processor. Most of the architectures considered as replacements for the NAS En Route

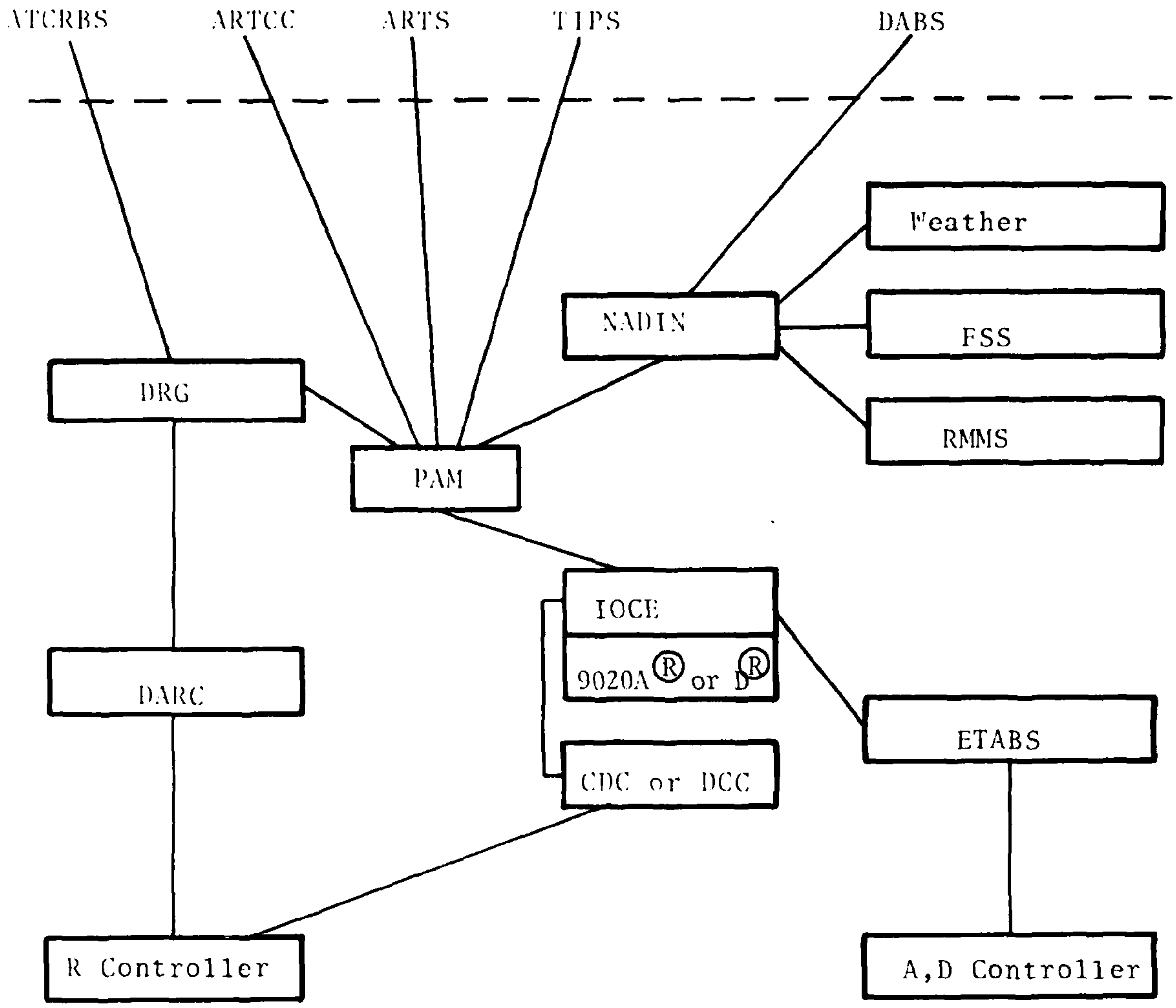

FIGURE C-7   PROJECTED CURRENT PLANS

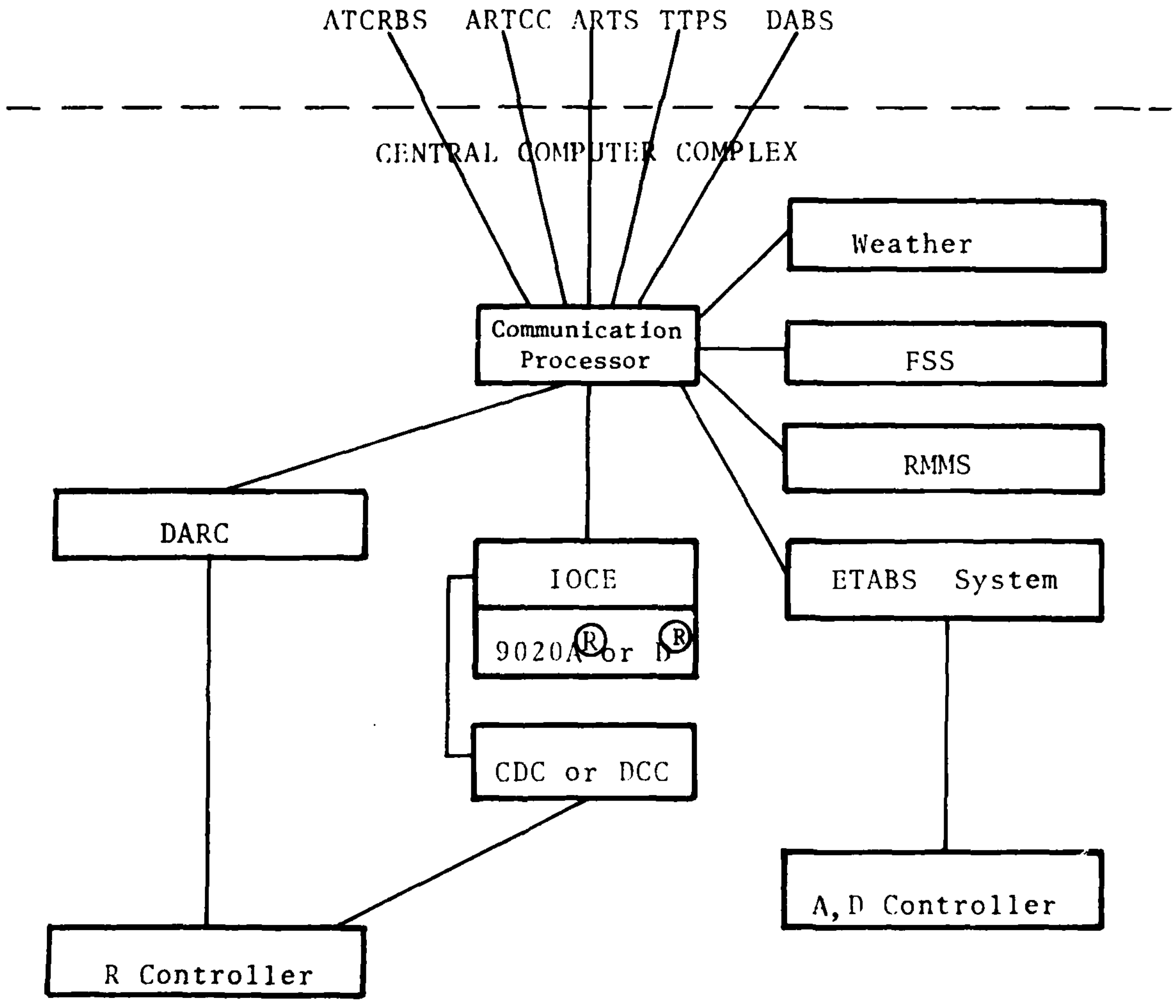

FIGURE C-8 COMMUNICATION PROCESSOR CONFIGURATION

System have a decentralized display support. The DARC system would be upgraded in the display processor area with one processor and display generator for each PVD. The simple star topology of the resulting configuration would isolate the 9020® system and facilitate its wholesale or evolutionary replacement.

One such transition configuration is depicted in Figure C-9. Although such considerations may be premature, the potential advantages of such configurations should be explored further.

The projection of current plans to the configuration in Figure C-7 is compatible with the assumed baseline functions. Other possible En Route configurations are not expected to change the basic system's architecture.

C.8 SUMMARY AND CONCLUSIONS

Summary

The order of magnitude of the accuracy for the functional processing load estimates has been verified for the functions which were common to the measurement data on the NAS En Route Stage A System Version 3d2.1.

The peak traffic loads for the busiest 9020A® and 9020D® ARTCCs were estimated through 1990. The ability of the 9020s to meet the projected traffic was surveyed. Alternatives for enhancing the 9020 CCC performance were reviewed. Projections of how the ARTCC configuration would evolve in the late 1980's were made.

Conclusions

The functional processing load estimates are accurate to within an order of magnitude.

The En Route System in the late 1980's will be very similar to the current system.

The busiest 9020A ARTCCs will require some enhancement of the 9020A hardware to meet peak traffic loads projected for the late 1980's. These possible enhancements will not affect baseline replacement considerations.

More performance measurement and analysis of the current NAS En Route System are needed to accurately predict system capacity and peak traffic loads.

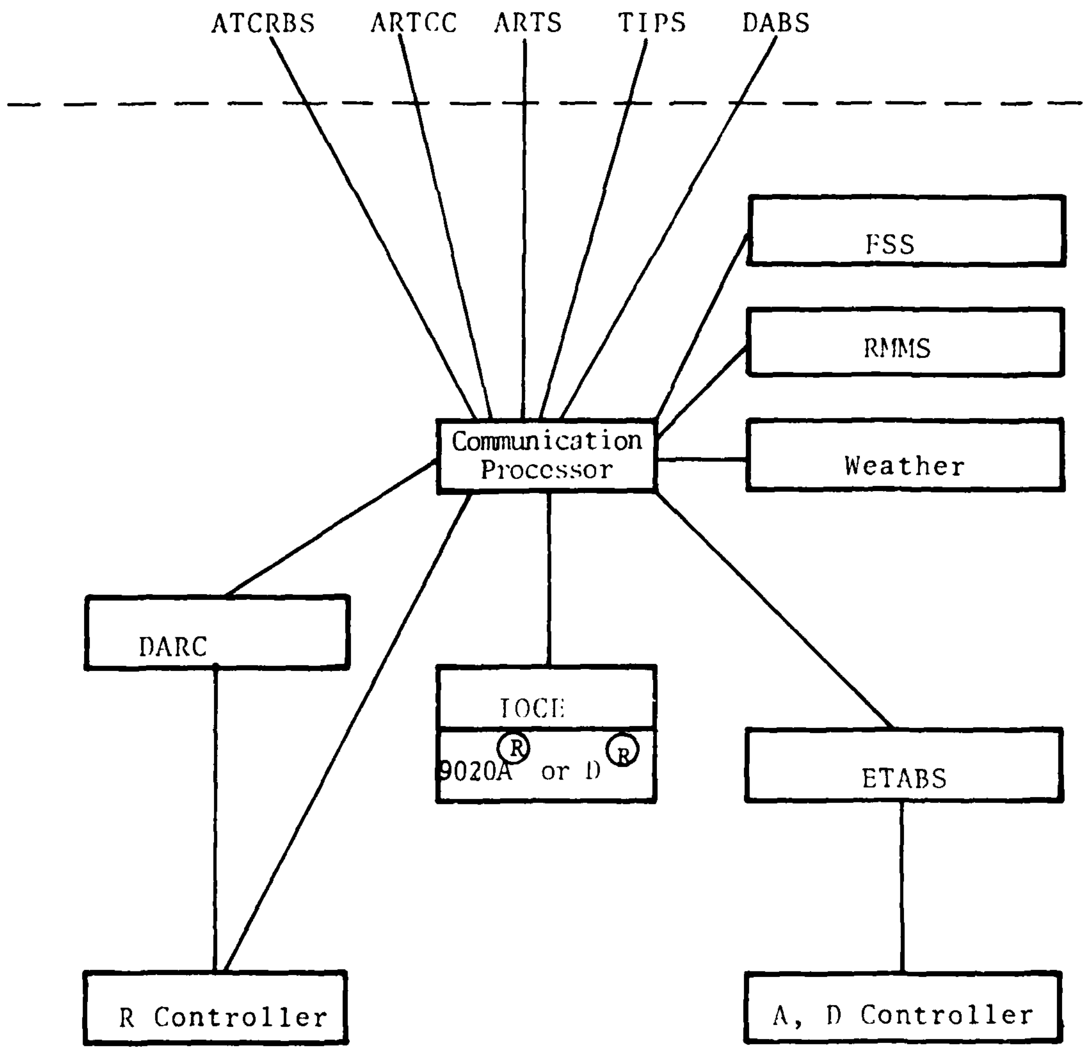

FIGURE C-9 TRANSITION CONFIGURATION

AD-A084 045 TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MA F/G 17/7
ANALYSIS OF EXPANDABILITY AND MODIFIABILITY OF COMPUTER CONFIGU--ETC(U)
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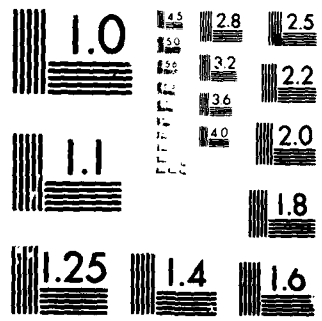
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

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