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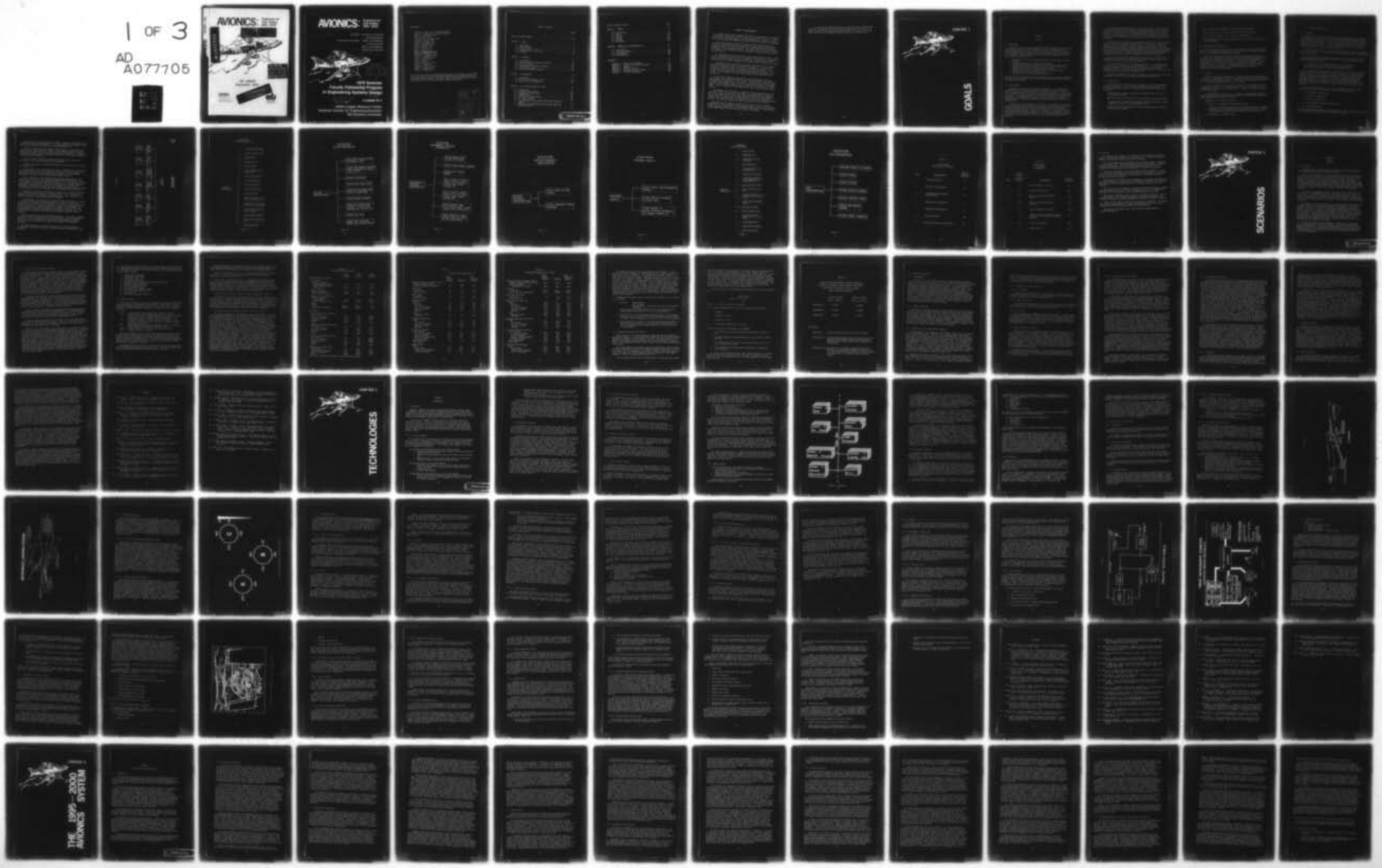

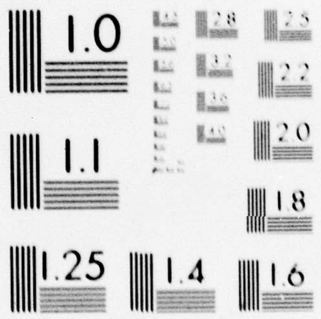

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AVIONICS: Projections for Civil Aviation 1995 ~ 2000

CR-159035
September 1979

NASA
National Aeronautics and
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Langley Research Center
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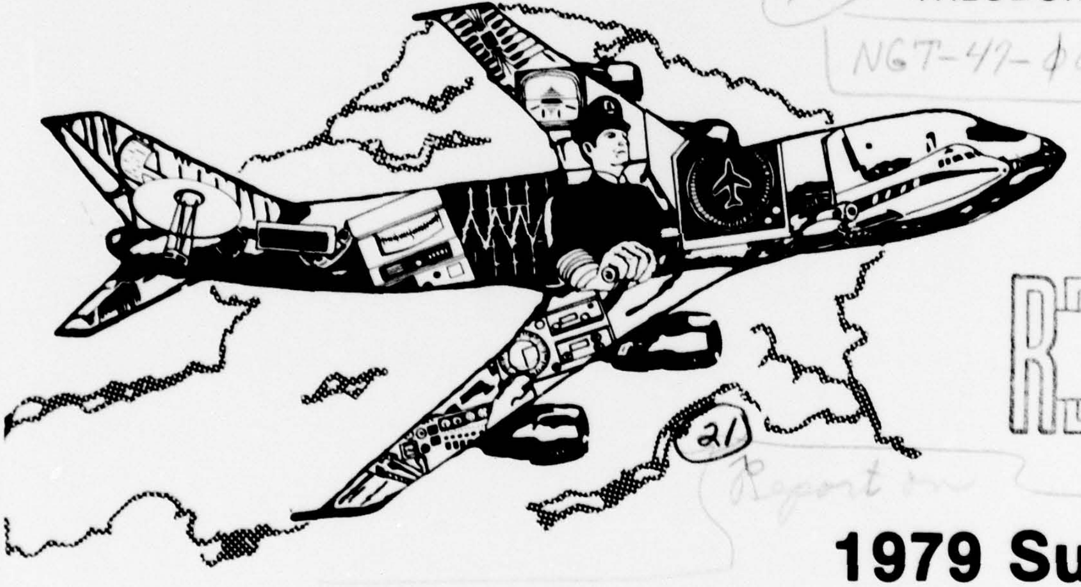

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1979 Summer Faculty Fellowship Program in Engineering Systems Design

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This report was compiled and written by the authors listed above, each of whom was a participant in the 1979 NASA-ASEE Summer Faculty Fellowship Program in Engineering Systems Design. The authors represented twenty different colleges and universities, and fifteen different academic disciplines.

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AUTHORS ACKNOWLEDGEMENTS

A report such as this represents the efforts of many people. The multiple authorship as indicated on an earlier page is only part of the story. These listed authors, brought together for an 11-week period to produce a study of this size, required considerable assistance to reach this level of achievement.

The first and most significant assistance came from Bill Mace and Ed Brummer of the Flight Electronics Division of Langley Research Center who picked the subject of our study and got us started with a clear and thorough explanation of the problem definition. They then took up the role of advisors and became a rich and ready source of information. Without them this report would not exist.

Dr. John Duberg, Associate Director at the Langley Research Center, acted as our co-director and was not only instrumental in creating this program and selecting the participants but also provided the constant support at the administrative level which allowed us to so easily perform our day-to-day tasks.

Frank Owens, of the Personnel-Training and Educational Services Branch, was our most immediate source of administrative support. The services he rendered to the entire group left virtually nothing to be desired. It is principally because of Frank's willingness and resourcefulness that a lack of administrative support never became even the slightest hinderance to our effort. On the contrary, our every need seemed satisfied even before we realized it.

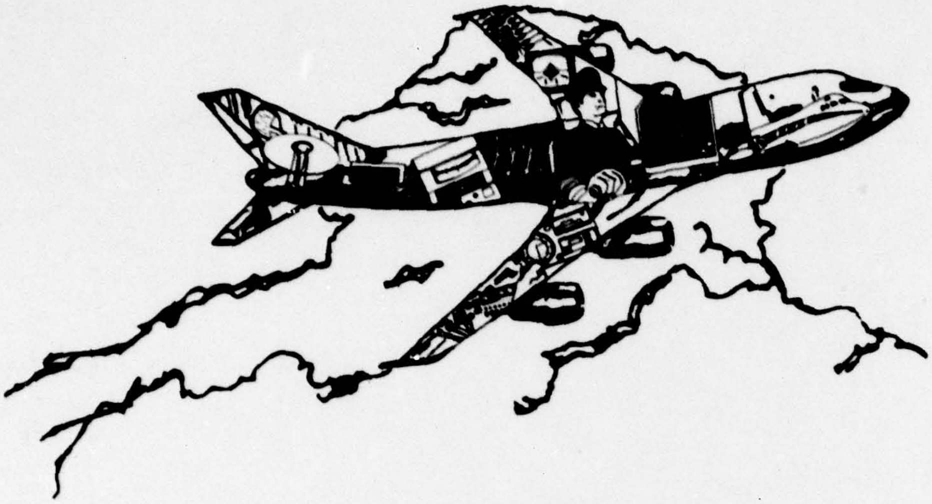
Our own staff, though working together only for the short period of eleven weeks, did an amazingly effective job of keeping the office operating and preparing the manuscript of this report. The secretaries, Beverly Dorton, Winifred Creech, Barbara Kehoe, and Carol Privette under Beverly's leadership managed to be extremely productive while maintaining a pleasant office atmosphere. Carol, in addition to her other duties, ran a very successful project library.

Kirt Babuder, our illustrator, in addition to being responsible for the cover and all the illustrations in the report, was responsible for preparing the several hundred color slides which were used when the Fellows presented an oral report on the study to the NASA community. He and his assistant, Beth Busick, put in many hours of overtime to accomplish this prodigious amount of work. The reader can judge for himself the quality of their efforts.

Mike Davis was the computer operator for the project and is primarily responsible for the effective role the computer played. He wrote the programs, entered the data, and produced the results which are evident in the paragraphs on the Delphi/Pattern work and in other places in the report.

It is obvious that the material in this report has been collected from many sources. We hope proper recognition has been made in all cases. The reader is urged to assign credit to sources where it is due but to realize that error in fact or judgment should be assigned to the authors only.

CHAPTER 1



GOALS

CHAPTER 1

GOALS

1.1 Background

The 1979 Program in Systems Engineering Design convened at Langley Research Center (LaRC) from June 4, 1979 to August 17, 1979. Co-sponsored by the National Aeronautics and Space Administration (NASA) and the American Society for Engineering Education (ASEE), this research endeavor was administered by the Old Dominion University (ODU) Research Foundation and enabled 22 participants, known as Design Fellows, to:

1. Contribute in a creative substantive manner to the selected research project;
2. Increase competence and professional knowledge;
3. Develop systems design concepts which can provide foundations for organizing and conducting multidisciplinary programs and courses, thereby enriching their colleges and universities;
4. Establish and improve communication and collaboration between engineering and other disciplines; and,
5. Provide stimuli to current NASA investigations.

Since 19 colleges and universities and 14 academic disciplines were represented, the opportunity for successful accomplishment of these goals was available in the research environment.

1.2 Modi Operandi

Recognizing the diversity of possible viewpoints to any research topic from the many disciplines and educational institutions and the variety of knowledge bases for the selected topic, the principal investigator and coordinators from NASA and ODU utilized several different methodologies to achieve the above goals. Successful coordination and cooperation among all organizational personnel, appropriate NASA functional areas and personnel, and selected representatives of industry, government, and society, as well as the fellows, were required.

Concurrent with an introduction to systems and the specific research topic, the 22 participants were divided into four groups. Each group was assigned a chairperson and each had representatives from the different disciplines, insofar as this was possible. These initial groups had a lifetime of approximately three weeks and were designed to give fellows an introduction to and assimilation of the involved technologies. Each group developed and presented a plan by which the research project could be accomplished and the report written.

New committees were then formed in accordance with the consensus-derived plan to recognize and investigate appropriate problem areas. Each Fellow was assigned to a minimum of four committees and was chairperson of at least one. Typically, the participants were assigned additional responsibilities such as initiating and coordinating visits and speakers, writing reports, and acting as editors. The interdisciplinary experience was most impressive during these activities.

A seminar and lecture series was conducted to enrich the Fellows' technical competence and amplify engineering systems design techniques. Experts were invited to discuss appropriate technical topics. These experts included representatives from academia, industry, governmental agencies such as NASA and the FAA, and organizations reflecting viewpoints of groups which could influence the design study. The speakers were available to the group for subsequent consultation and discussion. These seminars and group/individual discussions enabled the Fellows to assimilate viewpoints and technical knowledge.

Tours and visits provided opportunities to see appropriate facilities and determine current technology. Additionally, proposed research efforts were reviewed and discussed with appropriate personnel.

All applicable NASA facilities were made available. A highlight of the facility visits was a two day trip to Washington, D.C. The participants received an indoctrination to the realities of operating a busy airport, Washington National. The other day was spent by the Fellows visiting and interviewing appropriate governmental representatives.

The study coordinators, principal investigator, and the Design Fellows were responsible for initiating and coordinating the seminars and visits.

1.3 Design Project

The topic for this 1979 study was The Impact of Avionics Development on Future Civil Aircraft. The time period of 1995-2000 was emphasized. The following generalized questions initiated and stimulated the research and discussions:

> How can avionics be used to minimize environmental impact of the air transportation system?
>
> What will be the role of the pilot in future highly automated aircraft?
>
> In what areas of technological development should the government (NASA) concentrate its research and development effort?
>
> Will the cost of the application of the new technology be justified by benefits to the system?

What are the societal impacts of an advanced civil aircraft?

How can avionics be used to make aircraft more fuel efficient?

What role will avionics play in improving flight safety?

Will the application of avionics enhance the U.S. position in the world aircraft market?

1.4 Determination of Objectives

During the summer, group consensus was sought at the committee and program levels. The effects of group dynamics and inter-disciplinary interactions were not lost but rather were emphasized continuously.

The initial organization of groups lasted approximately three weeks and was intended to improve the assimilation of applicable technical knowledge and to develop an organizational and functional plan for the remaining weeks. Following this brief three week period, all Design Fellows convened to review these proposals. During this discussion, the objectives of avionics were reviewed, discussed, and argued. Some agreement was reached, but it became obvious there was no consensus. To provide assistance, a combined DELPHI/PATTERN exercise was suggested.

1.4.1 DELPHI

DELPHI is a systematic methodology for obtaining and expressing judgments. It consists of respondents' opinions on a particular subject provided by a series of specially designed questionnaries. These questionnaires contain summaries of data, information, and opinions from previous rounds.

A round is defined as completion and submittal of a questionnaire by the respondents. Generally, a sufficient number of rounds are completed to ensure a convergence of opinion or a consensus occurs. Normally, a DELPHI consists of four or five rounds.

A coordinating and control group is created to aggregate data, summarize previous responses, and provide editorial services. One committee accomplished these functions for this three round DELPHI.

Advantages of the DELPHI technique are

1. Anonymity - respondents never meet face to face;
2. Limitation of the negative aspects of most group techniques - dominance, persuasion by "silver tongued" orators, conflict, little or no input from people who hesitate to express themselves before groups, etc.;
3. Generation of a consensus; and,

4. Quantitative responses.

1.4.2 PATTERN

PATTERN, an acronym for Planning Assistance Through Technical Evaluation of Relevance Numbers, is a normative forecasting technique developed by the Honeywell Military Products Group. It utilizes a relevance tree, generally involves many variables, and attempts to provide a quantitative comparison of alternatives by means of relevance numbers. This technique necessitates disaggregation of a complex decision into its basic parts. Beginning with the primary objective, all elements are broken down into their constituents.

For this study, avionics was broken down into the major objectives provided by the group's consensus. These major objectives were then further disaggregated into sub-objectives.

Prior to the initial round, the DELPHI control team summarized the group's comments concerning the objectives of avionics. One group suggested the following definition of avionics:

> . . . the branch of electronics dealing with the development, manufacture, and use of electronic devices and equipment in aviation and astronautics. (New World Dictionary, p. 91)

Despite additional research and excellent seminars and speakers, it became apparent the definition of avionics is at best elusive and is interpreted by people differently. Viewpoints vary with one's employer, assigned responsibilities, functional job assignment, and funding. Because of these variables, the above definition was accepted and this study's avionics functionally selected to achieve our objectives. It was also decided that appropriate ground-based electronic equipment would be included in the definition. This meant the summer research would be an airborne and ground integrated systems approach.

With this definition, the control team distributed the Round 1 questionnaire which included the following five major avionics objectives:

1. Comfortable transportation
2. Economical transportation
3. Efficient transportation
4. Environmentally acceptable transportation
5. Safe transportation

Each of these was disaggregated into sub-objectives. Participants were requested to review these and add any which they thought appropriate.

After Round 1, the responses were reviewed. Economical transportation was changed to productive transportation. Two major objectives were added. These were national emergency transportation and employee benefits.

Several sub-objectives were added. Where possible, sub-objectives were grouped under a major objective. However, the respondents never did reach a consensus with regard to efficient and productive transportation, so there are sub-objectives which appear in both major objectives. Comfortable transportation also contains duplicates.

After the above aggregation and appropriate form design, Round 2 was distributed. This round was the first to use PATTERN.

Figures 1-1 through 1-8 present the relevance tree upon which this consensus was developed.

During Round 2, each participant was asked to distribute 100 points among each relevance tree node. This meant distribution of 100 points among the major objectives with the primary objective, according to the individual respondent, receiving a proportionally higher number of points.

Each respondent also distributed 100 points among each subset of sub-objectives, with the most important being awarded the greatest number. The local relevance is the points awarded multiplied by .01. The partial relevance is obtained by multiplying all the local relevances from the major objective through the appropriate tree branch to the sub-objective in which one is interested. The partial relevance provides a decimal number by which all items of the relevance tree can be compared. All 22 respondents completed Round 2.

The Round 3 questionnaire provided each respondent his individual Round 2 point distribution and relevance for each objective. Also, a statistical summary of relevances was provided for each objective. This consisted of the median relevance and interquartile range of responses.

The respondents were requested to review these data and decide if a change in the Round 2 point distribution were warranted. Generally, there were convergences of judgments for most objectives. Table 1-1 provides the ranking of major objectives. A review of this table indicates the respondents, as a group, believed the the primary objectives of avionics are safe, efficient, environmentally acceptable, comfortable, and productive transportation. The partial relevances provide indications of the relative importance of each objective.

Table 1-2 summarizes the top seven sub-objectives. It should be recognized that of these seven sub-objectives, the major objective, safe transportation, includes 1, 4, and 7; environmentally acceptable transportation includes 3 and 5; efficient transportation includes 2; and productive transportation includes 6.

The major objectives, comfortable transportation, national emergency transportation, and personnel benefits, did not have any sub-objectives in the top seven.

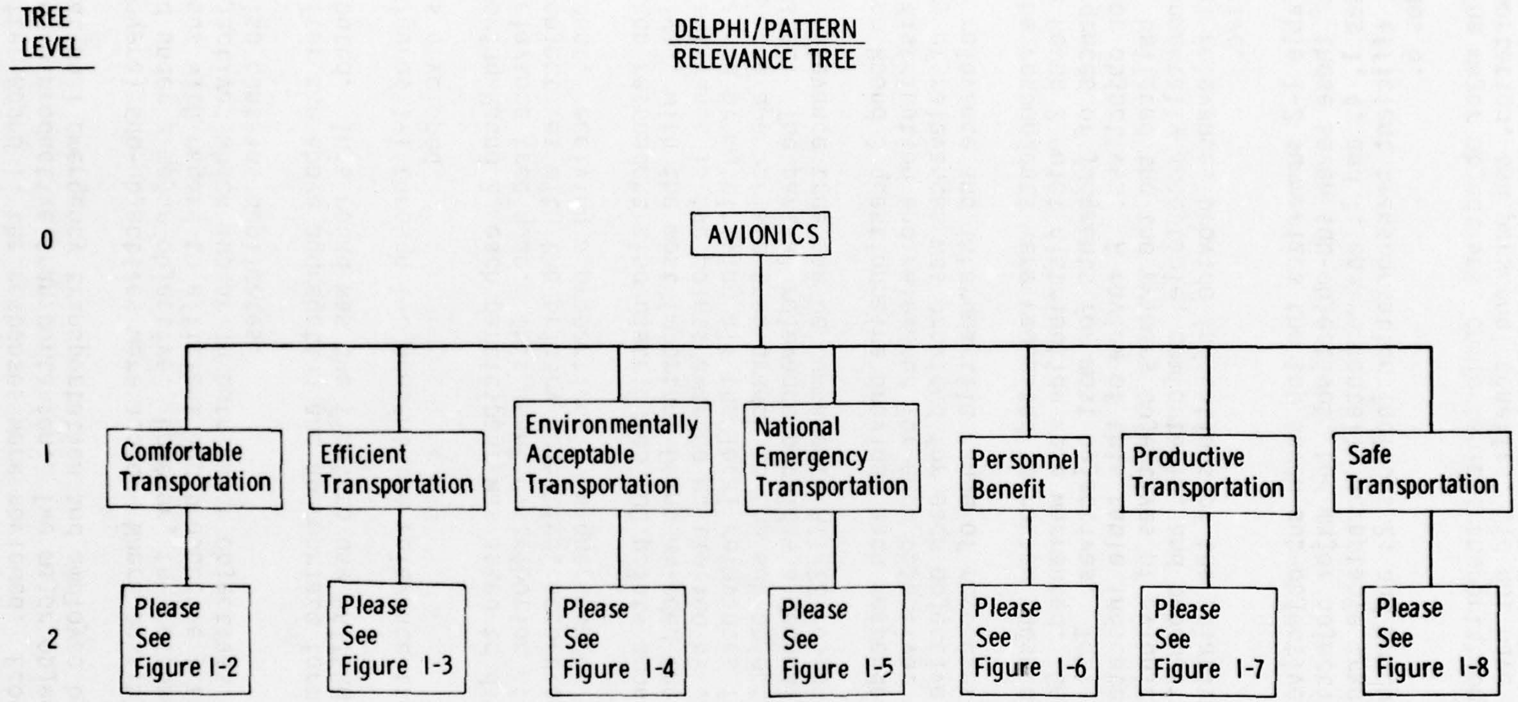

TREE LEVEL
DELPHI/PATTERN RELEVANCE TREE
0
AVIONICS
1
Comfortable Transportation
Efficient Transportation
Environmentally Acceptable Transportation
National Emergency Transportation
Personnel Benefit
Productive Transportation
Safe Transportation
2
Please See Figure 1-2
Please See Figure 1-3
Please See Figure 1-4
Please See Figure 1-5
Please See Figure 1-6
Please See Figure 1-7
Please See Figure 1-8

Figure 1-1

DELPHI/PATTERN
COMFORTABLE SUB-OBJECTIVES

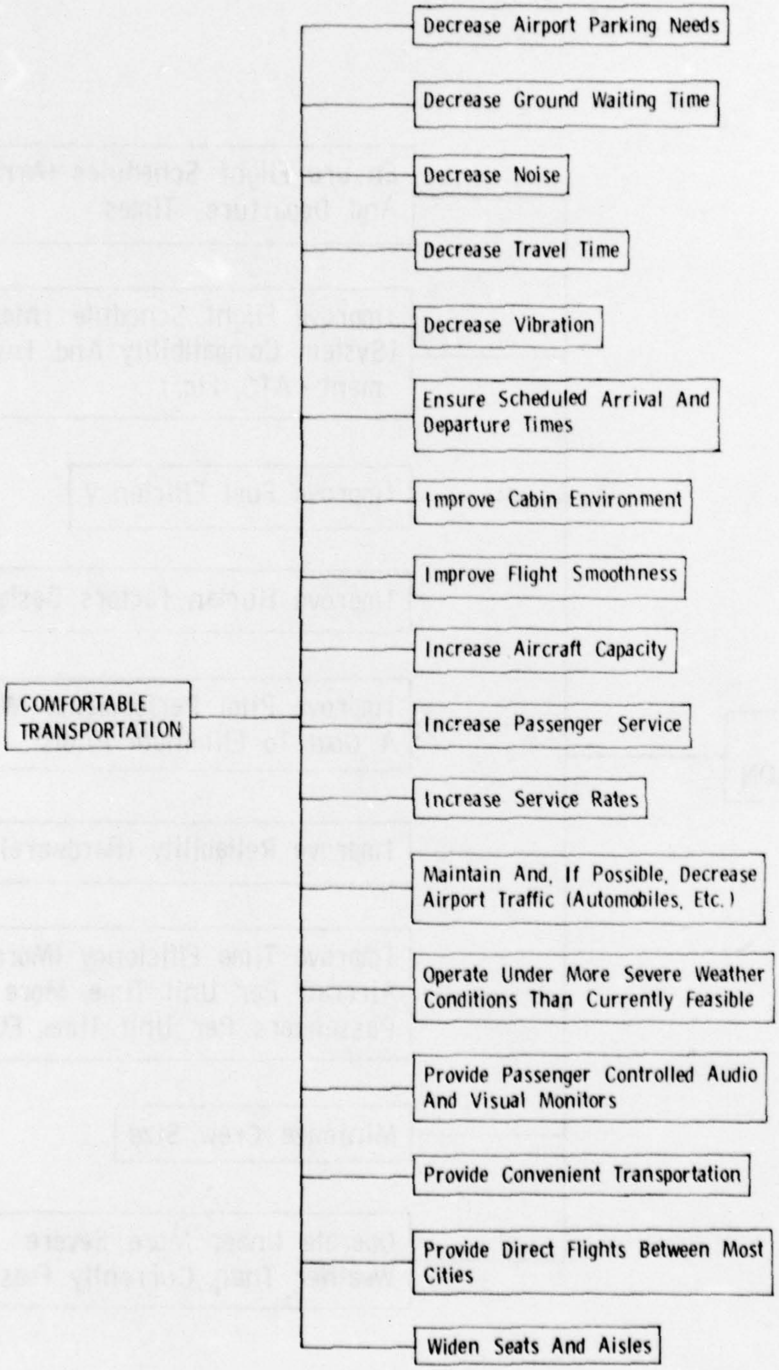


Figure 1-2

DELPHI/PATTERN

EFFICIENT TRANSPORTATION

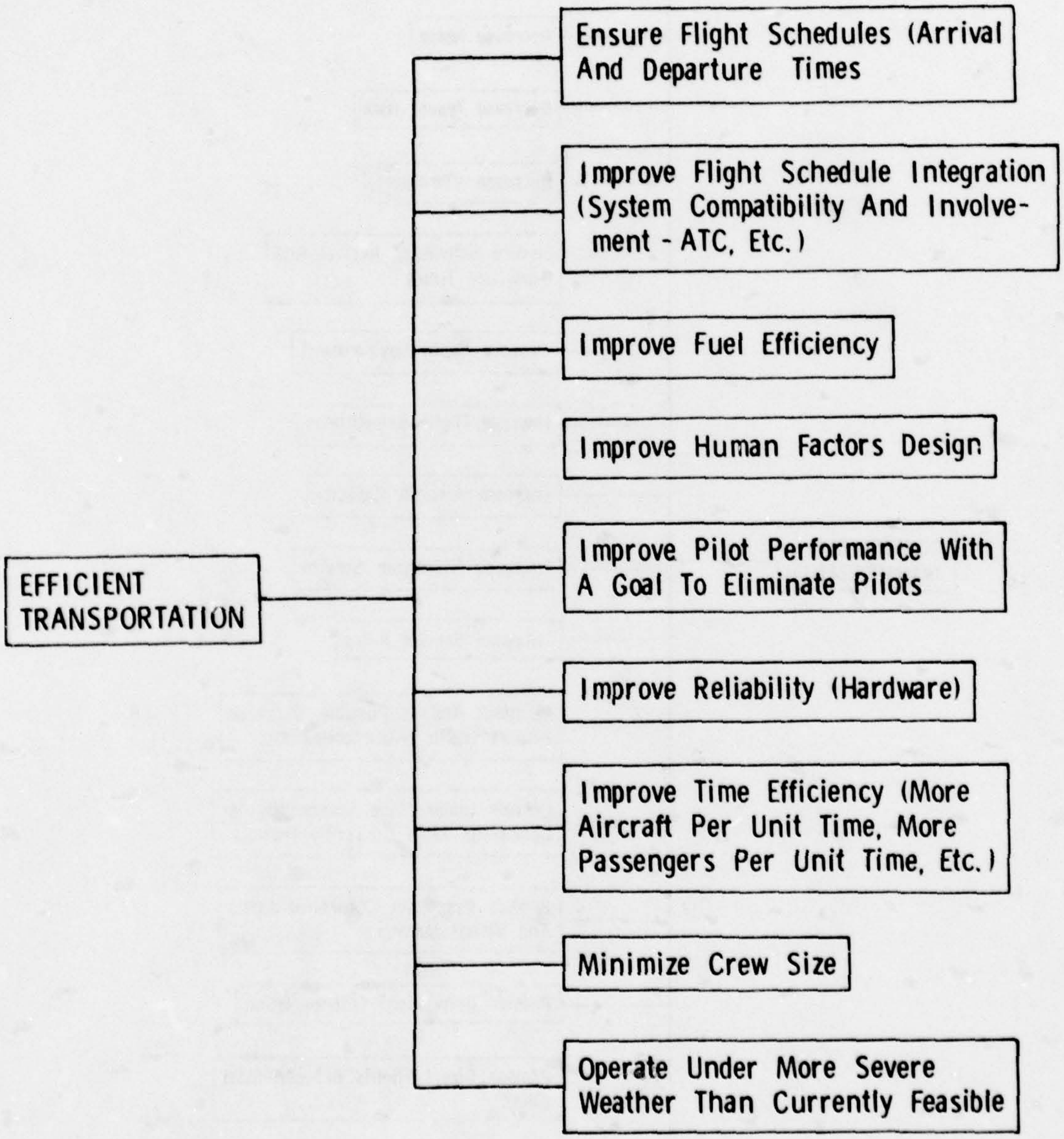


Figure 1-3

DELPHI/PATTERN

ENVIRONMENTALLY ACCEPTABLE TRANSPORTATION

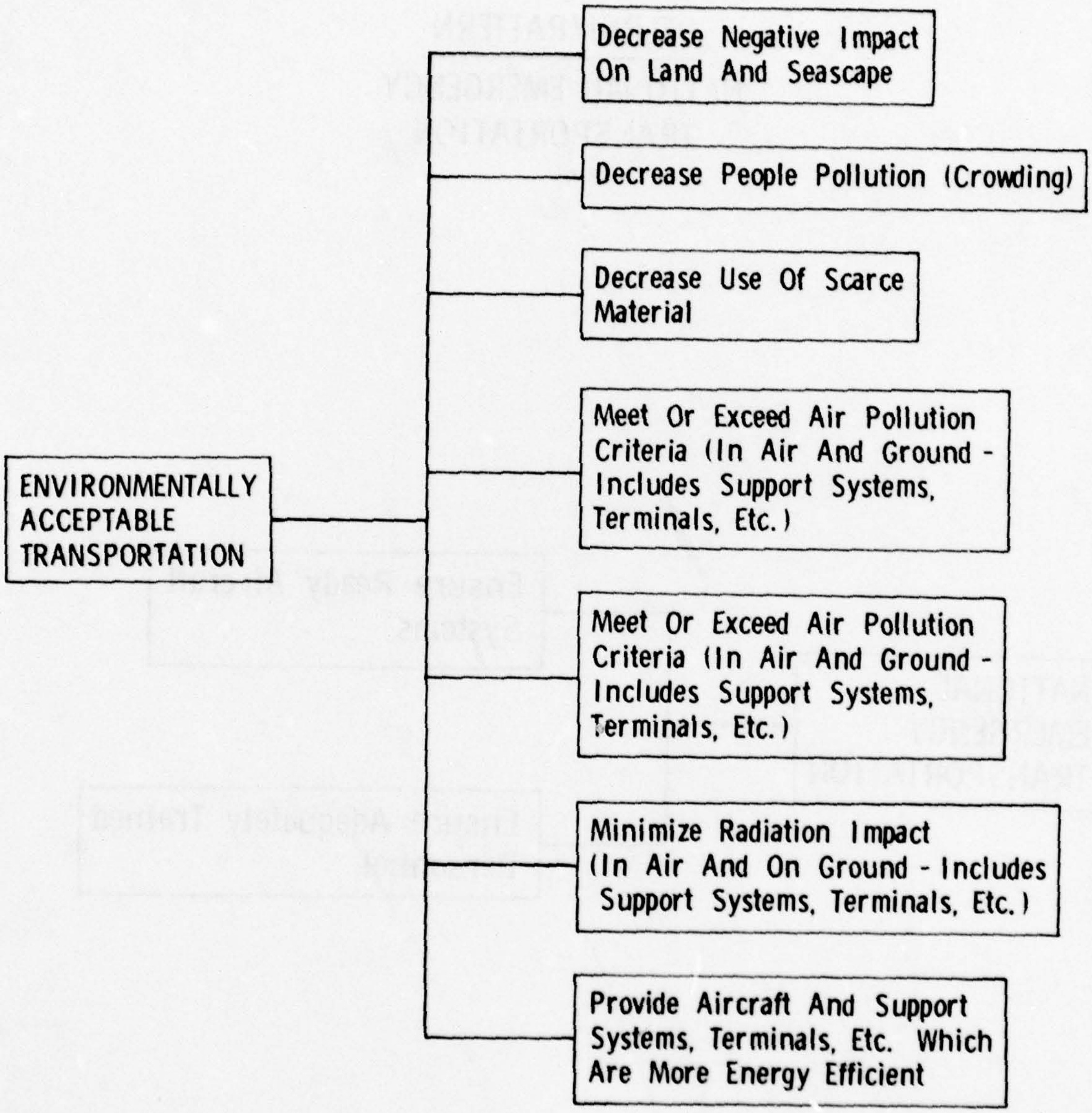


Figure 1-4

DELPHI/PATTERN

NATIONAL EMERGENCY TRANSPORTATION

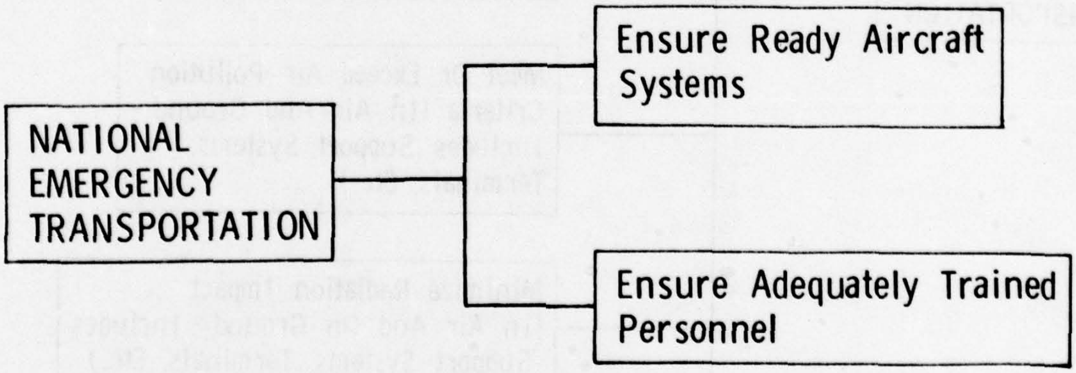


Figure 1-5

DELPHI/PATTERN
PERSONNEL BENEFITS

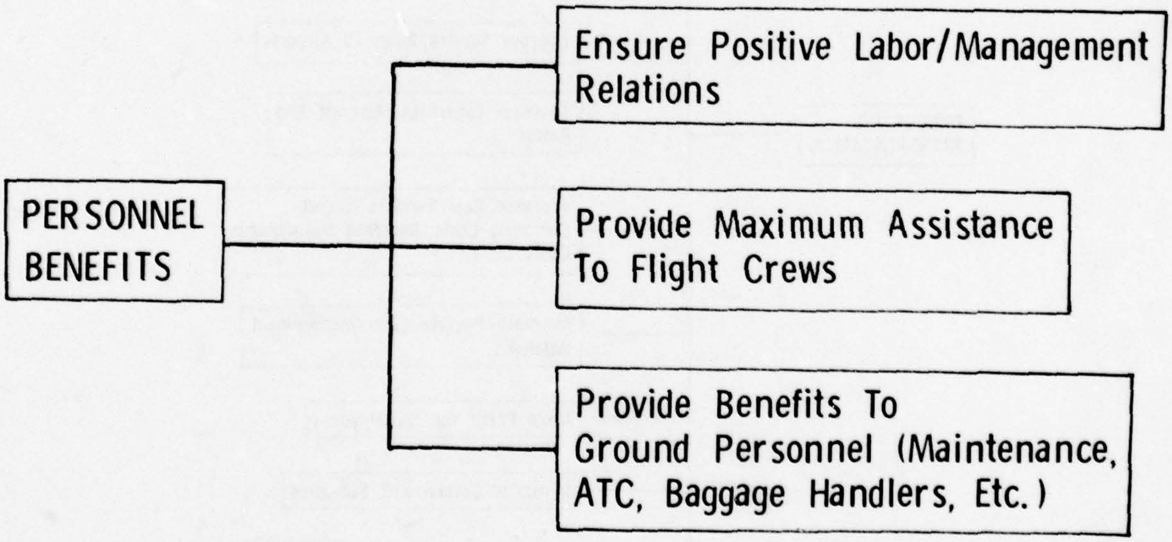


Figure 1-6

DELPHI/PATTERN
PRODUCTIVE TRANSPORTATION

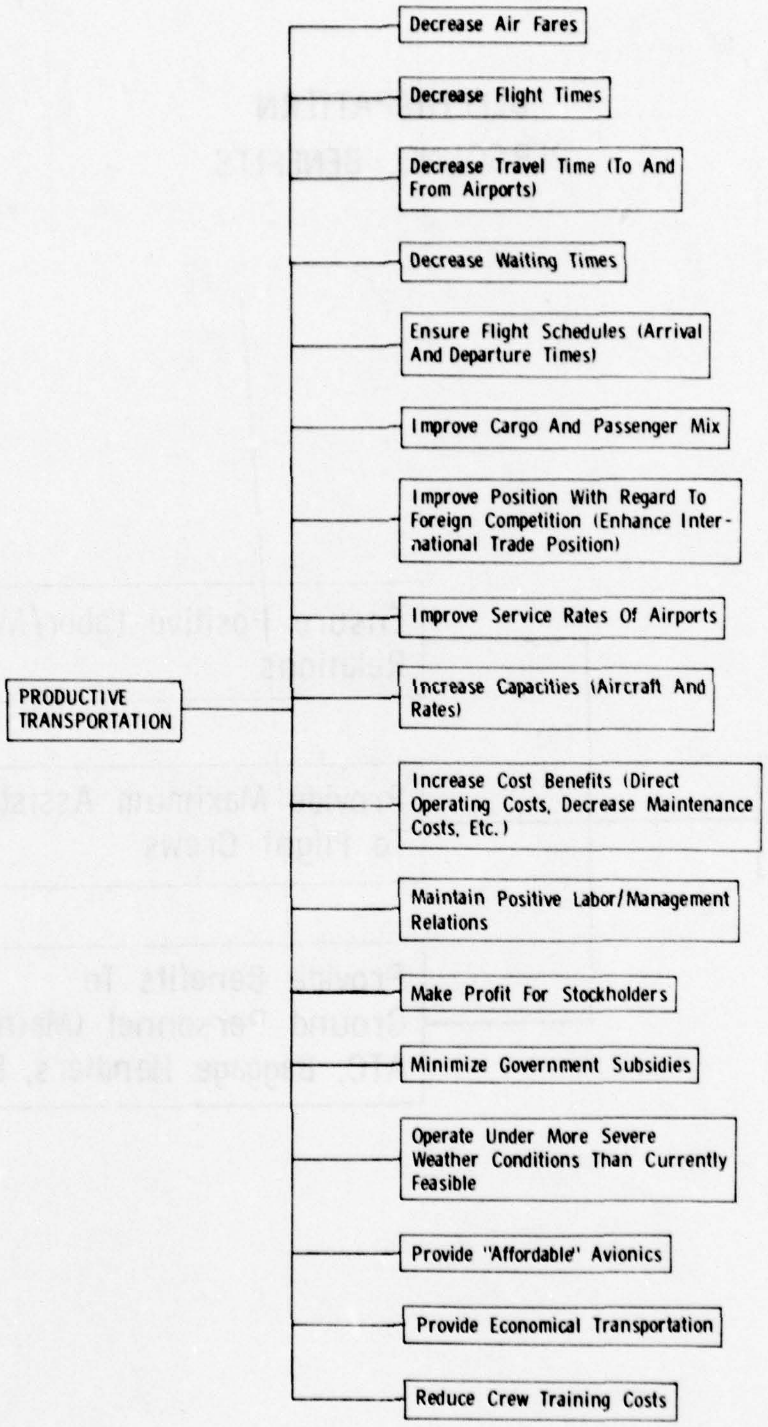


Figure 1-7

DELPHI/PATTERN

SAFE TRANSPORTATION

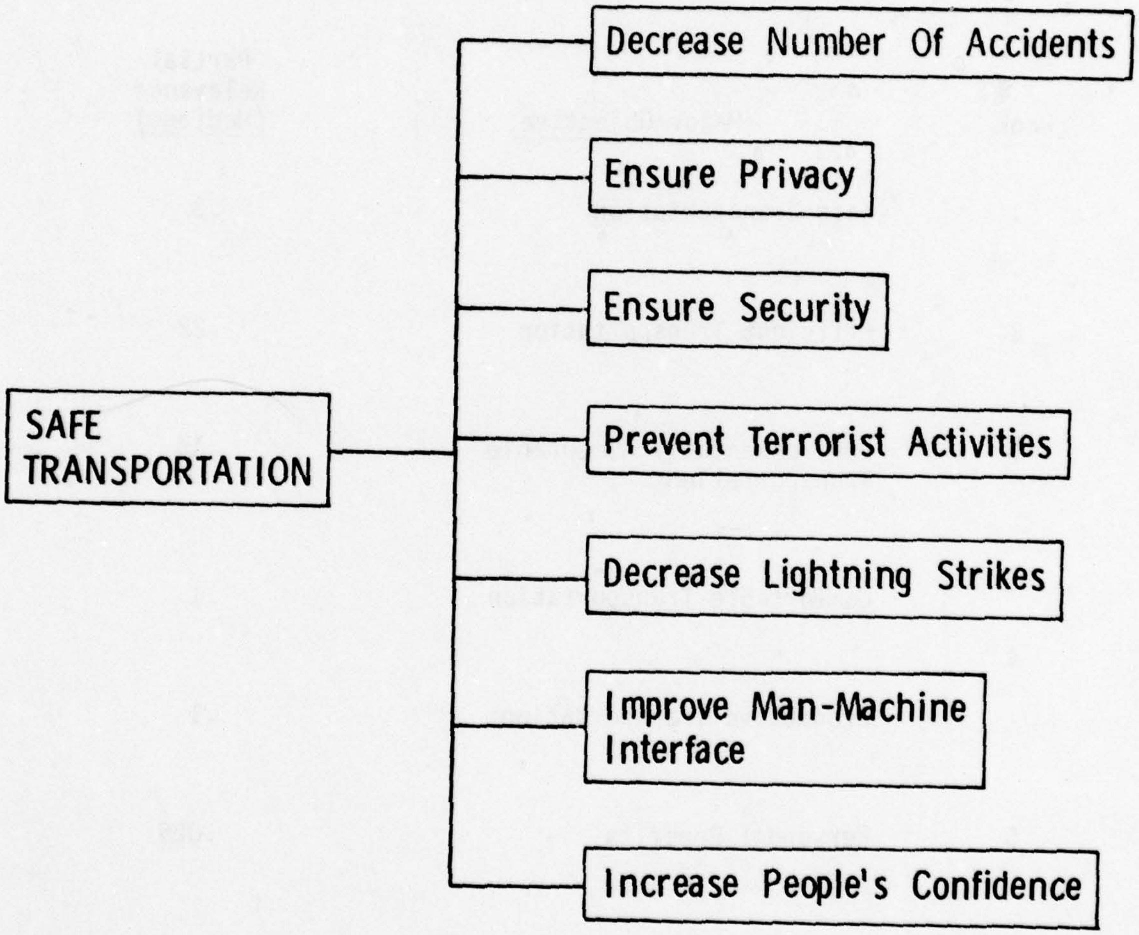


Figure 1-8

Table 1-1

DELPHI/PATTERN
Major Objectives Rankings

Rank	Major Objective	Partial Relevance (Medians)
1	Safe Transportation	.3
2	Efficient Transportation	.22
3	Environmentally Acceptable Transportation	.16
4	Comfortable Transportation	.1
	Productive Transportation	.1
5	Personnel Benefits	.025
6	National Emergency Transportation	.01

Table 1-2

DELPHI/PATTERN
Top Seven
Sub-Objectives

Rank	Major Objective And Sub-Objective Number	Sub-Objective	Partial Relevance
1	S 1	Decrease Number of Accidents	.21
2	E 3	Improve Fuel Efficiency	.04
3	EV4	Meet or Exceed Noise Pollution Criteria	.031
	EV5	Meet or Exceed Air Pollution Criteria	.031
4	S 6	Improve Man-Machine Interface	.0233
5	EV7	Provide Aircraft and Support Systems, Terminals, Etc. Which Are More Energy Efficient	.02
6	P10	Increase Cost Benefits	.015
7	S 3	Ensure Security	.014

1.5 Overview

This chapter has presented a brief summary of the 1979 Summer Fellowship Program, its objectives, sponsors, and administration. It also introduced the reader to the selected research topic and modi operandi.

The unique methodology, DELPHI/PATTERN, was utilized to obtain a consensus of avionics objectives. These results have been briefly presented. Knowledge of these objectives and their relationships provided participants with a foundation for evaluating avionics technologies, sub-systems, and systems.

The scenarios developed for this study are discussed in Chapter 2. A mainline scenario and an alternate provide the bases for development of a proposed avionics system. Both scenarios include variables and parameters affecting avionics and interested parties.

Technologies and selected avionics components, sub-systems, and systems are described in Chapter 3. The Fellows selected these as being the most important and critical to the 1995-2000 time period if the above objectives are to be achieved.

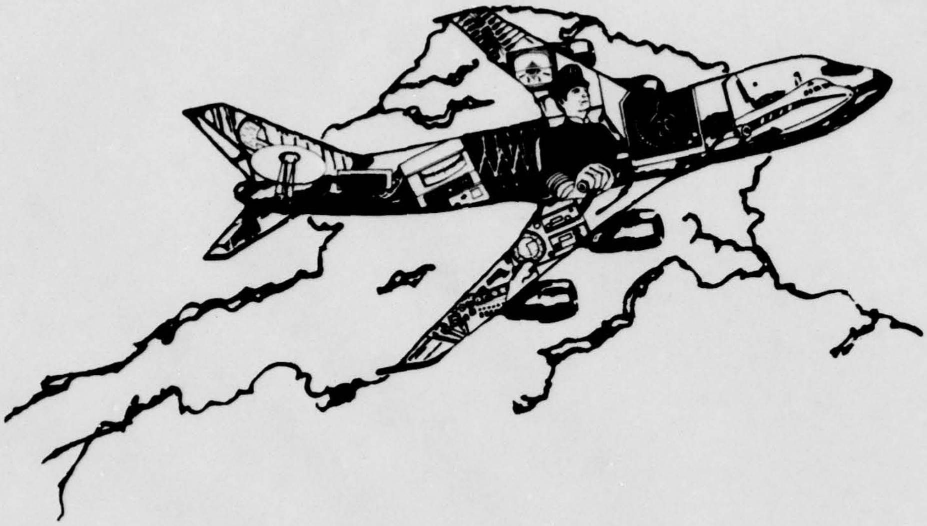
The reader will be introduced to the major electronic technological advancements which make possible significant improvements in avionics. Appropriate references will be provided if a more complete explanation is desired.

The proposed 1995-2000 avionics system is discussed in Chapter 4. Design and development of this system was based upon the appropriate scenario and analyses of 1995-2000 available technology to accomplish the goals of avionics.

Impacts of the proposed system will be presented in Chapter 5. The development of the proposed system, its impact, and evaluation constitutes a major contribution of the 1979 Systems Engineering Design Program.

A summary of the Design Fellows' conclusions and recommendations is provided in Chapter 6.

CHAPTER 2



SCENARIOS

CHAPTER 2

SCENARIOS

2.1 Introduction

Presented in the following pages are two scenarios describing possible aviation environments for the time frame 1995-2000.

The first, or mainline scenario, draws heavily on the FAA aviation forecasts-fiscal years 1979-1990. In FAA Aviation Forecasts-Fiscal Years 1979-2000, a "baseline" scenario and two alternative "economic" scenarios are presented. The latter are labeled "high prosperity" and "slow growth." The design team decided to treat these three scenarios as merely variations upon one scenario with the "high prosperity" and "slow growth" scenarios describing the upper and lower boundaries of the team's "baseline" scenario. The resultant composite scenario, extrapolated to 1995, was labeled the mainline scenario.

The second, or alternative scenario, describes a set of conditions which will result in a stabilization of the air transportation system, so that a condition of "no growth" is postulated in the total air traffic system. This scenario is based on the assumption that air traffic demand is a function not only of economic growth but also of a complex mix of societal and technological conditions.

Any attempt to assess the impacts of a given technology or technological system presupposes some knowledge regarding the environment in which the impacts are to occur. A realistic assessment of the general economic and societal conditions surrounding the technological development is the minimum standard necessary for determining the impacts of that technology. This is the case even if the impact study were related to a past or current technological development. When working with the future, the task is complicated by the fact that the surrounding conditions are yet to appear (ref 1). Consequently, some means must be devised for approximating these conditions before an impact assessment can be made.

A variety of tools have been developed to forecast future conditions. They include extrapolation, trend projection, cross-impact, and analytical modeling, among others. A problem with these methods is that they lack uniformity of results. The design team, therefore, concluded that the best way of approaching our study of avionics was to provide two scenarios based on different methodologies.

2.2 Justification for Scenarios Selected

The FAA Aviation Forecasting System for 1978 is the most complete and most detailed forecasting model available which specifically addresses U.S. civil aviation growth patterns. It makes use of the Wharton Econometric Forecasting Associates Economic Forecasts, data from the U.S. Department of Commerce, OBERS Projections of U.S. Economic Activity, the Data Resources Institute Economic Forecasts, and SRI International Economic Forecasts. The aviation environment is quite narrowly defined in terms of economic activity in this model; however, the major advantage of such a model is that it contains a wealth of detailed, precise information. The choice of the FAA model as a mainline scenario reflects the conviction that such a forecast, with its implicit assumption of the future as a continuation of the past, should constitute the skeletal element for planning. However, there is need to guard against catastrophic failure should this assumption prove unwarranted.

It seemed to the group that a cautious attitude toward the FAA forecast was justified for the following reason: The tacit and often explicit assumption of the FAA report, throughout, is that aviation activity is a strict function of disposable income which is a strict function of level of economic activity (economic throughput) which is, in turn, directly dependent upon the availability of energy. The picture has two disturbing features which motivated the team to construct a genuine alternative scenario.

First, it ignores the possibility of technological improvements such as telecommunication links and radical improvements in surface transportation which might provide alternatives to business-related air travel. Similarly, it ignores the possibility of technological breakthroughs in the area of recreation which might have drastic effects upon personal flying.

Second, it ignores the possibility of second, third, and higher order effects of both cheap and expensive energy. That is, it ignores the ramifying adjustments in the lifeways of individuals and aggregates of individuals as they respond to changes in their life chances.

Thus, the crux of the matter is that interaction of available energy with such factors as alternative technologies, demographic characteristics, changing values, and alterations in the world power structure may so radically alter the ambiance of American economic life as to negate the entire FAA model. In constructing the alternative scenario, the Design Fellows concluded that many variables, including even those which are qualitative or subjective, should be taken into account. It was recognized that populations change not only in number and economic status but also in characteristics and qualities (ref 2). For these reasons, it was decided that an alternative scenario would be constructed, one which would be more broadly based than an economic forecast. Underlying this scenario is the recognition that changes which involve a move away from current trends might ensue. Therefore, the alternative scenario is based more on the subjective predictions of knowledgeable persons than on strictly economic models.

Our alternative scenario will cover a mix of conditions, both in alternative technologies and latent functions, which will result in no growth in the air transportation system as it will exist in 1995. Factors which could bear on this scenario follow:

1. Urban center development
2. Telecommunication links
3. Prohibitive fuel costs
4. Recreational facilities
5. Strong correlation between air pollution and health
6. Improved surface population
7. Near zero population growth
8. Total disposable income
9. Distribution of disposable income
10. Relatively high air travel cost
11. World politics
12. Non-optimal regulatory decisions

2.3 Mainline Scenario

The mainline scenario is based on FAA forecasts for the years 1979-1990, with the necessary extrapolation to the year 1995. The FAA model utilizes forecasts from Wharton Econometric Forecasting Associates, Inc. as economic assumptions and makes Revenue Passenger Miles a function of the following variables:

Yield -average revenue per passenger mile on domestic flights
PP -price index of private transportation (1972 = 100). This index represents the cost of owning, operating, and maintaining a motor vehicle (Source: Bureau of Labor Statistics).
YPD -disposable personal income in constant 1972 dollars. This variable is indicative of the real purchasing power available to be spent on aviation.
NRUT -unemployment rate as presently computed. This is the familiar figure issued by the Bureau of Labor Statistics.
DUM 69 -a dummy variable. It has a value of zero after 1969.
STR -a dummy variable for strikes.

The overall outlook for the 16-year forecast period is moderate economic growth, declining unemployment, and slowly declining inflation. Over the forecast period, annual growth for real GNP is predicted to average approximately 3.3 percent in constant dollars. This rate is less than the historical average owing to the recent decline in population and productivity growth. These trends are expected to continue.

Unemployment rates are expected to decline steadily during the forecast period, reaching approximately 4.0 percent by 1990. The average annual inflation rate anticipated for the forecast period is 6.2 percent.

Consumption patterns are expected to shift, with a greater proportion of disposable income being spent on fuel and fuel efficient durable goods. However, growth in aviation demand is still expected to exceed GNP growth.

Fuel costs are assumed to rise 6.2 percent annually throughout the forecast period. In addition, the forecast assumes fuel usage will not be restricted by forces other than price.

In the area of regulatory reform it is expected that competitive market forces in the air carrier industry will be strengthened by legislation such that entry and expansion into existing and new markets will be facilitated. Proposed regulatory reform will also provide carriers with greater discretion in fare-setting, encourage air commuter service to small communities, and allow commuter carriers to operate larger aircraft. For an expansion, please see the full FAA Aviation Forecasts - Fiscal Years 1979-1990 (ref 3).

A summary of the mainline forecast to 1995 is presented in Table 2-1.

The predictive accuracy of this model declines as forecasts move further into the future. Planning must anticipate variations from the mainline, since there is really a range of conditions that can be anticipated. Each encompasses a slightly different set of assumptions about the future. Therefore, this mainline scenario will have high and low limits which will reflect higher and lower levels of economic activity. That is, the economy is assumed to experience either faster or slower growth relative to that of the baseline.

The limits around the mainline are shown in Tables 2-2 and 2-3.

The general conditions for the high limit are the following: A series of energy conservation measures assure an ample supply of fuel. The U.S. becomes less dependent on imported oil; the world price of petroleum drops; and the U.S. balance of payments comes into equilibrium. GNP grows at an average annual rate of 4.6 percent in constant 1972 dollars. The unemployment rate drops to 4 percent. Inflation rises at an average of 4.1 percent because of relatively stable energy costs. Disposable income rapidly rises and consumption grows by about 4.35 percent. Fuel prices rise in proportion to the general inflation rate. Regulation leads to an increase in air carrier operations, improved service, more rapid introduction of new aircraft, retirement of existing aircraft, and a slower rise in the price of air fares. Demand for all modes of transportation increases as a result of expansive growth in business activity, leisure time, and income. Fuel efficiency improves signficantly and aircraft noise levels are reduced as a result of accelerated fleet turnover. The expansive growth of income, leisure time, and business activity results in a boom for General Aviation (GA). A pilot's license and access to an airplane become a commonly pursued status symbol. Total private and commercially licensed pilots increase to more than a million by 1990. Over half a million pilots receive instrument ratings. Advanced avionics make navigation and communication equipment much lighter, less expensive, and simpler to operate. An expansion in international trade and disposable personal income results in a boom for international aviation.

Table 2-1
Aviation Activity Forecasts

	1979 Estimate	1995 Forecast	Growth (Percent)
Aviation Activity Forecast			
Air Carriers			
Revenue Passenger Enplanements(Millions)	317.7	645.2	103.1
Revenue Passenger Miles (Billions)	256.1	553.0	115.9
General Aviation			
Fleet (Thousands)	193.0	354.0	83.4
Hours Flown (Millions)	39.0	75.5	93.6
Commuter Carriers (Millions)			
Revenue Passenger Enplanements	9.9	25.8	160.6
Revenue Passenger Miles	1226.8	3268.4	166.4
Military			
Fleet	18623.0	19799.2	6.3
Hours Flows (Thousands)	5090.0	5354.0	5.2
FAA Workload			
Aircraft Operations (Millions)			
Air Carrier	10.4	14.2	36.5
Air Taxi & Commuter	4.3	11.2	160.5
General Aviation	53.4	85.3	59.7
Military	2.5	2.5	
Total	70.6	113.2	60.3
Instrument Operations (Millions)			
Air Carrier	10.7	14.6	36.4
Air Taxi & Commuter	3.2	8.7	171.9
General Aviation	17.2	49.0	184.9
Military	3.7	3.7	
Total	34.8	76.0	118.4
IFR Aircraft Handled (Millions)			
Air Carriers	14.1	19.0	34.8
Air Taxi & Commuter	2.2	8.5	286.4
General Aviation	8.1	25.1	209.9
Military	4.8	4.8	
Total	29.2	57.4	96.6
Flight Services (Millions)			
Pilot Briefs	19.0	37.0	94.7
Flight Plans Originated	9.8	20.4	108.2
Aircraft Contacted	10.5	9.8	6.7
Total	68.1*	123.8*	81.8

*FAA never explained the procedure for estimating the totals.

Table 2-2

	Annual Average Growth Rates (%)		
	Slow Growth Scenario	Baseline	High Prosperity Scenario
Scheduled Domestic Passenger Traffic			
Revenue Passenger Miles	3.0	4.9	6.0
Revenue Passenger Enplanements	3.5	4.5	6.7
Fleet Size			
Air Carrier	1.0	1.8	2.0
General Aviation	3.0	3.9	7.0
Hours Flown			
Air Carrier	1.2	1.9	2.8
General Aviation	3.8	4.2	4.7
Tower Operations			
Total	1.5	3.0	4.3
Itinerant	1.5	2.4	2.9
Air Carrier	1.4	1.9	2.3
Air Taxi & Commuter	5.3	6.2	6.7
General Aviation	1.9	3.0	3.6
Military	---	---	---
Local			
General Aviation	1.4	3.0	5.7
Military	---	---	---
Instrument Operations			
Total	1.9	4.9	6.2
Air Carrier	1.4	1.9	2.3
Air Taxi & Commuter	5.2	6.5	7.9
General Aviation	5.0	6.8	8.9
Military	---	---	---
IFR Aircraft Handled			
Total Handled	3.2	4.1	4.7
Air Carrier Handled	1.5	1.9	2.2
Air Taxi Handled	8.0	8.9	9.6
General Aviation Handled	6.3	7.3	8.1
Military Handled	---	---	---
Total Departures	2.4	3.0	3.5
Total Overs			
Flight Services			
Total	3.3	3.8	4.2
Pilot Briefs	3.1	4.3	5.9
Flight Plans Originated	3.8	4.7	5.6
Aircraft Contacted	0.8	-0.4	-2.0

Table 2-3
Alternative Forecasts for FY 1995

	Slow Growth Scenario	Baseline	High Prosperity Scenario
Scheduled Domestic Passenger Traffic			
Revenue Passenger Miles (Billions)	328.2	440.0	519.9
Revenue Passenger Enplanements (Millions)	396.5	595.1	671.3
Fleet Size			
Air Carrier	3037.5	3333.5	3544.1
General Aviation (Thousands)	335.5	354.0	462.2
Hours Flown (Millions)			
Air Carrier	7.7	8.8	10.3
General Aviation	7.3	75.5	91.5
Tower Operations (Millions)			
Total	96.4	113.2	143.2
Itinerant	65.0	74.0	81.7
Air Carrier	13.1	14.2	15.1
Air Taxi & Commuter	9.5	11.2	12.5
General Aviation	41.2	47.4	52.9
Military	1.2	1.2	1.2
Local	31.4	39.2	61.5
General Aviation	30.1	37.9	60.2
Military	1.3	1.3	1.3
Instrument Operations (Millions)			
Total	51.8	76.0	91.6
Air Carrier	13.4	14.6	16.7
Air Taxi & Commuter	7.0	8.7	12.0
General Aviation	27.7	49.0	60.2
Military	3.7	3.7	3.7
IFR Aircraft Handled (Millions)			
Total Handled	50.7	57.4	65.9
Air Carrier Handled	17.9	19.0	20.4
Air Taxi Handled	7.2	8.5	10.4
General Aviation Handled	20.8	25.1	30.3
Military Handled	4.8	4.8	4.8
Total Departures	19.0	21.6	24.1
Total Overs	12.7	14.2	17.7
Flight Services (Millions)			
Total	119.4	124.6	131.3
Pilot Briefs	35.4	37.0	39.4
Flight Plans Originated	19.7	20.4	21.1
Aircraft Contacted	9.2	9.8	10.3

The general conditions for the low limit are the following: The U.S. becomes increasingly dependent on foreign energy and is unable to sustain its technological lead in the world. The average annual economic growth is 2.4 percent per year during the 1980's. Unemployment remains at relatively high levels and is 7.4 percent in 1990. Inflation increases steadily at 7.0 percent per annum. Real growth in consumer spending is 2.3 percent per year. After several airline mergers in the mid-1980's, the air carrier industry concentrates on serving the business passenger. Fares increase slowly but steadily, and service quality is reduced. Operating costs for GA increase faster than the inflation rate as a result of significant increases in fuel costs and additional maintenance requirements on an aging fleet. Fewer individuals can afford to own their own aircraft. With lower growth in demand for commercial aviation capital for investment will be in short supply and purchases of new aircraft will be delayed.

Computational procedures used for the entries of Tables 2-1, 2-2, and 2-3 are as follows:

1. Using the #1979 Estimate
   #1991 Forecast
   #Average Annual Growth Rates (percent) for the period 1979-1991
   obtained from FAA and the methods of linear extrapolation and/or simple proportion,the entries of Table 2-1 were computed.

2. Using the entries of the various appropriate tables in FAA Aviation Forecasts-Fiscal Years 1979-1990 and the methods of linear extrapolation and/or simple proportion, the entries of Table 2-2 were computed.

3. Using the Table 2-1, Table 2-2, and the various appropriate tables in FAA Aviation Forecasts-Fiscal Years 1979-1990 and the methods of linear extrapolation and/or simple proportion, the entries of Table 2-3 were computed.

2.4 Corroboration of Mainline Scenario

Recent Bureau of the Census population projections lend some support to the Wharton forecast. If present migratory trends continue, mid-sized Standard Metropolitan Statistical Areas (SMSA's) located in the south and west will experience considerable growth during the next fifteen years while the larger SMSA's in the northeast and north central regions will experience comparatively little growth.

This trend toward a more balanced population distribution, both by region and SMSA's,should have the effect of increasing demand on the entire air traffic system. As an illustration of the effects of these anticipated population shifts on demand, the following gravity model calculation was made taking account of a five city system (Table 2-4) (ref 4).

First, current demand on the five SMSA system is calculated using current population figures. This calculation is made using three different denominators in the demand forecast equation (D, $D^{\frac{1}{2}}$, D^2). Second, demand is calculated on the assumption that New York and Los Angeles remain the same in population while Houston, Atlanta, and Phoenix each increase by 50 percent. Third, demand is calculated on the assumption that the same number of persons are added to the system but will be shared out among the SMSA's in proportion to their relative size. It should be pointed out that the actual growth rate for these three cities is much higher than is used in the calculations. The results presented in Table 2-4 show a clear difference for the two cases examined and support the previously mentioned effect.

The gravity model for the demand for air travel has the following general form:

$$T_{ij}(t) = K\frac{(P_i^{\alpha}(t)\ P_j^{\beta}(t))}{d_{ij}^{\delta}}$$

where : α, β, and δ are empirical constants.

$T_{ij}(t)$ = traffic between city i and city j during some time period t,

K = constant,

P_i = population of city i,

P_j = population of city j,

d_{ij} = the distance between city i and city j

The basic limitations of the model are as follows:

1. It is difficult to define precisely the population of a city or SMSA .
2. The model assumes that the population of a city lives at a node of the city.
3. City characteristics, such as average income, type of city, etc., are excluded from the model.
4. It is assumed that the same factors characterize the demand for all city points.

It should also be pointed out that a much larger proportion of the population will be in the 35-50 age group in 1995 than is currently the case. Ordinarily, this factor should also act to increase demand if current tastes prevail in 1995.

Table 2-4

Gravity Model Calculations for Systems Comprising New York, Los Angeles, Atlanta, Houston, and Phoenix Comparisons of Projected Increase in Demand Under Two Migration Patterns

	Percent Increase Pop. I → Pop. II	Percent Increase Pop. I → Pop. III
Denominator 1	45.5832%	33.9994%
Denominator 2	53.0110%	35.5089%
Denominator 3	39.9912%	32.2107%

Definitions:

Population I = current populations of the five cities involved.

Population II = projected populations of the five cities involved with New York and Los Angeles remaining constant and the populations of the other three cities increasing by fifty percent.

Population III = the same five city system as comprises population I with each city population augmented in proportion to its size, so that the total projected increase referred to in population II is shared out over the entire system.

2.5 Alternative Scenario

2.5.1 Introduction

A forecast of specific future scientific or technological development ought to contain, as an integral part, a consideration of the social, political, economic, and cultural factors impinging on it (ref 5). Unquestionably, no technological development takes place in a vacuum. A complex mixture of surrounding sociopolitical factors participate in shaping the future. When examining the possible introduction of an advanced avionics package, it is therefore necessary that some consideration be given to the qualitative factors influencing the development of the civil air transportation system (ref 6) . A thorough evaluation of these factors led the design team to conclude that by the year 1995, air traffic demand might well have stabilized at present levels. For purposes of analysis, the basic assumption is that the 1995 demand will be the same as that of 1979. Factors leading to this conclusion are analyzed in the following sections.

2.5.2 General Conditions

The cost of conventional energy will remain high and no radical alternatives will come on line during the time frame considered. Thus, energy supply will not keep up with demand. This will result in adjustments of personal living habits. Strong pressure will come into play leading to greater compaction of populations in urban areas as well as greater inter-urban compaction. Low energy alternatives will be sought and exploited. Persons not involved directly in the national business community will tend toward more local values and away from cosmopolitan values. This trend may eventuate in changes in laws and regulations directly impacting the aircraft industry.

2.5.3 Economic, Social, and Technical Aspects

The throughput of the economy will not exceed a growth rate of 2.5 percent during this period of time. There will be a tendency toward substituting labor intensive production for capital intensive production. This trend will be supportive of and supported by the local value orientation mentioned above. More goods will be produced locally and consumed locally. It is expected that the unemployment rate will hold steady or decline since local orientation is less supportive of a market economy. Thus, with a less active market, the inflation rate will slow during the 16 year period ahead. The team expects roughly 4 to 5 percent. Consumer spending patterns should change as a result of change in the characteristics of those in command of the surplus. Conditions outlined above should put more spendable income into the hands of the lower-middle class at the expense of upper and lower class.

Regulation activities on the part of local and national governments could be disruptive both to cargo and to passenger services in the environment of 1995. This will especially be the case if fuel is not only in short supply but uncertain. There is a strong possibility that by 1995, telecommunications will answer many of the business needs now requiring rapid long distance transportation. If the business market is even moderately reduced, the economic impact on the air passenger market could be severe because the tourist traveler is attracted by low fares made possible by high volume.

2.5.4 Forecast for Aviation Activity

2.5.4.1 Air Carrier

Operations will probably be less than current. More direct routes between major metropolitan areas will be employed with most service utilized by upper echelon business persons and tourist elite.

2.5.4.2 General Aviation

The team assumes that about the same number of planes will be in operation as is now the case. Perhaps there will be a moderate increase in air taxi service partially filling the void left by air carriers.

2.5.4.3 Air Cargo

These operations will probably be greater than current. Possibly there will be some introduction of lighter-than-air craft, made possible by advances in composites and metalurgy. A modest increase in air freight traffic is likely because there will be greater incentive to repair rather than replace existing machinery in the 1995 time frame. In the rapid supply of critical replacement parts, air transport is a must.

2.6 Why the Alternative Scenario?

Energy and Society--an Ecosystem Analogy: The guiding analogy which led to the formulation of the alternative scenario is that the elaboration of social institutions is a function of available energy. The germ of the idea of society as an ecosystem is present in Durkheim's conception of organic solidarity,(ref 7) while Lenski (ref 8) and others have made much of the relationship between level of technology and social system. White's (ref 9) explicit formulation of social complexity as a function of available energy is more to the point. A recent article of Frankena's (ref 10) sets forth some of the implications of this point of view in conjunction with the current and anticipated energy situation.

We begin by posing the question: If the complexity and elaboration of a social system is a function of energy, what sort of adjustments are likely if traditional energy is in short supply and what are the consequent impacts on lifeways and values?

2.6.1 Economics and the Mainline Model

The forecasting model discussed in the FAA Aviation Forecasts assumes that the basic structure of the equations will remain unchanged through 1981. Although this assumption was reasonable at the time of publication of the report, it is questionable now that large, presumably short-term changes have occurred in the price of fuel. One could argue that the short term effect of this will reduce the equivalent disposable income of the consumer and also reduce corporate profits. Since both of these variables enter positively in the regression equation, it seems likely that the short-run demand for air carrier operations will diminish, perhaps significantly.

The longer term effect would seem to depend upon the availability and cost of transportation alternatives, presumably automobile and rail. At the present time, these incremental costs are nearly the same. However, should load factors decrease for airplanes and increase for rail, one would expect rail to become much more competitive. This expectation follows from the fact that marginal fuel consumption is low for trains. On the other hand, if the cost of other factors-wages, equipment, etc.-increase at a rate similar to energy prices, then the marginal costs will maintain their current relationship.

The inclusion of both corporate profits and disposable income in the FAA model suggests that the two primary categories of air travel, personal and business, will react in a fashion similar to economic conditions and may also be extremely important in predicting future demand. For example, the primary substitute for business travel may be telecommunications, while that for personal use may be to stay at home. Thus, the regression model could show even greater deviations if these substitutions are realized. The decision of the consumer to go by air, auto, or rail has already been discussed, but the business traveler has an entirely different alternative, namely not to travel, but to do business by telecommunications. The variety of communications has increased in quality and availability while costs have decreased markedly.

While the business trip has come to be viewed as indispensable by many, one suspects that the relative productivity of such trips, per dollar, compared with the same figure for contact by phone or computer or both will decrease significantly because of the large increase in fuel price, all of which suggests the possibility of large scale switches from direct contact to telecommunications. Technological improvements such as business service satellite systems promise to make the telecommunications service even more flexible and inexpensive. Although there are some significant behavioral patterns to be altered, it is entirely possible that the economics of the matter have been altered sufficiently to inspire the change from personal contact to contact by wire.

Should these patterns of significantly less recreational and business travel be realized, naturally the mainline scenario (ref 11) would be negated. Indeed, it is possible to imagine 15 to 25 percent declines in air travel leading to a period of either very low profitability or retrenchment for the airline industry.

2.6.2 Alternative Technologies

Given increased cost of fuel and an increased drive toward cost effectiveness by business, new or existing means of accomplishing tasks now done by the business air traveler might well be utilized to an increasing extent. The FAA believes that if a general slowdown in the economic activity of the country occurs, increased use will be made of a potential telecommunications network. In three of five alternative 1978 scenarios for the year 2000, the FAA also postulated that increased use would be made of high-speed intercity transits (ref 12). Additional impetus to conversion to alternative forms of technology would be given by those employed in the businesses themselves. In recent years there has been an increasing trend toward spending more time with the family unit and remaining permanently in one locality. If there should develop a trend toward accomplishing business goals through means other than air travel, it is quite likely that such a movement will be adopted by the business community as a whole. Air travel will no longer be a status symbol. The above factors reflect an emphasis on the declining demand by business for the commercial air transport carriers. A lower degree of impact could be postulated for air traffic on business-owned airplanes. Here, however, an additional factor comes into play: that is, the types of demands made on the ground support systems for airplane travel. It is generally recognized that many of the major airports are reaching a saturation point, not only in terms of landings, but also in terms of ground access. If this trend continues, more private planes will be denied access to major city airports, thereby negating much of the advantage now derived for the businessman who is trying to save time. This possibility also holds for the business traveler attempting to reach the airport.

An additional factor to be considered and one which primarily applies to the private traveler is America's love affair with the automobile. A 1976 survey shows that Americans would rather travel by car, if given the choice. When this is taken in conjunction with the datum that less than one-half would be willing to pay higher taxes to improve public transportation, a significant conclusion emerges (ref 13). Unless the cost and convenience of air travel surpasses the advantages of the automobile, no significant rise in private air travel can be expected. Since air traffic is expected to depend on petroleum derived fuel for at least the next 25 years, any developments toward alternative fuels used in automobiles could have a significant negative impact on air traffic demand. That is, liquid hydrogen as a major energy transport vector should favor the automobile over the airplane. When conjoined with the above postulate that access to airports will take increasing amounts of time, many of the mid-distance air traffic routes could be endangered.

2.6.3 Environment

In a 1965 Gallup survey on domestic policy, only 17 percent of respondents chose air and water pollution from a list of 10 categories as one of the three areas to which maximum attention should be devoted. By 1970 an identical survey showed that 53 percent considered it one of the three top priorities (ref 14). A 1974 survey of seven national goals showed that pollution ranked number one with 72.3 percent of the respondents ranking it of extreme importance (ref 15). While the air traffic system produces very little of the total air pollution in the U.S., no significant steps are being taken to reduce this amount. Other polluters, however, are being forced to take such steps. Over time, therefore, the air transportation system will become a more visible segment of the pollution problem. If this is conjoined with a short term continued expansion of the air transportation system, a negative public reaction against air travel could set in.

One aspect of this concern can already be demonstrated in terms of studies regarding airport siting. A study of citizen participation in airport siting showed that noise and other human enviromental impacts ranked second on a list of nine criteria to be concerned with in airport siting. Concern for the natural environment ranked a close third (ref 16). Also, important here are the concerns of the local citizenry. A study of airport noise showed that the majority of the people living in the vicinity of Los Angeles International Airport were bothered by aircraft noise. They also expressed the belief that their property values would be lowered and that their neighborhoods would turn into environmental ghettos (ref 17). These studies show that an increased amount of resistance can be expected from the public if either new airports or expansion of existing airports is contemplated. Demographic trends also show more and more of the population is moving to urban areas. In the year 2000, the world for the first time will be more urban than rural (ref 18). This means that an ever increasing proportion of the population will be directly affected by airport pollution problems and can be expected to take an increasingly firmer stance against it.

2.6.4 Government Support

Recently, an even smaller proportion of the national economic resources have been committed to aerospace research and technology in each succeeding year. This trend reflects a lessening support for research and technology as a whole. It demonstrates the belief that the marginal return of further investments in aerospace activities is too small to justify further large-scale investments (ref 19). The important issue then is the extent to which the air transportation system can expand without further investment. It is questionable whether much expansion is possible without the introduction of avionics systems as are discussed later in the report. The team believes that if government is unwilling to fund the development costs in this area, it is unlikely that the aircraft industry will be able or willing to do so alone. This, in turn, would mean that increasing demands will be placed on the present transportation system with consequent negative public outcry.

2.6.5 Public Attitudes

The current public attitude toward technology is ambivalent. The public generally knows what benefits have been gained from technology, but it is also wary of possible adverse consequences (ref 20). There also seems to be an overall trend toward slackening of support of technology as a whole (ref 21).

Over 70 percent of the public believes that people have become too dependent on machines (ref 22), and over one-half the population believes that things are changing too rapidly (ref 23). One could thus expect that in the future there will exist some resistance to the increased use of avionics in particular. This, in turn, would mean that the development of the air transportation system would be limited to some extent by public opinion, especially in such instances where almost complete automation of the system is foreseen. If, however, automation is the only means by which the transportation system could expand, some justification for the design team's alternative scenario would be given.

Public attitudes are also important in relation to the public's perception of the impact any specific technology could have on the quality of life. This becomes an important determinant of whether it will or will not support future technological developments. A study in this reagrd showed that the public's support of STOL and SST aircraft was based on the estimation of benefits to be derived for the public by the innovations. The study showed that the perceived benefits were faster travel, saving of space, and airport convenience. Disbenefits, on the other hand, were seen to be noise pollution, air pollution, danger, overcrowding of the present air system, and arguments that life is too fast now (ref 24). It can thus be seen that the public is primarily interested in the benefits it believes it will derive form a given technological innovation.

These attitudes create a problem for the introduction of advanced avionics in the environment of 1995 because many of the benefits of advanced avionic systems are not readily visible. In fact, such benefits as are made possible by increased efficiency will tend to be masked by rising costs of the air transportation system as a whole. The disbenefits, on the other hand, will be much more visible to the public. If the air transportation system experiences a large amount of growth, pollution, overcrowding, and danger might be the only visible results apparent to the public. Therefore, there might be some resistance to increasing the capacity of the air transportation system before avionics can have a chance to lessen the impacts of these disbenefits.

In relation to public attitudes, a cautionary note should be appended. Attitudes are not constant over time; they, in fact, are influenced by a variety of external factors (ref 25). When determining what the sociopolitical environment of 1995 might be, one should thus keep in mind that this environment is in fact subject to some guidance in the intervening period. Design of the air transportation system should be based on the perceived needs of 1995, but these perceptions are guided by society's present needs. In the next 16 years, these needs and their underlying values may well change. They will change, however, only on the basis of decisions made in the present, the past, and the immediate future.

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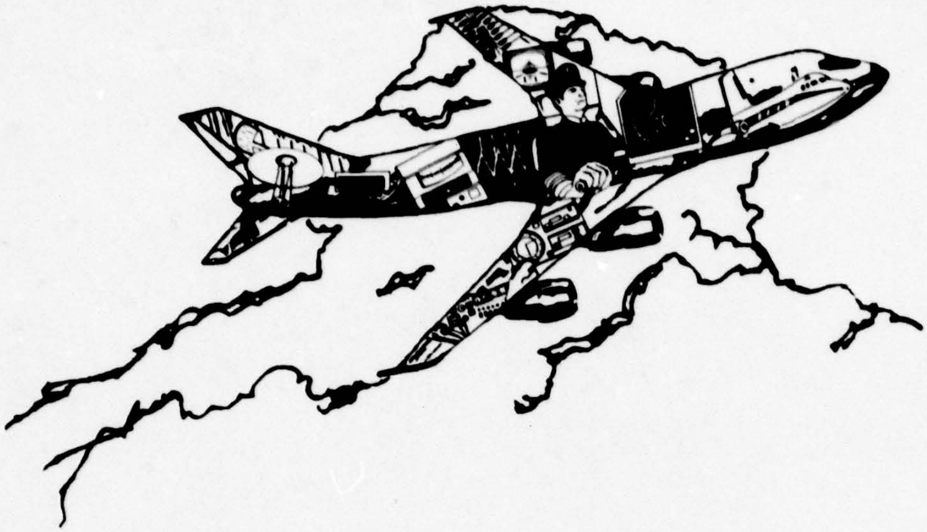
CHAPTER 3



TECHNOLOGIES

CHAPTER 3

TECHNOLOGIES

3.1 Introduction

Chapter 1 addresses the goals and objectives which the avionics system is intended to achieve, and Chapter 2 describes the social and economic environment within which these goals and objectives will be pursued. This chapter identifies the discrete avionics technologies from which the integrated avionics system of the 1995-2000 time period will be constructed.

This section of Chapter 3 examines the role of avionics within the total flight system. Section 3.2 introduces the trends within the digital electronics revolution which have been a driving force behind the emergence of the new generation of avionics technologies. Section 3.3 describes those avionics technologies, already developed and now emerging, which the Design Fellows judge will be the constituent technologies of the post-1995 advanced avionics system.

3.1.1 The Flight System

The function of the flight system is to get the aircraft off the ground at point A, direct it from point A to point B, and then get it back on the ground at point B safely, expeditiously, and unerringly. This flight function can be divided into three subfunctions: (1) navigation and guidance, (2) control, and (3) management and planning.

The navigation and guidance portion of the flight function

1. Acquires data about the aircraft's location relative to both the ground and other aircraft;
2. Compares this location with the desired location of the aircraft; and
3. Determines what, if any, change in the aircraft's flight path is required in order to return to the desired track.

The control portion of the flight function

1. Determines what changes in the aircraft's control surfaces and thrust are required to direct the aircraft along the desired flight path, and
2. Produces these changes.

The management and planning portion of the flight function

1. Acquires data about the characteristics, general condition, and current state of the aircraft, atmosphere, terrain, air traffic, and airport operations;

2. Determines the desired location for the aircraft at any given moment, that is, the desired route, airspeed, and aircraft performance profile; and
3. Organizes, plans, and exercises overall direction of the flight in order to assure optimal aircraft operation.

All these aspects of the flight function involve data acquisition, data evaluation, decision, and decision implementation. Two important issues arise with repect to these tasks. First, to what extent should these tasks be performed by humans and to what extent should they be performed by machines, in this case, by avionics. Second, to what extent should these tasks be performed on the ground and to what extent should they be performed in the aircraft. The first is the issue of the man-machine interface with respect to avionics, that is, the proper role of avionics within an integrated human-avionics system. The second is the issue of the cockpit-air traffic control system interface, that is, the proper sharing of responsibilities for the air and ground portions.

3.1.2 Man-Machine Interface

The discussion in this section is limited to just one aspect of the man-machine interface in the airborne part of the flight system, namely, to the pilot-avionics interface. Of course, many of the comments apply equally well both to the more general question of the cockpit crew avionics interface and to the question of the air traffic controller avionics interface.

During the early history of flight, pilots directly performed the generic tasks within the flight function. They acquired data through their five senses, intuitively evaluated it while "flying by the seat of their pants," and manipulated the aircraft accordingly. Today, virtually all of the information is acquired by instruments, much of the evaluation and integration of this information is performed by computerized systems, and the pilot shares the control of his aircraft with the autopilot. For example, in the area of navigation and guidance, automated area navigation systems exist which can fly the aircraft from the departure point to destination. In general, the trend within avionics has been toward increased automation of the flight function with a consequent diminishing of the pilot's role. (References 1 and 2 provide additional information.)

Before leaving the area of the man-machine interface, it must be noted that as long as humans are integral components of the flight system, no matter how extensive the automation and computer assistance, they must acquire, utilize, and transmit information. This fact highlights two important classes of auxiliary avionics, that is, avionics which assist the human components of the system to perform their share of the flight function. These are, first, data and information display avionics and, second, communication avionics. These will be discussed in Section 3.3 along with those avionics which perform parts of the flight function.

3.1.3 The Air Traffic Control System

The ground based air traffic control (ATC) system performs part of the flight function. It provides routing, altitude, and airspeed control to assure aircraft separation, thereby undertaking part of the navigation and guidance and the management and planning aspects of the flight function. These control actions are broadcast by ground based air traffic controllers to the pilot, who then performs the appropriate flight functions.

Projected future increases in the automation of the ATC system have recently reopened the question of the proper division of labor between the ground and cockpit in the performance of the flight function (refs 3, 4, 5). The ATC system is embedded in a regulatory and legal framework which allows slow changes and inhibits any replacement. The ATC system places definite constraints on the airborne flight system.

With respect to the particular context of this report, the advanced airborne avionics system of the post-1995 period will be required to interface with the ATC system of that period. This necessity will limit both the avionics technologies for constructing the avionics system and the methodology for assembling them.

3.2 Electronics Technology Trends

The current electronics revolution provides technologies and capabilities to make significant improvements in avionics. This section briefly summarizes some aspects of this rapidly developing field. Subsequent sections present discussions of specific avionics functions and systems.

It is important to remember that advances in avionics are part of the current digital electronics revolution. This means that when the aircraft industry buys state-of-the-art avionics, it will automatically be buying equipment that utilizes the available advanced digital electronic concepts. Consequently, developments within the electronics industry will be one of the driving forces behind the aircraft industry's adoption of increasingly more advanced avionics.

3.2.1 Digital Control Systems

The next generation aircraft will mark a change in approach for avionics. The revolution in digital electronics provides a new technology for increasing the reliability and capability of avionics, especially with respect to improving information processing and system integration.

Digital technology is most efficiently utilized if a central computer forms the heart of the system. All sensors can feed the computer and the computer can control all actuators and displays. Such a method allows feedback among all units.

The data bus concept provides a method of connecting all sensors, actuators, and computers to a common information carrying medium. Figure 3-1 illustrates an example in which the data bus is used. Actuators A and B need processed information from sensors 1, 2, and 3. Indicators use data from all sensors but actuator C uses only sensor 2 data.

Advantages of the data bus concept are

1. Multiple use of sensors
2. Reduction in wiring complexity
3. Reduction in weight of wire (up to 200 lbs. in large aircraft).
4. Increase in flexibility and addition of new or redundant units possible with changes only in programming software.

The USAF presently uses a digital system with functions interconnected by means of a serial digital multiplex data bus. Alternatives include an 8 or 16 bit parallel data bus and the fiber optics data bus. Fiber optics data busses are not affected by the electric and magnetic fields which result from short circuits and lightning strikes.

Families of sensors and actuators must be developed that will integrate easily with the digital systems. Memory mapped sensors and actuators use memory type instruction to access these input/output devices (ref 6). The advantage is that the same powerful instructions used for reading and writing memory can also be used to input and output data.

The trend toward digital avionic system architecture has been accelerated by developments in low cost microprocessor technology. Very large scale integration (VLSI) offers high density modular construction for all components. Each avionic function can be implemented with a dedicated digital microprocessor and associated firmware. The functional element receives its required data from the data bus and supplies its data output to the data for other functional users.

The digital microprocessor is a single chip monolithic device which may contain all the necessary computer components except input and output functions. Presently, the amount of memory included in the microprocessor chip is limited. Future ultra large scale integration (ULSI) devices will contain sufficient memory for most applications.

3.2.2 Memory Devices

A digital computer basically consists of three main elements:

1. A central processing unit (CPU) which contains the control unit and the arithmetic logic unit.
2. Memories, both permanent and temporary.
3. Input/output devices that allow the computer to interact and communicate with the outside world.

Avionics memories will be semiconductor and high density such as bubble memories and charge coupled devices.

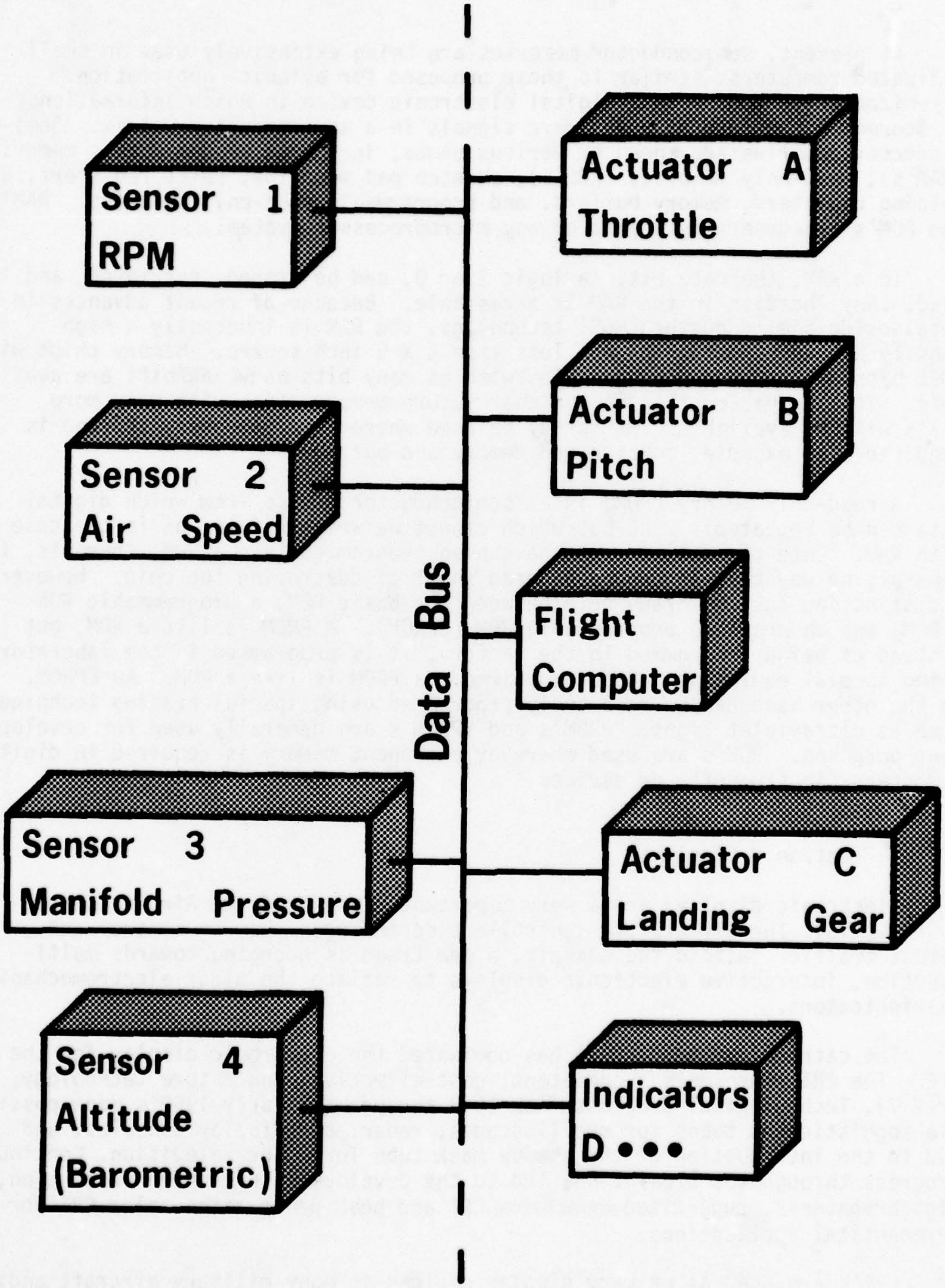


Figure 3-1 Data Bus

At present, semiconductor memories are being extensively used in small dedicated computers, similar to those proposed for avionics application. A semiconductor memory is a digital electronic device in which information is stored in the form of electronic signals in a semiconductor matrix. Semiconductor memories are known by various names, including random access memories (RAM's), read-only memories (ROM's), scratch pad memories, shift registers, holding registers, memory buffers, and programmable read-only memories. RAM's and ROM's are generally a part of any microprocessor system.

In a RAM, the data bit, a logic 1 or 0, can be stored, retrieved, and read. Any location in the RAM is accessible. Because of recent advances in metal oxide semiconductor (MOS) technology, the RAM is inherently a high density device. Most chips are less than ¼ X ¼ inch square. Memory chips with 4098 bits are very common and chips with as many bits as 64 000 bits are available. It is expected that in the near future memory chips with many more cells will be available. RAM's may be used wherever a temporary storage is required, for example, scratch pad memory and buffers.

A read-only memory (ROM) is a semiconductor device from which digital data can be repeatedly read but which cannot be written into, as is the case with RAM. Once the desired data have been programmed into a ROM, there is, in general, no way that it can be altered short of destroying the chip. However, a distinction must be drawn here between the basic ROM, a programmable ROM (PROM) and an erasable programmable ROM (EPROM). A PROM is like a ROM, but instead of being programmed in the factory, it is programmed in the laboratory using special equipment. Once programmed, a PROM is like a ROM. An EPROM, on the other hand can be repeatedly programmed using special erasing techniques, such as ultraviolet light. PROM's and EPROM's are generally used for development purposes. ROM's are used wherever permanent memory is required in digital computers, instruments, or devices.

3.2.3. Electronic Displays

Electronic displays are a very important element of the Air Transport System (ATS). The air traffic controllers depend upon them to control and direct traffic. Within the cockpit, a new trend is emerging towards multifunction, interactive electronic displays to replace the older electromechanical indicators.

The cathode ray tube (CRT) has dominated the electronic display for the ATS. The CRT represents a competent, cost effective, and mature technology (ref 7). Technological progress from 1940 through the early 1960's made possible sophisticated tubes for oscilloscopes, radar, and display consoles, and led to the introduction of the shadow mask tube for color television. Continued progress through the present has led to the development of a high resolution, high brightness, ruggedized monochrome CRT and beam penetration color CRT for aeronautical applications.

CRT's are used as primary display devices in many military aircraft and, to a much lesser extent, in civil aircraft. A CRT offers a flexible, software reconfigurable unit that can replace most of the electromechanical cockpit displays. The main advantages of a CRT over its rival technologies are (ref 8)

1. Addressability
2. Resolution
3. Brilliance
4. Dynamic Range
5. Flexibility
6. Accuracy
7. Environmental resistance

At present, there is every indication that the CRT will be a primary candidate for integrated display for the 1980's and 1990's.

The major disadvantages of using CRT technology are

1. High voltage
2. Implosion risk
3. Form factor
4. Low reliability

These disadvantages have led to research and development of other flat-panel display media.

The primary flat-panel display concepts are liquid crystals, electroluminescence, light emitting diodes, and plasma panels. Of these, only the plasma panel has emerged as a product and is being widely used as a military airborne display. Thin film electroluminescent panel technology shows great promise with defect-free area video and alphanumeric displays. The liquid crystal (LC) panel is based on MOS addressing technology used in the implementation of small display modules which can be interconnected to form large panels. The largest module this technology has produced to date is 2.54 by 1.905cm (ref 9). The light emitting diode (LED) display at present is characterized by low brightness and large power consumption. These candidate technologies are being investigated and probably will be available as alternatives to the CRT in the post-1995 environment.

3.2.4 Reliability

Reliability is defined mathematically as the probability that an item or component will operate for a given service period without failure. For example, if an item has a reliability of 0.999 over a year's service, the probability that the item will fail during the period is 1.000 minus 0.999 or 0.001. Conversely, there is a probability of 99.9% that the item will perform for the year without failure.

There are several ways to improve the reliability of an avionics system or device. The primary one is redundancy. If there are two identical units, either one of which will perform the function, the probability that both of the units will fail simultaneously is $(0.001)^2$ or 0.000001. By using triple redundancy, the probability that all three units will fail at the same time becomes $(0.001)^3$ or .000000001. Present practice is to design triple redundancy into the most vital avionics components on commercial aircraft. In general, redundancy has produced additional cost and weight for the systems. However, integrated circuits reduce these negative factors considerably.

Reliability is sometimes difficult to measure. When dealing with small probabilities, an error in estimating the probability of failure can be magnified many times in the final estimate of reliability. A further problem is that good data are difficult to obtain. Considerable time and expense are required to obtain enough test failures to make a good estimate. Accelerated life testing may not accurately represent real life conditions. Calculations based on engineering design are often used but supporting test data are difficult to obtain. However, pragmatically useful data are available on the reliability of most avionics components.

3.3 Major Avionics Technologies

3.3.1 Introduction

The scheme for organizing this discussion of major avionics functions and systems is to divide them into categories which are referenced to the flight function mentioned in section 3.1.

Accordingly, this discussion of avionics is divided into navigation and guidance, control, management and planning, displays, and communications.

3.3.2 Navigation and Guidance

The function of navigation and guidance is to provide an optimal track and safe aircraft separation. This is achieved by comparing the actual and the desired paths and using the error data to correct the flight path.

Several integrated avionics systems supply data about the altitude, heading, and speed of the aircraft. The aircraft avionics systems interact with those on the ground to track and route the aircraft from departure to destination.

Avionics associated with this function are divided into landing systems, enroute navigation systems, and aircraft separation systems for collision avoidance.

3.3.2.1 Landing Systems

It might be argued that the most significant contribution avionics has made to air travel is the capability to land during adverse weather. Current and proposed systems are based on highly directional radio frequency signals which are used to help the pilot align the aircraft with the runway, descend, and land at applicable rates and speeds. The existing system is the instrument landing system (ILS). The microwave landing system (MLS) has been proposed for future use.

3.3.2.1.1 Instrument Landing Systems

The ILS system consists of a pair of ground radio transmitters which produce a coded beam. This beam is an extension of the runway and the pilot attempts to "fly the beam". The airplane ILS instrument indicates the aircraft location with respect to the desired flight path. ILS is reliable and offers safe and efficient services within its technical and operational capabilities. Nevertheless, the ILS has certain inadequacies. These are

1. Limitation to 40 channel frequencies (20 of which are currently in use),
2. Inability to meet military tactical requirements, and
3. Adverse effects from heavy snow, terrain irregularities, and structures in close proximity to the runway.

An effective ILS system costs several thousand dollars (ref 10).

3.3.2.1.2 Microwave Landing System

During MLS operations, a scanning beam is transmitted toward approaching aircraft. The beam sweeps back and forth across a given arc. When the beam strikes an incoming plane, a signal is reflected to the MLS ground receiver. The time interval between the transmission and receipt of the reflected signal determines the elevation and azimuth headings of the plane. This information is transmitted to the airplane and displayed to the pilot as a deviation from the desired approach glide path. The pilot can then take action to align his plane with the correct path.

Data for a landing system can be either ground or air derived. In an air derived data system, the interrogation signal is broadcast from a fixed ground station. The responding signal from the aircraft provides position data. In a ground derived system, the signal is broadcast from the aircraft. The position data link is determined by the ground receiving station and rebroadcast to the plane.

MLS is expected to overcome the limitations of ILS (ref 11). The operational advantages of MLS are

1. Increased channel capacity - five times that of ILS - to provide adequate channels for any foreseeable need;
2. Curved and segmented approach paths for noise abatement procedures and interleaving of aircraft flying at different speeds;
3. Operation on closely spaced parallel runways to provide more efficient operations at high density airports;
4. Installation of a system which cannot be adversely affected by terrain features or local signal distortions, and installation at any airport regardless of approach terrain configuration.

By the year 2000, the FAA estimates that installation costs of ground based MLS equipment will be 1.25 billion dollars. The acquisition cost for the individual user will range from two thousand dollars for GA to thirty-four thousand dollars for commerical aircraft (ref 12).

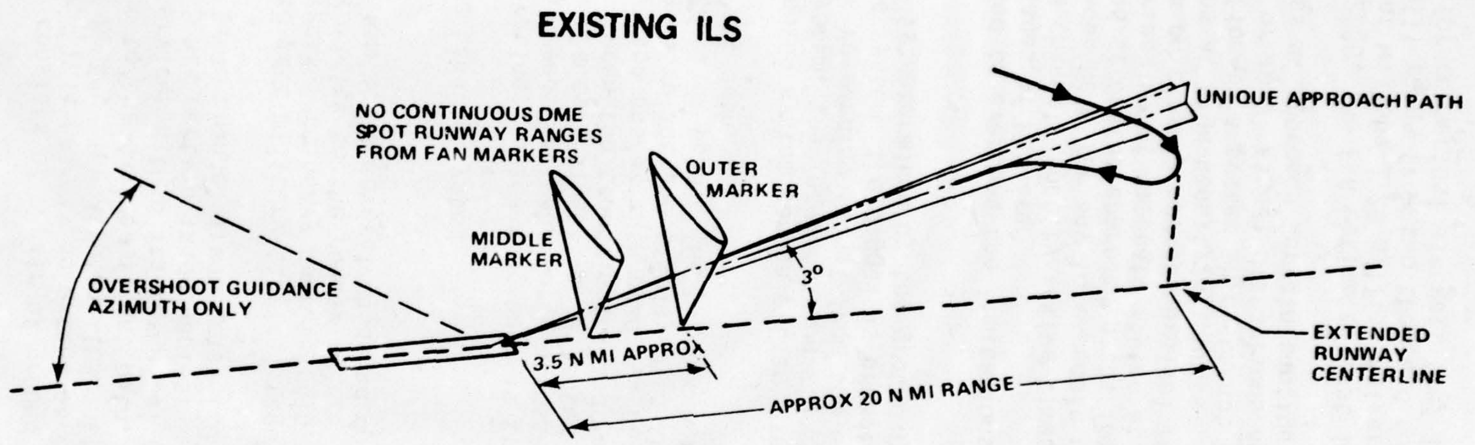
EXISTING ILS
NO CONTINUOUS DME SPOT RUNWAY RANGES FROM FAN MARKERS
OUTER MARKER
MIDDLE MARKER
UNIQUE APPROACH PATH
OVERSHOOT GUIDANCE AZIMUTH ONLY
3°
3.5 N MI APPROX
APPROX 20 N MI RANGE
EXTENDED RUNWAY CENTERLINE

Figure 3-2

MICROWAVE LANDING SYSTEM

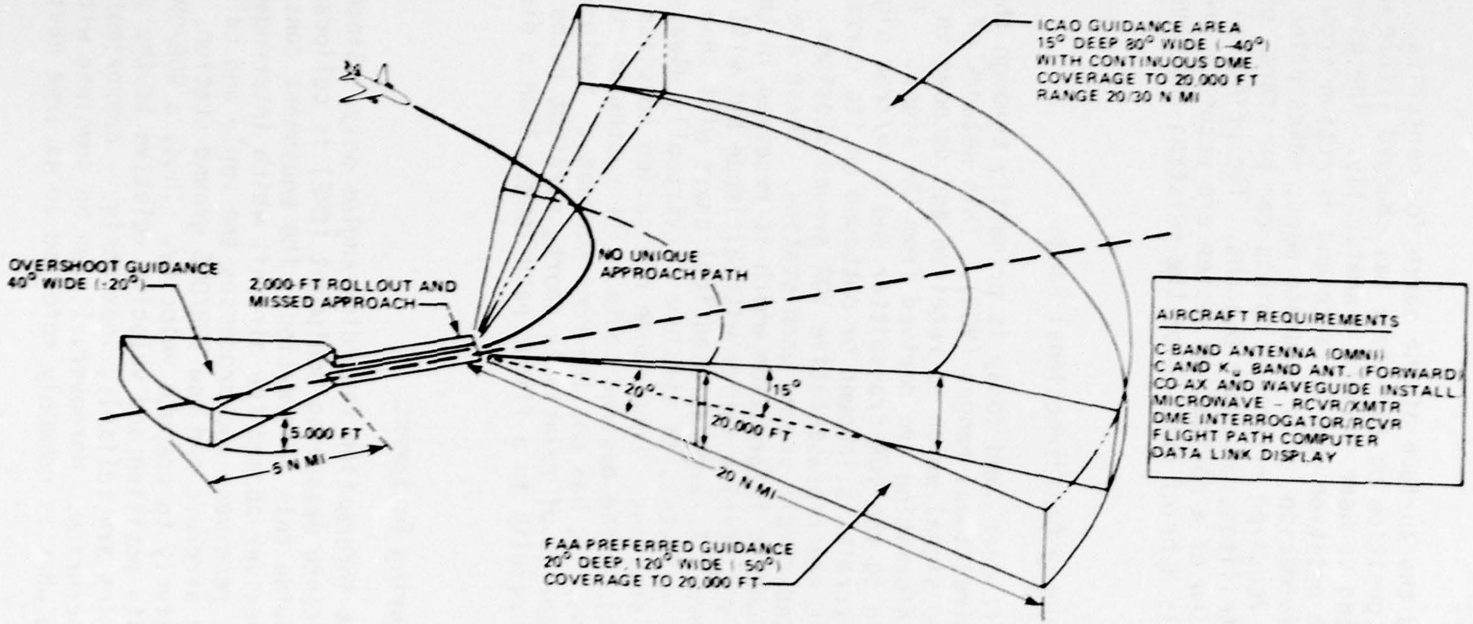


Figure 3-3

3.3.2.2 Navigation Systems

People have navigated the surface of the earth for centuries. The process of establishing a position on the globe has changed little while the technological aids for doing so have changed dramatically. The essence of navigation is to determine position and distance and direction from a known reference point. This information, plus accurate maps, makes point to point navigation possible. The required reference points can be stars, prominent geographical features, satellites, or radio beacons. The principal factors that influence the selection of a navigation system are accuracy, reliability, and cost. The following is a brief outline of the existing and developing navigation systems.

3.3.2.2.1 Very High Frequency Omnidirectional Range

Navigation of aircraft over land today is primarily through the use of very high frequency omnidirectional ranges (VOR). This network of ground stations transmits an encoded signal which is received and decoded in the airplane. Two pieces of important information are derived from the signal. These are the magnetic position relative to the VOR transmitter and a to/from signal indicating whether the aircraft is inbound or outbound on its current heading. In Figure 3-4, A, B, and C are representative VOR ground stations. Notice the 0-360 degree calibrated circle around each station. These are called radial, and it is this magnetic information which is received in the aircraft. The effective range of a VOR station varies with altitude but will average approximately 93 kilometers. A large aeronautical chart will show that many points over the United States, an airplane is virtually always within range of one or more VOR stations. Long range navigation consists of flying from one VOR to another along the desired route. The system is reliable, efficient, and inexpensive. It has one inherent weakness. Navigation between VOR stations leads to a series of relatively short, straight paths comprising a zig-zag pattern. This results in a flight path longer than a direct route (ref 13).

3.3.2.2.2 Distance Measuring Equipment

The VOR system gives information regarding angles only. Since distance is also desired, adjunct distance measuring equipment (DME) is collocated with many VOR stations to provide this information. The equipment consists of a microwave transmitter/receiver aboard the aircraft which interrogates the ground station repeater, receives, and processes the reply and calculates the distance between the aircraft and the VOR/DME ground station. This system can also be used repetitively to compute velocity. Thus, a VOR/DME equipped aircraft can determine its position and velocity relative to the ground stations. VOR/DME avionics are reliable, inexpensive - approximately three thousand dollars - and accurate. Moreover, it can be combined with multiple VOR receivers to provide what is commonly referred to as area navigation (ref 14).

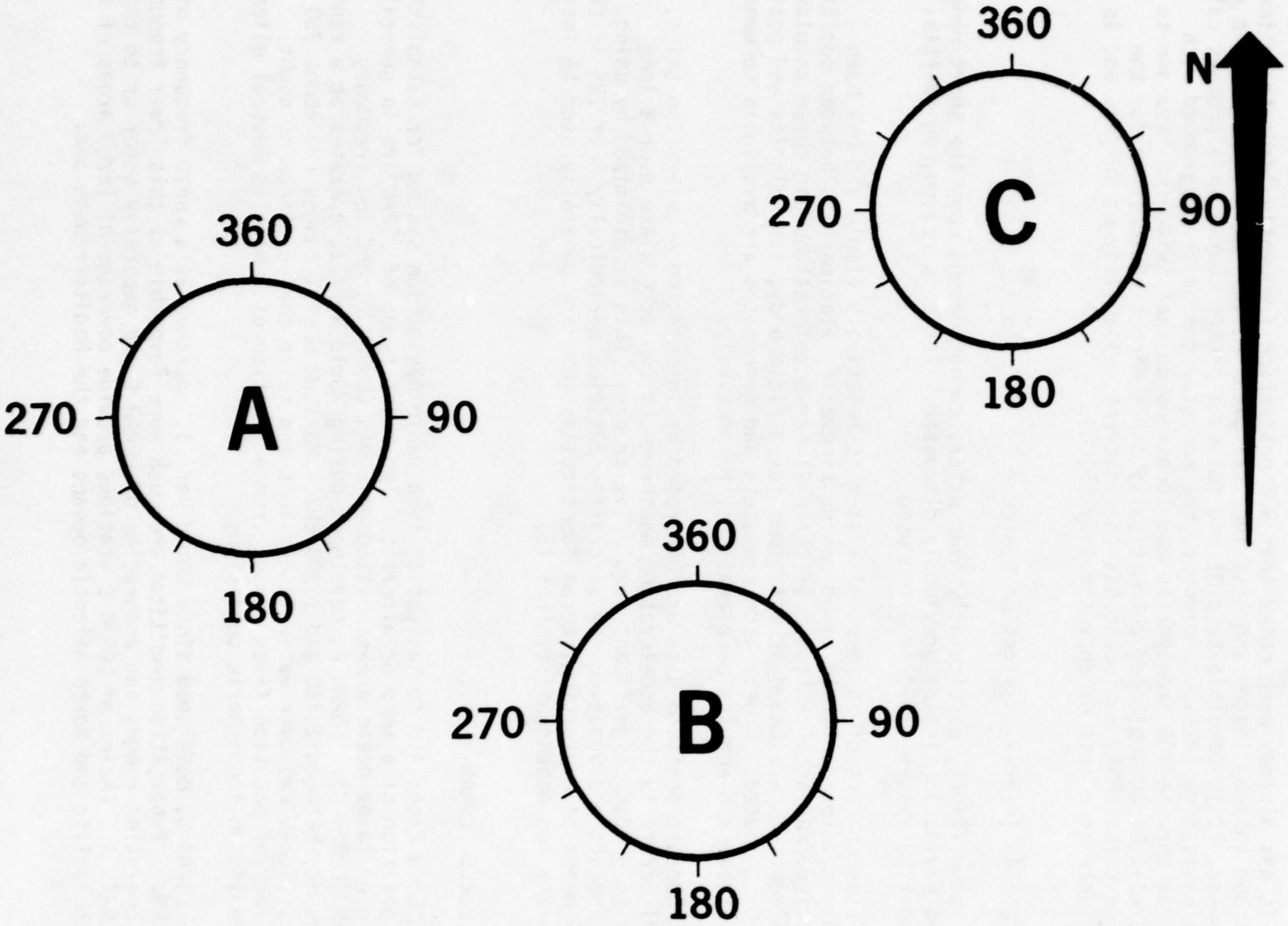


Figure 3-4 Representative VOR Ground Stations

3.3.2.2.3 Area Navigation

It has already been noted that VOR navigation frequently leads to an indirect and thereby longer and less fuel efficient route. With VOR/DME and a small computer, it is possible to plot and follow a direct course in a process called area navigation (RNAV). Moreover, the computer can be preprogrammed with several enroute VOR frequencies and locations so that switching from one to the next will be accomplished automatically and a direct route flown for the entire trip. RNAV equipment has the inherent reliability of VOR/DME and is available at a cost of approximately $5,000.

3.3.2.2.4 Inertial Navigation System

Long flight, particularly over water, cannot depend upon the short range radio navigational aids previously discussed. For this reason, an inertial navigation system (INS) is often used.

The concept of an inertial system is relatively simple and has been highly developed. It is based on the kinematic relationships between position, velocity, and acceleration. If three linear accelerations and three angular accelerations are known at all times for a rigid body, its velocity and position can be computed. Linear accelerometers and gyroscopes are available to measure the linear and angular accelerations, respectively.

Because position data are generated by integrating acceleration twice, small errors in the acceleration measurements can accumulate over a long trip to produce significant cumulative errors. This is minimized by using checkpoints and updating the aircraft's position periodically. If INS is the only means of navigation, three identical systems are generally used to insure accuracy and dependability (ref 15).

3.3.2.2.5 LORAN

Long Range Aid to Navigation is a radio navigation system for establishing the position of a ship or aircraft. Two major types of LORAN are in general use over large ocean areas: standard LORAN (LORAN A) and low-frequency LORAN (LORAN C). LORAN A, developed during World War II, operates at a radio frequency between 1,750 and 1,950 kHz. Maximum useful ranges are about 750 miles (1,200 km) over water in daylight and twice that distance at night. Accuracy of position fixes varies from a fraction of a mile to several miles, depending on ionospheric conditions.

LORAN C, developed since World War II, operates at a radio frequency of 100 kHz. Propagation conditions are much more favorable at this lower frequency, and operating ranges and accuracies of LORAN C are generally superior to those of LORAN A. Chains of LORAN C stations provide coverage of large areas of the North Pacific and North Atlantic oceans and the Mediterranean Sea.

LORAN C is currently used by civilian maritime users, some U.S. military aircraft, and some Navy submarines. Military aircraft carrying LORAN C receivers include some Air Force and Navy cargo aircraft, some Air Force fighters, and some Navy patrol airplanes.

Except for strategic submarines, the military will be phasing out their use of LORAN C in the 1980's (ref 16). However, the number of civilian users is expected to grow as LORAN A receivers are replaced with LORAN C receivers. LORAN A will remain in operation until the end of 1979.

LORAN C receivers cost from one to five thousand dollars for civilian maritime receivers to as much as twenty thousand dollars for a military airborne receiver.

3.3.2.2.6 Omega

Omega is a network of eight transmitting stations located throughout the world to provide worldwide navigation. These stations transmit a phase stable signal in the very low frequency (VLF) band. These signals have ranges in thousands of miles. The eight stations are located in Norway, Liberia, Hawaii(USA), North Dakota (USA), La Reunion, Argentina, Trinidad, and Japan.

Presently each station transmits on three basic navigational frequencies: 10.2 kHz, 11.33 kHz, and 13.6 kHz, in sequenced format. This time sequenced format preventsinter-station signal interference. The pattern is arranged so that during each transmission interval, only three stations are radiating, each at a different frequency. With transmissions from the eight stations and a 0.2 second pause between each transmission, the entire cycle repeats every 10 seconds. A fourth frequency of 11.05 kHz is being added to each station which will allow more navigation flexibility by increasing the lane resolution capability. Experience has shown that the Omega network is capable of providing consistent navigation and guidance information at an accuracy of 3.7 kilometers depending upon the sophistication of the receiver/processing system. Omega receivers are available at a cost of thirty to fifty thousand dollars.

3.3.2.2.7 Four Dimensional Navigation

All of the systems described thus far provide an aircraft's position in three dimensional space. With an eye toward future automation potential, it may be desirable to include time as an explicit parameter in the navigation system, hence the name four dimensional navigation. This system is intended to enable more precise control of aircraft operations, as well as reduce the workload of the air traffic controller. While 4D NAV can be used for navigation during the entire flight, its principal advantages accrue during the terminal phase of the flight by enabling a greater traffic capacity and more fuel efficient landing profiles.

The currently envisioned 4-D navigation system will operate by specifying a series of waypoints during the flight route with altitudes and times assigned to waypoints such that the vertical profile and speed are defined during the entire flight. Two methods proposed to maintain the scheduled 4-D profile are (ref 18)

1. Precisely controlling the airplane to the 4-D profile from the ground using vector and speed commands, and
2. Providing the scheduled 4-D profile to the airplane and allowing the pilot to use onboard navigation and guidance equipment to fly the optimum path.

In terms of the system evolution, it seems likely that initially the 4-D path profile will be computed using the aircraft's onboard computer facilities. As the system gains wider acceptance, it may become economical to permit ground control.

For either of the proposed methods, it is necessary that the system utilize a discrete address beacon system (DABS), to be discussed in section 3.3.6.2, in order to communicate with the plane. It will be advantageous for the plane to be equipped with a CRT type display to enable the pilot to fly the 4-D path.

The principal advantages of 4-D navigation are an increase in landing capacity because of more precise timing of aircraft arrival and a decrease in the controller workload. It is estimated that by 1995 the 4-D navigation system will enable a siginifcant increase in operational capacity as well as a marked decrease in landing delays. This will result in annual benefits of five hundred million dollars using present day estimates for direct operating costs, landing fees, and airline revenues. Inclusion of passenger time and decrease of controller workload would increase this estimated amount.

The greatest danger inherent in the 4-D navigation system is one of reaction to system failure. Because of the increased number of planes in the terminal area and the decreased direct controller supervision, it might prove extremely difficult to cope with severe operational deviations. These could be a result of unexpected weather conditions or aircraft equipment problems causing flights to miss waypoints, unauthorized aircraft entering the terminal area, a computer failure on the ground or in the air, a communications failure, or deliberate sabotage attempts. The system must be designed to be fail-safe in order to handle these possible occurrences. This appears to be the primary development challenge. Nevertheless, a 4-D navigation system should increase the safety margin because each flight knows its precise 4-D profile and could continue without conflict should communications with one or more aircraft be lost, and controlling the plane with onboard navigation while tracking it with ground based radar provides an additional level of redundancy.

3.3.2.2.8 Global Positioning System

The Global Positioning System (GPS) is a very high technology approach to navigation and guidance and offers nearly the ultimate in capability.

The fully operational GPS system will consist of 24 satellites, eight in each of three planar regions. They will orbit at 19 261 kilometers and have

12 hour periods. This configuration assures that at least six satellites will be in view from any point on earth, with an average of eight to nine being in view. Since only four satellites will be required by a user, failure of a satellite function will not inhibit the system (ref 19).

At present, six satellites are in orbit for the system concept validation phase. Preliminary testing has shown this system to be extremely accurate in providing continuous position and velocity information to aircraft. GPS can determine the position of an aircraft within 10 meters on the guarded military transmission channel and 110 meters on the channel intended for civil users. Velocity can be determined with an accuracy of 0.03 m/sec on the military channel and 0.2 m/sec on the civil channel. The complete GPS is expected to be operational by 1985 (ref 20).

Operation of the satellites requires a control segment on the ground in order to periodically update the atomic clocks and to provide coded information. The satellites can continuously beam their positions and an accurate time standard. The user requires a passive receiver which can obtain position and time from the satellite. The receiver must also be capable of ascertaining the aircraft's position and velocity based on the solving of equations in the X, Y, and Z axes and the correction for user clock bias. This requires listening to four satellites, three for range and one for time correction.

GPS requires no user transmission. Therefore, it can sustain an unlimited number of users. It can also be operational under all weather conditions (ref 21).

The full potential of GPS, however, will be realized only in combination with an air/ground data link. This data link would establish communications between the aircraft and ground adding the following capabilities (ref 22):

1. Automated position reporting/surveillance,
2. In-trail separation assurance,
3. Collision avoidance,
4. Cockpit-displayed traffic information,
5. Automated flight service/ATC information, and
6. Meteorological reporting.

Capital and operational costs of the satellite system will be paid by the military users. Estimates of receiver costs range from three-thousand six hundred dollars for a small GA aircraft to forty thousand dollars for a sophisticated military receiver. NASA believes that the cost of a simple receiver must be decreased below two thousand dollars for the system to become universally operational. It is likely that this goal could be achieved with a fail-operational design.

Introduction of the GPS data link combination eliminates the need for a number of present ground based systems including VOR, DME, Omega, and en route radars (ref 23). It would thus entail a savings for the air transportation system as a whole.

An added problem for the entire aviation industry is the fact that GPS satellites are intended primarily for the use of the military and will be under military control. Therefore, some fear exists that the availability of GPS for the civil user is not guaranteed.

3.3.2.3 Collision Avoidance System

A direct result of increased air traffic is increased probability of an air collision. In good weather, the primary method for avoidance is visual. "See and avoid" is the pilot's credo (ref 24). However, in poor weather, the responsibility for maintaining separation between aircraft rests primarily with the air traffic controllers. Control refers to control of altitude and heading of the aircraft. This control is stringent in terminal control areas (TCA).

3.3.2.3.1 Air Traffic Control: The Ground-Based System

The principal avionics technology is the radar which provides to the controllers a visual representation of aircraft position. The transponder has been used for several years and provides an important adjunct to radar-derived information. The transponder is on board the aircraft and is actually an airborne radar repeater which can be interrogated by a signal from the ground. This gives the standard azimuth and range information of conventional passive radar, but provides more reliable information.

Transponders also have dialable codes which allow the air traffic controllers to assign different codes to aircraft for identification purposes. A recent improvement in transponders, mode C, allows altitude information to be automatically encoded on the transponder signal so that the ground controllers have access to aircraft range, azimuth, and altitude. The latter data are very important for maintaining aircraft separation and control. Mode C transponders are now required for TCA descent and landing at several of the nations busiest airports.

The ground controllers use the Automatic Radar Terminal System (ARTS III) which consists of a console having as its primary components a computer and radarscope. The computer stores and updates transponder returns. This allows the controller to select from a wide range of graphical displays (ref 25).

3.3.2.3.2 Airborne Systems

A collision avoidance system (CAS) must provide the capability of protecting aircraft from collisions not only in areas under FAA control but also in uncontrolled airspace. In order for this goal to be accomplished, an airborne CAS will be necessary, operating either in conjunction with or independently of the present ground-based ATC system (ref 26).

Five potential future airborne CAS's are now being developed. They are the Honeywell AVOIDS, the M.I.T. Intermittent Positive Control (IRC), the

McDonnell Douglas EROS, the RCA SECANT, and the Litchford Semiactive BCAS. All five require an airborne transponder which must be detected by the air traffic system. The difference among these systems is the amount of interaction with and dependence on the present ATC system (ref 27).

A brief description of IPC will introduce the reader to the general characteristics of airborne CAS systems. IPC is the system supported by the FAA and designated by the agency as ATARS (Automated Traffic Advisory and Resolution Service). It is tailored to the requirements of individual airports and has some potential for serving as a backup to voice communication between the pilot and the controller (ref 28).

The ATARS system will require a DABS transponder, a display panel, and an encoding altimeter. The transponder will receive digital information from the ground and present cockpit display indications which may range from proximity warnings to evasion commands. Required on the ground is a fully automated DABS interrogator and the ATARS computer system. Since there must be a link between aircraft and the ground in this system, ATARS will work only with DABS coverage (ref 29, 30).

In order for ATARS to give the aircraft CAS capability while operating outside the coverage of the ATC network, a system called Synchro-DABS will also be required. Synchro-DABS is an air to air interrogator-transponder system among aircraft. This could provide either an active beacon collision avoidance system (BCAS) or a full BCAS. The active BCAS allows only vertical escape maneuvers because of antenna limitations. The full BCAS, which is based on high speed computer technology, present an electronic display of all aircraft in the immediate vicinity (ref 31).

Implementation of any CAS system is estimated to cost more than one billion dollars. It is believed that an airborne system may be more cost effective. An important factor to be considered is that well over two billion dollars have already been invested in the air traffic control radio beacon system (ATCRBS) so that any compatible CAS will probably have some advantages (ref 32).

3.3.3 Controls

The control aspect of the flight function includes both control surfaces and the command loops to these surfaces. Avionics developments are occurring in both of these areas, and are presented individually for discussion purposes.

3.3.3.1 Electronic Command Loops

Until recently, movement of aircraft control surfaces and the adjustment of engine throttle settings have been accomplished via cable connections controlled by the pilot. The control cables are being replaced by primarily electronic control systems that are referred to as the fly-by-wire capability. Initially, fly-by-wire referred only to the replacement of hydraulic and mechanical linkage devices with primarily electrical devices. Now, fly-by-wire implies not only attitude and manuever control but also automatic thrust control.

NASA's manned space program has demonstrated the advantages of digital fly-by-wire systems in terms of control system flexibility and reliability (ref 33). However, the transfer of this technology from spacecraft to aircraft will not be easy. Until the reliability of the aircraft fly-by-wire systems is proven to be as good as or better than the cable system, pilots may be reluctant to accept a total fly-by-wire aircraft.

3.3.3.1.1 Attitude Control

Attitude avionics are designed to provide aircraft control by sensing and altering roll, pitch, and yaw. Present day analog devices will change to primarily digital devices by 1995-2000. Until complete cockpit automation is achieved, a digital flight management computer will provide roll, pitch, and yaw data to assist the pilot in aircraft orientation. Reliability of these avionics will be enhanced by multiple redundancy.

For present-day overland flights, the roll and pitch orientations are sensed by redundant "strapdown" gyroscopic units. Inertial gyroscopic platforms are available for transoceanic flights, but are seldom used for overland flights because of much higher cost than the "strapdown" units. The inertial units have the advantage of greater accuracy but are affected by gyroscopic drift. Technological improvements by 1995-2000 may resolve the problem of gyroscopic drift and possibly cost.

3.3.3.1.2 Automatic Thrust Control

In a jet airplane, the thrust for a particular flight condition requires a specific engine pressure ratio (EPR). EPR is determined by throttle setting. A pilot becomes familiar with various throttle settings through experience and reference to instruments. Variations in operating environment and deviations from planned operating conditions cause the pilot to alter settings.

Trial and error is employed to obtain trimmed thrust. The larger size and complexity of proposed airplanes tend to increase difficulties in setting the correct thrust for a particular condition.

An automatic throttle control system which can control engine thrust from takeoff to landing has been used on Boeing 747 aircraft. The system has three primary methods of control: EPR control, mach hold control, and speed control. The system is claimed to aid smooth operation by responding to airplane control surface setting changes, selected reference changes, flight path changes, and gust disturbances in a manner that avoids excessive and undesirable thrust level movements (ref 34).

Current design philosophy for primary thrust control is represented in Figure 3-5 (ref 35). This scheme provides electronic supervisory fuel control with backup hydromechanical control. The electronic control eliminates throttle stagger and the effects of cable hysteresis, enables control by computed thrust rating, closes the fuel control loop between desired and actual engine speed to simplify the thrust setting operation--especially on takeoff, climb, and go-around--and provides thrust limit computation for cockpit instruments and autothrottle. The heart of the system is a thrust management computer (TMC), shown in Figure 3-6, which serves two primary functions. These are rating limit computation and display and autothrottle, as well as providing subsystem monitoring and fault data storage for subsystem maintenance.

As a result of the ability to set the correct thrust for the conditions at hand, the thrust management system should result in increased fuel efficiency. Ultimately, the pilot will play little or no role in thrust control as this function will be performed by the thrust management computer.

3.3.3.2 Active Controls

As commonly defined, aircraft active controls (ACT) consist of control surfaces activated by computer signaled inputs from sensors which are not pilot commanded (ref 36,37). The sensors, normally accelerometers, indicate a change in the attitude of the aircraft or in the status of some aircraft component. Change in control surface deflection then returns the aircraft to its original state. The role of these controls is to provide benefits in aircraft performance and/or reduction in operating costs.

The following comprise the set of ACT under development (ref 38,39):

1. Augmented or artificial stability (AS)
2. Gust load alleviation (GLA)
3. Manuever load alleviation (MLA)
4. Flutter mode control or flutter speed enhancement (FMC)
5. Ride control or improvement (RC)

HYBRID ENGINE CONTROL

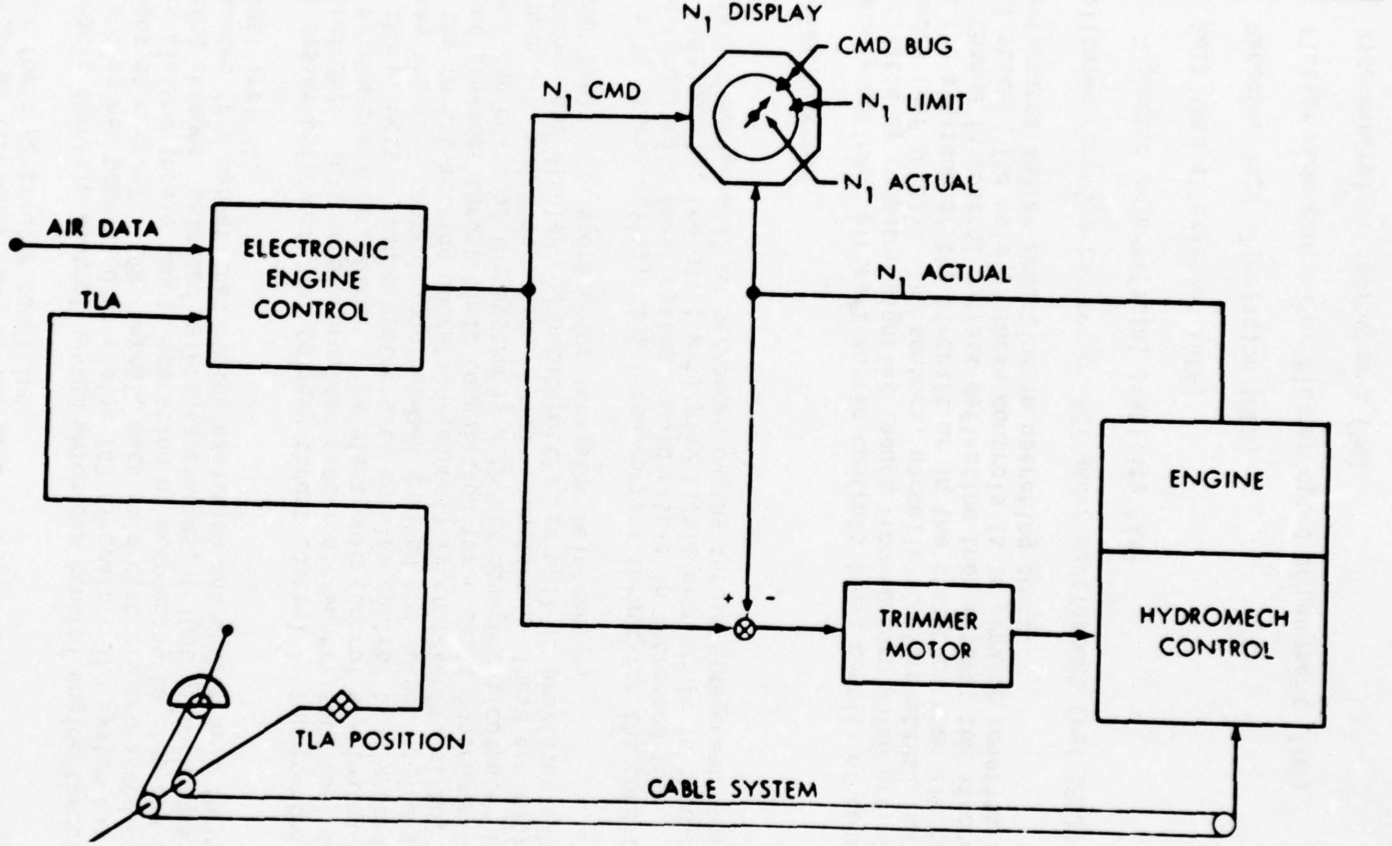
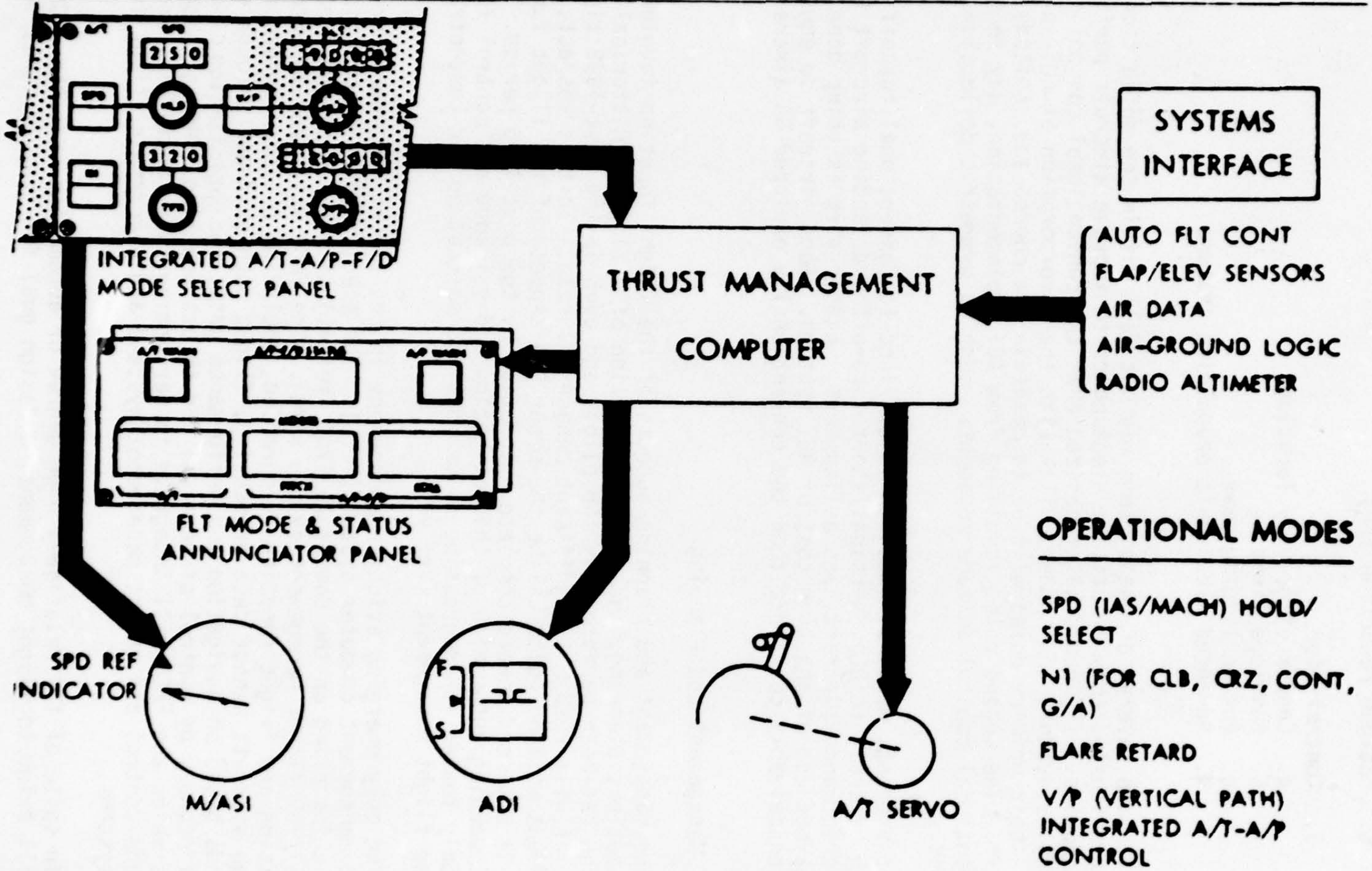


Figure 3-5

THRUST MANAGEMENT COMPUTER

(AUTOTHROTTLE SUBSYSTEM CONFIGURATION)



OPERATIONAL MODES

SPD (IAS/MACH) HOLD/ SELECT

N1 (FOR CLB, CRZ, CONT, G/A)

FLARE RETARD

V/P (VERTICAL PATH) INTEGRATED A/T-A/P CONTROL

Figure 3-6

6. Fatigue reduction (FR)

7. Controls for
   a. Center of gravity location
   b. Envelope limiting
   c. Active landing gear
   d. Advanced electronic propulsion systems

Although several of these items may not fall within the definition of ACT given previously, they do utilize electronics to improve aircraft performance and economics. It should be emphasized that the conventional control surfaces, ailerons, elevator, and rudder, will--with the incorporation of ACT--play a role. Their primary roles will be to maintain the course and attitude of the aircraft. The second role, resulting from ACT implementation, may require unconventional control surface movements, such as symmetric deflection of the ailerons.

At present, most ACT research is confined to conventional takeoff and landing aircraft (CTOL), vertical/short take-off and landing aircraft (V/STOL), high performance aircraft, and helicopters. Little work is being done in the GA area because of the high cost of ACT systems. Some aircraft so equipped could conceivably cost more than the conventionally equipped GA aircraft.

3.3.4 Management and Planning

The management and planning aspects of the flight function involves the organization, planning, and overall direction of a flight. Historically, this function has been performed by the pilot, and even in the post-1995 time frame the pilot will retain a significant managerial role. In this respect, flight management will be quite unlike the other two aspects of the flight function, since it may tend toward complete automation by the post-1995 period. In fact, this impending automation of the navigation and guidance and control functions is widely touted for decreasing pilot workload so that he can concentrate his time on flight management (ref 40).

The only emerging avionics technology in the flight management area is the flight management computer system (FMCS). The specific version of this which will be installed on the Boeing 757/767 (ref 41) will be an integral part of the 757/767 flight management system (FMS). The FMCS will provide automatic navigation and flight function integration, including position determination through aircraft sensor data processing, flight path guidance through control commands based on navigation and performance data, and optimization of operational economy by control of vertical and thrust profiles. Among those system inputs which the FMCS will integrate in performing these activities are the attitude control and thrust management systems and electronic flight instrument systems.

In spite of the relatively high degree of automation that the FMCS and FMS will bring to flight management, a design goal for these systems is to increase the pilot's effectiveness as the overall flight manager (ref 42). The Boeing design team considered the total man, machine, and operating environment in order to optimize its integrated FMS. Specifically, Boeing designed the FMS and FMCS

1. To emphasize and enhance the pilot's unique capacity for adaptive response to unplanned conditions, particularly those imposed by the ATC system;
2. To allow the pilot to function as the flight manager for all flight phases;
3. To provide the pilot with as much appropriate information relative to the flight management function as can be used effectively; and
4. To distribute pilot workload to reduce peak requirements and to minimize time critical actions.

Points 1 and 2 explicitly reserve some of the flight management function for the pilot. Features were included in the FMS and FMCS specifically to enhance the pilot's performance of this function.

3.3.5 Integrated Flight Data Display

The generation of aircraft entering the civil air transportation system during the last decade of this century will be new in concept to satisfy more stringent regulations. The aircraft will provide safe, productive, environmentally acceptable, and comfortable transportation. They will be highly automated, have integrated flight controls, and operate in an Advanced Air Traffic Management System (ATMS) with precise control in space and time to accomodate the increased air traffic.

Within the cockpit, the role of the pilot will include monitoring and managing as well as controlling a highly automated aircraft. These responsibilities will necessitate a more efficient flow of information concerning aircraft status and position. A new cockpit interface will be required with the necessary controls and displays to allow the pilot to operate efficiently and effectively.

The most obvious changes to the cockpit scene will be displays from which the crew will gain its information about the conditions of the aircraft, its position in the airspace, the requirements placed on them by the ATC systems, and other external influences.

In the current civil air transport aircraft, the majority of the displays are in the form of electromechanical rotating drum or pointer instruments, ranging from the simple, single reading meters showing mach number, temperatures, pressures, etc. to the complex flight direction displays in which a large number of different parameters are shown on a single integrated instrument, fringed with appropriate alarm flags. Already, some of these instruments are being replaced by the cathode ray tube (CRT) display. The McDonnell Douglas DC-10, for example, uses seven CRT's on its flight deck.

Major advantages of using CRT's or other types of electronic displays are the increase in system feasibility and reduced cost of system maintenance. The maintenance of electromechanical equipment requires expensive and rare skills, which are related to watchmaking, to maintain equipment at the necessary performance level. On the other hand, the flexibility of an electronic display makes it possible to integrate the whole of the displayed information, providing the pilot with data he requires at any given time with a minimum of redundancy. As an example, conventional instruments require the pilot to scan over a radius of some 22 cm from the center of the attitude detector indicator (ADI) to cover major information displays. This area is sufficiently large for pilots to miss vital cues, such as the warning flags on the ADI. With a CRT display on which he sees only the necessary data, the pilot's scan radius can be as little as 6.4 cm.

Figure 3-7 shows a conceptual future air transport cockpit as conceived by NASA-LaRC (ref 43).

The future high technology aircraft will incorporate many of today's emerging technologies. The elements of the cockpit as shown in Fig. 3-7 are identified by number as follows:

1. Electronic Attitude Detector Indicator (EADI)
2. Electronic Horizontal Situation Display Indicator (EHSI)
3. Head-Up Display
4. Systems status/alert annunciator
5. Weather/terrain imaging display
6. Systems Management Display (SMD)
7. Engine Management Display (EMD)

Each type of cockpit display will be discussed.

3.3.5.1 Electronic Attitude Detector Indicator

The Electronic Attitude Detector Indicator (EADI) replaces the conventional electromechanical attitude indicator with a CRT.

The EADI represents

1. Altitude information
2. Rate of climb

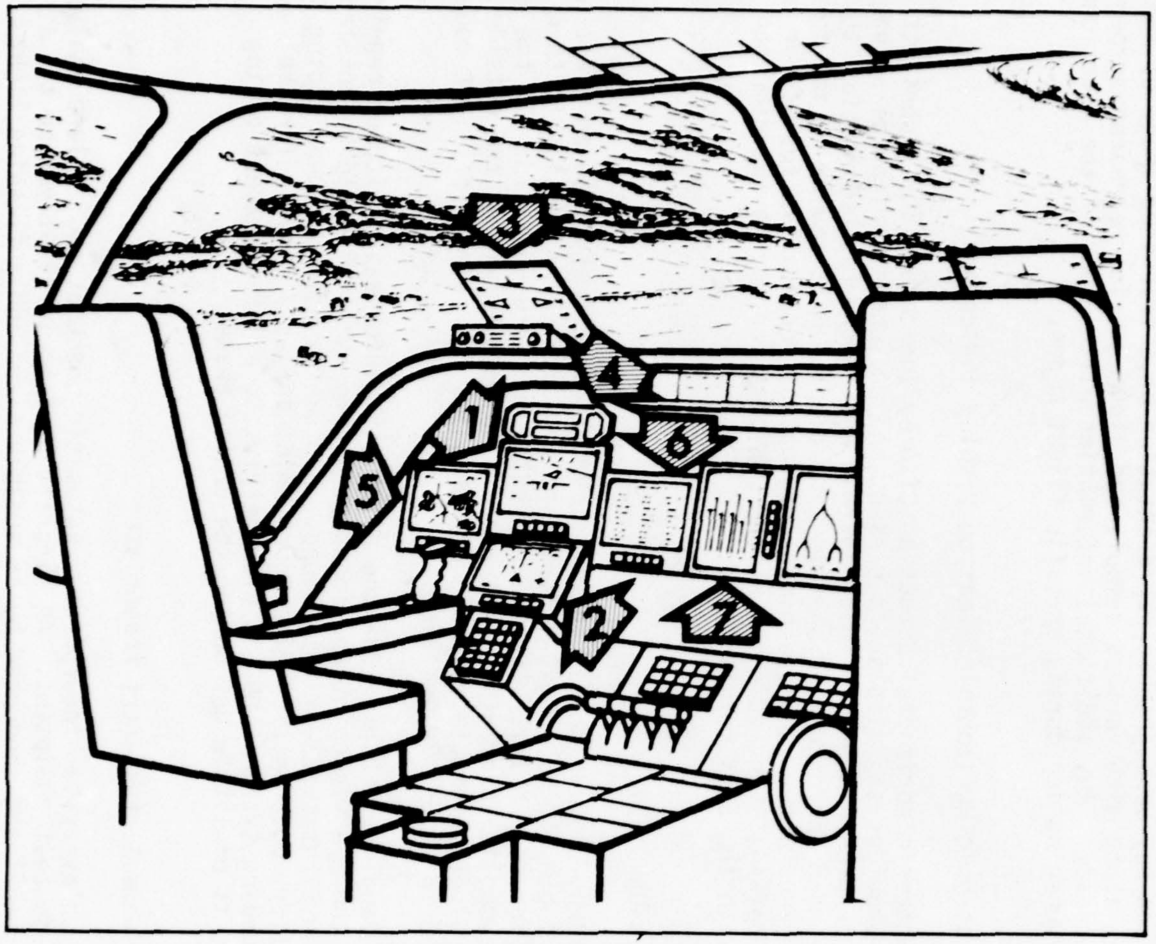


Figure 3-7 NASA-LaRc Conceptual Future Air Transport Cockpit

3. Heading

4. Altitude reference, and

5. Any other desired information.

The information may be a graphic representation or a televised image of the real terrain, along with various symbols and alphanumerics representing pertinent flight data. Any additional information will appear on the electronic display only when needed during specific flight modes.

3.3.5.2 Electronic Horizontal Situation Display Indicator

The Electronic Horizontal Situation Display Indicator (EHSI) consists of a CRT which provides the airplane's present and projected horizontal situation. It can also be programmed to display terrain and geographic information thus reducing the need for hand-held charts. The display maps may be in the form of diagrams or of actual topographical information recorded in full-color on 35 mm film (ref 44). In addition, weather information may be superimposed on the screen with the EHSI information.

3.3.5.3 Head-Up Display

The Head-Up Display (HUD) generates symbolic information on an electronic flat panel display to represent aircraft flight data. The display is then collimated (focused at infinity) and projected on the windshield. To the pilot, the symbolic information thus appears to be overlaid on the outside scene. The display formats, symbols and graphics, for specific flight modes can be stored in read-only memories.

During landing, HUD provides the pilot with information without requiring a change of the eye viewpoint and focus at a time when he should be constantly alert for the first signs of the ground. HUD can be helpful when landing in poor visibility, both in providing touch point and as a monitor for the automatic landing system. HUD is also helpful to a lesser extent during takeoff, but is of little use during the cruise phase.

3.3.5.4 Systems Status/Alert Annunciator

This display system incorporates automatic checkout and failure analysis using built-in test equipment. An aircraft problem is displayed on the status and warning panel and announced by an audible alarm and a flashing light appropriately colored red (warning), yellow (alerting), or green (advisory). Further details, as necessary, for immediate corrective action by the crew are presented either on the systems management display or engine management display. Thus, the pilot is informed during critical flight phases.

3.3.5.5. Weather/Terrain Imaging Display

The airborne radar system with multi-color display is used for weather detecting and ground mapping. It operates in the frequency range of 9345 ± 30 MHz.

In the weather mode, the most advanced of presently available radars detect and locate various types of storms along the flight path of the aircraft and display them in colors against the black background of the CRT screen. Areas of heaviest rainfall appear in red, the next level of rainfall in yellow, and the least rainfall in green. On a normally unused portion of the CRT screen such information as range/mode alphanumerics can also be displayed to help the pilot chart his course through or around the storm.

In the terrian mode, the amount of reflection from various ground surfaces will be displayed in colors showing the variation from the most reflective to the least reflective. With considerable practice and experience in interpreting color display patterns, the pilot may be able to identify the water regions, coastlines, hilly or mountainous regions, or even large structures.

The radar capable of performing the aforementioned functions is currently available at a cost of about ten thousand dollars.

In addition, research is currently underway for developing ways to detect, locate, and display the turbulence on the CRT screen. Unfortunately, because of the extreme complexity of the problem, a practical solution is still several years away. Once the problem is resolved, this new capability can be integrated with MLS in order to safeguard MLS against unexpected turbulence weather.

Weather display has gained widespread use in multiple-engine GA and commercial aircraft. The inherent difficulty in mounting the antenna and the relatively high cost have precluded the use of weather radars on single-engine GA aircraft.

3.3.5.6 Systems Management Display

The function of the System Management Display (SMD) is to monitor the status of various aircraft system components. The element being monitored can be anything vital to proper and safe aircraft operation, such as the hydraulic or fuel system.

The signals from sensors monitoring the status of various elements of the aircraft are monitored by a systems management computer which controls a cockpit CRT display. As soon as any malfunction is sensed, a warning is displayed on the CRT along with an audible signal to alert the pilot. The whole display system is under software control and hence very flexible. The information format displayed can change depending upon the requirements of the aircraft, pilot, or the flight route.

The major cost factors for the SMD are the CRT and the dedicated control computer. However, the SMD will replace a number of meters and lights in the cockpit, which are expensive to repair and maintain. It is expected that the cost of using a SMD will be comparable to the cost associated with the existing hardware it will replace.

3.3.5.7 Engine Management Display

The Engine Management Display (EMD) supplies engine data and may consist of one or multiple displays. A multi-engined aircraft can have one EMD per engine or one per pilot. The EMD can combine the display of engine data with the functions of thrust management and monitoring engine performance.

As an example of the EMD function, at engine start up time, the start checklist appears with a cursor or marker enclosing the first checklist item and its response. Once a check has been performed, the cursor can be moved down the EMD by a control key. The pilot can skip a checklist item, but it is not possible to move to a new page of checks until a skipped check either has been performed or deliberately overridden. The EMD may interface with a thrust management system, an engine management computer, and a centralized test facility.

3.3.6. Communication

Economical use of the radio frequency (RF) spectrum is as important to radio communications as is conservation of oil to the availability of jet fuel. Even though the span of the usable RF range is a huge 40 billion Hertz (Hz), today there are more demands on frequency allocations than can be met. The frequency bands allocated by the Federal Communication Commission (FCC) to the civil aviation industry for the purposes of navigation and communication are in the VHF band starting at 108 MHz. Information is transmitted over 720 voice channels each with a 25 KHz channel spacing.

Although the VHF and UHF bands are, at present, the most used in civil aviation, the FCC years ago allocated a specific high frequency (HF) band for use by general aviation and air carrier fleets. The HF band is effective for long distance over-the-horizon transmissions and is principally used on the transoceanic air route whereas VHF/UHF are used only for line-of-sight transmissions. The FCC has also allocated two narrow bands for use by civil aviation to implement the proposed discrete address beacon system (DABS) data link.

Even though a wider bandwidth is required to transmit digital information, several factors make digital transmissions more attractive than the conventional analog methods. These are

1. The continuing decrease in the cost and increase in the efficiency of digital circuitry.

2. The availability of powerful error-correcting codes.
3. The improvements in coders-decoders (codec) design which enable signals such as speech to be encoded into a smaller number of bits. Codecs convert analog signals into a bit stream or convert bit streams into analog signals.
4. The ability to use repeaters to reconstruct clean pulse streams, thereby maintaining a digital signal that is virtually free of noise.
5. The trend to develop facilities to handle much wider bandwidths.

Where multiple locations must share the same channel, time-division multiple access (TDMA) methods are used. The various time slots for a given channel are allocated by a control or reservation mechanism.

A discussion of digital data links employing some of the previously mentioned concepts follows.

3.3.6.1 Automatic Communication and Reporting System

The Automatic Communication and Reporting System (ACARS) is intended for use in conjunction with existing airborne radio equipment to enhance the effectiveness of air-ground operational control communications. This enhancement accrues from the ability of the system to provide air-to-ground voice as well as data communications. The airborne management system receives ground-to-air digital messages from the radio transceiver and controls the transmission of air-to-ground digital messages. In one mode of operation, the system will transmit messages when the need arises and it determines that the ACARS radio frequency channel is free of other traffic. In another mode of operation, it will transmit only in response to a message or poll from the ground containing the coded address of the aircraft in which it is installed.

The control unit (CU) interfaces the pilot with the ACARS system. The CU supplies the facilities necessary for the pilot to enter data on departure, arrival, fuel consumption, and estimated time of arrival and the code designation of those with whom he desires to communicate. Although ACARS technology has been available for over a decade and has been promoted by Aeronautical Radio, Inc. (ARINC), it has only recently been implemented. Implementation has been slow because potential users have not been convinced that the savings provided by the system will be greater than the cost. The basic unit costs about $5,000 per aircraft and interfaces with existing VHF transceivers.

3.3.6.2 Discrete Address Beacon System

The Discrete Address Beacon System (DABS) is being developed as part of a more efficient ATC System. When fully developed, DABS will

1. Improve the accuracy and reliability of the ATC surveillance systems.

2. Provide a digital air-ground data link for the Automatic Traffic Advisory and Resolution Service (ATARS) and other ATC functions.

3. Eliminate the "synchronous garble" from the present Air Traffic Control Radar Beacon System (ATCRBS). The garble is caused by overlapping replies from multiple aircraft in close proximity. With DABS each aircraft will respond only when addressed.

A study (ref 45) has shown that DABS should be able to handle even the highest aircraft density predicted for 1995. By the mid 1990's, ATC could use DABS for all of its contacts with airplanes and let the airline companies have exclusive use of the VHF/UHF band, including voice and the ACARS data link.

When fully implemented, DABS will convey the following types of information data between aircraft and the air traffic control system:

1. Clearances,

2. Runway surface winds (wind shear, wake vortex),

3. Weather information,

4. Minimum safe altitude warning,

5. Confirmation of assigned altitude,

6. Automated Terminal Information Services (ATIS),

7. Runway visual range,

8. Holding instructions,

9. Approach and departure clearance,

10. Conflict alert and resolution instructions, and

11. Instructions as to proper heading, speed, altitude, and the time to execute the ATC instructions.

All of these instructions will be displayed on an electronic display with appropriate aural messages or warnings. The availability of the digital data link will allow properly equipped aircraft to be under fully automatic control from takeoff through landing, although the safety and reliability of such fully automated systems will have to be proved beyond doubt before being implemented by air carriers.

Some of the subsystems that will provide the necessary data to make DABS effective are

1. NWS/FAA. The National Weather Service in conjunction with FAA is developing a weather observation system that will provide a two-hour, short-range thunderstorm forecast and a zero to four-hour aviation weather forecast plan.

2. ATARS. The Automatic Traffic Advisory and Resolution Service system is a ground based collision avoidance system. ATARS is designed to improve safety by eliminating both midair collisions and near misses between all aircraft equipped with altitude reporting transponders (DABS or ATCRBS). Although ATARS is designed to alert the pilot and to give details about potential aircraft conflicts, it would be possible to use ATARS to maneuver aircraft automatically if a potential conflict persists or worsens.

3. BCAS. The Beacon Collision Avoidance System acts as an airborne interrogator, which obtains information on altitude and range from other aircraft employing DABS transponders. A CAS display gives pilots the necessary information to avoid conflicts. BCAS and ATARS interface protocols will have to be resolved to prevent possible operational conflicts.

4. NADIN. The National Air Data Interchange Network provides non-critical flight plan data between air traffic control centers over leased telephone lines. Although not directly associated with DABS, NADIN does provide useful supplementary information for the ATC system.

Synchro-DABS is an extension of the basic DABS system in which all aircraft are tracked in range and the time of interrogation from the ground adjusted so that all aircraft receive their interrogation at the same time. Each aircraft can use the reply from other aircraft to determine the relative bearing, identity, and altitude for all nearby properly equipped aircraft. Proximity warning indicators (PWI) and collision avoidance systems (CAS) can be incorporated with Synchro-DABS.

3.3.6.3 Long-Range Projections

The introduction of the new digital electronics in aircraft communications represents a quantum jump in potential capability for information transfer compared to the present voice links. Large satellites weighing several tons will be in geosynchronous orbit by the 1990's. These satellites operating in the 12-19 GH and 20-30 GH range will allow additional channel capacity to be allocated to the airlines and the ATC system.

Other opportunities for communication services include:

1. Onboard radio telephone service for public use.
2. Some instructions and replies between ground and air which will be transmitted by alphanumerics but received as an aural and/or visual

from planned operating conditions cause the pilot to alter settings.

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message with resultant better communication between receiver and sender.

3. Vocoders, which synthesize speech without attempting to preserve the original voice waveform.
4. Computers that will respond to voice commands, easing the workload for pilots and the air traffic controllers.

3. Ride Control or Improvement (RC)

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CHAPTER 4

THE 1995 — 2000 AVIONICS SYSTEM

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4.1 Introduction

In the earlier chapters, the goals of avionics were identified, two possible scenarios for the 1995-2000 environment were developed, and various avionics technologies which will be available in this time frame were described. In this chapter, an anticipated avionics system for the years 1995-2000 is derived.

The proposed system takes account of the goals of avionics specified in Chapter 1, as well as the technologies discussed in Chapter 3. As detailed in Chapter 1, the principal goals of avionics technologies are safety, efficient transportation, environmentally acceptable transportation, and productive transportation. Efficient and productive transportation can be viewed as improving the economics and capacity constraints of the air transport system. Each of the technologies described in Chapter 3 produces benefits in one or more of these areas. Some, however, may have accompanying disbenefits. In developing an integrated avionics system, attention must be paid to the above factors as well as the overall environment for this time period. The proposed system is predicated on the mainline scenario of Chapter 2. The impact of the alternative scenario is also discussed.

The anticipated avionics system represents the Fellows' best guess as to what will be operational in 1995-2000. It does not, therefore, present what we might consider an "optimal" avionics system, but rather a view as to which avionics technologies are most likely to be operational.

This chapter is divided into eight sections. The next five sections cover the four technology areas developed in Chapter 3 as well as the air traffic control system. Each section describes the technologies in those areas which will become operational and the reason for these selections. These reasons vary from necessity to political expediency. Section 4.7 contains a description of how the avionics system would be affected if the alternative rather than the mainline scenario came to pass. Finally, section 4.8 presents a summary of the anticipated avionics system for 1995-2000 assuming the mainline scenario.

In developing the anticipated avionics system, an integrated viewpoint was taken, noting that many of the avionics technologies impact each other as well as the entire air transport system. A complete exposition of anticipated avionics system impacts is detailed in the following chapter.

4.2 Navigation and Guidance

As discussed in Chapter 3, the principal role of navigation and guidance technologies is to aid pilots and aircraft in traversing the airspace between their point of origin and destination. While there are several types of avionics equipment participating in this process, the principal systems currently in use are VOR/DME for flight over the Continental United States (CONUS) and OMEGA and INS for transoceanic flight. LORAN-A, which had also been used for transoceanic flights, was recently phased out. Developments over the next fifteen years will include an upgrading of current systems and introduction of enhanced technologies such as GPS and RNAV. Further navigation improvements will be possible with availability of onboard weather information.

One of the most ambitious navigation systems currently under development is GPS. This system is being developed by the military and is currently planned for its use only. While there are certain benefits to the civil aviation community, principally in terms of accuracy and cost, the greatest question with regard to GPS is availability. Pressure to gain access to the system could come from both the aviation and shipping communities. However, the degree of pressure that these communities exert is not great because of the availability of reasonable alternative systems and reservations about relying on a military controlled system. In particular, the airline industry is concerned about the access to GPS during a national emergency and the cost of maintaining the system if the military should abandon it. Hence, it seems reasonable to expect the military to persist in their demands for a restricted GPS system. The military advocates have little to gain from civilian access but could lose much in terms of security. The military could also use the restricted system as a trump card, agreeing to allow civilian access in exchange for financing of a more advanced system in the future.

Domestic flights currently have adequate navigation and guidance capabilities via VOR/DME. This will be further enhanced by not only more and better VOR/DME transmitters but also RNAV. RNAV, currently available on top of the line GA aircraft, will become standard on all commercial and most GA aircraft. This is because of potential fuel savings from the inexpensive system. Even if GPS were available to the civilian sector, VOR/DME would continue to serve a large sector of the commercial and GA community as little retrofitting would be expected. Some airplanes, built after civilian access is allowed for GPS, would most likely utilize this technique as the onboard equipment required is certainly cost competitive with existing navigation systems.

The greatest potential benefit from GPS will accrue to transoceanic navigation. Current systems available for this are OMEGA and INS. There is some question concerning the future usefulness of OMEGA because of a problem with shadowing. It appears that the airlines are using OMEGA as a replacement for LORAN-A in older jets for which an INS system would not be cost effective. It seems reasonable, therefore, to expect that the OMEGA system will over the next fifteen years be either eliminated or severely limited.

LORAN-C, like OMEGA, is a radio based navigation system. While it is currently used for ship navigation, the system does have the potential for adoption in civil air navigation. However, for such a system to be useful for transoceanic navigation, the operational range of the LORAN-C stations will have to increase substantially beyond their current range of 1000 miles. Present-day cost estimates for LORAN-C navigation equipment make it reasonably affordable for use by commercial and higher priced GA aircraft.

INS is currently the transoceanic navigation system preferred by most U.S. overseas carriers. The principal detraction of INS is expense. Today's INS systems cost on the order of several hundred thousand dollars. Airlines accept this expense in order to have a self reliant, accurate, and reliable onboard navigation system. While there are some drifting problems with INS requiring correction every several hours, this is not a significant detriment to performance. Future developments of this system, such as the advent of laser gyros, should further reduce the cost of INS and thereby increase its relative attractiveness. Eventually, it is anticipated that automatic correction of gyro drift can be accomplished through reference updates on a radio system such as OMEGA.

While weather information equipment is not properly a navigation system, such data plays an important role in navigation. Advances in onboard weather radar systems as well as more accurate weather information via ground transmission should enhance the navigation process. Improvements in weather prediction models as well as a broadening of the scope of current weather collection should make real-time weather information accessible to the pilot by 1995-2000.

4.3 Integrated Flight Display

Flight deck instrumentation has evolved as a result of increased experience in manned flight processes and has been implemented in an "add-on" manner as the growing complexities of flight demanded that the pilot have more data available at required times. The result of this "add-on" approach is a cockpit which is cluttered with electromechanical indicators, the majority of which are dedicated to monitoring single system functions. In round numbers, it has been estimated that the captain and co-pilot's panel in a contemporary large transport aircraft contain instrumentation that gives sixty bits of information in addition to sixty flags and annunciators.

Such an arrangement which requires the pilot to integrate various discrete data is inefficient and adds to the workload and stress level of the crew. This situation is likely to worsen in the near future. Additional modifications to the airframe and to operation procedures necessitated by more demanding noise regulations, the need to conserve fuel, and the need to fly under more severe weather conditions will require even more complex data. Therefore, a number of aviation experts have stressed the need for redesigning the traditional cockpit, making use of advanced avionics systems to provide integrated data displays on flight decks of future aircraft.

Increasing knowledge in the field of human factors research and dramatic developments in electronics technology have combined to allow great advancements in the man/machine interface of the future cockpit. While an exact blueprint for future flight deck instrumentation cannot be given at the present time, any cockpit reconfiguration for the time period of 1995-2000 will have to satisfy certain basic needs. These include a reduction in pilot workload through information integration, an increase in reliability through functional redundancy, easier pilot interface with the aircraft and with ground control, and provision for system flexibility.

The man/machine interface is crucial in the design of the future flight decks. Crew station technology for the 1995-2000 period will maximize crew effectiveness and minimize confusion and clutter which increase human error in piloting functions. There will also be a reduction in the number of dedicated electromechanical devices as well as the area required to display these data. Some specific concepts which will be incorporated include an EADI, an EHSI, a Navigation and Control Display Unit (NCDU), a Heads-Up Display (HUD), a Systems Status/Alert Annunciator, a Weather/Terrain Image Display, a Systems Management Display (SMD), and an Engine Management Display (EMD). These devices may be even further refined to include electronic map display with touch-sensitive overlay, multi-dimensional keyboards, and a voice feedback which will verbally repeat keyboard entries. There is even some indication that a pair of multipurpose flat panel displays can replace all primary instrumentation.

A fully reconfigured flight deck will place all controls and displays within the reach and view of two pilots, thus eliminating the need for the flight engineer. Despite strong opposition by the International Federation of Airline Pilots, this two person crew configuration will become standard in the cockpit of the 1995-2000 aviation environment.

There are a number of U.S. and foreign programs currently underway which examine the potential of reconfigured cockpit display panels. The results of these studies indicate that as many as seven and as few as two CRT displays will be incorporated in the large commercial air transport flight deck of the future. These CRT's will display information on flight, engine, and systems functions and management. Of these possible CRT displays, the Electronic Altitude Direction Indicator, the Electronic Horizontal Situation Indicator and the Navigation Control and Display Unit are crucial for the future aviation system since they provide the instrumentation capabilities necessary for the sophisticated flight management required by 4-D navigation and MLS. Older commercial aircraft which expect to fly into airports requiring 4-D NAV and MLS will have to be retrofitted with compatible technical capabilities.

Cathode ray tubes have dominated flat surface cockpit display research and implementation because they represent a mature technology with a long history of commercial and industrial utilization. They are currently in place on many Department of Defense (DOD) aircraft and are being incorporated into designs for future commercial air transports manufactured by major domestic and foreign airframers. Certain negative characteristics of CRT's have prompted research in alternative modes of flat panel display. Feasible candidate technology in this area include liquid crystals, electroluminescence, light emitting diodes, and plasma panels. However, of these four, only the last has actually reached the stage of implementation. In addition, CRT technology is being refined and improved for cockpit use. Therefore, it is unlikely that by the 1995-2000 time frame CRT's will have been significantly replaced by any of the candidate technologies.

Much of the postulated flight deck instrumentation integration for 1995-2000 is made possible by fairly recent electronics advancements. Digital avionics are increasingly applied in aviation systems; and, if the present trend continues, future aircraft will incorporate avionics which are almost exclusively digital in nature. This, in conjunction with improved computer architecture and improved software reliability, will enhance integration efforts. Increasing implementation of microcomputers, microprocessors, databusses, and fiber optics will also aid in the design feasibility of the reconfigured cockpit.

Integrated flight display capability has definite benefits for GA operations, especially in single pilot aircraft during instrument flight rules (IFR) where the workload becomes heavy or in such high workload situations as crop dusting. The single most important factor in equipping GA aircraft with integrated flight data displays is affordability. Some relatively inexpensive items are presently on the market, with more expected in the future. In 1995-2000, it is believed that high cost GA aircraft will probably be equipped with instrumentation in every way as sophisticated as the commercial air transport. Less expensive GA aircraft, however, will still depend upon dedicated electromechanical instrumentation for a substantial amount of their flight data.

4.4 Communication

Aviation communication entails the exchange of information between the aircraft and its external environment. The environment includes not only terrestrial communications but also inter-aircraft communications.

The predominant mode of communications has historically been VHF, UHF, and HF voice telecommunications. During the 1995-2000 time frame, however, advanced avionics technologies will rely on the integrated use of a vast amount of aviation information. In order to make this information available, the present communication system will have to undergo a transition from the current voice-oriented system to that of an electronic system from which the desired information may be selectively chosen. In order to exchange this information, the communication system will rely on a digital data link.

To exchange the required amount of data between the aircraft and the ground, the Discrete Address Beacon System (DABS) will be used. DABS provides a digital data link between the aircraft and ATC capable of satisfying the communication needs expressed above. Initially, the DABS data link can be used as a parallel with voice communication to relieve frequency congestion and reduce pilot and controller workload. Ultimately, the DABS data link will replace most voice communication and increase the automation potential of the ATC system. A gradual transition from a voice-oriented to a data-linkoriented information system would create no significant disadvantage to aviation users, and yet, would provide many advantages.

DABS is currently under development by the FAA, which is planning to convert the current Air Traffic Control Radar Beacon System (ATCRBS) to DABS. Evolution from the present ATCRBS to DABS requires that present transponders be replaced with DABS transponders at a cost acceptable to aircraft owners. DABS offers substantial benefits through reducing the amount of voice communication between the controller and the pilot. Obviously, voice communication will still be necessary to provide information to aircraft not equipped to take full advantage of these data link services.

The Automatic Communications Addressing and Reporting System (ACARS) is intended for use in conjunction with existing airborne radio equipment to enhance the effectiveness of operational control communications. The system provides commercial aviation with a means of monitoring aircraft location and performance. Although ACARS technology has been available for over a decade, few airlines adopted the system. The majority were unconvinced that the savings derived from its use would be greater than the cost of implementing it. However, further adoption can be expected in the future since it now appears that users are deriving substantial benefits by monitoring their aircraft with ACARS. DABS and ACARS will both be operational systems in 1995-2000. DABS is used to provide ATC with information, whereas ACARS provides the airlines with data about their airplanes.

Communications with mobile terminals over wide areas represent a service that could be provided by satellites. Communications with aircraft have been provided by HF radio. This, however, is narrow banded and subject to static which results from thunderstorms and ionospheric disturbances. Satellite communications offer a clear technical advantage that has been demonstrated experimentally and operationally. At one time, aviation had available an experimental satellite telecommunication system known as Aerosat. However, this system was terminated because of high costs. While it is possible that the cost of the system could be reduced if the Aerosat transponder were incorporated into a large satellite in geostationary orbit, it does not appear that satellite communications will be used in the 1995-2000 period.

4.5 Attitude and Thrust Control

The purpose of attitude and thrust control avionics technologies is to aid the pilot both in maintaining the proper orientation of the aircraft with respect to the earth and in adjusting engine throttle settings so as to require minimum fuel usage. Since most of these functions have been cable controlled in the past and are now becoming electronically controlled, they are referred to as the fly-by-wire capabilities of the aircraft.

Although fly-by-wire technology is currently available, its incorporation in new designs has been limited because of lack of confidence by pilots. Until the reliability of the avionics is proven to be as good as or better than the older cable system, pilots will be reluctant to accept a total fly-by-wire aircraft. Even with these shortcomings, it is considered likely that new commercial and higher priced GA aircraft will have a greatly increased fly-by-wire capability because of the potential benefits in weight reduction and multiple redundancy of control systems. As a result of the high cost of such technologies, however, little fly-by-wire capability will be used by the lower priced, smaller GA aircraft.

The complexity of operation for the larger 1995-2000 aircraft will be substantially greater than that of today because of advancements of technologies in the fields of navigation, guidance, communications, and control. To assist in piloting such aircraft, a flight management and control computer will be installed on virtually all new commercial airlines aircraft as well as higher priced GA aircraft. This type of computer will rely almost totally on digital electronics, with particular emphasis on the digital data bus. Limited retrofitting of older commercial aircraft will also occur.

By 1995-2000, the "strapdown" gyroscopic units used today to control roll, pitch, and yaw may be replaced by an inertial gyroscopic platform, particularly for transoceanic flights. The problems of gyroscopic drift will be resolved by technological improvements. Hence, the inertial gyroscopic platform will provide exceptional accuracy as well as the threshold required for an optimal attitude configuration. This will result in minimal drag and maximized energy management. The instantaneous determination of heading will emanate from the azimuthal gyroscope, a component of the inertial platform. To maximize effectiveness, the inertial platform will be used in conjunction with a suitable transoceanic radio system or the Global Positioning System, should this technology become available to the civil sector. The cost of this type of gyroscopic system will deter its use, particularly over land where VOR/DME will be available and compatible with today's "strapdown" units.

Active controls have the potential of improving aircraft performance and reducing operating costs. These systems will, by necessity, be part of the overall aircraft design. By 1995-2000 non flight-critical active controls, such as gust load alleviation, maneuver load alleviation, ride control, and fatigue reduction will be most likely to appear on new commercial airlines aircraft and large GA aircraft. Flight-critical active controls, such as those allowing a large reduction in static stability margin or flutter mode suppression below dive speed, will not be incorporated, except possibly on military aircraft, because of catastrophic effects if system failure occurs. As a result of the cost and, in many cases, lack of need, most active controls will not appear on smaller, lower-priced GA aircraft.

The need to reduce fuel usage will be paramount in 1995-2000. To assist in this goal, automatic thrust control systems will be utilized on commercial air transports as well as on the higher priced GA aircraft. This system will electronically control aircraft speed and engine thrust by considering flight parameters such as cruise altitude, length of trip, and duration of climbout and descent. The heart of the system controls will be a thrust management computer, which will drastically reduce the role played by the pilot and insure minimum fuel usage, thus reducing direct operating costs.

Much of the above avionics dealing with attitude and thrust control will be an integrated part of the aircraft, not just another add-on. In general, previously added on items will be either integrated into the system or discarded.

4.6 Air Traffic Control

Integrated control capability provides a means by which aircraft can make a transition from the airspace to the ground. There are several types of avionics equipment currently available and proposed to aid in this function. They all impact what is commonly known as the air traffic control (ATC) system.

The current ATC system can best be characterized as a sharing of responsibility between the pilot and ground controller. It has evolved gradually over the past forty years in response to technological advances as well as increases in airspace utilization. Its primary function is to maintain the safety of the airspace, a feat at which it has excelled. The job, however, will become increasingly more difficult as the airspace becomes more crowded because of future air traffic growth. Additional considerations, such as aircraft fuel usage, will play an increasing role in determining ATC policies.

As a result of the above factors, ATC will become more heavily dependent on electronic computers and automatic control systems. Some of the control presently exercised by the pilot will be subsumed by the air traffic controller. In turn, the air traffic controller will come to rely more heavily upon computer based algorithms for sequencing and scheduling of aircraft.

The principal avionics components of today's ATC are ground based radar, ILS, electronic computers, and onboard transponders. Human interaction plays a predominant role with information being exchanged between pilot and ground controller via voice communications. Collision avoidance is principally the responsibility of the pilot. In certain designated areas known as terminal control areas (TCA) and in terminal service radar areas (TSRA) during inclement weather conditions, the ground controller plays a more important role.

In TCA's, aircraft must be equipped with suitable avionics to enable the ground controller to perform this function. In Group I TCA's, currently numbering nine, aircraft must have a mode C transponder, two way radio, and VOR capability. In Group II TCA's, currently numbering twelve, similar equipment is required; however, the transponder does not have to have mode C capability. Flight into a TSRA during IFR conditions requires the aircraft to be equipped with the capability of following a radio beacon signal such as ILS.

The growth in air traffic will make it increasingly more difficult for ATC to maintain the current safety environment. In order to insure an acceptable level of safety, advances in tracking, landing systems, communications, and computational equipment must be forthcoming. Systems currently under development to meet these demands in 1995-2000 are MLS, 4D RNAV, Wake Vortex Detection and Alleviation, DABS, and CAS. Additional work is also being undertaken to develop the appropriate software required to fully utilize these systems.

Current computer hardware capabilities should be adequate for such an advanced air traffic control system; however, it is reasonable to expect substantially more powerful computers will be available in the future.

Advances made in the field of radar during the past forty years are expected to continue. These advances should result in improved information through more complete coverage, less interference, and better display presentation. There are currently approximately 14,500 airports in the U.S. of which 1,537 have some form of radar service and 428 have FAA control towers.

The most advanced radar system currently in operation is ARTS III. This system utilizes both secondary radar (ATCRBS) and a computer to supply air traffic control not only with aircraft location but also with altitude for those planes equipped with a mode C transponder. As air traffic at existing airports continues to grow, it is reasonable to expect additional airports to gain both primary and secondary radar capability and to see an enhancement of current radar technology at many other airports. A substantially larger percentage of GA aircraft will be equipped with transponders and other required avionics systems to enable appropriate radar tracking.

In general, most aircraft landings rely on visual control by the pilot. During times of poor visibility, such control is impossible and the pilot must rely on radio electronics to supply him with a landing path. The principal system in the United States today for accomplishing this is ILS. The system is currently in operation at approximately 660 runways in 400 airports. By ICAO agreement, the United States is committed to maintaining the ILS system until at least 1985.

One alternative to the present day ILS system currently under development is MLS. This system has been approved by ICAO as the eventual successor technology to ILS. MLS has several operational advantages over ILS. For example, Aspen, Colorado, which is surrounded by mountains which make an ILS system inoperational, is currently installing a MLS system. The ability to make curved descents can result in some improvement in terminal noise pollution and has the potential of increasing air traffic throughput over that available using ILS. To exploit this latter potential, however, appropriate air traffic control systems must also be developed. MLS also provides increased reliability and capabilities over an ILS system.

While the advantages of MLS are substantial, it remains questionable whether these benefits outweigh the cost of the system. Adoption of an MLS system not only requires new ground equipment but also new aircraft equipment. It seems reasonable to expect MLS systems will be in operation at a number of airports in the U.S. by 1995-2000. These will principally be larger airports for which traffic densities warrant the investment as well as airports for which MLS is the most practical system because of terrain constraints. Because MLS is recognized worldwide as the "American" system, there may be some political pressure favoring MLS. Some airports which currently do not have ILS may adopt MLS systems because of this pressure. Also, for this reason a small number of airports currently equipped with ILS may convert to MLS. During the next twenty years, it is expected that additional ILS systems will also be installed. ILS will remain the predominant system for instrument landing during this period because of the large current investment in such systems, both on aircraft and on the ground. It is anticipated that nearly all MLS systems installed before 2000 will be ILS compatible.

4-D navigation will most likely become operationally available in the early 1990's. This system will allow for increased throughput of planes in the terminal area because of precise specification of both location and time. The system will most likely require an onboard computer, air-to-ground data link, and suitable cockpit display equipment. New systems algorithms will be necessary for the ATC to optimally sequence and schedule aircraft. Because much of this development work must be carried out under government sponsorship, the date of actual introduction of the system will be a function of governmental priorities.

It seems likely that major airports will require 4-D navigation in order to meet the increased traffic demands. At these airports, some form of segregation between general and commercial aviation will also probably be required. This is principally because only a limited number of GA aircraft will initially be equipped with this system. The segregation could range from a spatial separation, dedicated runways, to a temporal separation, reserved landing times, or even to a complete ban on GA. The degree of segregation will depend on traffic growth as well as political pressures. A complete ban on GA at major airports in the 1995-2000 time frame is a remote possibility at best. It is expected that an increase in landing fee costs will also serve to substantially limit the amount of GA traffic at these airports.

The extent of improvements in capacity available with 4-D RNAV will by necessity be somewhat restricted in the 1995-2000 time frame. This will be due to both a limited participation of aircraft in the system as well as to the limited development of optimal control algorithms for this system. While MLS has the potential of increasing the throughput of a 4-D RNAV system, it is questionable whether the system can be designed to fully exploit this potential within the stated time frame. Utilizing MLS with 4-D RNAV will, however, provide a safer operating environment over that obtained through ILS.

4-D navigation's ability to increase traffic capacity is further enhanced by wake vortex alleviation systems. These systems are currently in the experimental stage, and it is unclear whether such a technology will be feasible by 1995-2000. Essential to such a system is the ability to perform wake vortex detection. Detection alone would be of substantial benefit to the ATC system in terms of increasing throughput capacity. It seems likely that some form of elementary wake vortex detection will be available at major airports by 1995-2000 and will be integrated into the 4-D navigation system.

Additional gains in efficiency can be obtained through an effective information exchange between ATC centers. Aircraft delayed while on the ground rather than in flight due to terminal congestion result in decreased fuel usage. An expansion of the current capabilities of the NADIN system will enable such an information exchange.

Collision avoidance systems have been on the drawing boards for the past forty years. The principal motivation for such systems is that of safety. The major deterrent to the systems has been the issue of cost. Functionally, commercial aircraft safety has been superior to that of any other means of travel. While the safety record for GA has not fared as well, it is still comparable to alternative transport technologies. As the amount of general aviation traffic grows, it is expected that the overall safety record of air travel will show a slight degradation. This may, in turn, result in some additional political pressures towards improved collision avoidance systems.

A number of different collision avoidance systems are currently under development. These include Honeywell AVOIDS, MIT Intermittent Positive Control, McDonnell Douglas EROS, RCA SECANT, and Litchford Semiactive BCAS. The principal difference between these systems is in the amount of supplemental information required from a source external to the aircraft. The advent of DABS should enable the effective transmission of this information, however obvious reliability problems will still remain. Cost plays a major role in system evaluation. All systems will require substantial expenditures by the airline companies and GA aircraft owners. Total system costs would approach $1 billion.

It is believed that unless there is a substantial increase in the number of midair collisions, an onboard collision avoidance system will not be operational by 1995-2000. It does seem likely, however, that improvements in collision avoidance capabilities will be obtained in the terminal area through improvements in the ATC system.

Finally, it is believed that complete responsibility for the entire flight will remain vested in the pilot. While he will rely on information supplied, either verbally or via data link from ATC, control of the aircraft will continue to be in the pilot's domain. In no instance will ATC have any active airborne control of civil aircraft.

4.7 The 1995-2000 Avionics System Under the Alternative Scenario

This section discusses the anticipated avionics system for 1995-2000 under the alternative or no growth scenario. In this case, traffic demands will remain at today's level, thereby alleviating the need for increased system capacity. Hence, avionics technologies which have as their principal benefit the potential for an increase in system capacity will, in general, not become operational by 1995-2000. Safety, economics, and environmental factors, however, will continue to be the major goals of avionics.

It is anticipated that the alternative scenario will result in a slowdown in the implementation of avionics as compared with that achievable under the mainline scenario. This is because of a decrease in aircraft demand, as planes will only be required for replacement purposes in the U.S. market or to satisfy international demand. The decrease in demand will be accompanied by increased aircraft costs, thus slowing development of new aircraft. While derivative aircraft will continue to be developed, the pace of such development, as well as the likelihood of new generation aircraft, will be reduced.

Hence, avionics systems which are required to be integrated into the aircraft design, rather than simply being add on in nature, will be less likely to become available.

In navigation and guidance, the impact of almost all technologies is principally on the economics of air transport. Furthermore, these systems are basically add on's in nature or can easily be incorporated into derivative aircraft design. Hence, the avionics used for navigation and guidance will generally be the same as that used under the mainline scenario.

The likelihood of GPS being made availabe to the civil aviation community will be even less than that under the mainline scenario. This is because the accuracy provided by this system would not be required in order to increase system capacity.

Integrated flight displays primarily impact on the economics of air transport also. These, however, are not by nature add on devices, but rather usually part of an overall cockpit design.

Under the alternative scenario, the degree of utilization of integrated flight displays will be less than under the mainline scenario. Use of displays which aid in the terminal flight phase and those relating to active controls will be reduced. The decreased development rate of new aircraft will also result in a decrease in the amount of integrated flight display equipment onboard the aircraft. Despite these factors, however, the amount of integrated display equipment and the utilization of CRT type devices will still increase substantially over today's levels. This will be due to decreased manufacturing costs, easier maintainability, and improvements in aircraft operations affordable by such systems. The two person flight crew will also become standard under the alternative scenario.

In the area of communication, avionics development under the alternative scenario will parallel the mainline scenario. While DABS has significant benefits in increasing system capacity, it also has substantial safety as well as economic benefits. It can be easily retrofitted onto existing aircraft. These factors will insure the adoption of DABS. Economic benefits will serve to motivate an increased use of ACARS.

Attitude and thrust controls affect the economics and comfort of flight and allow some environmental improvements. While some technologies in this area lend themselves to retrofitting, many others must be integrated into the aircraft design. Hence, a decrease in new aircraft development will result in a decreased use of integrated attitude and thrust control technologies.

Fly-by-wire, digital data bus, and flight critical active control technologies will be utilized to a lesser extent under the alternative scenario due to the integrated nature of such equipment. Technologies such as automatic thrust control, the flight management computer, and inertial gyroscopic platforms will probably be implemented to the same degree under both scenarios. This is because of the ease of incorporating these features into derivative aircraft design or adding them onto existing aircraft. The principal impetus for the adoption of these technologies will be economic considerations.

The alternative scenario will result in a slower evolution of the air traffic control system than under the mainline scenario. As the number of planes in the air will remain virtually unchanged from today's levels, there will be no need to accomodate an increase in systems capacity. Rather, the ATC advances will be geared toward increasing safety and making the system function more economically.

The degree of adoption of MLS will be severely limited. Only a small number of airports, principally those with terrain constraints or with heavy traffic demands,will utilize this system. Radar will continue to improve, however probably not to the extent under the mainline scenario. Because of safety concerns, the number of TCA's as well as the number of airports utilizing ILS will increase. This increase, however, will not be as great as under the mainline scenario.

The development of 4-D RNAV will be impeded and will most likely not be available in this time frame. Rather, improvements in metering and spacing techniques will serve as a means of reducing unnecessary fuel consumption and air pollution, and increasing safety. The air traffic control system will come to rely heavily on computer based algorithms, but these systems will not be as sophisticated as those which would be developed under the mainline scenario. Segregation of general and commercial aircraft at airports will probably not progress beyond today's levels. Collision avoidance will still be restricted to the terminal area and will be a function of ATC. Again, the sophistication of this system will be lower than that achieved under the mainline scenario.

The above description contains our best guess as to what avionics system would be most probable under the alternative scenario. As can be seen from the above, many of the avionics technologies will be in place regardless of which scenario comes to pass. The degree of adoption and acceptance will depend upon the scenario which actually evolves.

4.8 Summary of the 1995-2000 Avionics System Under the Mainline Scenario

The following is a brief summary highlighting the anticipated avionics system for 1995-2000 under the assumptions stated for the mainline scenario.

4.8.1 Navigation and Guidance

1. There will be continued use of VOR/DME for domestic air transport navigation.

2. There is a small likelihood of GPS being made available for use by the civil sector. If such a system were made available, its utilization would not be widespread.

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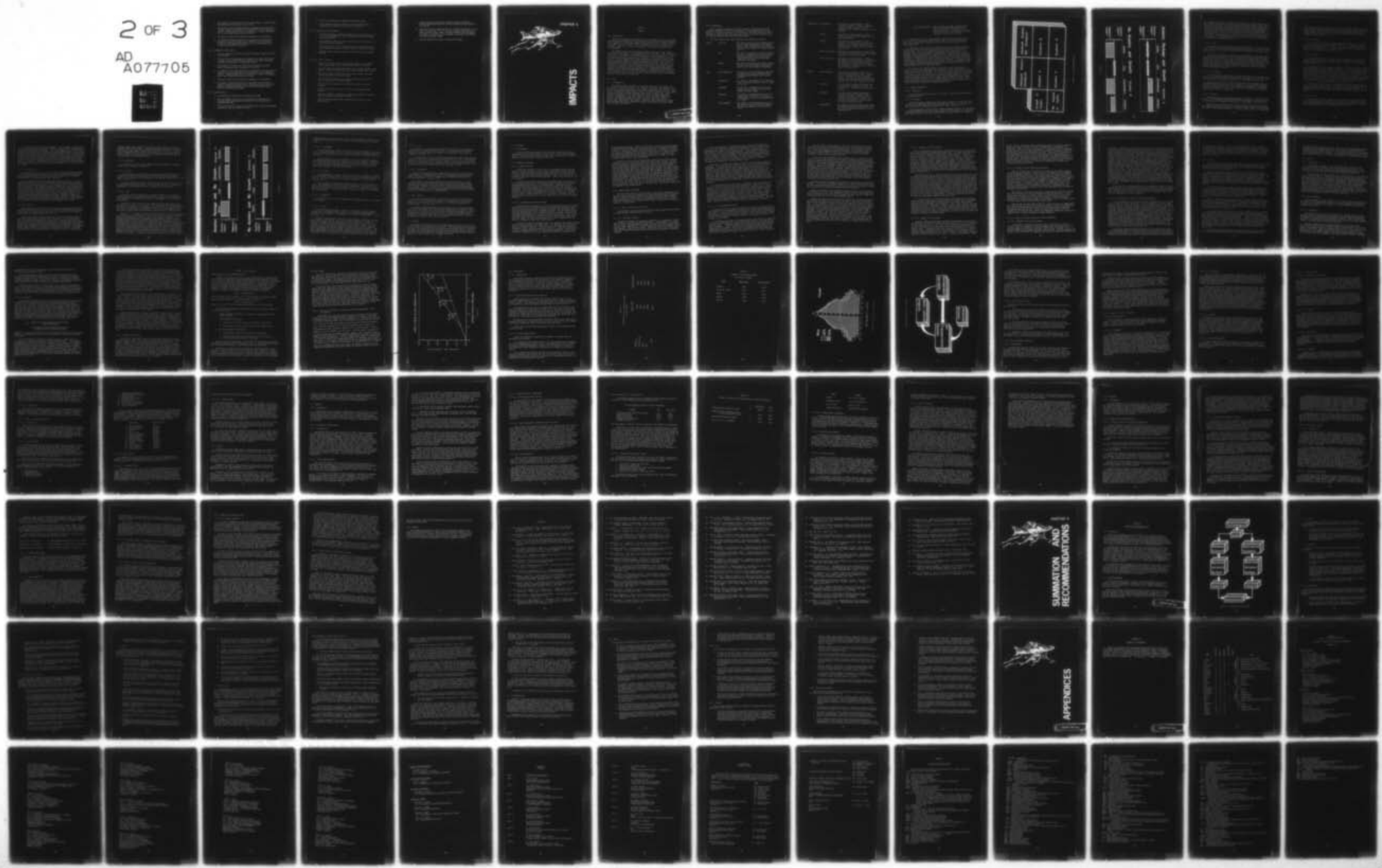
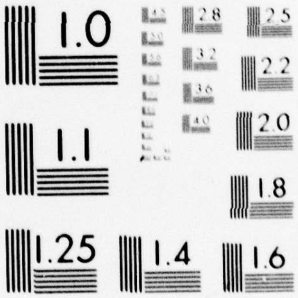




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

3. New commercial aircraft will have CRT type displays to supply highly integrated flight information to the pilot.

4. The amount of individualized displays on commercial aircraft will be severely reduced as information is presented in a more integrated fashion. These displays will rely primarily on digital electronics, with a small number being analog in nature.

5. Two person crews will be standard on commercial air transports.

6. The degree of sophistication of the integrated flight display on general aviation will primarily be a function of aircraft cost. In general, individualized display will be the predominant means of the pilot obtaining flight data.

4.8.2 INTEGRATED FLIGHT DISPLAY

1. All new commercial aircraft will have CRT displays required for MLS 4-D navigation.

2. There will be a limited amount of commercial aircraft retrofitting in order to provide them with the capability of flight into major airports which required 4-D navigation and MLS.

3. New commercial aircraft will have CRT type displays to supply highly integrated flight information to the pilot.

4. The amount of individualized displays on commercial aircraft will be severely reduced as information is presented in a more integrated fashion. These displays will rely primarily on digital electronics, with a small number being analog in nature.

5. Two person crews will be standard on commercial air transports.

6. The degree of sophistication of the integrated flight display on general aviation will primarily be a function of aircraft cost. In general, individualized display will be the predominant means of the pilot obtaining flight data.

4.8.3 Communications

1. All commercial aviation will be equipped with DABS.

2. Most new general aviation will be equipped with DABS and a substantial number of existing GA aircraft will be retrofitted to accomodate the DABS.

3. The existing ARTS III system will be modified to incorporate enhanced information available through the DABS.

4. ACARS will continue to be adopted by commercial users.

5. Voice communication will continue to be an important mode of communicating, especially for aircraft to aircraft.

4.8.4 Attitude and Thrust Control

1. A flight management and control computer will be installed on virtually all new commercial airlines aircraft as well as on higher priced GA aircraft.

2. The "strapdown" gyroscopic units used today may be replaced by an inertial gyroscopic platform.

3. Non-flight critical active controls will be an integrated portion of new commercial airlines aircraft as well as large GA aircraft.

4. Automatic thrust control systems will be utilized on jet powered aircraft.

4.8.5 Air Traffic Control

1. There will be wider usage of better radar systems. The number of primary and secondary radar installations will also increase.

2. ILS will remain the predominant system for instrument landing. The number of runways utilizing ILS will increase beyond today's level.

3. MLS will be used at major airports and those airports for which terrain constraints dictate its usage.

4. 4-D RNAV will be required at some major airports during certain times of the day or on certain runways.

5. There will be an increased use of both ILS and MLS at smaller airports.

6. General aviation will increase its use of radio based landing systems.

7. Spatial or temporal segregation of general and commercial aviation will be required at some major airports.

8. There will be elementary wake vortex detection systems at some major airports.

9. Ground controllers will become increasingly more reliant on computer based algorithms for optimally sequencing and scheduling of aircraft.

10. There will be an increased ability for collision avoidance in areas under ATC authority. This is because of better radar, computer based tracking systems, DABS, and better onboard alerting systems for pilots. Aircraft will not, however, be equipped with onboard. collision avoidance systems.

11. Aircraft control will remain in the pilot's domain.

CHAPTER 5

IMPACTS

CHAPTER 5

IMPACTS

5.1 Introduction

Chapter 4 presented two predictions of the 1995-2000 avionics system based upon the projected conditions of the mainline and alternative scenarios developed in Chapter 2. The present chapter investigates some of the impacts which the avionics system of the post-1995 time period will have on five parties of interest. These are (1) Users (2) Personnel (3) Society (4) Industry, and (5) Government.

The impacts of an advanced avionics system on the user -- here defined as the airline passenger -- are evaluated in terms of safety, cost, convenience, and comfort. The impacts of an advanced avionics system on personnel -- principally the pilot and the air traffic controller -- are analyzed in terms of the effects of increased automation on manpower assessments and human factors issues. Societal impacts are examined with respect to effects on the environment, demographic behavior, and public attitudes and values. The impact of implementation of an advanced avionics system on the aviation industry -- here defined as airframers, aircraft component manufacturers (including computers and avionics producers), and the airlines -- are investigated with regard to economic, legal, and regulatory considerations. Government considerations are discussed with reference to the FAA's certification procedures, the FAA regulatory function vested in the air traffic control system, and the environmental policies of both the EPA and the FAA.

5.2 Users

5.2.1 Introduction

The average airline passenger is relatively ignorant of the hardware in the aircraft on which he travels. His interests focus upon such things as safe arrival at his destination, cost of the ticket, convenience, and comfort. While he can articulate his expectations of the air transport system, he is not likely, unless considerable consumer education takes place, to demand that specific hardware be employed. Airline passengers as users are highly impacted by avionics implementation, but their input into major decisions concerning avionics implementation takes the indirect form of reaction to changes in safety, cost, convenience, and comfort. Therefore, this section will address those factors which can be expected to impact most directly upon these dimensions of public perception.

5.2.2 Methodology

Exact quantative measures of avionics impacts as perceived by the air transport passenger are difficult to produce. The methodology used in this section is to define an ordinal scale for each of the impact areas and then to estimate the level of impact on these scales for each of four different cases of avionics implementation and air traffic growth.

The scales used in the impact evaluation are defined as follows:

SAFETY:	Very Safe	--the ratio of fatalities per revenue passenger mile drops below that of the safest year to date, and the statistical probability of a fatal accident is extremely remote (ref 1).
	Safe	--the ratio of fatalities per revenue passenger mile is comparable to today's aviation system; catastrophic airline disasters occasionally occur and are given major exposure in the media.
	Unsafe	--the ratio of fatalities per revenue passenger mile rises above that of the current system, and is thus deemed unacceptable.
COST:	Very Inexpensive	--the price of air travel drops to the point of making it the most affordable from of transportation available to the entire populace.
	Inexpensive	--air travel is affordable for a larger portion of the entire populace than is currently the case.
	Affordable	--air travel is affordable for the entire middle class as defined in terms of disposable personal income.
	Expensive	--air travel is affordable for most of the middle class, but its cost is a major consideration, causing it to be perceived as a luxury.
	Very Expensive	--air travel is not affordable for most of the middle class and is utilized only by the business community and the tourist elite.

CONVENIENCE:	Very Pleasing	--the phases of the passenger's flight, including scheduling, routes, connecting flights, layovers, and arrival and departure times, interface smoothly with no problems.
	Pleasing	--the phases of the passenger's flight interface in an expedient manner with only minor hinderances.
	Adequate	--the phases of the passenger's flight interface, but there are occasional major problems such as delayed departures and arrivals, missed connections, long layovers, and the like.
	Mildly Frustrating	--the phases of the passenger's flight interface, but difficulties in maintaining flight itineraries are likely to occur.
	Very Frustrating	--the phases of the passenger's flight do not interface with any degree of consistency, and takeoff and landing times become an approximation, long layovers are common, and schedules are adhered to with a limited degree of predictability.
COMFORT:	Very Comfortable	--the individual passenger experiences no significant discomfort in route. Seating space is adequate even with high load factors. The ride is smooth and there is only minimal uneasiness during takeoff and landing, even in severe weather conditions.
	Comfortable	--the individual passenger experiences only inconsequential discomfort in route. He arrives at his destination none-the-worse-for-wear.
	Acceptable	--the individual passenger experiences discomfort during the flight because of crowding, turbulence, abrupt aircraft maneuvers, and the like. However, this will not be a deterent in his decision to use the air transport system.
	Uncomfortable	--the individual passenger experiences major discomfort during his flight and will take this into account when electing to use air transportation.

Very Uncomfortable	--the individual passenger experiences degrees of discomfort which approach his level of tolerance. Crowding, air sickness, and general stress fatique are common aspects of commercial air travel.

The middle term in each scale represents the mean value for that scale; that is, the terms preceding it define the range of positive impact within that scale and the terms following it define the range of negative impact within that scale.

In order to provide a basis of comparison for evaluating these areas of impact, two states of avionics technology implementation are hypothesized for the year 1995. The first hypothesized situation posits that there is no implementation of advanced avionics systems beyond the present-day, in-use hardware. Piloting functions are accomplished in essentially the same manner and with the same equipment as currently in place on domestically manufactured airframes. In addition, air traffic control procedures and capabilities have hypothetically remained the same as present-day standards. The second hypothesized situation assumes that the avionics systems discussed in Chapter 4 under the mainline scenario have been brought on-line by the year 1995 and are functional elements in the air transport system.

Placing both the "growth" and the "no growth" scenarios developed in Chapter 2 under these two hypothetical states of avionics implementation produces four possible combinations: (a) the avionics system described in Chapter 4 and growth in aviation traffic, (b) no avionics beyond present day and growth in aviation traffic, (c) the avionics system described in Chapter 4 and no growth in aviation traffic, (d) no avionics beyond present day and no growth in aviation traffic (See Fig. 5-1). These four possibilities for the 1995 avionics/aviation environment can then be examined in order to generate impact levels for the four areas of assessment defined above.

5.2.3 Impact Assessments

5.2.3.1 Situation A

This section discusses the case of air traffic growth and the introduction of advanced avionics.

5.2.3.1.1 Safety

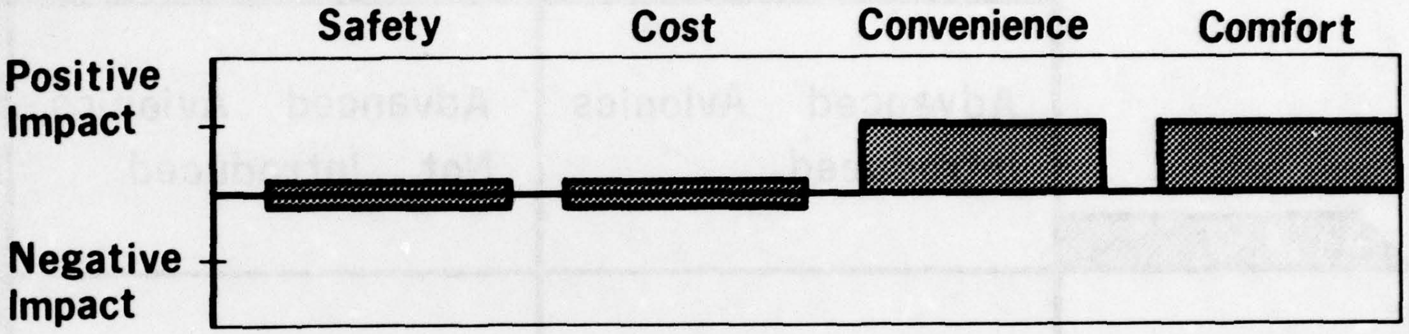
Given the avionics capabilities discussed in Chapter 4, an increase in air traffic of the magnitude projected by the mainline scenario for the year 1995 will produce an air transport system which is "safe" (See Fig. 5-2).

The proposed MLS, 4-D Nav system, flight management computer, CRT integrated displays, and DABS network will tend to improve the navigational, communication, and control aspects of air safety, particulary in the terminal area. However,

	Advanced Avionics Introduced	Advanced Avionics Not Introduced
Growth In Traffic	Situation A	Situation B
No Growth In Traffic	Situation C	Situation D

Figure 5-1 Four Situation Matrix

Avionics Package and Growth — Situation A



No Avionics and Growth — Situation B

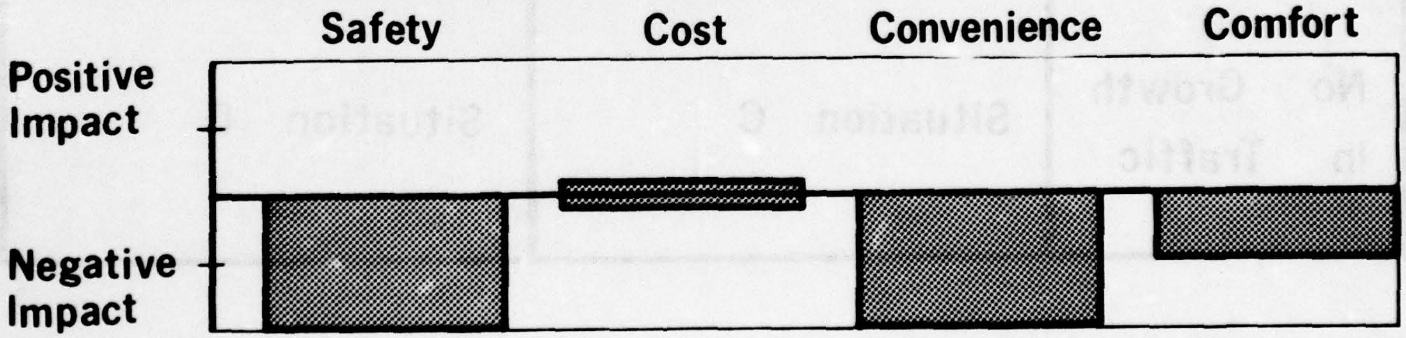


Figure 5-2

the assumption that traffic growth will continue at an average annual rate in the vicinity of 10 percent implies that many of today's larger airport facilities will be saturated. With the prospect of major new airport construction being quite small and the expansion of most existing airports being almost impossible, saturated airports will become more common. Spacing between aircraft will be decreased in landing procedures in an effort to handle the increased traffic. Stress and strain on air traffic controllers will increase. Fortunately, the probability of a midair collision will be no greater than today, because these disadvantages of increased air traffic will be balanced by the benefits of advanced avionics.

5.2.3.1.2 Cost

Given the avionics capabilities discussed in Chapter 4, an increase in air traffic of the magnitude projected by the mainline scenario for the year 1995 will produce an air transport system which is "affordable" on the cost scale (See Fig. 5-2).

The cost of installation, operation, and maintenance of the 1995 proposed avionics will be high, but this will be balanced by reduced operating costs made possible by the fact that many of these avionics reduce fuel consumption. For example, automatic thrust control, in conjunction with the MLS and 4-D Nav system, will allow a thrust idle descent from cruise altitude to landing, and active controls, such as manuever load alleviation, gust load alleviation, flutter mode suppression, and reduced static stability, will allow reduced structural weight for aircraft.

5.2.3.1.3 Convenience

Given the avionics capabilities discussed in Chapter 4, an increase in air traffic of the magnitude projected by the mainline scenario for the year 1995 will produce an air transport system which is "pleasing" (See Fig. 5-2).

The use of the MLS and 4-D Nav systems will help insure adherence to the scheduled departure and arrival times. Moreover, with all-weather operations possible, airport operations will be suspended less frequently. In addition, more flights between cities will be possible, thus allowing the user greater flexibility in choice of flight time.

5.2.3.1.4 Comfort

Given the avionics capabilities discussed in Chapter 4, an increase in air traffic of the magnitude projected by the mainline scenario for the year 1995 will produce an air transport system which is "comfortable" (See Fig. 5-2).

The use of active controls such as gust load alleviation and ride control will reduce and perhaps eliminate the occasional bumpy ride now felt by passengers when flying through turbulence. The use of thrust control, in conjunction with the MLS and 4-D Nav systems, will allow a thrust idle descent to landing, thus eliminating the thrust surges now felt by passengers during letdown and final approach. Air sickness, not a particularly common problem now, will become even less common. On the ground, active landing gear will provide smoother taxiing operations.

5.2.3.2 Situation B

The impacts of air traffic growth without the availability of advanced avionics are summarized in this section. This case is somewhat artificial since significant growth in air traffic would be unlikely without advanced avionics. Nevertheless, it is included to provide a frame of reference for analyzing four disjoint and exhaustive cases.

5.2.3.2.1 Safety

A continuation of today's ground control system and aircraft avionics, coupled with an increase in air traffic of the magnitude projected by the mainline growth scenario for the year 1995, will produce a system which is "unsafe" (See Fig. 5-2).

According to the Flight Safety Foundation of Arlington, Virginia, approach and-landing mishaps comprise nearly 60 percent of all fatal accidents since 1959, and take-off mishaps comprise 25 percent (ref 2). The factors contributing to this high accident rate in the terminal area are complicated maneuver under dense traffic conditions and high pilot workload. Increased traffic without the benefit of advanced avionics can only worsen these factors, thereby increasing the probability of accidents during approach, landing, and take-off. The risk of midair collision also rises as air traffic density increases if the air traffic control system remains in its current state.

Note that the larger loads of wide-bodied jets makes the fatalities per collision increase substantially. For example, a collision between two wide-bodied aircraft, each carrying 500 passengers, could triple the number of fatalities from midair collisions for the last 15 years in just one accident (ref 3).

5.2.3.2.2 Cost

Continuation of today's ground control capability and current aircraft avionics, coupled with an increase in air traffic of the magnitude projected by the mainline growth scenario for the year 1995, will produce a commercial air transport system which is "affordable" (See Fig. 5-2).

Several factors enter into this judgment. The assumption is made that the cost of manufacturing aircraft will rise, even though no new, sophisticated avionics will be added by airframers. This rise, however, will not be dramatic because all airframers will be working with established designs and any modifications of these derivative aircraft will not be major. Fuel is assumed to be available, but at costs which will, on average, triple today's price per gallon. Increased user demand and higher load factors per flight (because of larger planes in service and fewer empty seats on the average flight) should offset these cost increases. Deregulation will also allow airlines to drop unprofitable routes and to operate existing routes and schedules in a more cost-effective manner.

5.2.3.2.3 Convenience

Continuation of today's air traffic control system and current aircraft avionics, coupled with an increase in air traffic of the magnitude projected by the mainline scenario for the year 1995, will produce an air transport system which is "very frustrating" (See Figure 5-2).

It is expected that by 1984, twenty-one major hub airports will reach operational saturation if air traffic grows at the projected rate and the air traffic control system remains as it is at present (ref 4), and by the 1995-2000 time period, an even greater number of airports will have reached operational saturation. The consequence will be an extension to these airports of the delays and other operational inefficiencies currently experienced at only a few airports during peak traffic periods. That is, missed take-off and landing times will have become endemic to the air transport system, as well as the scheduling difficulties that result from this. Moreover, connecting flights will require more time between the flight segments, thereby possibly decreasing the number of flights per day between some cities. These factors will make the air transport system much less convenient than today.

5.2.3.2.4 Comfort

Continuation of today's air traffic control system and current aircraft avionics, coupled with an increase in air traffic of the magnitude projected by the mainline scenario for the year 1995, will result in an air transport system which is "uncomfortable" (See Fig. 5-2).

Airlines will focus on cost-cutting, so the system will be arranged to move the maximum number of people in a given space. It is possible that a more cost-effective arrangement of seating will be devised, with low-yield sectors--such as first class--being eliminated. Carry-on luggage will probably be even more severely restricted than under today's procedures. With fewer vacant seats, passengers will find less room to spread out than on present-day flights, which operate at an average of 60 percent of capacity. Prolonged holding patterns around saturated hubs will result in more air sickness and increased aggravation, should the passenger be aware that he is in a "no progress" phase of the flight. In-route conditions, especially service, will deteriorate as the emphasis becomes more and more on "no frills." Ability to avoid turbulence and to control thrust rates will be similar to that on today's flights, and should not add to the discomfort of the passenger any more than they do at the present time.

5.2.3.3 Situation C

The impacts of no air traffic growth and the introduction of advanced avionics are evaluated in this section.

5.2.3.3.1 Safety

The introduction of the avionics capabilities discussed in Chapter 4, coupled with no growth situation such as is projected by the alternative scenario for the year 1995, will produce an air transport system which is "very safe." (See Fig. 5-3).

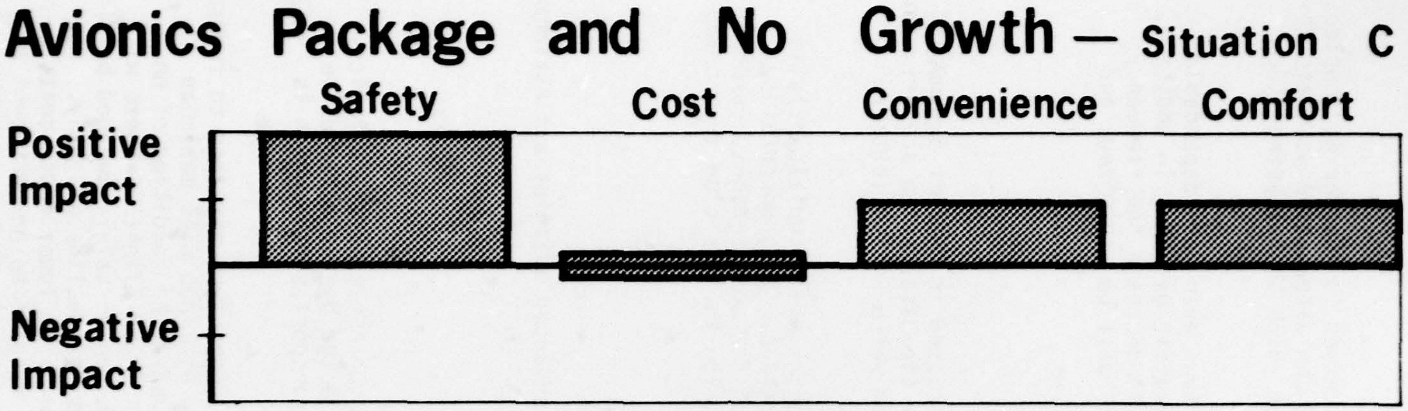
The safety advantages of DABS, 4-D navigation, MLS and the like will not be counterbalanced by increased air traffic, as was the case in Situation A. Consequently, airline safety will be at a higher level than today.

5.2.3.3.2 Cost

Given the avionics capabilities discussed in Chapter 4, a no growth situation such as is projected by the alternative scenario for the year 1995 will produce an air transport system which is affordable to the individual ticket-holder.

Equipping a fleet of aircraft with advanced avionics may require substantial capital outlay for an airline. This expenditure must be covered by the airline. Therefore, if no subsequent savings accrue from advanced avionics and revenue from passenger volume does not rise, the cost of upgrading the fleet may be passed along to the consumer and the price of a ticket may rise.

However, it is probable that the cost-cutting benefits of advanced avionics to the operation of the airline will offset their initial expense. The huge outlays for development--financed largely by government and industry--will have been recovered by 1995. Furthermore, while possibly costly to install, advanced avionics will be competitive with alternative equipment, which--if available at all--will have risen in installation cost and will be more expensive to maintain than a largely digital, fly-by-wire system. Also, as outlined in the section on economics, the use of avionics can contribute a fuel savings of up to 18.5 percent compared to present 1979 practice. It is expected that the added cost of avionics will not exceed the savings realized in improved fuel economy, thus the price of an airline ticket will be no more (or less) affordable than it is today. In addition, there may be only one or two pilot/flight


Avionics Package and No Growth — Situation C

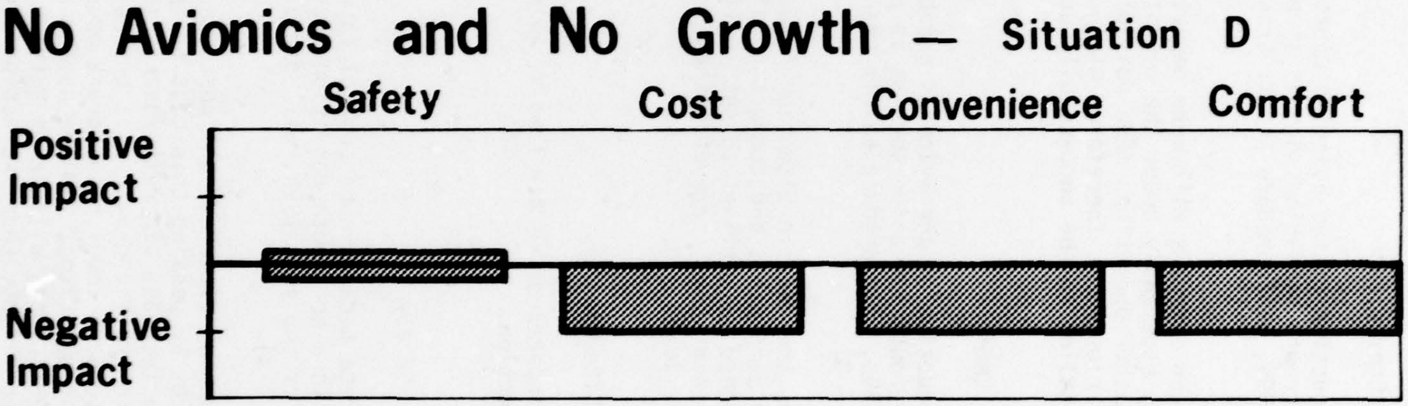

No Avionics and No Growth — Situation D

Figure 5-3

managers on board, and there may be fewer flight attendants and fewer frills in an effort to keep the cost of air travel from rising above the affordable level.

5.2.3.3.3 Convenience

Introduction of the avionics capabilities discussed in Chapter 4, coupled with a no growth situation such as is projected by the alternative scenario for the year 1995, will produce an air transport system which is "pleasing" (See Fig. 5-3).

Advanced avionics will make departure and arrival even more dependable than today, especially under the condition of no traffic growth. In addition, the all weather operations made possible by MLS will decrease the frequency of airport closings. Therefore, missed connections will be minimized, and tight scheduling can be successfully achieved.

5.2.3.3.4 Comfort

Introduction of the avionics capabilities discussed in Chapter 4, coupled with a no growth situation such as is projected by the alternative scenario for the year 1995, will produce an air transport system which is "comfortable". (See Fig. 5-3).

As was the case in Situation A, advanced avionics will significantly increase the smoothness and comfort of aircraft operation. Only uncertainty about the need of airlines to cut inflight "frills" for cost reasons, perhaps including seat space, prevents the comfort estimation in this case from being at a higher level.

5.2.3.4 Situation D

The impacts of no air traffic growth and no advanced avionics are evaluated in this section.

5.2.3.4.1 Safety

The present-day ground control capability and current aircraft avionics, coupled with a no growth condition such as is projected by the alternative scenario for the year 1995, will produce an air transport system which is "safe" (See Fig. 5-3).

Because of elevated fuel costs and the unwillingness of airlines to reduce their market by passing this cost to the consumer, airlines will maximize efforts to increase aircraft load factors, which under the condition of no increase in traffic growth will probably result in fewer flights. There will continue to be a level of aircraft operation which can be safely managed by present day practices, and the number of accidents may decline slightly. However, larger planes will be in service and there will be fewer empty seats on the average flight, thus increasing the number of fatalities per accident and causing the ratio of fatalities per revenue passenger mile to remain stable.

5.2.3.4.2 Cost

The present day ground control capability and current aircraft avionics, coupled with a no growth condition such as is projected by the alternative scenario for the year 1995, will produce an air transport system which is "expensive" (See Fig. 5-3).

Escalating fuel prices and rising energy conservation taxes could increase fares by as much as 50 percent by the year 2000 (ref 5, p. 170). Airlines will employ cost cutting measures in order to retain as much of the tourist trade as possible, but without either advanced avionics or increased passenger volume they will not be able to keep fares at the "affordable" level.

5.2.3.4.3 Convenience

The present-day ground control capability and current aircraft avionics, coupled with a no growth condition such as is projected by the alternative scenario for the year 1995, will produce an air transport system which is "mildly frustrating." (See Fig. 5-3).

The airlines' cost-cutting route and flight consolidations will make scheduling less convenient than at present, and take-off and landing delays presently experienced at a few major airports during peak operating periods will continue. However, airlines will try to keep the system from plunging below the passenger's level of tolerance because this would lead the passenger to elect an alternative form of transportation.

5.2.3.4.4 Comfort

The present-day ground control capability and current aircraft avionics, coupled with a no growth condition such as is projected by the alternative scenario for the year 1995, will produce an air transport system which is "uncomfortable." (See Fig. 5-3).

It has been assumed throughout this no growth portion of the assessment that the airlines would still see the middle income tourist traveller as their major market. The image of air travel and the marketing techniques to exploit it would increasingly rely on the "no frills" concept, hoping that various advantages of air travel over other forms of transportation would offset the disadvantage of deteriorating levels of comfort.

5.2.4 Summary

The impact of avionics on the airline passenger will be felt in the area of user safety, cost, convenience, and comfort. Projecting toward the post-1995 time frame, the introduction of the advanced avionics system which is described in Chapter 4 gives the passenger increased safety, affordability, more convenience, and more comfort than the continuation of present-day avionics under the conditions of both "growth" and "no growth" scenarios.

5.3 Personnel

5.3.1 Introduction

In this section two personnel issues that may be influenced by the implementation of advanced avionics are discussed. These are the manpower impacts of avionics in the aviation industry and the human factors impacts of avionics on the pilot and air traffic controller.

5.3.2 Manpower Assessment

5.3.2.1 Manpower Impacts

Occupational categories are necessary for personnel analysis because members of these categories are not freely interchangable either from the point of view of individuals making occupational choices or from the point of view of those who supervise the production process. Two occupational categories are used in the following analysis: these are pilot and air traffic controller.

In general, the impact of avionics on personnel under the conditions of the mainline scenario and the anticipated avionics system results from increased demand for and use of air transportation. Elementary economic principles state that as demand for a service increases, the factors of production, such as employees, must be increased in order to accomodate the new demand. If avionics technology were to remain constant, the demand for personnel would increase in proportion to increased air traffic. However, if avionics improve, labor demands will still increase as the demand for air transportation increases, but at a rate slower than in the case of unchanged avionics.

5.3.2.2 Consolidation of Work Functions

Avionics have been heralded as a means of relieving pilot and air traffic controller workloads. However, instead of allowing the workload of individuals to decrease, employers will attempt to transfer and consolidate work functions and then will dismiss unneeded employees. The net effect will be that even though demand for air transportation will increase significantly, the demand for personnel will increase at a much slower rate. That is, the post-1995 advanced avionics system will be less labor intensive than the present system. The remaining employees will press for higher wages, and they will attempt to prevent job consolidation.

The exact outcome for personnel levels will depend on the extent to which advanced avionics actually eliminates jobs. An important factor in this regard is the Railway Labor Act. This Act applies to almost all commercial aviation (ref 6). Under the provisions of the Act, it would be possible for a union to prevent the adoption of new avionics technology. The aviation unions will probably react to job consolidation attempts by seeking to use featherbedding techniques. These are "make work" rules or practices designed by unions to restrict personnel output by artificially increasing the amount of labor or labor-time employed on a particular job. For example, the Trainmen's Union has demanded that railroads eliminate the use of radio telephones by crewmen and revert back to hand signals and lanterns. Similarly, the Railroad Brotherhood was able for years to maintain a "fireman" on diesel locomotives which have no such requirement.

One aspect of aviation job consolidation within the post-1995 avionics system will be sure to come under attack from the unions - namely, the shift from the three-man to two-man cockpit crew. During the 1979 annual meeting of the International Federation of Air Line Pilots' Association, member associations voted to boycott all two-man-cockpit versions of future aircraft, including the Airbus Industries' A-310 wide-body transport, the Fokker Sniper F-28, and the Boeing 767. IFALPA delegates from 66 member associations representing 54,000 airline pilots voted in favor of retaining a three-man-crew cockpit configuration of current flight and navigation instrumentation. The association agreed to make known its stand against the two-man cockpit configuration both to aircraft manufacturers and individual airlines now buying new aircraft. An IFAPA official said, "We will not accept any version that will be flown by two men" (ref 7). He said most new aircraft would have optional two-man or three-man cockpit configurations, and that the association was opposed to the two-man option.

5.3.3 Human Factors Assessment

The post-1995 avionics system assumes an evolutionary deployment of new aircraft avionics and the continuation of the current philosophy of ground-based air traffic management with a high degree of tactical and strategic control automation. This system will allow both the pilot and air traffic controller to function as a manager rather than as a controller of minute-by-minute air traffic events.

5.3.3.1 Impact of Avionics on the Pilot

The personnel group on which the avionics system proposed by this study is likely to have a primary impact is pilots.

5.3.3.1.1 Electronic Displays

Electronic displays, as discussed in Section 3.3.5, represent a significant increase in information display potential. These displays, in conjunction with the flight management computer, present a pictorial image of the current flight situation in a form consistent with the pilot's mental image of the situation. These display formats permit the pilot to deal effectively with more information than would be possible using conventional information displays.

Early in the Boeing SST development program, simulation revealed the pilot's need for additional manual pitch information for more precise control. Subsequent work produced a multifunction display which combined several guidance functions with a computer-generated map. Later programs addressed pilot displays as part of a complete navigation and guidance system operating in an air traffic control environment. The fundamental lesson learned from these experiments is that effectiveness is truly a systems problem. The man, the machine, and the operating environment must be considered together if the resulting partnership is to be optimized (ref 8).

There will be a change from analog to digital aircraft control/display symbology. This means that the pilot will have to rely on highly synthesized information. With the present control mechanism, for example, he is still directly connected by cables to the control surfaces of his aircraft. In the fly-by-wire mode, however, the control commands are made by electrical impulses. Thus, direct "touch" feedback is lost between man and machine. The process of controlling the aircraft becomes less dynamic when working a keyboard than when rotating, pulling, or pushing conventional controls, and it can be assumed that the pilot's perceived operational environment will shrink to that of the cockpit and, in particular, to that of the display and keyboard interface.

It is anticipated that change from a conventional to an electronic cockpit will drastically affect pilot and crew behavior. There may be a high demand on specific mental and cognitive functions, depending upon the degree of automation and sophistication. For example, the pilot's memory may be strained while coping with digital readouts on some of the CRT's. System designers do not always anticipate the entire set of human factors problems involved in the implementation of a concrete system. Occasionally, what seems to be a technical, economical, or even an operational improvement really decreases system effectiveness because of human limitations. Moreover, what is easier for one pilot can make life more complicated for another.

5.3.3.1.2 Flight Management System

The pilot's ability to adapt and respond positively to unexpected situations exemplifies his fundamental involvement in aircraft safety and operating efficiency. In many situations only the pilot has sufficient information and understanding to exercise appropriate judgment. The flight management system as discussed in Section 3.3.4 offers new ways of enhancing the pilot's effectiveness in this regard.

In determining what type of information will be most useful in augmenting the pilot's adaptive ability, there must be exploration of the range of possible decision circumstances and the time likely to be associated with each. Such circumstances range from unplanned but frequently encountered to truly unanticipated situations. Time-critical information must be directly and immediately accessible, and care must be exercised in the design phase to assure that the post-1995 avionics system aids the pilot in such situations.

To be an effective flight manager, the pilot must manage the airplane safely and efficiently while retaining sufficient workload capacity to cope with further anticipated or unanticipated events. As indicated in Section 3.3.4, the flight management system has the potential to provide several different types and levels of assistance to the pilot that can increase efficiency, reduce normal workload, or both.

First, the flight management system provides data in a form best suited for use. By not requiring the pilot to perform extensive mental processing before information can be used, fewer errors can be expected and less training required. The computer generated displays offer signficant advances in this direction. The flight management system will reduce the need for performance charts and tables during flight. Instead, the performance data required for the immediate task are directly presented. Where use of the information warrants, these data are converted into graphic or symbolic form for presentation within the context of the primary displays. In other cases, numeric data are more suited to the application and will be presented as such. Even in these cases, improvements in the pilot interface are achieved, because only relevant data are presented. Data are grouped to give all pertinent information to the pilot at one time.

Second, the flight management system modifies traditional pilot workload patterns. The specific techniques employed are to shift selected tasks out of the high workload terminal areas, to reduce or eliminate time-critical actions, and to provide pilot-selectable automatic control assistance.

Many of the terminal area navigation and guidance tasks can be shifted in time with the aid of the flight management system. Some of the shifted tasks are accomplished during cruise, others during preflight, and still others are accomplished entirely by the flight management system.

Minimizing time-critical tasks involves establishing operating procedures which permit all required pilot inputs to be made at one time for each task and not requiring mode or function selections at particular points in space or time. As with present day avionics, use of the autopilot for routine, repetitious, or high precision tasks is a key element in ensuring that the pilot has sufficient time to manage the airplane effecitvely. The ultimate automatic assistance is provided by preprogramming the entire flight in the flight management computer. The pilot has the option of using the fully automatic capability or using lower levels of control assistance as may fit the particular circumstances. Regardless of the method or level of control, the flight management system provides pertinent information to the pilot. With this extensive flexibility, the system is adaptive to the changing needs for pilot involvement and allows the pilot to reduce or eliminate manual control tasks.

5.3.3.1.3 Changes in Pilot Selection

There are problems associated with the proposed avionics system which go beyond those concerning engineering optimization. They start with the selection of pilots best suited to operate these systems, and this requires a systems approach in which the pilot's needs are considered. In the future, the pilot will have to monitor predominantly static instead of kinetic processes or information, and he must be suited to meet the mental demands, particularly memory demands, imposed by such systems. He will need to be equipped to remember and use complex codes, keyboards, and switching sequences to initiate actions or respond to operational requirements, and he must be capable of performing several of these tasks simultaneously and making the right decisions based on computer logic and information. Consequently, mental ability and theoretical inclination will be emphasized more in pilot selection than at present (ref 9).

Attempts must be made to develop reliable tests of cognitive skills, such as memory, information processing, time-sharing, and decision making, and to apply them to the selection of pilots qualified to cope with the requirements of integrated digital avionics systems. Selection standards and test methods must be established. Such selection tests and procedures may be so severe or restrictive that not enough individuals will be found among the present class of pilots who meet the requirements. A possible solution to this dilemma may lie in the fact that the environment, equipment, and working conditions in an advanced cockpit will allow an exchange of certain physical standards in favor of specific perceptual or mental requirements. Thus, there may be individuals within the pool of applicants presently rejected as pilots because of deficiencies in color vision, visual acuity, or similar perceptual shortcomings who meet the requirements imposed by the new system.

If it actually turns out that the effects associated with the advanced display/control systems should demand different or higher mental functioning and/or different temperament or personality of the pilots, the training specialists are faced with several problems. One of these concerns the older generation of pilots. There was a similar situation after World War II when, first the military, and later the airline pilots made the transition from the conventional aircraft to jet. A percentage of the older pilots could not be trained to cope with the demands posed by jet aircraft, and either stayed with propeller airplanes or chose to retire.

5.3.3.1.4 Changes in Pilot Stress

Recently conducted experiments concerning pilot behavior as related to the automation of aircraft control processes reveal that in a fully automated flight system, the pilot is in a more or less permanent dilemma since he is entirely responsible for system and mission performance but has no direct control input. In addition, there will always be a probability of automatic control failure, and the pilot consequently must be in a constant state of alertness to take immediate action. This situation is not brought about by a mental or perceptual overload, but rather is caused by underloading. Modern cockpit layouts, improved aircraft handling qualities, and reliable automatic systems may induce aircrews, at times, to become bored, complacent, and inattentive. Thus, the pilot finds himself in a permanent conflict situation, and the possibility of a sudden change from monotony to action may exceed his psychological capabilities and result in panic. The possibility then exists that the demands of the post-1995 avionics system will cause psychological and mental stresses exceeding those associated with the demands imposed by the present system. Overwhelming demands and traumatic operational stresses, as demonstrated in the military setting, can bring about various types of anxiety which can manifest themselves in the form of psychosomatic disorders and disfunctional behavior (ref 10).

5.3.3.1.5 Changes in Pilot Motivation and Morale

There is concern about the problems of motivation and morale caused by increased cockpit automation. Indeed, there is an inherent conflict between the design engineer, whose aim is to fully automate the display and control aspects of the aircraft, and the pilot, whose professional self-image has been built on the preservation of personal responsibility, judgment, and airmanship. The pilot does not want to lose his assignment, job gratification, and the associated glamour. He instinctively objects to pushbutton control of the aircraft. Hence, the problem is not only one of intelligence, skill, and ability, but equally one of temperament, motivation, and personality--the importance and assessment of which are even less understood than the mental or perceptual prerequisites.

Nevertheless, the advanced electronic integrated display/control systems offer many advantages to the well-selected and well-trained flier. As discussed above, the ability of these systems to concentrate data acquisition, handling, and evaluation in the cockpit may actually increase the pilot's responsibility, command status, power, and efficiency--quite a different impact for these systems than that perceived by many pilots.

What can be done about these problems? First, more data are needed about the actual demands and the effects of the new systems. This is a prerequisite for a program of matching pilot profiles with the psychological functions demanded by these new systems. Second, an appropriate "care of the flier" program can be initiated, which may include repeated psychological checkups and rehabilitation in case of emotional or mental problems.

5.3.3.2 Impact of Avionics on the Air Traffic Controller

5.3.3.2.1 Changes in Air Traffic Control

Automation is the primary impact of future avionics on air traffic control. This will establish, to a large degree, not only the skill mix, but also the number of controllers required. Historically, the number of air traffic controllers has grown more slowly than aviation. This has been possible because of the introduction of computers and the use of interactive graphics on radarscopes. Controllers now handle as many as ten aircraft at one time whereas four or five was considered a heavy load previously. The FAA plans to increase automation during the forecast period as a way of coping with increased demand. Moreover, a more highly automated fourth generation ATC system is considered likely by the 1990's. All of this suggests that the number of controllers will continue to lag growth in air traffic. Total aircraft operations at tower airports will grow at a 3.5 percent annual rate in the mainline scenario. With increasing automation, but continued manual procedures, the expected growth rate for controllers will be considerably lower. The real question is whether some fully automated air traffic control system will be developed and implemented which might eliminate the need for continuous manual intervention. Obviously, this could dramatically reduce the required number of controllers. The technology appears to be at hand--for example, 4-D Navigation, radar, DABS, and automatic landing systems. While it is doubtful that such a system can be in place by 1995, it seems inevitable at some future date. The most complicated part of the problem would appear to be the development of software to handle large queues such as those envisioned at future hub airports. Certainly this is not a greater problem than those encountered in managing large air interceptor forces during full scale operations. Thus, the software and hardware seem to be state-of-the-art, although very recent.

Deterrents to the implementation of fully automated air traffic control systems are likely to be societal acceptance, opposition by unions representing affected groups and the inertia of the industry, and the regulatory environment. Revolutionary changes are always difficult to implement, and at this time full automation is in this category.

5.3.3.2.2 Psychological Impacts of Increased Automation

A fully automated ATC system may create an environment which is disbeneficial to the air traffic controller. A fully automated air traffic control system may result in controllers feeling less motivation and less job satisfaction. When the controller becomes a passive element in the system, he may no longer be able to directly relate his performance to his function. An automated system may not provide the controller with a mechanism for achieving individual visibility, credit, or identity. The controller's role may no longer provide direct task-oriented feedback, such as that which occurs when a controller is able to handle an unusually large number of aircraft. Thus, there is a definite danger of a highly automated ATC creating a job which is uninteresting and performed under conditions of low motivation. The greatest danger of an automated system is that the air traffic controller may lose confidence in his ability to take control of an emergency situation. An automated system with a passive controller may produce a degraded emergency response after a failure has occurred (ref 11).

Despite the apparent problems associated with an advanced ATC system, a fully automated system will actually result in many benefits and the alleviation of many problems. The controller will no longer have to be constantly vigilant since an automated system is configured in such a way that excessive vigilance is not required. Stress will consequently be reduced. Moreover, the controller's function is made less intricate and more straightforward, and it requires minimal manual activity in the execution of procedures. Therefore, the likelihood of error-free operation increases. The job will also become less restrictive in that it will permit parallel execution of other functions, tasks, or activities.

5.3.4 Summary

The discussion in this section indicates that the proposed avionics system may reduce both the human rewards and the stress associated with aviation. However, this reduction can be moderated by the introduction of new control functions into aviation operations.

Where personnel have direct authority and responsibility for system operations and are held accountable for their actions, they derive rewards in terms of job satisfaction and motivation, but they also experience stress. The position of authority and responsibility requires a commensurate degree of technical expertise and a commensurate capability to apply the expertise. Technical expertise results from extensive training and the mental ability to structure spatial relationships and logically assess the consequences of control actions.

As planning and tactical control functions become more automated, the reduction in human rewards and stress becomes more pronounced. The automation of planning functions removes much of the direct human interactions among personnel and does not appear to introduce new control functions that significantly compensate for the loss of job satisfaction and motivation. However, automation of planning functions does reduce stress.

Where a high degree of automation occurs, job satisfaction, motivation rewards, and stress are largely removed. The job may be relegated to inputting and processing miscellaneous data. Skills required for this system need not be as highly developed as those for predecessor systems. As a result, personnel may become less competent to handle failure situations and less likely to maintain awareness of the situation.

In summary, the most promising of the future systems in terms of compatibility between operational design and human factors will enable personnel to apply their skills to review critically computerized actions, and these systems will therefore not severely limit the ability of personnel to exercise highly trained capabilities. A situation in which the pilot or air traffic controller is almost completely "out of the loop" but acts as overall systems manager would be acceptable, given a change in both the type of person performing the job and the training received. This, of course, assumes technological components of such quality and redundancy that a person could safely be removed from the control loop.

Because the system may reduce the employee's ability to apply his expert skills, inconsistencies between human expectations and rewards may result.

Although the system requires as high a level of skills as the present system, for such tasks as recovery operations in the event of automation failure, underutilization of these expert skills could undermine the ability to respond to failures, regardless of training. In any event, the unions will set forth these arguments in order to restrict implementation of labor reducing avionics.

5.4 Society

5.4.1 Introduction

The decision to implement a new technology always involves social, political, and ethical issues, as well as technical ones (ref 12). These non-technical issues mold society's attitudes about the new techology, and, therefore, they significantly influence the implementation decision.

Paramount among the non-technical issues associated with a new technology are its societal impacts. These are difficult to project because many are second and third order indirect impacts, but they are important because they have long term and usually irreversible consequences. This section examines a few of the potential societal impacts of the advanced avionics system which is projected in Chapter 4. Since other sections of this chapter explore the impacts of the advanced avionics system on those social groups which are directly involved in the air transport industry, the analysis in this section is restricted to the impacts of the system on society-at-large. Three societal impact areas affected by the advanced avionics system are examined: the environment, demography, and public attitudes and values.

5.4.2 The Environment

The environment has many dimensions, all of which directly contribute to the quality of life enjoyed by society. This section examines the impacts of the 1995 avionics system on two aspects of the environment--air quality and community noise level.

5.4.2.1 Introduction

Aircraft engines emit both air pollution and noise pollution, and the advanced avionics system which is projected for the 1995-2000 time period has the potential to reduce both of these negative impacts. Prior to describing the manner and magnitude of these reductions, the pollutants and their negative impacts on the environment are briefly discussed.

The major types of air pollutants emmitted by aircraft engines are particulates, carbon monoxide, nitrogen oxides, and hydrocarbons. Most of the negative environmental impacts of these emissions occur in the airport vicinity and takes the form of smoke, photochemical smog, and direct physiological effects such as the reduced oxygen intake caused by carbon monoxide. Although aircraft engine emissions represent a very small percent of total air pollution in the United States, they constitute a large fraction of the total air pollution in the airport vicinity.

Aircraft-generated nitrogen oxides have another environmental impact besides localized effects in the airport vicinity. Nitrogen oxides emitted at higher elevations during flight have the potential to alter the concentrations of stratospheric ozone. However, this effect is not completely understood. Current practice is to treat this effect as negligible (ref 13-18).

Aircraft engine noise also produces most of its negative environmental impact in the airport vicinity. This negative impact takes the form of psychological stress and loss in property value. Noise levels which are high enough to cause physiological damage to ground observers occur only within the airport boundaries, and usually only airline and airport personnel are exposed to it.

5.4.2.2 Air Quality

Quantitative measurement of the air pollution produced by aircraft engines is made in terms of the Environmental Protection Agency Parameter (EPAP) (refs 19, 20). The EPAP is not a measure of total aircraft engine emissions over all phases of flight. Instead, the EPAP is a measure of the fraction of total emissions which are produced during a landing/takeoff (LTO) cycle. The LTO cycle consists of 1) taxi out, 2) takeoff, 3) climbout to an altitude of 3000 feet, 4) descent from altitude of 3000 feet to the initiation of landing approach, 5) landing approach, and 6) taxi. In the definition of EPAP which has recently been proposed by the Environmental Protection Agency (EPAP), the functional relationships among aircraft engine air pollution, mass of engine emissions, and amount of fuel consumed are stated as follows (ref 21):

$$\begin{aligned} \text{EPAP} &= \frac{\text{total mass of engine emissions per LTO cycle}}{\text{rated engine thrust}} \\ &= \frac{\text{total amount of fuel consumed per LTO cycle}}{\text{a constant specific to the engine type}} \end{aligned}$$

Therefore, a reduction in the amount of fuel consumed during the LTO cycle would produce a proportionate decrease in aircraft engine air pollution as measured by the EPAP.

One of the benefits claimed for advanced avionics is their ability to conserve fuel. These fuel savings are of two different types. First, the taxi out segment of the LTO cycle includes the queuing time that occurs at crowded airports during peak traffic periods. A potential benefit which is claimed for MLS and 4-D Nav is an increase in the efficiency of airport operations which would significantly reduce, if not eliminate, the queuing (ref 22). This would reduce the amount of fuel consumed over the LTO cycle. Second, automatic thrust control during descent and approach and the weight savings involved with advanced avionics would result in fuel savings during the approach and landing phases of the LTO cycle.

Using EPA's equations for calculation of the EPAP and data about the emission characteristics of advanced high pressure ratio gas turbine engines, a rough approximation can be made of the reduction of the EPAP which would result from a reduction in the queuing portion of the LTO cycle. For example, a 50 percent reduction in queuing time would produce approximately a 50 percent reduction in the total mass of engine emissions during the LTO cycle. Because the bulk of the emissions during the LTO cycle consists of the hydrocarbons and carbon monoxide (CO) which are generated in the ground modes--almost 90 percent of the total--a 50 percent reduction in queuing time would also produce approximately a 50 percent reduction in the mass of hydrocarbon and carbon monoxide emissions over the LTO cycle. And in general, a given percent decrease in queuing time would produce an equal percent decrease in aircraft engine air pollution as measured in terms of the EPAP.

Note, however, that the EPAP is a per engine measure. Therefore, a decrease in EPAP would not necessarily result in decreased air pollution in the airport vicinity. The EPAP could be summed over all operations at a given airport to give a measure for total per day aircraft air pollution. This total pollution measure would be proportionate to the total amount of fuel consumed by all aircraft over the LTO cycle, and under conditions of a constant mix in aircraft types, this would be proportionate to the total number of airport operations. In this case of constant aircraft mix, a given percent increase in number of airport operations would produce an equal percent increase in the total aircraft pollution at the airport.

Another benefit which is claimed for the 1995 advanced avionics system is an increased number of daily airport operations. Given the above analysis, the potential reduction in total aircraft air pollution at an airport which would result from a given percent reduction in EPAP would be counterbalanced by an equal percent increase in number of airport operations. Therefore, the projected 1995 avionics system will have a positive impact on air quality only if the system produces a percent decrease in queuing time which is greater than the percent increase in airport operations which is enabled by the system. Unfortunately for this analysis, the relative sizes of queuing time decrease and airport operations increase under the 1995 avionics system cannot be forecast.

5.4.2.3 Community Noise Level

Quantitative measurement of the noise pollution produced by aircraft engines is made in terms of two indices, the effective perceived noise level in decibels (EPNdB) and the noise exposure forecast (NEF) (refs 23-26). The EPNdB is a measure of the noise intensity which is experienced by a ground observer as the result of a single aircraft flyover. It is derived from the noise intensity at the location of the observer with corrections for such factors as the duration of the flyover and the differential human perception of sound at different frequencies. For purposes of this analysis, the key variable in the determination of the magnitude of the EPNdB is the distance of the ground observer from the aircraft. The difference in EPNdB which results from different distances from the aircraft is given by

$$\Delta \text{ EPNdB} = 20 \log (d_1/d_2),$$

where d_1 and d_2 are the distance terms.

The NEF is a measure of the total noise experienced by a ground observer as the result of total daily aircraft operations over the observer's location. It is derived by summing the EPNdB for the individual aircraft with a correction for the mix of daytime versus nighttime operations. For purposes of this analysis, the key variables in the determination of the magnitude of the NEF are (1) the distance of the ground observer from the aircraft and (2) the number of aircraft. The difference in NEF which results from different distances is given by an equation similar to that above for ΔEPNdB,

$$\Delta \text{ NEF} = 20 \log (d_1/d_2),$$

where d_1 and d_2 are the distance terms. The difference in NEF which results from a different number of aircraft operations is given by

$$\Delta \text{ NEF} = 10 \log (n_1/n_2),$$

where n_1 and n_2 are the terms representing number of aircraft operations.

Noise control and abatement alternatives which do not involve engine or aircraft design include

1. Source Abatement Alternatives - Operational changes such as two-segment landings
2. Path Abatement Alternatives
    a. Rerouting of aircraft by means of modified flight paths
    b. Construction of noise barriers along airport staging areas
3. Receiver Abatement Alternatives
    a. Improvement of indoor sound insulation in buildings
    b. Receiver relocation out of the proximity to the airport or aircraft landing and takeoff flight path.

Advanced avionics developments--specifically MLS and 4-D Nav--would make possible the implementation of Alternatives 1 and 2a. Therefore, these avionics have the potential to decrease aircraft-generated noise pollution.

Alternative 2a involves routing flights over areas which are not noise-sensitive. Specific figures for the reduction in noise produced at a given airport by modified flight paths can be calculated only by means of a detailed model of the operations at that airport. However, estimation of the reduction in noise produced by the two segment landings of Alternative 1 does not depend on such a model.

MLS makes possible many instrument approach paths besides the one available under ILS. One such has the aircraft following a two-segment approach path (6 degree glide slope at the 5 mile marker to the 1 mile marker, then a 3 degree glide slope). The reduction in noise due to the increased altitude of the aircraft on the MLS two-segment approach path ranges from 5.1 dB at the five mile marker to 3.5 dB at the two mile marker (See Fig. 5-4).

To put the size of this reduction into perspective, two equally noisy planes make only 3 dB more noise over a given distance than just one of them. Therefore even a doubling of airport operations would not counterbalance the reduction in NEF which would be achieved through an MLS two-segment approach path. A doubling in airport operations is an exceedingly optimistic expectation for the 1995 advanced avionics systems. Therefore, reduction of NEF along the landing approach path would represent a significant contribution to a decrease in community noise levels especially since the turbofan jets on the commercial airfleet generate at least as much noise in landing as in takeoff, and in many cases more (ref 27). These reductions in NEF would be large enough that people along the track would experience significant decreases in the extent to which they perceived aircraft noise to be a problem.

5.4.2.4 The Cost of Society of Avionics and Related Improvements in the Environment

Reductions in air and noise pollution which may result from the implementation of the 1995 advanced avionics system are, in effect, "free goods." A reasonable goal with respect to the environment is to minimize the total cost of pollution, where the total cost of pollution (C_T) can be expressed as the sum of the cost of pollution damage (C_D) and the cost of pollution abatement (C_A). Now, the reductions in air and noise pollution which result from implementation of MLS represent a reduction in C_D, and the point at issue is whether or not this exceeds C_A in this case. At first glance, C_A appears to be primarily the cost of implementing MLS. However, MLS is not being implemented to reduce pollution, it is being implemented to make airport operations more efficient and productive. The air transportation industry is bearing the cost of MLS in order to gain direct operational cost benefits, and pollution reduction is a side-effect. Therefore, the cost of implementing MLS should not be included in C_A. Reductions in pollution are secondary benefits of avionics which are implemented primarily for reasons of direct cost benefits such as reduced fuel consumption, decreased airport foul-weather closure, and so on.

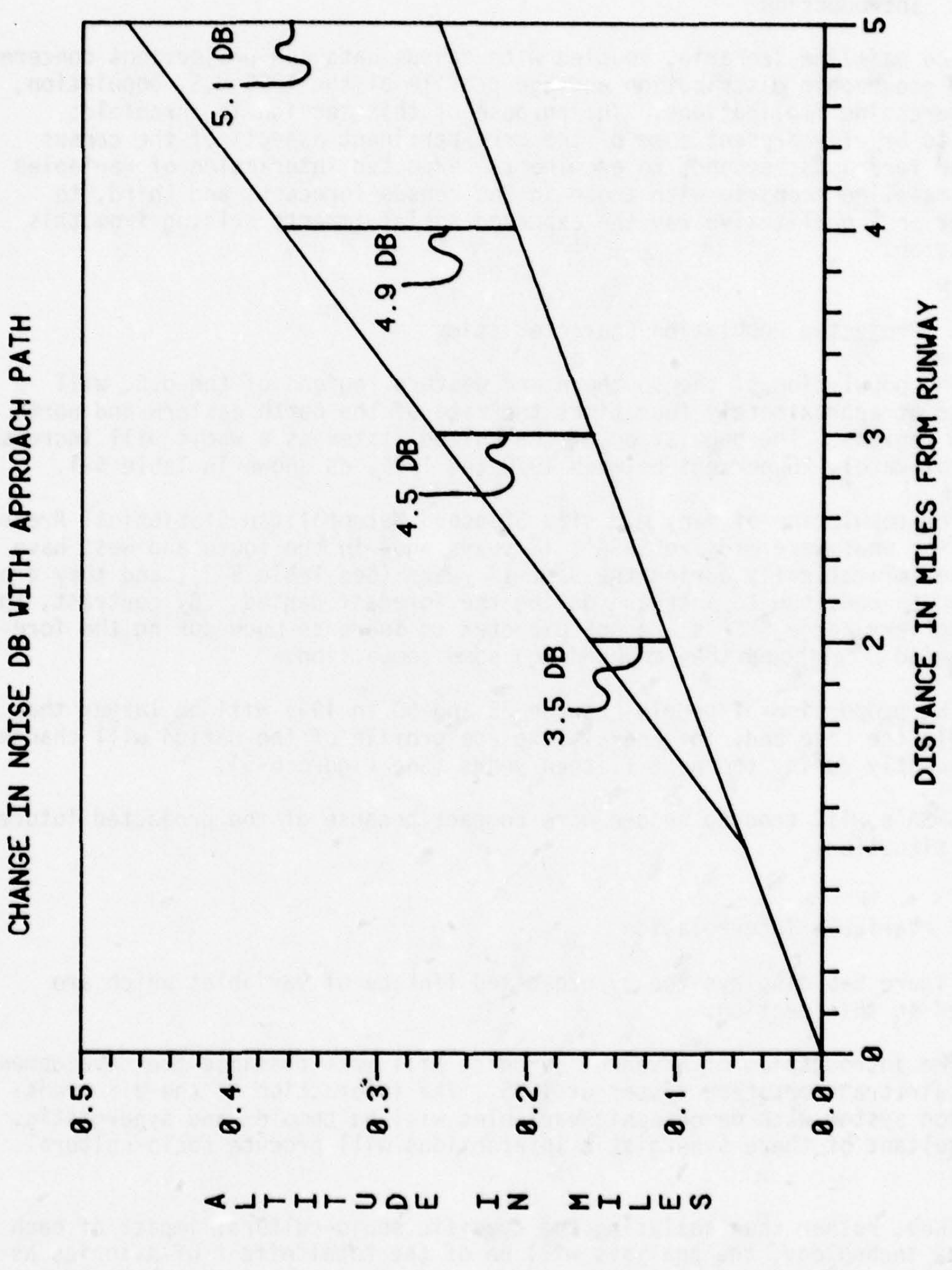

CHANGE IN NOISE DB WITH APPROACH PATH
ALTITUDE IN MILES
0.0
0.1
0.2
0.3
0.4
0.5
DISTANCE IN MILES FROM RUNWAY
0
1
2
3
4
5
3.5 DB
4.5 DB
4.9 DB
5.1 DB

Figure 5-4

5.4.3 Demography

5.4.3.1 Introduction

The mainline scenario, coupled with census data and projections concerning the geographic distribution and age profile of the 1995 U.S. population, has interesting implications. The purpose of this section is threefold: first, to briefly present some of the more pertinent aspects of the census data and forecasts; second, to examine the expected interaction of variables in the mainline scenario with those in the census forecast; and third, to consider in a qualitative way the expected social impacts arising from this interaction.

5.4.3.2 Projected Population Characteristics

The population of the southern and western regions of the U.S. will increase at approximately four times the rate of the north eastern and north central regions. The population of the United States as a whole will increase by approximately 25 percent between 1970 and 1995, as shown in Table 5-1.

The population of many mid size Standard Metropolitan Statistical Areas (SMSA)--or what were midsize SMSA's 18 years ago--in the south and west have increased dramatically during the past 18 years (See Table 5-2), and they are expected to continue to increase during the forecast period. By contrast, the existing very large SMSA's are not expected to increase much during the forecast period , although they may undergo some compaction.

The proportion of people between 35 and 50 in 1995 will be larger than is currently the case and, in general, the age profile of the nation will change significantly during the next fifteen years (See Figure 5-5).

SMSA's will tend to become more compact because of the projected future energy situation.

5.4.3.3 Variable Interrelation

Figure 5-6 displays the hypothesized linkage of variables which are analyzed in this section.

The introduction of advanced avionics will make possible the development of the air transportation system of 1995. The interaction of the air transportation system with demographic variables will be complex and synergistic. The resultant of these synergistic interactions will produce socio-cultural impacts.

Thus, rather than analyzing the specific socio-cultural impact of each avionics technology, the analysis will be of the total effect of avionics as transmitted collectively through the projected air transportation system as it interacts with the demographic variables.

Table 5-1

Projection of U.S. Population 1995
(in thousands)

	Census 1970	Projection 1995
Northeast	49061	52637
North Central	56593	62514
South	62813	88244
West	34838	48858
TOTAL	203305	252253

Table 5-2

Growth in Five Selected SMSA's
(Millions of People)

SMSA	1970 Census	1976 Estimated
Atlanta	1.596	1.805
Dallas-Ft. Worth	2.378	2.611
Denver	1.239	1.438
Houston	1.999	2.422
Phoenix	.969	1.224

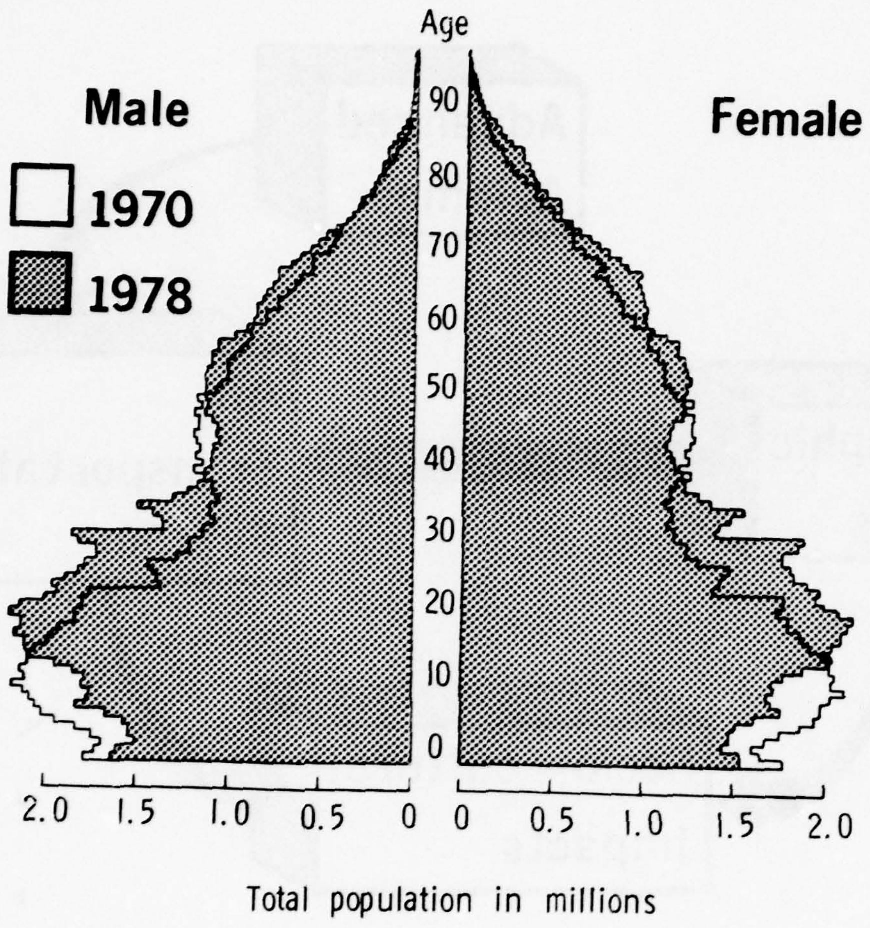


Figure 5-5 Age and Sex of Population

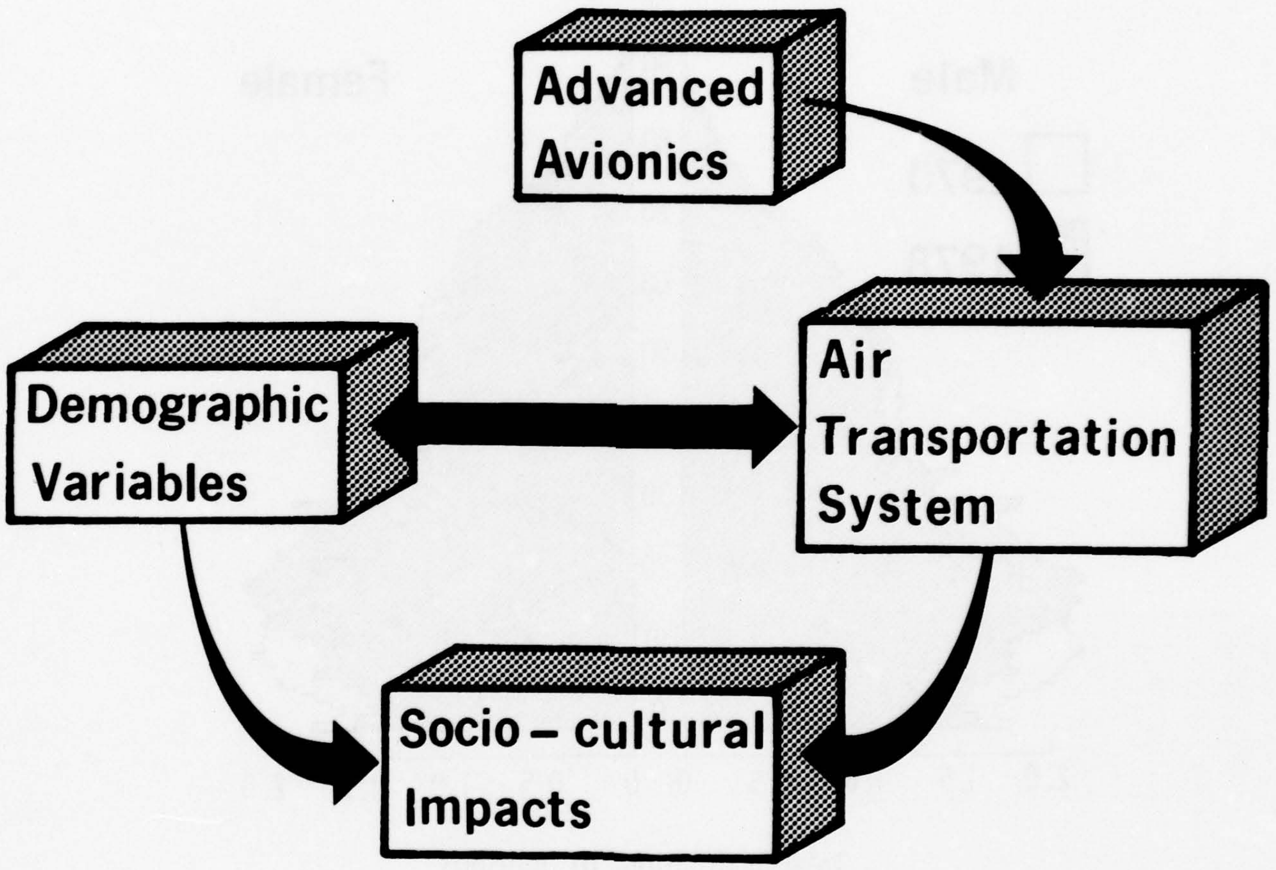


Figure 5-6 Variable Interrelation

The mainline scenario projects growth rates in all sections of the air transportation system which greatly exceed projected population growth rates (See Table 5-1). Conjunction of this fact with the projected population distribution changes forecast for 1995 provides a tentative explanation of how this can occur. In addition, some of the major impacts of this situation can be anticipated.

The population data present a picture of population shift toward a more homogenous regional density, with populations tending to increase in what are currently second level SMSA's and, perhaps, a compaction of SMSA's. Taken together, these factors should provide a driving force for creating demand in all sectors of the air transportation system, as is illustrated in the gravity model calculations presented in the Scenario chapter. The shift toward a higher median age for the population together with the large proportion of persons in the 35-50 age bracket in 1995 could also be a force tending to generate demand in general aviation.

5.4.3.4 Socio-Cultural Impacts

Several significant socio-cultural impacts can be hypothesized based on the above data.

1. The expected population shifts together with compaction of SMSA's can be expected to work to the benefit of more conservative political elements. The local elites in both the south and west tend to be conservative in political orientation. The movement of unorganized immigrants into these regions will tend to bolster the power of local elites, providing they can retain political control.

2. The expected population movements together with increased energy costs could have the effect of creating two relatively distinct social strata--those who fly and those who do not. The flying group could tend toward becoming a self-conscious elite group of cosmopolitan orientation, while remaining politically conservative.

3. Compaction of SMSA's taken together with higher energy costs could have the effect of isolating the lower strata in discrete SMSA pockets. As a consequence, they can be expected to become more local in their orientation.

5.4.4 Public Attitudes and Values

5.4.4.1 Introduction

As demonstrated by the recent DC-10 incident in Chicago, the response of the public can have important consequences for the future viability of any technological system. In this particular case, the response of the public was such that it is now seen as highly unlikely, against all previous expectations, that the DC-10 production run will ever reach the break-even point. The planners of a future innovation in the aviation system are thus well advised to examine possible impacts of such changes on public attitudes in order to take into account any possible unplanned, negative effects.

Underlying public attitudes, which are directed to specific objects, is a value system. The value system of the nation as a whole is important in that it tends to be more stable and enduring than specific attitudes. Impacts on values thus tend to affect the social system at its very roots. Possible impacts on the value hierarchy supported by contemporary Americans will therefore also be examined in the following section.

When considering the value and attitude impacts of the introduction of the projected 1995 avionics system, two separate dimensions must be considered. First, attitudes might well be directly affected by the introduction of the avionics. Attitudes would thus be affected solely by the nature of the introduced hardware and attendant software. Second, and this is the more important dimension, impacts on attitudes and values can be expected as a result of what the avionics system will make possible, that is, a large growth in the air transportation system. These second order impacts will be the most visible and enduring. The following analysis will examine both the direct and indirect value and attitude impacts which might result from the implementation of the 1995 avionics system.

5.4.4.2 Impacts on Public Attitudes

5.4.4.2.1 Direct Impacts

Public attitudes, as mentioned above, will be impacted in two ways by avionics. The first of these is the direct impact caused by the avionics system. The major areas of concern in this regard are research, the technologies involved, safety, and fuel conservation.

5.4.4.2.1.1 Research

The attitudes of the public in relation to research will be of importance prior to the implementation of the advanced avionics system. At issue is the extent to which private enterprise can support the necessary research and the extent to which government would have to support such research. It can be expected that the public will not lend additional support beyond the present level to aeronautics research. Statistics show that government support of aerospace research has been decreasing each year (ref 28). This is also reflected in the low value the public has assigned to space exploration (ref 29). The public at the present time is more concerned with immediate environmental problems relating to urbanism (ref 30). The major brunt of development costs will probably have to be borne by the aircraft manufacturers. If this implies even a short term rise in fare costs, the public can be expected to react negatively.

5.4.4.2.1.2 Technology

The current public attitude towards technology is an ambivalent one. On the one hand, the public is clearly aware of the benefits which it has derived from technology, and on the other hand, the public is becoming more aware of the possible dangers of technological innovation (ref 31). At issue, then, is to what extent the public will perceive the benefits derived from avionics to outweigh the potential dangers.

Research has shown that if the perceived benefits appear to have a high degree of certainty, they will outweigh potential disbenefits (ref 32). Benefits are usually judged by the public in terms of direct consequences of the technology, but disbenefits are judged in terms of indirectly caused consequences of the implementation of the technology. It can therefore be expected that if the public can be convinced that avionics technology will decrease travel cost, make the air transportation system more efficient and safe, and so on, the public will react positively to the addition of the new technology. If, in addition, the public believes that avionics are intended to diminish harmful side effects of the current air transportation system such as pollution, it can be expected to react very positively to the introduction of the technologies. The danger here is that the public will react negatively to an increased emphasis on automation because of a belief that its employment potentialities are threatened.

5.4.4.2.1.3 Safety

The public is very aware of the safety dimension in aviation, if only for the short period following a highly visible air transport disaster. One of the major selling points of avionics will be the potential for increasing safety. Should this not occur, either because of problems in the avionics themselves or because of the growth in the air transportation system made possible by the use of avionics, the public can be expected to react quite negatively, thereby negating any monetary advantages derived through the use of avionics. The main danger as far as public reaction in this area is concerned is the danger that the safety issue will not be addressed to avionics per se.

5.4.4.2.1.4 Fuel Conservation

It can be expected that fuel will become an increasingly important issue for the public. Savings in fuel resulting from avionics, even if they are a minimal part of the overall fuel usage in the U.S., can be expected to engender positive reaction.

5.4.4.2.2 Indirect Impacts

5.4.4.2.2.1 Noise and Air Pollution

The public, especially those members living in the vicinity of airports, can be expected to be impacted negatively by growth made possible through the introduction of advanced avionics (ref 33). First, the inhabitants dwelling near airports fear for the value of their homes and for the demographic makeup of their neighborhood. Public attitudes can be expected to be impacted negatively by the protests raised by those immediately affected by a large increase in air traffic. Second, air pollution created by increased traffic has a negative effect on the general public.

Avionics will directly tend toward preserving the environment, but as a secondary effect will permit expansion of the air traffic system, which will tend to increase pollution. An interesting additional factor in this regard is that most people are somewhat unwilling to invest money for the improvement of environmental conditions (ref 34). The paradoxical result is that systems such as MLS are potential noise and air pollution reducers, but the eventual impact on the public may actually be a perceived increase in pollution.

5.4.4.2.2.2 Airports

Growth in the air traffic system will require either expansion of operations at current airport facilities or the construction of new airports. Public reaction can be expected to be negative to both. The addition of traffic to present sites can be expected to increase the already substantial public opposition to airports in their neighborhoods. Construction of new facilities can be expected to encounter more opposition than in the past (ref 35). One countervailing consideration in this regard is that the public, relevant to this consideration, is narrowly defined as those people living in the vicinity of an airport.

5.4.4.2.2.3 Recreation

The public can be expected to be favorably impacted by the growth in the air transportation system with regard to recreational possibilities. A primary consideration in determining the public's attitudes are its beliefs with respect to the derived personal benefits. With growth in the system, these can be expected to increase. Further discussion of this issue can be found in Section 5.2.

5.4.4.2.2.4 Urbanism

Growth in the air transportation system could result in either decreased or increased urbanism. If the proposed avionics system leads to increased concentration of traffic in major airports, then the public will be negatively impacted. Over one-fourth of the current city dwellers want to leave the city.

This proportion increases among people under 30 (ref 36). Thus, having to live in urban areas because industry is concentrated there will result in a negative public attitude. On the other hand, if implementation of the avionics system means primarily diversification in the system and an increased emphasis on business related GA travel, then the public will react positively. It is likely that some combination of the above two conditions will occur. Thus, the public's attitude in this regard should remain fairly stable and ambivalent.

5.4.4.2.2.5 Employment

The public will probably view growth in the air transportation system as increasing possibilities of employment. This factor is one of the primary dimensions of the public's favoring a new technology. Therefore, public attitudes can be expected to favor system growth in terms of this dimension.

5.4.4.3 Impacts on Value Hierarchies

5.4.4.3.1 Introduction

Values, unlike attitudes, tend to be quite enduring. They are slow to react to changes in society and therefore transcend the temporary fluctuations of events. Yet they are susceptible to change on a long term basis. They are thus an excellent guide to studying long-range impacts on society. By the same token, if it is estimated that significant value structure changes will occur as a result of a technological innovation, then the question of values becomes an important determinant in assessing such an innovation.

5.4.4.3.2 Current Studies

The recent advances in the empirical study of values have been made possible by the recognition that the appropriate means for their study is not an estimation in an absolute sense, but rather the construction of an hierarchial arrangement. Shifts in the hierarchy can then be observed over time (ref 37), although a study undertaken in the years 1968-1971 by M. Rokeach demonstrated that little alteration of the public's value hierarchies occurs in the relatively short span of three years (ref 38).

Two recent studies are relevant to the analysis in this section because they directly address some of the chief concerns of the American public.

The first study, undertaken by Dillman and others in 1974, established a rank ordering of public values. In order of decreasing commitment, the public's value priorities are (ref 39):

1. Law and order
2. Pollution control
3. Protection of nature
4. Public education

5. Employment opportunities
6. Personal health and security
7. Urban problems
8. College youth concerns
9. National defense
10. Assistance to agriculture
11. Aid to foreign countries
12. Space exploration

The second study, undertaken by Christenson and others in 1976, attempted to distinguish between values on the basis of whether they were societally or self directed. It can be expected that negative changes in important personal values will be perceived as detrimental by the individual concerned. For the purposes of this analysis, however, it is the societal dimension which is of primary importance. The results of the study are as follows (ref 40):

	Rank Order	Type of Value
1.	Moral integrity	Social
2.	Personal freedom	Personal
3.	Patriotism	Social
4.	Job	Personal
5.	Practicality	Personal
6.	Political democracy	Social
7.	Humanitarianism	Social
8.	Getting ahead	Personal
9.	National progress	Social
10.	Material comfort	Personal
11.	Leisure	Personal
12.	Racial equality	Social
13.	Individualism	Personal
14.	Sexual equality	Social

5.4.4.3.3 Value Changes

An important issue is the extent to which it can be expected that changes in the above hierarchies will occur as a direct or indirect result of the introduction of a technologically advanced avionics system.

5.4.4.3.3.1 Personal Values

The personal values in Christenson's hierarchy describe qualities of the individual and, hence, would tend to be resistant to technologically induced change. Nevertheless, given the specific nature of these values and their places in the hierarchy, it would seem that the growth in the air transportation system would actually be quite supportive of the current value structure. Personal freedom, the ability to work, and being practical and efficient can all be expected to receive strong support. The values of material comfort and leisure can expect to receive further upgrading.

5.4.4.3.3.2 Social Values

More pronounced impacts can be expected for social values. A look at Dillman's scale of public values is instructive. Ranked numbers two and three on his scale are pollution control and the protection of nature, respectively. It is clear that if the air transportation system grows without a concomitant emphasis on the preservation of these values, negative public reaction can be anticipated. Employment opportunities and urban problems should remain at about the same level of importance unless avionics has its primary impact on commercial traffic, in which case concern with these problems could be intensified as a result of increased urbanization. This would result from increased industry concentration around the major hubs.

National defense, aid to foreign countries, and space exploration could become more important concerns. National defense would come more to the forefront because the world dynamics become global in nature and thus the U.S. could feel more immediately threatened.

It can be seen that most nationalistic values are not very highly placed on either of the value scales. Therefore, deterioration in this regard might not be very pronounced. Aid to foreign countries can be expected to become more important, again because of the growing integration of the world. Space exploration would receive increased emphasis due to the technological fallout from avionics developments. This would be, parenthetically, an interesting reversal of past developments in the space industry.

5.4.5 Summary

Implementation of the 1995 avionics system would result in significant impacts on the environment, demography, and public attitudes and values.

Advanced avionics could significantly increase air quality in the airport vicinity, but only under conditions of little or no increase in the number of airport operations. However, advanced avionics could significantly reduce community noise levels even under conditions of a relatively large increase in the number of airport operations.

Demographic variables and the advanced avionics system will interact synergistically, with the demographic factors reinforcing the tendency of advanced avionics to support growth of air traffic.

The impacts of the avionics system on the public's attitudes will be mixed. This is only to be expected. As one study shows: "This complexity of response [to technology] suggests that attitudes toward technology are multidimensional rather than unitary." (ref 41). The attitudes will be influenced largely in terms of benefits derived from the system. On the whole, public perception in this regard can be expected to be positive. The major potential perceived disbenefit is the indirect one of additional pollution as a result of growth. However, if avionics actually retards increases in pollution and the public perceives this, then public attitudes will be favorably impacted as a result of the introduction of advanced avionics.

5.5 Industry

5.5.1 Introduction

Airlines and aircraft equipment manufacturers are the parties of interest which comprise the aircraft industry. Manufacturers include producers of airframes and producers of avionics subsystems such as computers and equipment for navigation, guidance, communication, and control. While anticipated impacts on these parties are expected to be primarily economic, legal impacts must also be considered.

5.5.2 Airlines and Manufacturers

5.5.2.1 Introduction

Advanced avionics will have primarily an economic impact on airlines and aircraft equipment manufacturers. Airlines will pay the cost of airborne avionics while the federal government will pay the major costs of new air traffic control technology. Airborne avionics include attitude and thrust control, the flight management system, active controls, the integrated flight data display, and communications. None of the present U.S. produced aircraft incorporate digital avionics on an extensive basis. Most systems are analog in nature. A current jet transport incorporates twelve or more systems that serve as computers (ref 42). Digital systems improve precision, capacity, and reliability. For a given function they may cost about half as much to construct and deliver as the analog systems which they replace. Their maintenance cost can be as little as half that of a nonintegrated analog system (ref 43). By providing a reduction in weight, digital avionics contribute to fuel conservation.

5.5.2.2 Direct Operating Cost

One criterion used by airlines for assessing the possible benefits of advanced avionics technology is its effects on aircraft annual direct operating cost (DOC). The major components of direct operating costs which can be affected directly by the application of advanced avionics are first cost, fuel cost, labor cost, and maintenance cost.

1. First cost is the amount of money required to purchase the equipment, whether it is an entire aircraft or a major component. The first cost is depreciated over the life of the aircraft. The typical cost today of a new airplane ranges from $17,000 for a small general aviation trainer to $40,000,000 for a fully equipped jumbo jet (ref 44).

2. Fuel costs are becoming an increasingly important factor in operating performance. In May 1979, the 11 major domestic trunk carriers used 551 million gallons of fuel at a total cost of $274 million. This represented a 304 percent increase in fuel costs over July 1973. The increase would have been even greater had not United Airlines been on strike during this period. Fuel costs in 1978 accounted for 20.3 percent of direct operating costs for the U.S. trunk carriers versus only 11.7 percent in 1973.

3. Labor costs for the cockpit crew and flight attendants comprise about 14 percent of airline direct operating costs.

4. Maintenance costs contribute about 16 percent to direct operating costs. These costs include test equipment, replacement parts, and the labor necessary for these activities.

Advances in avionics technology which can reduce aircraft direct operating costs will be highly beneficial to airline economic prospects. A combination of a 30 percent reduction in fuel cost and a 20 percent reduction in maintenance cost would result in a 15 percent reduction in direct operating costs. As aircraft complexity increases, avionics system costs increase. However, the rate of cost increase is less for advanced systems than it has been for current systems.

Digital techniques applied to near-term derivative aircraft can reduce the number of line replaceable units by 50 percent and the number of different parts by 50 percent (ref 45). Also, the mean time between failures (MTBF) would be expected to rise from 350 hours to more than 800 hours. This will produce significant reductions in the weight, size,power dissipation, failure rates, and the cost of avionics equipment. Better reliability and maintainability will reduce the time the aircraft is out of service for overhauls, thereby increasing aircraft utilization

Advanced avionics technology may eliminate the need for the third flight crew member. Reducing the crew from three to two reduces flight crew costs about 15 percent to 20 percent, thereby reducing the direct operating cost. Flight crew's pay increases with increasing flight length and maximum takeoff gross weight (ref 46). Therefore, technology which reduces maximum aircraft weight while accomplishing the same or a better mission objective provides some additional hope of reducing flight-crew costs.

Various advanced avionics technologies do not always combine so as to yield their full potential when they are applied to a single aircraft. Therefore, the potential economic gains and fuel savings provided by individual avionics technologies are not directly additive. Economic impacts will be evaluated for the airborne avionics technologies of attitude and thrust control, flight management, active controls, integrated flight data displays, and communications, and for satellite and groundbased avionics used for navigation and guidance,and air traffic control.

5.5.2.3 Airborne Avionics Technologies

5.5.2.3.1 Attitude and Thrust Control

The major benefit to the airlines of aircraft attitude and thrust control will be improved fuel efficiency. Fuel consumption may be reduced between 4 percent and 5 percent. Avionics for attitude and thrust control will increase the complexity and cost of the aircraft. The cost increment will be only a small fraction of the price of a commercial airliner or a sophisticated general aviation plane. However, the additional cost will probably make avionics for attitude and thrust control prohibitive for small general aviation aircraft. Improved attitude and thrust control will require increased research and development (R & D) effort and expense. This cost will be passed on to the purchaser of the aircraft, although some R & D may be funded by the federal government.

5.5.2.3.2 Flight Management and Onboard Computer Control

Fuel savings are estimated to be about 1 to 2 percent over fuel consumption without flight management and onboard computer control (ref 47). The major disbenefit will be the cost of R & D which should be small compared to the benefits derived. The airlines will benefit through fuel efficiency, smoother flight characteristics, and possible reduction of delays and loitering at destination airports. The major disbenefits include the cost of the equipment, the increased personnel training required, and the increased maintenance complexity. Avionics manufacturers will benefit through sales of added equipment. On the other hand, aircraft manufacturers will have to modify their engineering designs to accomodate the new flight management and onboard computer technologies. The pilot's job will be aided through automating some calculations and operations which he cannot perform efficiently. The maintenance of the onboard computer may be simpler than the maintenance for present manually operated mechanical and hydraulic controls.

5.5.2.3.3 Active Controls

Active controls technology (ACT) has the greatest prospect for offering near term, low cost, effective relief to the airline economic dilemma. Active controls offer the opportunity to make an aircraft more adaptable to its operating environment and thereby avoid weight and drag penalties.

The extent to which the efficiency of a commercial transport can be improved by applying active controls has been the subject of several studies (ref 48-50). For new commercial transports the gains in efficiency that can be expected are about 5 percent for an all-out reduced static stability system and about 7 percent for the combination of gust load alleviation, maneuver load alleviation, and flutter suppression systems (ref 51). Resulting improved fuel efficiency from 5 percent to 10 percent has been estimated for transports, for example, in the NASA Aircraft Energy Efficiency (ACEE) Program, which would be equivalent to an annual fuel savings of 400 million to 800 millon gallons for the current U.S. fleet (ref 52).

The estimated quantification of the gains and the effects of each ACT concept for DC-10 technology are noted below (ref 53):

Percent Reduction Relative to DC-10 Technology

Concept	DOC	Fuel Burned
High-Aspect-Ratio-Supercritical Wing	4.5	9.0
High-Aspect Ratio	(1.0)	(4.0)
Supercritical Wing	(3.5)	(5.0)
Advanced High-Lift System	1.9	1.5
Augumented Stability	0.5	1.7

The improvements in both DOC and fuel usage for each concept are substantial.

Application of active controls technology, coupled with wing tip modifications, can result in fuel cost savings, based on February 1978 fuel prices, in the order of $100,000 to $200,000 per year per airplane for typical Boeing 747 operations (ref 54). Use of active controls for wing load alleviation and for stability augmentation would result in a combined fuel savings of 6-7 percent for the L-1011 (ref 55). The overall potential fuel savings from active controls and advanced guidance systems are summarized in Table 5-3. In terms of the fuel used by the U.S. scheduled airlines, the savings would be 18.5 percent of the total fuel consumption of 1.85 billion gallons per year at a cost savings approaching $740 million (See Table 5-3). Active controls and advanced guidance technologies will most likely result in increased maintenance costs. This is a result of the critical importance of such technologies.

5.5.2.3.4 Integrated Flight Data Display

Integrated flight data displays will cost less to install and maintain than the individual mechanical displays which they will replace. Benefits to the airlines of using integrated digital data displays include:

1. Fewer parts, spares and interfaces
2. Simplified installation
3. Improved maintenance aids, fault identification and flagging
4. Multifunction standard modules
5. Improved reliability of parts and system

The following table taken from (4) quantifies the impact on performance improvement and cost reduction.

Table 5-3

Potential Increases in Efficiency Due to Airborne Electronics

	%	Gallons/Yr.	$/Yr.
Reduced Static Stability System	5	500 M	200 M
Maneuver, Gust Load Alleviation, Flutter-Suppression System	7	700 M	280 M
Vertical, Horizontal Guidance	5½	550 M	220 M
4-D, (X, Y, T, Z) Guidance	1	100 M	40 M

Area	Effect
Weight	1/5 to 1/10 reduced
Maintenance Cost	1/2 or less reduced
Initial Cost	Equal or less
System Flexibility	Significantly improved

5.5.2.3.5 Communications Technology

Improved communications would improve the profit margin of airline companies. Aircraft equipment manufacturers would certainly benefit from the increased sale of new communications equipment along with increased profits from research and testing of the equipment. Benefits to airlines because of improved communications would be higher crew productivity. Disbenefits might be a large initial investment in the installation and testing of new communications equipment.

5.5.2.4 Navigation and Guidance

Fuel economy will be improved by a number of navigation and guidance systems. For example, GPS and RNAV, which will enable aircraft to fly direct routes point ot point with improved weather information, should produce about a 1 percent saving in fuel usage. It is believed that an additional 1 percent saving in fuel consumption can be realized by reducing the time spent in holding patterns. This improvement may result from 4-D RNAV which will enable an aircraft to meet its expected time of arrival with greater accuracy.

5.5.2.5 Air Traffic Control

As a result of improved air traffic control, airlines may experience improved utilization of aircraft, better in-flight communications, reduced fuel usage, no increase in flight times over those of today, and better on-time performance. The introduction of MLS will enable more fuel efficient landing patterns to be implemented. It is estimated that a 5 percent reduction in flight times due to air traffic control improvements will result in a 3.1 percent decrease in direct operating costs. However, airlines may have to pay higher landing fees and increased avionics costs for airborne equipment needed to interface with ground based air traffic control. Today's flight safety standards will be maintained.

As a consequence of increased air traffic, general aviation may have its access to major airports reduced and restrictions on its airspace increased. To navigate in more highly restricted air space, new, expensive, onboard avionics equipment may be needed. General aviation aircraft may anticipate more fuel-efficient landings, a safer flying environment at small airports, and higher landing fees.

5.5.3.1 Product Liability

Product liability law can be traced back to the nineteenth-century English case of Winterbottom v. Wright. Since the defendant in this case was not the manufacturer of the product in question, he was judged not liable for its defects. In other words, under this interpretation a direct contractual relationship between the consumer and the manufacturer had to exist before the user could be awarded damages bacause of the product's malfunctioning. The requirement that there be "privity of contract" between the injured party and the perpetrator/manufacturer was commonly accepted until 1916 when the Court of Appeals of New York handed down a ruling which began the modern trend of product liability law. In the case of MacPherson v. Buick Motor Co., the court ruled that the manufacturer was liable for his finished product and its component parts even though privity of contract did not exist between him and the individual consumer.

The next milestone decision in product liability law occurred in the case of Henningson v. Bloomfield Motors (1960). The New Jersey Supreme Court ruled that not only the manufacturer but also the vendor were responsible for a product's malfunction. Recourse under the law was extended to any person whose use of the product might reasonably be anticipated. In addition, this decision clearly established the concept of negligence in product liability law by declaring that the manufacturer had a definite duty to insure that his final product was not defective by providing for inspection and quality control. A 1963 case heard in California extended the concept of negligence to a higher legal standard, "strict liability." Under this ruling a manufacturer of a dangerous item is liable for all injuries suffered, whether or not the injury was the result of negligence or an unforeseen event.

In summary, the evolution of product liability law has moved from a position more favorable to the manufacturer to a position more favorable to the consumer. As currently interpreted, the law holds that by placing an article on the market, the manufacturer has certified that the product will safely do the job for which it was built. The intent of product liability la today is to see that the costs of injuries resulting from defective products are borne by the manufacturer who put the item on the market and not by the user who is powerless to protect himself.

Recent court cases involving aviation and product liability law have resulted in the following interpretations. First, that a product liability case can be brought in one or a combination of three ways; (1) negligence, (2) breech of am implied or expressed warranty, and (3) strict liability. Second, that the airframer and <u>not</u> his subcontractors is liable for the safety of the aircraft and its component parts. Third, that in designing aircraft, the airframer must take into account safety and survivability for the crash mode, since he is strictly liable for all modes of operation and the total environment in which the product is used. Fourth, claiming that the product conforms to "state of the art" technology is--in general--no defense in a suit involving an unreasonably dangerous product.

This legal environment has direct ramifications for advanced avionics implementation. Product liability cases against airframers and operators have increased over the past years--even though the U.S. aviation safety record (based upon number of fatal crashes) has improved. In 1975, for example, there were one million aviation product liability suits in the U.S. Boeing alone was sued 400 times for product liability in the period from 1971 through 1976 (ref 56). While the safe operation of aircraft has always been a primary goal of the industry, the severity of judgments in aviation product liability cases in recent years has forced airframers to adopt an extremely cautious approach. There is even some indication that manufacturers may be reluctant to introduce product improvements for fear that this would be interpreted as poor initial design. Thus, intimidation of airframers by product liability litigation will probably be a constraining factor in the implementation of advanced avionics on future aircraft and is responsible for the "evolutionary" rather than "revolutionary" attitude toward change in design which dominates the industry today.

5.6 Government

5.6.1 Introduction

The implementation of the 1995 avionics system will have important impacts on government agencies and their regulatory policies. This section considers the impacts of advanced avionics on two government agencies, the Federal Aviation Administration (FAA) and the Environmental Protection Agency (EPA). The FAA is examined with respect to certification, international regulation, air traffic control, organization, and noise control policy. The air quality standards of the EPA are also treated.

5.6.2 Federal Aviation Administration

5.6.2.1 Changes in FAA Certification Considerations

Digital equipment has been FAA certified for some time. As long as these items were limited to a relatively discrete function and as long as the software was treated in the same way as hardware, no special certification problems were encountered. However, because neither of these conditions apply to advanced avionics, and since strict product liability has now become a guiding legal principle, the whole concept of certification must be rethought.

Among other things, the FAA currently requires that avionics manufacturers provide:

1. A clearly specified validation procedure with documentation to show that this validation procedure has been carried out.

2. Documentation that "state of the art" tools were employed in the validation procedure.

The FAA will require in the future, especially where a considerable number of functions are integrated, additional and far more stringent criteria. These will include, but will not be limited to: hardware design, software specifications, a total systems description, and a total systems demonstration.

The FAA will require hardware design to include provision for a high degree of redundancy, sensor and actuator interface, self testing, failure detection, failure annunciation, and failure isolation.

Software specification will include at least: validation and verification of the total functioning system to insure that no unintended function appear; code analysis to insure that the code employed correctly implements software design; and an integration analysis and text procedure to insure that the hardware modules interface with the software. Specifications must also be incorporated to insure that any software modifications are subjected to the above procedures and that the incorporation of the modification is thoroughly documented. The manufacturers will certainly be called on to provide a complete "total systems description" and system demonstration.

Although we have barely scratched the surface here, it is clear that the certification problems generated by an attempt to implement new avionics systems may be formidable. It is possible that the U.S. may, in a sense, "fall behind the leaders" because of bureaucratic protectionism in a consumer advocacy environment. The situation can be understood by analogy to the relation of the Federal Drug Administration (FDA) to new drugs. Typically, these drugs are "tested" on European populations while the FDA waits and sees. Whether or not this procedure is in the public interest is debatable. What is not debatable is that such "conservative" practices are in the interest of those who administer the agency.

5.6.2.2 International Regulatory Aspects

The FAA changes its rules and regulations in response to improvements made by manufacturers of avionics equipment. The FAA generally does not change its rules to encourage change in avionics, but merely reacts to safety problems and responds to proposals of avionics manufacturers. When the FAA changes regulations to allow the implementation of new avionics in the U.S., this has an impact on the international regulatory environment.

Adoption of new techology on the international scale is subject to significantly different pressures than is adoption of technology by the FAA within the U.S. Introduction of new technology in the field of international civil aviation is likely to have a direct impact on the formulation of what are called "International Standards and Recommended Practices" (SARPS).

The International Civil Aviation Organization (ICAO) formulates such SARPS through a delicate process of persuasion and consensus-building (refs 57,58). Introduction of advanced avionics is likely to increase the demands on the ICAO to formulate a number of international standards and practices relating to specific avionics technologies. Experience with the MLS standard formulation by the ICAO has shown that it takes a long time to formulate SARPS--almost nine years for this specific technology (ref 59).

This lengthy decision-making by the ICAO was due to the complex politico-technical considerations associated with the decision. The ICAO bodies are staffed by technical experts who generally evaluate aviation technology from the viewpoint of its technological efficiency. But on the other hand, when competing national technologies are evaluated by the experts, political considerations do enter into the decision process. When one nation's bid for a specific technology wins against the other nations , the winner derives immense politico-economic benefits by marketing the technical product. An example of this may be seen in the decision by the All Weather Operations Committee of the ICAO about the choice of the MLS system in April 1978 (refs 60,61).

Introduction of advanced avionics like GPS is likely to demand even more from the ICAO's decision-making structure. Although the process of formulating standards for advanced avionics by the ICAO seems cumbersome, its lack of authority to ensure compliance with such standards by contracting states is still weaker.

Underdeveloped nations may oppose ICAO adoption of advanced avionics due to the costs associated with changes in the air transport system. Underdeveloped countries realize that an indication of their level of development is the degree to which they have adopted available technology. Consequently, if they do not have funds available for updating their current avionics systems, they would probably oppose an updating proposal in order to reduce the perceived stigma of being behind the times in the field of avionics. Therefore, the federal government might have to consider providing financial assistance to underdeveloped countries in order to assure ICAO adoption of improved avionics.

In addition, since the FAA issues its rules and regulations pursuant to international agreements as well as congressional mandate, it will have to bear in mind that it is constrained by the international agreements entered into with the ICAO. Therefore, the internal political pressures of the ICAO bear upon the adoption of new avionics.

5.6.2.3 Air Traffic Control

5.6.2.3.1 Introduction

Air traffic control (ATC) is one of the most important aspects of the civil air transportation system. While the typical civil aircraft spends only 18 percent of its operational time in the immediate terminal area, this phase of flight accounts for 79 percent of all accidents. Even more dramatic evidence is available from looking at the final approach and landing phases of flight. These phases account for 4 percent of flight exposure, but 44 percent of all accidents. Thus, from a safety standpoint, air traffic control in the terminal area is of critical importance.

From an economic standpoint, the role of air traffic control is also significant. Planes delayed in flight because of landing and takeoff difficulties cost money. Fuel is needlessly burned by planes while waiting for takeoff clearance or circling airports because of landing congestion. Additionally, passengers are delayed and plant utilization deteriorates. This results in still further passenger delays downstream, causing a substantial loss in productivity for all parties involved. In response to this situation, airlines have lengthened route travel times in order to adjust for expected terminal delays. Despite this, the scheduled arrival performance by airlines has been disappointing. An analysis of airlines serving the top 200 U.S. markets in March of 1979 indicated that only 68 percent of flights arrived on time. Here, on time is interpreted as an arrival within 15 minutes of the stated schedule.

5.6.2.3.2 Present ATC Environment

The present day ATC environment can be best characterized as a sharing of responsibility between pilot and ground control. The system is either radar or visually based with a modest degree of computer interface and a strong reliance on human monitoring. There are, for example, currently no operational computer based algorithms to aid in systems control.

Currently, there are approximately 14,500 airports in the U.S. with roughly 428 having FAA control towers. Of these, approximately 63 have some computer facilities (ARTS III) and there are additionally 20 enroute domestic flight centers which also have computer based systems.

The FAA budget is currently on the order of $2.8 billion (1978). This is expected to grow to between $5.7 and $6.2 billion in FY 1987. Another doubling of the budget could reasonably be expected by 1995-2000. There are currently about 50,000 FAA employees with 26,200 actively involved in air traffic control.

Approximately 10 percent of the FAA budget is devoted to facilities and equipment. In 1979, this amount was divided as follows:

Enroute ATC - $33 million

Terminal ATC - $83 million

Flight Service - $16 million

ILS and VOR/DME Operating Costs - $67 million

ILS and VOR/DME Facilities Cost - $15 million

Aircraft Related Equipment - $7 million

5.6.2.3.3 Planned Improvements

Future increases in air traffic will make the air environment potentially more dangerous. The FAA, which expects air traffic to more than double by the end of the century, is committed to improving the current ATC environment to maintain and perhaps exceed today's standard of safety. The FAA is currently planning major improvements in the enroute ATC system in the mid 1980's. This system will cost on the order of $1 billion. Current research is also being undertaken on the utilization of computer based algorithms for optimally scheduling and tracking flights in the terminal area. The FAA will also probably take a more active role in the development of ATC systems which emphasize fuel efficiency.

5.6.2.3.4 New Technologies

Improved air traffic control has the potential for dramatically reducing fuel consumption in the terminal flight phase. Improvements in the ATC systems, and development of systems such as 4-D RNAV, MLS, and wake vortex detection will result in reduced terminal flight delays, more fuel efficient landing profiles, and increased throughput capacity. The NASA Terminal Configured Vehicle (TCV) has demonstrated advanced electronic systems compatible with future ATC demands and the increased need to fly fuel-efficient profiles. Early flight testing by Boeing of the NASA B-737 airplane equipped with a precision 4-D navigation system demonstrated time errors (deviation from preselected schedules) of about 2 seconds on final approach. This performance value is compared to current outer marker delivery precision of 15 to 20 seconds which is achieved by controllers manually spacing unequipped aircraft for final approach. With other constraints removed, this increased accuracy can double the runway acceptance rate. Boeing estimates that 4-D RNAV alone has the potential for annual benefits on the order of $500 million just in terms of airline direct operating costs, airport landing fees, and airline revenues in 1995.

The microwave landing system (MLS) may bring scheduled service to existing airports where ILS cannot be economically installed. According to an FAA study (ref 62), the resulting improvement of air transport facilities may provide a $450,000,000 benefit in terms of increased economic activity. Additional airport capacity may be provided by segregation of traffic through the use of the flexible course and glide slope capabilities of MLS. Increased airport capacity may provide direct and indirect long term economic benefits of $150,000,000 annually (ref 63).

5.6.2.3.5 Economic Impact of Improved Air Traffic Control

The major economic impact of improved air traffic control capability on the federal government will be increased spending by the FAA on computer based systems. The number of FAA personnel engaged in air traffic control should remain constant. An increase in FAA controlled airspace is anticipated, requiring additional equipment and greater coverage at more airports. The government may attempt to charge civil aviation, the users of airports, for services rendered by the FAA. The effect on airports of improved air traffic control may be increased avionics costs, increased landing fees, and additional pressures from local communities regarding noise, pollution, and congestion.

5.6.2.4 Effect of Avionics on FAA Organization

In a discussion held with FAA officials in Washington, it was stated that due to a lack of manpower and expertise the FAA was unable to perform a leadership role in the field of avionics. The FAA has limited manpower available to cover such diverse areas as control of the airspace, the aircraft industry, and air traffic management. The FAA is also responsible for periodic inspection of all aircraft, for regulating airline maintenance procedures, and for certifying new aircraft.

These complex tasks in regulating advanced avionics and the air transport system utilizing them may become so great that the FAA is no longer able to accomplish them single handedly. Reorganization of the FAA may therefore be proposed. The most probable reorganization would authorize the FAA to perform the sole function of a safety agency. The Federal Aviation Act currently delegates to the FAA a dual mission. On the one hand, it is supposed to insure the "highest possible degree of safety" (Section 601, 49 U.S.C. 1421). On the other hand, it is supposed to "encourage and foster the development of civil aeronautics" (Section 305, 49 U.S.C. 1346). The two goals appear to conflict. Reorganization may alleviate the problem. Undoubtedly proposals will be made to create two agencies. The FAA would continue to be responsible for safety, and the new agency would be responsible for encouraging and fostering the development of civil aeronautics.

5.6.3 Federal Environmental Policy

5.6.3.1 Air Quality Standards

The Clean Air Amendments (1970) give the Environmental Protection Agency (EPA) exclusive regulatory authority over particulate and gaseous emissions from aircraft engines (ref 64). The EPAP, which was discussed in Section 5.4.2.2, is not only a measure of the air pollution emitted by aircraft engines. The EPA also uses it to define air pollution emission standards for both newly manufactured and newly certified aircraft engines.

In order to assign the EPAP a value that can serve as an emission standard, the EPA first defines a standardized LTO cycle which is intended to reflect the time actually spent in each of the LTO cycle modes by aircraft at major airports during peak traffic periods, and second, defines a standard engine power setting for each mode of the LTO cycle which reflects actual operational procedures in that mode. The standardized power setting determines the emission rate for each pollutant in the various modes, and the standardized LTO cycle determines the time at each emission rate, thereby allowing calculation of a specific ceiling value for the EPAP (ref 65).

As shown in Section 5.4.2.2, if future avionics do in fact conserve fuel, they will do so either by shortening the actual LTO cycle of aircraft or by otherwise altering the amount of fuel consumed in mode. These actual changes in aircraft operations would allow aircraft to significantly best the current ceiling value for the EPAP.

Allowable pollution levels generally tend to be a function of the state of the art in pollution control, and new standards establishing lower allowable pollution levels are formulated when these lower levels become technically and economically feasible. Moreover, the Clean Air Amendments (1970) specifically direct the EPA to set aircraft engine emission standards which are consistent with technical feasibility and to set the timetable for compliance with these standards only after considering technical feasibility and cost. Presumably this wording of the law implies revision of the standards whenever technical advances make lower standards possible.

Thus, when the implementation of a given avionics technology or system causes a *de facto* reduction in the LTO cycle of aircraft or power setting of aircraft engines in the various modes of the LTO cycle, the EPA will most likely adopt a lower EPAP, since this downward revision of the EPAP will amount to nothing more than making the standard coincide with actual practice. Moreover, because the potential of new avionics technologies and systems to reduce aircraft fuel consumption is favored justification by the air transport industry for the capital investment required for implementation of these avionics, each successive generation of avionics can be expected to produce a further reduction in aircraft fuel consumption, which in turn will cause a further reduction in aircraft engine emissions, and this in turn will most likely initiate a further downward revision of engine emission standards. Therefore, the effect by avionics implementation on aircraft engine emission standards will be a progressive reduction in the regulated ceiling value for the EPAP.

Unfortunately there are two factors which keep a reduction in the EPAP ceiling value from being identical with a reduction in aircraft produced air pollution. First, the EPAP normalizes the total mass of emissions over the LTO cycle with the rated thrust of the engine. This means that air quality standards which are stated in terms of the EPAP cannot stop an escalation of air pollution by aircraft engines, since the EPAP licenses, in effect, an increase in engine emissions provided that it is accompanied by an increase in thrust. However, this seems inconsistent with the goal which the EPAP supposedly serves--namely, the reduction of aircraft-generated air pollution to some minimum level which guarantees overall environmental quality. Second, the EPAP applies to single engines, and this exacerbates the inability of EPAP-based standards to assure air quality. Increased traffic at an airport would produce a proportionate increase in air pollution in the airport vicinity, but if each engine met the current EPAP, the EPAP-based standard would not be able to stop this decrease in air quality.

Therefore, the implementation of advanced avionics could lead to stricter ceiling values for the EPAP. However, this increased strictness in governmental air quality standards will actually improve air quality only under conditions of static engine size and little or no growth in airport operations.

5.6.3.2 Noise Control and Abatement Procedures

The Amendment of the Federal Aviation Act (1968) adds the control and abatement of noise to the FAA's responsibilities. The Noise Control Act (1972) further amends the Federal Aviation Act to include "public health and welfare" among the criteria for regulatory actions and defines a joint responsibility for the FAA and EPA in the control and abatement of aircraft noise. Under this joint responsibility, the FAA is required to issue Federal Air Regulations (FAR's) to limit aircraft-generated noise to a level consistent with public health and welfare, but only after consulting with the EPA, and the EPA is required to periodically submit to the FAA proposed noise regulations (ref 66).

Within the regulatory framework established by these laws, the FAA has issued FAR's of two different types. FAR Part 36 establishes noise emission standards for aircraft. The standards are stated in terms of EPNdB (See Section 5.4.2.3), and they specify the ceiling EPNdB that can be generated by an aircraft at the measuring points (takeoff, sideline, approach), where this ceiling value is scaled according to the aircraft's weight. FAR Part 91 establishes noise abatement operational procedures for aircraft and air traffic control. Rather than setting limits on emitted noise, these procedures are designed to lower existing noise levels, especially in the vicinity of airports. The noise reduction impacts of avionics which are discussed in Section 5.4.2.3 lie entirely in the domain of FAR Part 91.

As is the case for aircraft air pollution emission standards, the fact that the implementation of advanced avionics will permit the institution of certain noise abatement procedures will prompt the FAA to make these procedures mandatory. That is, future avionics will support FAR Part 91 operational procedures that will greatly reduce aircraft-generated noise pollution, and the FAA will consequently adopt these.

5.6.4 *Summary*

The proposed 1995 avionics system will have pronounced impacts on the Federal Aviation Administration. These range from possible changes in certification procedures to a possible reorganization of the FAA. Implementation of the avionics system will also result in the EPA's adoption of more strict air quality standards and an expanded set of noise abatement procedures.

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CHAPTER 6

SUMMATION AND RECOMMENDATIONS

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6.1 Introduction

This study has emphasized a systems view of the place of avionics in the future air transportation system. As such it has considered not only avionics hardware, but also the relationships among the various technologies, the relationships between the technologies and those persons directly involved in the air transportation system, and the relationships between the technologies and society. A broad spectrum of variables has thus been considered.

The concluding portion of the study seeks to draw together the insights previously gained. The process by which the design team formulated its conclusions is graphically illustrated in Figure 6-1. The first part of the assessment consists of a summation of the major conclusions implicit in previous sections of the report. The second part briefly deals with some questions which planner or layman alike would seek to have answered about a proposed technological system. Finally, the design team offers a series of recommendations to parties of interest involved in the process of making decisions regarding the future of advanced avionics.

The conclusions and recommendations demonstrate that the future of avionics, in the current fuel and environment conscious society is a bright one. They also point to some surmountable difficulties connected with the introduction of advanced avionics. While the parties of interest will decide on the future utilization of the technologies, this report has pointed out some of the benefits and pitfalls associated with various options.

6.2 Concluding Summary

In this section the major conclusions which have emerged from the team's study of avionics are presented. Although they are listed by chapter, it should be clear that many of the conclusions are the result of an interactive and iterative process.

Since only the major conclusions are briefly listed, the reader is urged to acquaint himself with the entire text of the report in order to gain insight into the complexity of the issues surrounding avionics developments. In addition, the summation should be read in conjunction with the NASA concerns discussed in the next section.

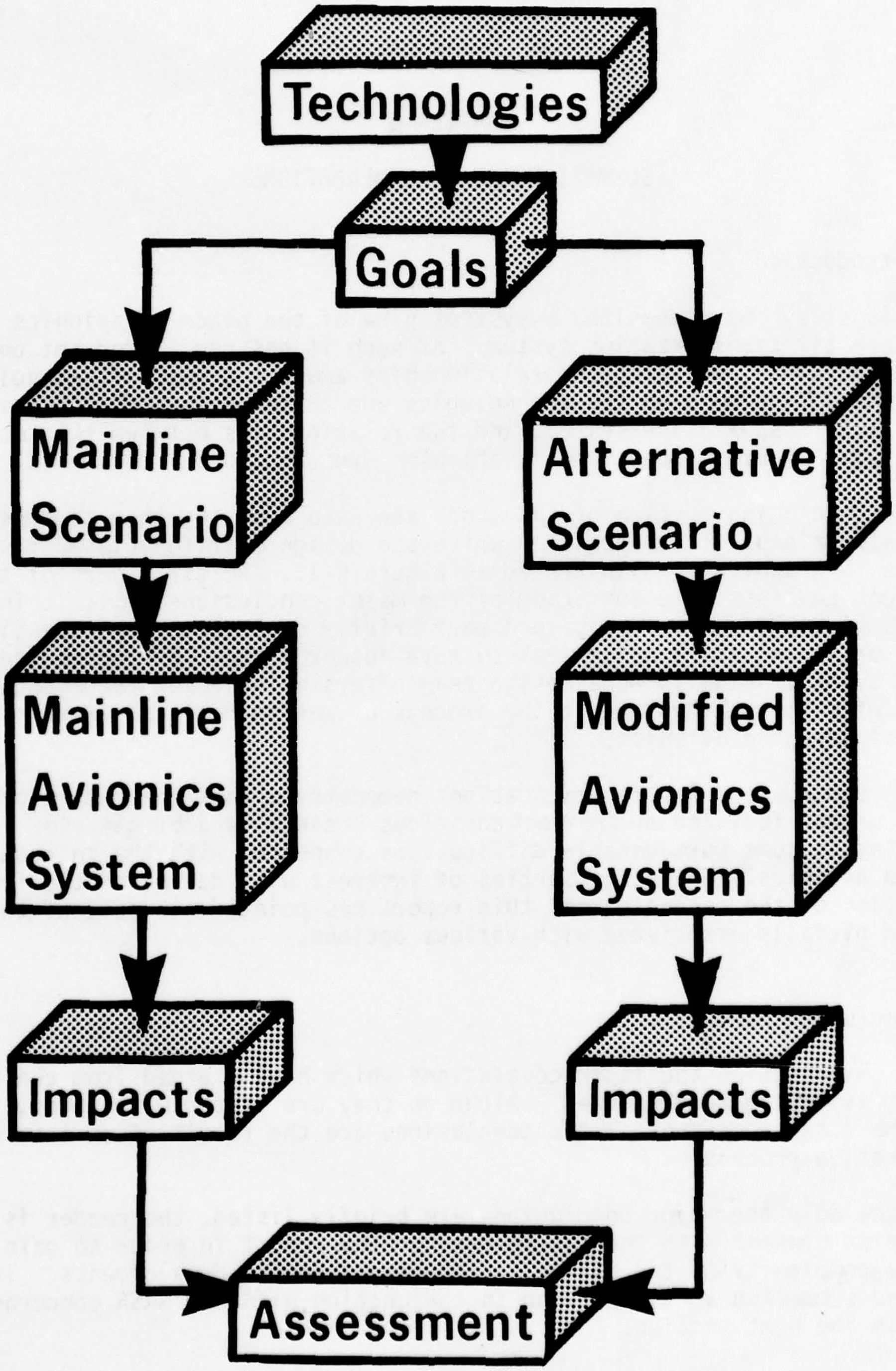

Figure 6-1 Generation of Assessment

6.2.1. Goals

The design team, after being introduced to the range of avionics technologies, formulated the following goals for avionics through a DELPHI/PATTERN process:

1. Of all objectives for avionics, safe transportation should be paramount in avionics R & D, installation, and operation.

2. Other important objectives for avionics development should be fuel efficiency, reduction of air and noise pollution, concern for the man-machine interface, energy efficiency, and reduction of costs associated with air traffic.

6.2.2. Scenarios

Study of the future aviation environment resulted in the following conclusions:

1. FAA forecasts define the future aviation environment in terms of economic activity. Projections for 1995 include moderate growth in gross national product, declining umemployment, and slowly declining inflation.

2. The FAA expects that aviation growth will exceed the growth of the U.S. GNP.

3. The design team concluded that future aviation growth will be determined by a complex mix of societal and technological conditions not simply economic activity. Alternative technologies, demographics, changing values, and alterations in the world power structure are factors which should be considered in looking at the future of air transportation.

4. It is at least a possibility that air traffic demand will stabilize or after a modest increase return to current levels.

6.2.3 Technologies

The scope of avionics technologies in use today, those which are practical now but not yet commonly employed, and those which are only in the planning stages, is enormous. Review of these technologies resulted in the following conclusions:

1. Technologies being developed show a trend toward increased automation of flight function and a consequent diminishing role for the pilot.

2. A major driving force behind avionics developments is the general trend in electronics to make use of digital technology.

3. In the future it can be expected that increased use will be made of computers on aircraft to support other avionics technologies.

4. Many technologies are being developed which can only be used in conjunction with other technologies. A trend toward systems integration exsits.

5. Avionics are being designed for meeting the goals of better fuel efficiency, increased airport capacity, adverse weather operation, and workload reduction.

6. Redundancy of functions and performance reliability have become explicit design goals in avionics developments in order to satisfy the demands of pilots and the public.

7. Many GA aircraft will not be able to take advantage of a number of proposed avionics developments because of system costs.

6.2.4 Future Avionics System

No matter what economic, political, and social environment may exist in the future, avionics will be an important component of the future aviation system. However, the degree of growth in air traffic demand will influence the amount and types of avionics which will be used. Interface of possible technologies with the two projected scenarios resulted in the following assessments of avionics which will most likely be in place circa 1995:

1. Avionics will be used which provide fuel savings, reduce operating costs, and increase efficiency in the air traffic system.

2. If the FAA projected growth in air traffic occurs, commercial airlines will have RNAV, Integrated Flight Data Displays, Digital Data Links, Digital Communication, Attitude and Thrust Controls, Non-Flight Critical Active Controls, and a variety of computers on board.

3. Even if there is no growth in demand, avionics which contribute to safety, economics, and preservation of the environment will be utilized.

4. If there is no growth in demand those avionics which are add-ons will be utilized, while those which must be integrated with the rest of the aircraft electronics will not be readily introduced.

5. No universally applicable judgements about which avionics technologies will be in place in 1995 can be made, because of difficulties associated with retrofitting and general aviation applications.

6. A number of avionics introductions, such as fly-by-wire, will face difficulties in achieving pilot acceptance.

7. The air traffic control system will become much more automated as a result of the introduction of avionics.

8. Major airports will require 4-D navigation, so some form of segregation bewteen GA and commercial aircraft can be expected.

6.2.5 Impacts

The impacts of avionics research, development, and use are broad and varied, affecting to some degree all aspects of life in this country as well as a substantial portion of the world. The following summary highlights the impacts which can be expected as a result of the introduction of avionics in the 1995 air transportation system:

1. Even though growth is expected in the aviation system, the user will find it to be safe, affordable, convenient, and comfortable if extensive use is made of advanced avionics. Should avionics not be employed, these factors will deteriorate.

2. Should avionics be employed while there is no growth in the air transportation system, safety will be increased to the "very safe" level.

3. The pilot environment will change dramatically. He will receive more information, but it will be synthesized. Reduced workload for the pilot will result. He will become more of a manager and will require more theoretical training.

4. The future cockpit will be less labor intensive, thereby making it possible to eliminate the flight engineer's position on commercial airplanes.

5. Pilots and air traffic controllers will experience less stress, but will also receive fewer psychological rewards from their work. Problems with motivation and inability to deal with emergency situations may result.

6. Air pollution caused by individual planes will decrease, but overall aircraft generated pollution will remain stable or increase.

7. Changes in landing patterns made possible by avionics will result in an absolute reduction of noise pollution, even if the amount of air traffic increases significantly.

8. U.S. demographic factors will reinforce the tendency of advanced avionics to support growth of the air traffic system.

9. The public will respond favorably to the introduction of advanced avionics.

10. Currently held personal values will be supported by the introduction of advanced avionics, while public values may be severely stressed if appropriate safeguards against environmental degradation are not taken.

11. The impact of avionics introduction on the aircraft industry will be primarily economic. They will improve fuel economy, capacity, reliability, and reduce the number of parts to be replaced.

12. Industry will have to devote additional funds to R & D.

13. Product liability problems will have to be resolved before advanced avionics can be introduced on the basis of the benefits alone. The FAA will require more stringent design validation.

14. Landing fees for aircraft might have to be increased as a result of increased automation of ground operations.

15. New international agreements will have to be formulated through the ICAO.

16. The FAA will mandate lower levels of noise and air pollution as a result of the introduction of avionics.

17. Airplane throughputs in terminal areas will be increased as a result of the introduction of avionics.

18. It can be expected that while the introduction of advanced avionics will produce a number of immediate benefits, it can also produce a backlash effect because it will allow a large increase of air traffic.

6.3 NASA Concerns

As indicated in section 1.3 of this report, project research and discussion was initiated through a set of eight questions posed by the design team's NASA hosts. These questions provided much of the focus for the team's subsequent grappling with the issues pertinent to a study of the future of advanced avionics. Although the project design was not structured around the questions, a number of them are answered in some detail in this report.

Because these questions influenced so many of the team's deliberations they deserve some independent discussion. This section therefore briefly explicates the team's answers to the questions and references the reader to pertinent parts of the report.

1. How can avionics be used to minimize the environmental impact of the air transportation?

In general, the less time aircraft engines must be operating, the less adverse impact the air transportation system will have on the quality of the environment. As discussed in sections 4.6 and 5.6.3, MLS and 4-D navigation have the potential of reducing both noise and air pollution. They will reduce warm-up, taxiing and flying time through better time control and more fuel efficient departures and landings. MLS will allow landings over non-noise sensitive areas. Automatic thrust control will reduce power settings in environmentally critical areas (3.3.3.1).

It should be recognized, however, that advanced avionics will also make possible an increase in traffic which will largely offset the gains made by individual aircraft. As shown in section 2.6.5, public perception might thus be that the use of avionics is responsible for a degradation of the environment. A public education program might be necessary to inform the population of the inherent benefits of avionics in reducing pollution.

2. How can avionics be used to make aircraft more fuel efficient?

In light of the recent energy crises and subsequent rise in the price of jet fuel, an important selling point for any technology has become its ability to conserve fuel. A number of advanced avionics technologies are explicitly intended to achieve this aim.

-4-D navigation will allow direct flight routes and improve throughput in the terminal area (3.3.2.2) (5.2).

-Automatic thust and throttle controls will reduce fuel usage during the cruise and landing phases of flight (3.3.3.1) (5.4).

-MLS will allow better timed and more fuel efficient landing profiles (3.3.2.1) (5.4).

-The data bus and other onboard avionics will reduce aircraft weight (5.5.1).

-Flight management computers and active controls will reduce drag penalties on the aircraft (5.5.2).

3. What will be the role of the pilot in the future highly automated aircraft?

The pilot of the future will be a systems manager, his direct role as a controller of the airplane will be diminished. (3.1.2). A number of advanced avionics functions, such as automatic thrust controls and active controls will not require his input. (3.3.3) DABS and appropriate controls on the aircraft will make totally automatic flight possible (3.3.6). There will be less voice communication (4.4) and some shift of function from the pilot to the controller (4.6).

The positive aspect of automation is that it will decrease the pilot's workload and allow him to concentrate on flight critical tasks (3.3.4). He will monitor and manage the flight systems (3.3.5).

It is not foreseen that the pilot will be removed from his active role as commander of the airplane ; however, crew size on commercial airlines could be reduced, given the introduction of advanced avionics (4.3).

The danger inherent in the pilot's new role is that there will be too much underloading of the pilot, that he will not be able to react to emergency situations. Systems must be designed into the advanced cockpit to preserve alertness and perhaps new pilot election and training procedures will have to be instituted (5.3).

4. What role will avionics play in improving flight safety?

Avionics' role in flight safety will be most noticeable in the general area of navigation and guidance, particularly in the regions near airports. MLS will create a safer terminal operating environment (4.6). In addition, avionics involved in integrated flight data display, automated digital communications, and integrated control capability will lessen the pilot's workload, thus allowing greater attention to safety considerations during take-offs and landings, the times when most accidents occur.

Collision avoidance systems is the other major area with potential for increasing safety (3.3.2). A number of different CAS have been proposed, but none has been universally accepted. The team felt that no onboard collision avoidance system would be implemented. This restricts the effective range of any system to the terminal area (4.6). An increase in mid-air collisions could, however, influence developments in the area of collision avoidance.

5. In which areas of technological development should the government (NASA) concentrate its research and development efforts?

As recommended in section 6.4.1, research and development with respect to avionics should be directed toward increasing safety, reducing costs, minimizing fuel consumption, and reducing adverse enviromental impacts. Research in the areas of performance, stability, control, reliability and range should be pursued only if it contributes substantially to the above goals. Guiding research should be the assumption that safe transportation is paramount in the minds of the public.

Other important areas for research recommended by the team are the man-machine interface and an increased emphasis on digital applications (5.3) (3.2).

6. Will the application of avionics enhance the U.S. position in the world aircraft market?

While this question is not directly addressed in the report, it was the subject of much discussion among members of the team. The consensus was that avionics will indeed help improve the U.S. competitive position in the world market. Much of the current crop of avionics is being produced in the U.S., although foreign firms are providing definite competition in such areas as integrated display technology. It is in fact necessary that the U.S. expend more research and development dollars on avionics to remain ahead of the competition. The success of the airbus on the international markets demonstrates that U.S. manufacturers must make use of the best and most economical technology available.

Two cautionary notes must be appended to this view as discussed in section 5.6.2. First, given the consumer advocacy environment in the U.S., certification problems might arise if requirements for system demonstration become too stringent. Second, a growing portion of the aviation market will be the developing nations which will have difficulties employing or affording the advanced avionics.

7. Will the cost of the application of the new technology be justified by benefits to the system?

Given man's limited ability to foresee the future, this is an extremely difficult question to answer. The costs of research and development, installation, operation, and maintenance, reduction of replacable parts, and increased mean time before failure, would all be tangible benefits derived from advanced avionics (5.5.1). In addition, environmental and fuel benefits could be achieved as indicated in previous answers.

Benefits are not measured in tangible terms only. Such intangibles as time saved, convenience, and comfort of ride must also be considered. Social costs must then be added to the dollar cost of implementation. A preliminary assessment can only consider the proximate impacts. On the basis of these, as indicated in section 4.7, it would seem that many of the proposed avionics technologies will be a sound investment even if the size of the air traffic system remains static. However, it should be recognized that some of the proposed avionics will not be cost-effective in smaller GA aircraft (3.3).

8. What are the societal impacts of an advanced civil aircraft?

As fully discussed in Chapter 5, societal impacts of advanced avionics in civil aircraft are numerous. Society will be impacted indirectly through the growth in the air transportation system which the introduction of advanced avionics will permit. Direct impacts are noise and air pollution reduction efforts, improved safety, and increased comfort and convenience of the airplane trip.

A summation of the important societal impacts can be found in section 6.3.5.

6.4 Recommendations

Based on its intensive study of the role of avionics in the future air transportation system, the design team considered it appropriate to offer a set of recommendations for assessment by various decision makers. Suggestions were solicited from all members of the team. A process of consolidation and consensus building was then initiated in order to arrive at those recommendations which the team considered of primary importance. While the resulting recommendations do not all directly concern avionics, each of them is relevant to the study of avionics within a wider societal context.

Recommendations are addressed to the following decision making parties: NASA, the FAA, the aircraft industry, and public policy makers.

6.4.1 NASA

The following recommendations are offered for consideration by NASA:

1. Research in propulsion systems that reduce fuel consumption as well as research in non-petroleum based fuels should be continued in order to reduce this country's dependence on energy imports and to reduce the direct operating costs of the airlines.

2. Research and development in those areas of avionics which are designed to improve safety, reduce costs, and lessen the adverse impacts of the aeronautics industry on the environment should be especially emphasized in the future.

3. The pilot's role in advanced aircraft should be reevaluated. After determining the factors motivating a pilot as well as those placing him under stress and strain, a program to analyze the man-machine interaction should be initiated which considers the pilot as one "component" of the overall avionics system, rather than as a seperate system.

4. Future studies designed to encourage the use of advanced avionics should be undertaken. Where possible cost-benefit analyses should be conducted and made available to aircraft manufacturers, airlines, and the public.

5. The avionics system resulting in the safest possible aircraft operations should be outlined, regardless of the costs of the system, in order to serve as a guideline for future activities. Research and development in those areas which are most critical for safety, while at the same time conserving costs, fuel, and the environment, should be encouraged.

6. Environmental impact studies of increased air traffic on air quality in the vicinity of airports should be conducted. These studies should be conducted prior to the advocation of advanced avionics which allow increased traffic.

7. More consideration with respect to costs, benefits, and impacts should be given to the integration of new avionics technologies into existing avionics systems in order to help eliminate consequences not acceptable to the public or not economically justifiable.

8. Technically qualified humanities and social science professionals should periodically evaluate the societal implications of proposed technological advances in order to insure public acceptance of such advances.

9. The multiplier effect of advanced avionics use should be studied by technically qualified economists and social scientists. Impacts on job creation and reduction, economic gains and losses, as well as environmental changes should be considered before public advocation of such systems.

6.4.2 FAA

The following recommendations are offered for consideration by the FAA:

1. The role of aviation promoter should be dropped and taken over by NASA, so that the FAA can devote its full energy to safety and certification. If this step is taken, greater public acceptance of the FAA will result.
2. The FAA should no longer certify aircraft or aircraft components as flightworthy on the basis of testing by the manufacturer. It should consider utilizing military or NASA facilities for certification procedures.
3. The FAA should take the lead in improving and insuring operations safety by constantly upgrading standards as the state-of-the-art of technology improves and the cost of avionics installation becomes practical.
4. Voice communication between pilot and air traffic controller should be reduced in order to reduce misunderstandings-one identifiable cause of accidents-in the future environment of increased air traffic.
5. A changing role of the air traffic controller should be encouraged as the state-of-the-art of technology improves and costs allow. Increased computer usage should allow the controller to become more of a manager of automated systems, with consequent modification of selection and training procedures for personnel being required.
6. The FAA should work more closely with NASA on the research and development phase of avionics in order to insure that optimally safe technologies become operational.

6.4.3 Industry

The following recommendations are offered for consideration by airplane manufacturers and airlines:

1. The aircraft industry, in conjunction with the FAA, should establish a program whereby any employee may, without fear of retribution, indicate to his employer and to the FAA, potential design, construction, and/or operation errors in aircraft or their components. To encourage participation in this safety program cash awards should be offered by industry in its own best interests.

Part II, pp. 647-685.

2. Two man flight crews should be used in commercial aircraft in conjunction with redesigned cockpits utilizing advanced avionics. Advanced avionics would actually reduce the number of tasks to be performed by the crew, and the pilots would better be able to perform their roles as managers.

3. Potential commercial pilots should be selected and trained as overall systems managers as well as aircraft controllers, given the introduction of advanced avionics.

4. As a safety and emergency feature, systems for total ground to air control of commercial aircraft should be incorporated in future designs.

5. Pilot information programs should be undertaken to convince pilots of the advantages of new advanced avionics technologies such as fly-by-wire.

6. Aircraft industry coordination of research and development should continue and be encouraged on a national and international basis as long as company sensitive information remains secure.

7. U.S. airlines should continue to expand their existing joint arrangements with other domestic and foreign airlines for sharing facilities, crews, and other types of services.

8. The aircraft industry should try to meet the needs of general aviation by producing inexpensive advanced avionics compatible with those on commercial aircraft.

6.4.4 Public Policy Makers

The following recommendations are offered for consideration by local and national U.S. public policy makers:

1. Total airport system capacity, including ground access terminal facilities, and airplanes, should be expanded to meet expected increased traffic demands. Highly and moderately utilized airports should either be expanded to full capacity or new airports should be planned.

2. Increased use of satellite airports as feeders for major hubs should be seriously considered, with the goal of relieving traffic congestion.

3. The Global Positioning System should be made available to civil users or, alternatively, a satellite navigation and communication system for the exclusive use of the civil sector should be developed.

4. In the immediate future the Microwave Landing System should be installed at all major airports in Terminal Controlled Areas and at as many moderately used facilities outside TCA's as is economically feasible.

5. Congress should establish laws which, although strict, limit the liability of the aircraft industry. Airlines and aircraft manufacturers and subcontractors are hesitant to take full advantage of advanced avionics technologies in the current legal climate.

6. A global awareness program for political leaders and for the U.S. public regarding the direct benefits of advanced avionics should be initiated. Concerns about future automation of the air traffic system could thus be alleviated and potential negative public reaction avoided.

7. A committee consisting of representatives from the public, the aircraft industry, and government should be established and charged with the responsibility of advising the U.S. political leadership on the planning and coordination of the introduction of advanced avionics.

8. The Environmental Protection Agency standards for measuring air and noise pollution caused by aircraft should be updated to include total emissions from airports, so that potential health hazards may be minimized.

9. The Department of Transportation should continually update its comprehensive plan to take account of technological advances in the field of aviation, as well as their political, social, and economic impacts.

10. The classification of commercial and general aviation aircraft should be standardized. All revenue producing flight should be classified as commercial flights in order to aid in a proper assessment of airport utilization.

11. The U.S. government should analyze the needs of developing nations when advocating the introduction of advanced avionics. Much of this technology will have to be used uniformly throughout the world and potential problems could thus be avoided.

12. The U.S. government should consider a technical and financial assistance program to the developing nations to enable them to acquire the avionics necessary to participate in the future air traffic system.

13. International consortiums for avionics production should be encouraged by the U.S. government in order to promote international cooperation.

APPENDICES

APPENDIX A

SUMMARY OF ASSIGNMENTS

Initially, the design team was organized into task groups so that each team member contributed to each of the three dimensions crucial to production of the final report. These dimensions were technology, impacts, and thematic chapters. Later in the project two additional teams were formed; a presentation team which set forth a verbal synopsis, and a team which summarized and organized the design team's recommendations. The following is a summary of assignments.

Figure 6-1 Generation of Assessment

Name	Technology	Impacts	Chapters	Presentation	Summary
Carlson	B	I	N		
Choi	C	G	K		
Crittenden	E	I	N	P	S
Dozier	C	J	N		
Eastman	D	G	O		
Gravander	D	F	M	P	
Hargrove	A	G	M		
Keaton	C	H	L		
Koay	B	F	K		
Krobock	E	J	K	P	
Lueg	C	I	M	P	
Luegenbiehl	A	H	L		S
Mohapatra	D	G	O		S
Pasternack	D	G	N		
Penrod	D	J	L		
Rakow	E	F	L	P	
Ram	A	G	L		S
Robertson	E	F	O	P	
Sachs	A	I	O		
Sheskin	B	F	O		
Trehan	B	G	M		
Waugaman	E	I	M		

<u>Key</u>

Technology	A	Navigation and Guidance
	B	Integrated Flight Display
	C	Communication: Aircraft/Ground
	D	Integrated Control Capability
	E	Aircraft Attitude & Thrust Control
Impacts	F	Environment
	G	Economics/Energy
	H	Society
	I	Users
	J	Personnel
Chapters	K	Goals
	L	Scenario
	M	Technologies
	N	Alternatives
	O	Impact and Evaluation of Alternatives
Auxiliary	P	Presentation
	S	Summary and Conclusions

2. A major driving force behind avionics developments is the general trend in electronics to make use of digital technology.

APPENDIX B
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NASA-ASEE ENGINEERING SYSTEMS DESIGN PROGRAM

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June 7	Mr. Jack Hatfield NASA/Langley Research Center "Cockpit Display/Crew Station/Human Factors"
June 8	Mr. William E. Howell NASA/Langley Research Center "Flight Management Technology"
June 12	Mr. Amos Spady NASA/Langley Research Center "Oculometers"
June 13	Mr. Jerry Elliott NASA/Langley Research Center "Guidance & Control"
June 14	Mr. Harry Verstynen NASA/Langley Research Center "1995 ATC Scenario"
June 18	Dr. John Warfield University of Virginia, Charlottesville, Virginia "Societal Systems"
June 22	Mr. Kohn Hitchcock Aviation Consumer Action Program "Aviation Safety, Public Policy & Other Considerations"
June 26	Mr. Russ Lawton Aircraft Owner's and Pilots Association "Contemporary General Aviation: An Overview"

June 26	Mr. Dennis Wright AOPA "Contemporary General Aviation: An Overview"
June 27	Mr. Earl Migneault NASA/Langley Research Center "Flight Tolerant Computers"
June 28	Mr. Bernard Hainline Boeing Commercial Airplane Company "Commercial Airplane Technology"
June 29	Mr. Homer Morgan Acoustics & Noise Reduction "Aircraft Noise"
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July 9	Mr. Robert Steinberg NASA/Langley Research Center "Meteorological Predictions"
July 10	Mr. Roger Schaufele McDonnell Douglas Corp. "Future Commercial Aircraft Trends"
July 13	Mr. Rick Climie ARINC "Role of ARINC in Civil Air Transportation System"
July 13	Mr. Bernard Sindermann Lockheed "Future Aircraft Technology"
July 19	Mr. J. Thomas Ratchford AAS "Social Control of Research"

APPENDIX D
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The Design Team's deepest appreciation goes to the following persons and organizations for their invaluable assistance. Their help is gratefully acknowledged. The accuracy, authenticity,and completeness of the design project and report is due in no small measure to these individuals and organizations.

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APPENDIX E

ACRONYMS AND ABBREVIATIONS

The following are definitions and explanations of acronyms and abbreviations which appear in this document.

ACEE - Aircraft Energy Efficient Program
ACT - Active Controls Technology
ADC - Analog to Digital Computer
ADI - Attitude Directional Indicator
AGARD - Advisory Group for Aerospace Research and Development
AM - Amplitude Modulation
A/P - Auto Pilot
ARINC - Aeronautical Radio Incorporated
ARTS - Automatic Radar Terminal System
(Console consisting of computer cathode ray tube scope of radar system and other minor components)
ARTS III - Automated Radar Traffic System
(A system that displays alphanumeric as well as radar and beacon video on a cathode ray tube in the Air Traffic Control Center in the airport. Information to ARTS III comes from other Air Traffic Control centers, Air Traffic Control Beam Interrogator, Airport Surveillance Radars subsystems and from locally, electronically stored flight plans)
AS - Augmented Stability
A/T - Autothrottle
ATARS - Automatic Traffic Advisory and Resolution Service
(A system that assists and reinforces voice communication between pilot and ground control)
ATC - Air Traffic Control
ATCAC - Air Traffic Control Advisory Committee
ATCRBS - Air Traffic Control Radar Beacon System
ATIS - Automated Terminal Information Services
AVOIDS - Avionic Observation of Intruder Danger System
(A collision avoidance system developed by the Honeywell Co.)
AVP - Office of Aviation Policy
(A subdivision of the Federal Aviation Administration)
BCAS - Beacon Collision Avoidance System
BEA - British European Airways
Bit - Binary Digit
(A single occurrence of a character in a language that employs exactly two distinct kinds of character - i.e. 1 or 0)
BOAC - British Overseas Airways Corporation
CAPS - Civil Aviation Purchasing Service
CAS - Collision Avoidance System
CATS - Civil Air Transportation System
CLB - Climbout

CMD BUG - Command Bug
(Desired speed reference point on display panel)
Codec - Coder-decoder
CONT - Continuous
CPU - Central Processing Unit
(Computing portion of the digital computer)
CRT - Cathode Ray Tube
CRZ - Cruise
CTOL - Conventional Take-off and Land
DABS - Discrete Address Beacon System
DAMA - Demand Assignment Multiple Access
(Assignment of frequency channel on demand of user)
DAVSS - Doppler Acoustic Vortex Sensing Subsystem
DELPHI - (A systematic methodology for obtaining and refining group opinion by iteration and controlled feedback)
DLH - Deutsche Lufthansa
(Airline)
DME - Distance Measuring Equipment
DOD - Department of Defense
DOT - Department of Transportation
DUM 69 - (A dummy variable that has value of zero after 1969)
EADI - Electronic Attitude Director Indicator
EARB - European Air Research Bureau
EHSI - Electronic Horizontal Situation Indicator
EMD - Engine Management Display
EPA - Environmental Protection Agency
EPAP - Environmental Protection Agency Parameter
(Maximum level of engine emissions)
EPR - Engine Pressure Ratio
EROS - Eliminate Range Zero System
FAA - Federal Aviation Administration
FAD - Fuel Advisory Departure
FBW - Fly-By-Wire
(A system in which all connections between aircraft cockpit and aircraft control surfaces are electrical)
F/D - Flight Director
FDM - Frequency Division Multiplexing
(Division of radio frequency ranges into narrower bands)
FDMA - Frequency Division Multiple Access
(Allocation of frequency channels among various broadcast users)
FIT - Fault Isolation Test
FMC - Flutter Mode Control
(Flutter speed enhancement)
FR - Fatigue Reduction
4-D - Four Dimensional
GA - General Aviation
G/A - Glide/Approach
GCA - Ground Control Approach
GLA - Gust Load Alleviation
GNP - Gross National Product
GPS - Global Positioning System

GWSS - Ground Wind Sensing Subsystem
HF - High Frequency
(Electromagnetic waves in the 3 to 30 million hertz range)
HUD - Head-up Display
IAS/Mach - Indicated Air Speed in Mach Number
ICAO - International Civil Aviation Organization
IFR - Instrument Flight Rules
INS - Inertial Navigation System
IPC - Intermittent Positive Control
(A system on board aircraft that receives information from ground control and presents one of four warnings on a cockpit display)
KLM - Royal Dutch Airlines
LC - Liquid Crystal
LDVSS - Laser Doppler Vortex Sensing Subsystem
LED - Light Emitting Diode
LaRC - Langley Research Center
LSI - Large Scale Integration
(A monolithic device with 100 to 1000 transistors)
LTO - Landing and Take-off
M/ASI - Mach/Air Speed Indicator
(Air speed indicated in Mach numbers)
MLA - Maneuver Load Alleviation
MLS - Microwave Landing System
MNPS - Minimum Navigation Performance Standard
MSAW - Minimum Safe Altitude Warning
MTBF - Mean Time Between Failures
NADIN - National Air Data Interchange Network
NASA - National Aeronautics and Space Administration
NAV - Navigation
NCDU - Navigation Computer Display Unit
N_1 - Engine Speed (RPM)
N Mi - Nautical Miles
NRUT - Unemployment Rate in Present Terms
OBERS - Office of Business, Economic, and Agricultural Research Service
OVERS - (Number of Aircraft Handled Minus Twice the Number of IFR Aircraft Departures)
PAR - Precision Approach Radar
PATTERN - Planning Assistance Through Technical Evaluation of Relevance Numbers
(A method of identifying and providing a quantitative comparison of alternatives)
PAYSS - Pulsed Acoustic Vortex Sensing Subsystem
PCA - Positive Control Airspace
PCM - Pulse Code Modulation
(Radio pulse train is altered by spacing between pulse according to a code)
PIREPS - Pilot Reports
PP - Price Index of Private Transportation
(1972 = 100)
PPM - Pulse Position Modulation
(Width/duration of pulses in a train of pulses is varied.)
PRF - Pulse Repetition Frequency

PROM - Programmable Read Only Memory
(A storage device in which data can be read in only, either directly or by program)
PWI - Proximity Warning Indicator
RAM - Random Access Memory
(Stored data that can be retrieved or replaced at will)
RC - Ride Control
(A system that improves ride control and provides a smoother ride)
RCA - Radio Corporation of America
(An electronic device manufacturing company)
RCA SECANT - Separation and Control of Aircraft Using Nonsynchronous Techniques
RCVR - Radio Receiver
RF - Radio Frequency
(Broadcast waves in the .01 to 100,000 megahertz range)
RNAV - Area Navigation System
ROM - Read Only Memory
(Stored data that is fixed and cannot be changed)
SARPS - International Standards and Recommended Practices
SAS - Scandinavian Airways System
SCPOM - Suppressed Clock Pulse Duration Modulation
(Clock information in pulse train is suppressed)
SECANT - Separation and Control of Aircraft Using Non Synchronous Techniques
(A special collision avoidance system developed by RCA - Radio Corporation of America)
SMSA - Standard Metropolitan Statistical Area
SST - Supersonic Transport
STR - Dummy Variable for Strikes and Labor Management Disputes
STOL - Short Take-off and Landing
SYNCRO-DABS -Synchronized Discrete Address Beacon System
TA - Technical Assistance
TAP - Transport Aereos Portugueses
TCA - Terminal Control Area
TCV - Terminal Configured Vehicle
TDM - Time Division Multiplexing
(Time slots in broadcasting at regular intervals are allocated to various separate channels)
TDMA - Time Division Multiplexing Access
(Time slots for a given broadcast channel are allocated by a control or reservation mechanism)
TF - Trust Fund
TLA - Thrust Level Adjustment
TMC - Thrust Management Computer
(A system that computes thrust limits and monitors and stores fault data)
TRACON - Terminal Radar Control
TRSB - Time Referenced Scanning Beam
UDL - Universal Data Link
UHF - Ultra High Frequency
ULSI - Ultra Large Scale Integration
(A monolithic device with more than 10,000 transistors)
UNDP - United Nations Development Program

VAS - Vortex Advisory System
VFR - Visual Flight Rules
VOR - Very-High-Frequency Omnidirectional Radio Range
V/STOL - Vertical or Short Take-off and Land
VLSI - Very Large Scale Integration
(A monolithic device with 1000 to 10,000 transistors or simular devices)
Vocoder - A speech synthesizer that does not preserve the original voice waveform
V/P - Vertical Path
VTOL - Vertical Take-off and Land
WVAS - Wake Vortex Avoidance System
XMTR - Radio Transmitter
YPD - Disposable Personal Income in 1972 Dollars

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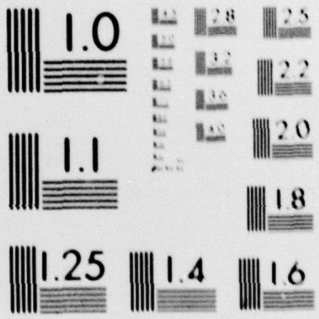
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APPENDIX F
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16. Abstract

This report provides the results of the 1979 NASA/ASEE Engineering Systems Design Group. It summarizes a view of the 1995-2000 civil aviation avionics system. Following discussion of the Group's and avionics system's objectives, it describes the scenarios considered, the avionics technologies, the 1995-2000 avionics system, and the evaluation of impacts. The last chapter provides conclusions and recommendations.

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