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THE IMPACT OF MICROCOMPUTERS ON AVIATION: A TECHNOLOGY FORECAST--ETC(U)

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# THE IMPACT OF MICROCOMPUTERS ON AVIATION: A TECHNOLOGY FORECASTING AND ASSESSMENT STUDY

## VOLUME II: CONSTRAINED FORECASTS AND ASSESSMENT OF MICROCOMPUTER TECHNOLOGY

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**FINAL REPORT**

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16. Abstract

The study of the impact of microcomputers on aviation consists of two parts. The first part, technological forecasting of microcomputers, with specific reference to aviation applications, has been reported in Volume I. This volume (Volume II) presents the results of technology assessment of microcomputers, with special emphasis on the impacts of microcomputers on the National Aviation System (NAS), and their policy implications.



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# TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# LIST OF FIGURES

# CHAPTER ONE

# INTRODUCTION

The study of the impact of microcomputers on aviation consists of two parts. The first part, technological forecasting of microcomputers, with specific reference to aviation applications, has been reported in Volume I. This volume (Volume II) presents the results of technology assessment of microcomputers, with special emphasis on the impacts of microcomputers on the National Aviation System (NAS), and their policy implications.*

## I. Definition and Purpose of Technology Assessment

Technology assessment has been succinctly defined as "the systematic study of the effects on society that may occur when a technology is introduced, extended, or modified, with emphasis on the impacts that are unintended, indirect, and delayed" [1]. Thus, the side effects as well as the primary impacts of technology are to be identified and analyzed in technology assessment. This has become necessary since the side effects (or externalities) of technology are often as important as, if not more important than, its primary impacts. For example, although the primary impact of the automobile was a rapid increase of speed and mobility in ground transportation, the side effects of the automobile

*The two parts of the project did not receive equal resource allocations. Technological forecasting is a necessary component of any comprehensive technology assessment, and therefore Volume I provides a necessary basis for Volume II. About 75 percent to 80 percent of the total project resources was therefore allocated to the work leading to Volume I, the remainder to Volume II.

have had significant social consequence - urban sprawl, air pollution, changes in life style, etc. Similarly, one can think of the side effects of television in terms of the changes in family behavior, political campaign styles, rising expectations of the disadvantaged, as well as the primary impact on home entertainment. If the microcomputer is indeed the third major cultural invention in the American technological society, following the automobile and the television [2], then the side effects of microcomputers will truly be significant and far reaching.

The purpose of technology assessment is to develop policy options to enhance the positive and to alleviate the negative side effects of technology. Thus technology assessment is policy-oriented. The orientation stems from the milestone events that contributed to the establishment of technology assessments as legitimate and substantive programs within the realm of governmental activities in the United States. These milestone events were the proposal in the Daddario Bill to establish a Technology Assessment Board [3], and the formal establishment of the Office of Technology Assessment in the U.S. Congress [4]. In the executive branch of the Federal Government, the National Science Foundation as well as a number of mission agencies have sponsored over a hundred technology assessment projects [5]. One of the larger completed projects is the <u>Technology Assessment of Intercity Travel</u> co-sponsored by the Department of Transportation and the National Aeronautics and Space Administration [6]. Microcomputers, being an exploding technology only in the last few years, have not been a subject of formal technology assessment prior to this project.

## II. Methodology of Technology Assessment

Given its policy orientation, technology assessment itself is more a technology than a science, with all the implications of the difference between science and technology. Consequently the philosophical and methodological approaches to technology assessment are multifarious [7].

A major taxonomy of technology assessment methodologies consists of the following three categories of technology assessment (TA):

Technology-driven TA

Problem-driven TA

Goal-driven TA

In technology-driven TA, a particular technology (e.g., the automobile) is given, and its impacts on society are to be assessed. In problem-driven TA, a particular problem area (e.g., energy shortage) is given, and a range of technological options to alleviate the problem are to be assessed. In goal-driven TA, a particular social goal (e.g., increased job satisfaction) is given, and a range of technological packages to facilitate the goal realization are to be assessed. The project at hand begins with the technology of microcomputers and asks what may be its impacts (especially on the National Aviation System) and its policy implications (especially for the FAA) between now and the year 2000. The study is thus primarily a technology-driven TA. Of course, no one can know for sure what will happen in the next two decades. However, it is important that the plausible impacts of microcomputers on the NAS be assessed now, so that the FAA can formulate appropriate policies in anticipation of, not in reaction to, the revolutionary developments of microcomputers.

A typical methodology for technology-driven TA is the following 7-step procedure [8]:

1. Define the assessment task
2. Describe relevant technologies
3. Develop state-of-society assumptions
4. Identify impact areas
5. Make preliminary impact analysis
6. Identify possible action options
7. Complete impact analysis

This 7-step procedure has been used to guide this technology assessment of microcomputers, not only in the organization of relevant tasks within this project, but also in the use of relevant results from other projects sponsored by the Federal Aviation Administration/Office of Aviation Policy (FAA/AVP). Each of the seven steps in the context of these interrelated FAA projects and tasks are subsequently discussed.

Step 1. Task definition.

As pointed out previously, a technology-driven TA of microcomputers has been undertaken. The time horizon is the year 2000. Special emphasis has been put on the impact of microcomputers on the National Aviation System (NAS), although a broad assessment has also been made of comprehensive and higher-order impacts of microcomputers on society. The affected parties were identified for the impacts on NAS, so that specific policy implications from the FAA standpoint would become clear.

The archetypal technology assessment is understood to be a single, ad hoc study performed by a multidisciplinary team on a budget of at least $300,000 (1974 dollars), in a period of about a year. Given the fact that 75 percent to 80 percent of the current project has been devoted to technology forecasting, the technology assessment to be undertaken should be categorized as a mini-TA [9].

Step 2. Technology description.

The basic work for this step has been taken. Volume I of this report describes today's microcomputer technology and projects its development to the year 2000. Special emphasis for instrumentation and control (primarily airborne) and for data processing (as a part of ground-based mainframe computer systems).

For technology assessment, the supporting and competing technologies vis-a-vis microcomputers should also be described. The most critical supporting technologies for aviation-oriented microcomputers are the peripheral equipment (input-output devices, instruments, transducers, etc.). These have also been described in Volume I of this report. Other supporting and competing technologies, ranging from satellite communications to high-speed ground transportation, have been described in the final report of a previous project conducted by The Onyx Corporation for FAA/AVP [10]. All these technological descriptions will form the basis of the subject mini-TA.

Step 3. State-of-society assumptions

Five alternative aviation futures up to the year 2000 have been described in an FAA report [11] on the basis of a project conducted for FAA/AVP by The Futures Group with the assistance from Urban Systems Research and Engineering. These aviation futures have been considered for this technology assessment study. Three of the five aviation futures which provide the state-of-society assumptions are:

- Expansive growth
- Resource allocation
- Muddling through

As will be discussed in the next chapter, these three alternative future scenarios represent, respectively, the upper, middle, and lower span of the spectrum of future aviation activities. For simplicity the two other aviation futures, Individual Affluence and Limited Growth, will not be considered in the mini-TA.

Step 4. Impact areas.

If microcomputers are indeed as significant as the automobile and the television - and the initial indications are affirmative - then its impact will pervade the American society. To fully appreciate the policy implications for the FAA, the impact of microcomputers on NAS should not be assessed in isolation of the impact of microcomputers on the entire society.

In this step, a structured brainstorm approach [12] has been used to identify all major impacts of microcomputers on society. The structured brainstorming was facilitated by computer conferencing [13], and the comprehensive scope of the exercise makes the exercise itself resemble a technology assessment. Since the portion of the project reported in Volume II is considered a mini-TA, the exercise in this step is a micro-TA and the results will be presented in Appendix A of this Volume.

Step 5. Preliminary analysis.

This step will focus on the impacts of microcomputers on the National Aviation System. The magnitude and timing of the impacts on NAS will be analyzed and reported in Chapter IV in this Volume. An overview of the cross impacts resulting from aviation applications of microcomputers will be summarized in Chapter IV, along with an extended examination of some of the dynamic feedbacks, as well as the qualitative description of the significant impacts. All of these analyses will be made in the context of the three alternative aviation futures mentioned previously, assuming no deliberate FAA policy modifications in anticipation of the microcomputer impacts.

Mathematical models (for cross impacts and dynamic feedbacks) will be explained in Appendices B and C. Appendix B will describe how a matrix could be used for analysis of cross impacts, and Appendix C will describe how a simulation model could be used to analyze the dynamic nature of NAS impacts.

Step 6. Action options.

This step is to develop and analyze various policy options for obtaining maximum public benefits and minimizing disbenefits from microcomputers. Naturally, this step must take into account the political sensitivity and feasibility of the various programs and policy options. Although it is an important step in the T.A. process, the delineation of action option was beyond the scope of this report.

Step 7. Complete impact analysis.

This step is to analyze the degree to which the action options identified in step 6 or suggested elsewhere would alter the NAS impacts of microcomputers discussed in Step 5. Although this step is beyond the scope of this project, the mathematical models described in Step 5 can be used in the future in combination of judgments, to assess the effect of FAA policy options in modifying microcomputer impacts on the NAS.

## III. Conceptual Structure of the Specific Approach

While the 7-step procedure described above (in the context of the interrelated FAA projects) delineate what specific steps, methods, and previous results will be used in the technology assessment task at hand, the procedure has not explicated the structural relationship among these steps. This will be done in this section.

The ultimate objective of this technology assessment is to aid policy making by the FAA. As a federal regulatory agency, the FAA has the authority to make policies which will have great influences in certain technological and socioeconomic areas but very little in some other areas. The alternative future scenarios (of which aviation activities are a part) are largely to be determined by social values and future events on which the FAA cannot and should not have much influence. The three alternative futures; viz., expansive growth, resource allocation, and muddling through [11], will thus determine the basic premises upon which the technology of microcomputers will be forecast and assessed. In other words, the technological description and social impact of microcomputers must be imbedded in each alternative future as depicted in Figure 1.

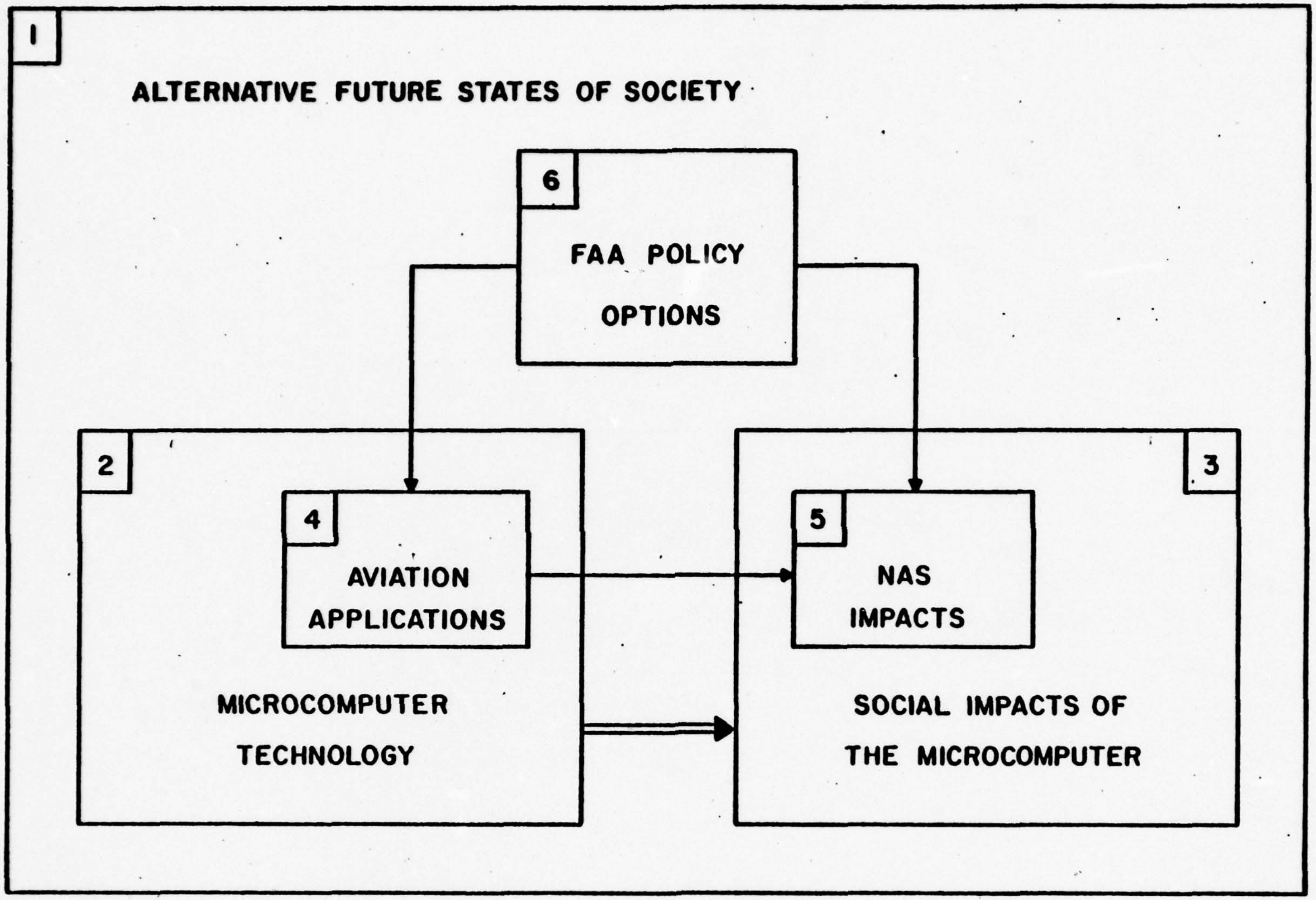



FIGURE 1: CONCEPTUAL STRUCTURE OF THE SPECIFIC TA APPROACH

In the same diagram (Figure 1) it is shown that microcomputer technology and its pervasive social impacts are largely unaffected by FAA policies. What can be affected by FAA policies will be the application of microcomputers to aviation activities and the corresponding impacts of those applications. Therefore, in the diagram, aviation applications are imbedded in microcomputer technology, and the corresponding impacts are imbedded in the much larger collection of social impacts. In the context of the interrelated FAA/AVP-sponsored projects and tasks, Block 1 in Figure 1 contains the most recent results of the project conducted by The Futures Group. Block 2 contains the results of the bulk of Volume I and in Chapter II of this volume (Technology Forecasts). Block 3 contains the results to be presented in Appendix A in this Volume. Block 4 contains the aviation applications identified in Chapter VII of Volume I. Block 5 contains the analyses in Chapter III in this Volume. Finally, Block 6 contains future work which could be done to assess policy implications and affected parties/organizations.

Blocks 4, 5, and 6 in Figure 1 can be further expanded conceptually as in Figure 2, which shows the paths linking microcomputers to FAA policy implications. Starting from the left-hand side of the diagram, there are two ways in which microcomputers can perform aviation functions in NAS. The more immediate way is to perform those aviation

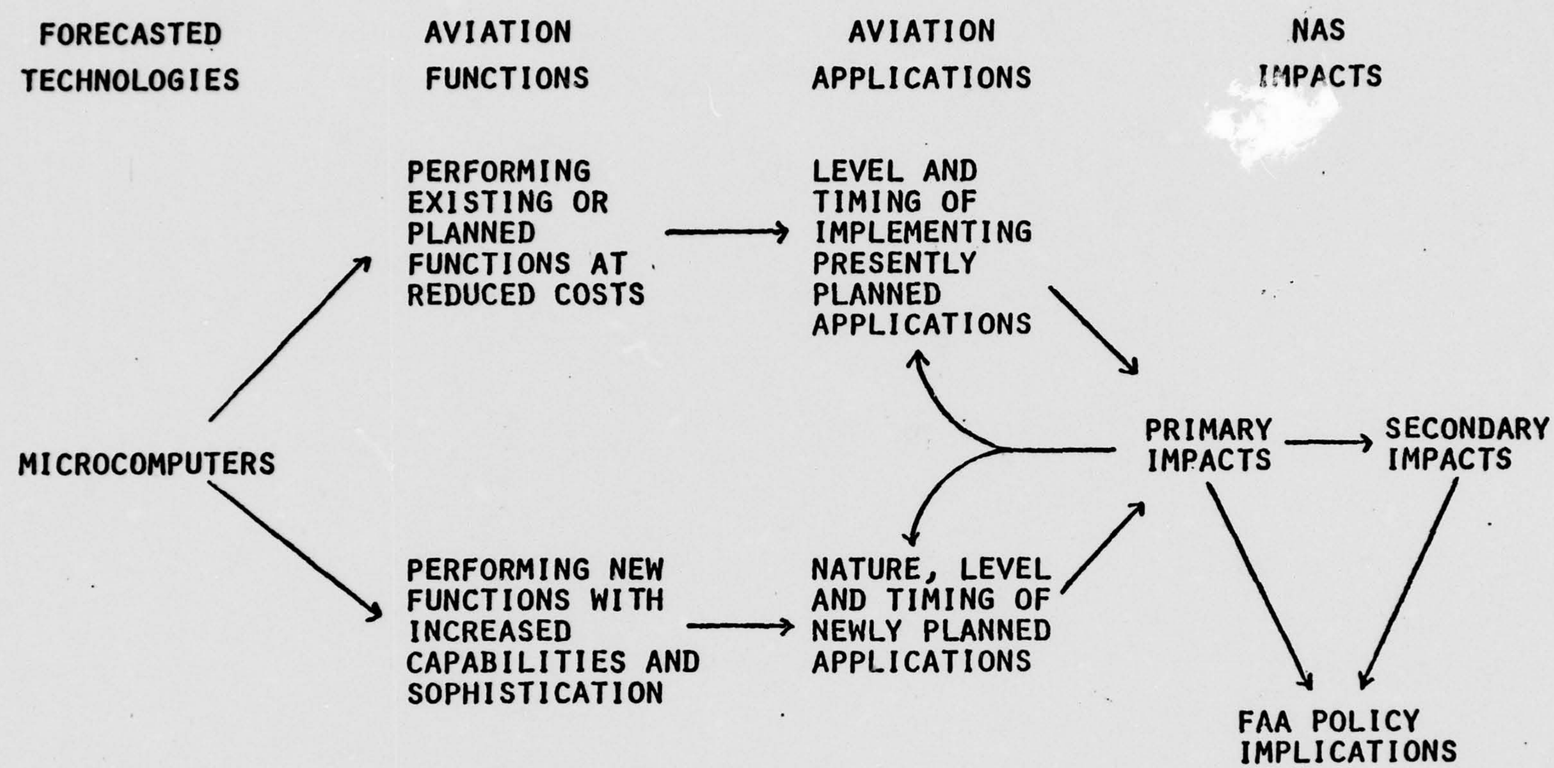



FIGURE 2: FLOW DIAGRAM RELATING MICROCOMPUTERS TO FAA POLICY IMPLICATIONS

functions which already exist (e.g., FAA management information data processing) or which have been planned without the prior knowledge of future developments of microcomputers (e.g., most of the UG3RD air traffic control systems). Such uses of microcomputers will be justified or motivated mainly by cost reduction considerations, and will result in either a higher level of aviation applications, or accelerate implementation of the presently planned applications (e.g., UG3RD), or both. The other way in which microcomputers will find their ways to be applied in NAS is to perform certain new functions which have not been practical or feasible with previous technologies. For example, the very compact and very low-cost microcomputer logic and memory may provide highly sophisticated and highly reliable (self-monitored and self-correcting) avionics for general aviation that has not been hitherto considered practical.

The NAS impacts can be generally categorized into primary (direct) and secondary (indirect or higher-order) effects. Both are important for technology assessment as both may have important FAA policy implications. Primary impacts include such variables as general aviation (GA) avionics costs, which may in turn affect the level of applications. For example, widespread use of microcomputer application in GA avionics would further reduce the cost of microcomputers for such applications, thus increasing the level and accelerating the timing of microcomputer applications in GA.

Secondary impacts include such variables as the number of IFR flights to be handled by air traffic controllers. The number of IFR flights is directly affected by the number of GA aircraft equipped with appropriate avionics, and is therefore indirectly affected by microcomputers. FAA policy implications include FAA regulations, procedures, plans, programs, etc., which need to be generated, modified, or reviewed in anticipation of the primary and secondary impacts of microcomputers on the NAS.

# CHAPTER TWO

# TECHNOLOGICAL FORECASTS IN THE CONTEXT OF AVIATION FUTURES

## I. Introduction

Forecasting differs from prediction in that the former describes the future as a function of policy decisions and the socioeconomic environment that will impinge on the future, whereas the latter does not. The results of technological forecasting should, therefore, be conditioned on a number of "what ifs," An important set of "what ifs," or conditioning factors, includes the socioeconomic, institutional and political factors that may constrain the techologies (in this case microcomputers) and their applications. In particular, three combinations of conditioning factors, corresponding to three of the five alternative futures as described in the Federal Aviation Administration (FAA) Aviation Futures to the Year 2000 [1], will be used to modify the unconstrained forecasts presented in Volume I.

An overview of the five alternative future scenarios is provided in Tables 1 through 3. Table 1 lists the primary economic factors assumed in each of the five scenarios. The scenario names, "Limited Growth," "Muddling Through," "Resource Allocation," "Individual Affluence," and "Expansive Growth" are somewhat self-defining. However, the specific values presented in Table 1 provide a more quantitative summary of the scenario key variables and "subjective"

TABLE 1: COMPARISON OF PRESENT AND YEAR 2000 LEVELS OF KEY VARIABLES FOR THE FIVE SCENARIOS

| KEY VARIABLES | 1974 | LIMITED GROWTH | MUDDLING THROUGH | RESOURCE ALLOCATION | INDIVIDUAL AFFLUENCE | EXPANSIVE GROWTH |
|---|---|---|---|---|---|---|
| GROSS NATIONAL PRODUCT | | | | | | |
| – TRILLIONS OF 1973 DOLLARS | 1.3 | 1.9 | 2.1 | 2.9 | 4.1 | 4.3 |
| POPULATION | | | | | | |
| – MILLIONS OF PEOPLE | 212 | 250 | 297 | 250 | 250 | 297 |
| BUSINESS PRODUCTIVITY | | | | | | |
| – OUTPUT/MAN-HOURS INDEX (1973 DOLLARS) | 112 | 168 | 161 | 250 | 408 | 354 |
| UNEMPLOYMENT RATE | | | | | | |
| – PERCENT | 5.6 | 6.1 | 8.6 | 4.8 | 4.4 | 5.0 |
| COST OF DOMESTIC CRUDE OIL/BARREL AT THE WELL | | | | | | |
| – 1973 DOLLARS | 11.0 | 8.5 | 14.0 | 8.0 | 6.0 | 7.5 |
| OPERATIONS AT TOWERED AIRPORTS (MILLIONS) | | | | | | |
| – AIR CARRIER | 12 | 17 | 10 | 17 | 25 | 46 |
| – GENERAL AVIATION | 43 | 97 | 39 | 105 | 154 | 283 |
| – TOTAL OPERATIONS[1] | 57 | 115 | 52 | 125 | 182 | 333 |
| ENPLANED PASSENGERS | | | | | | |
| – MILLIONS | 207 | 406 | 272 | 471 | 788 | 1,113 |
| TOTAL REVENUE PASSENGER MILES (BILLIONS/YEAR) | 131 | 259 | 167 | 304 | 485 | 597 |
| AIR CARGO–TOTAL REVENUE TON MILES (BILLIONS OF TON MILES) | 3.2 | 8.3 | 3.8 | 9 | 35 | 65 |
| JET FUEL CONSUMPTION | | | | | | |
| – AIR CARRIER AND GENERAL AVIATION (MILLIONS OF BARRELS) | 190 | 317 | 158 | 317 | 517 | 850 |

[1] Total Includes Military

differences [2]. Tables 2 and 3 provide some of the major findings of the previously referred to study. The relevancy of those findings to this study is the manner in which the findings would impact microcomputer technology and visa versa. The societal impacts on microcomputer technology developments, in the context of the five alternative aviation scenarios, will be explored in this chapter. The reciprocal relationship, of the impacts of microcomputers on society, especially on aviation, will be explored in the following chapters.

The most common error in comparing alternative future scenarios is to focus one's attention only to the gross national product (GNP) and ignore all other variables. If one were to single out GNP from Table 1, the "Limited Growth" scenario has the lowest GNP in the year 2000 as evidenced by the following ranking:

| SCENARIO | GNP ($T) in 2000 |
|---|---|
| Expansive Growth | 4.3 |
| Individual Affluence | 4.1 |
| Resource Allocation | 2.9 |
| Muddling Through | 2.1 |
| Limited Growth | 1.9 |

However, other key variables should also be taken into consideration for a more realistic comparison of alternative futures. For the present project, aviation activities, R&D activities, and Air Traffic Control (ATC) technologies are clearly important. The following table singles out aviation activities from Table 1:

| SCENARIO | AIRPORT OPERATIONS (M) | ENPLANED PASSENGERS (M) | JET FUEL CONSUMPTION (Mbbl) |
|---|---|---|---|
| Expansive Growth | 333 | 1,113 | 850 |
| Individual Affluence | 182 | 788 | 517 |
| Resource Allocation | 125 | 471 | 317 |
| Limited Growth | 115 | 406 | 317 |
| Muddling Through | 52 | 272 | 158 |

Thus, the "Muddling Through" scenario has by far the lowest aviation activities, which actually decline from the 1974 level in this scenario. Moreover, Tables 2 and 3 show that the "Muddling Through" scenario also ranks lowest in R&D activities and in air traffic control technology advances. Therefore, for the purpose of this study, "Muddling Through" is considered at low end of the technological growth spectrum, and the "Expansive Growth" scenario at the higher end, with "Resource Allocation" near the middle.

## II. Specific Conditioning Factors

To identify the specific factors which have crucial conditioning effects on microcomputer technologies, four basic assumptions were made and a four-step procedure to identify the crucial factors was developed to explore how these crucial conditioning factors affect microcomputer technologies. The basic concept to be used is essentially that of technological acceleration or retardation by socioeconomic, institutional and political factors. According to this concept, technological development must go through a certain sequence of stages. However, the speed with which this sequence evolves will vary with a number of conditioning factors, which are mostly

## TABLE 2: SUMMARY OF MAJOR FINDINGS* BY SCENARIO

| | AIR CARRIER TRENDS | GENERAL AVIATION TRENDS | FUEL CONSUMPTION | AIRCRAFT TECHNOLOGY |
|---|---|---|---|---|
| LIMITED GROWTH | • Small increase in operations.<br>• No new aircraft introduced.<br>• Enplaned passengers increased from 208 million (1975) to 406 million. | • From 72% (1970) to 84% of operations at towered airports.<br>• 95% plus of total aircraft. | • Jet: 65% increase to 317 million bbls/yr.<br>• Avgas: 115% increase to 27 million bbls/yr. | • Low R&D activity except for fuel efficiency.<br>• Stretched versions of existing aircraft. |
| MUDDLING THROUGH | • Decline in operations.<br>• High load factors.<br>• Enplaned passengers increased from 208 million (1975) to 272 million. | • From 72% (1970) to 75% of operations at towered airports.<br>• Decline in GA ops by 4 million. | • Jet: 17% *decrease* to 158 million bbls/yr.<br>• Avgas: 23% *decrease* to 10 million bbls/yr. | • Low R&D activity.<br>• Only minor changes in existing types of aircraft. |
| RESOURCE ALLOCATION | • Small increase in operations.<br>• Enplaned passengers increased from 208 million (1975) to one-half billion. | • From 72% (1970) to 84% of operations at towered airports.<br>• 95% plus of total aircraft. | • Jet: 65% increase to 317 million bbls/yr.<br>• Avgas: 115% increase to 28 million bbls/yr. | • Moderate R&D activity, concentrating on fuel efficiency and noise reduction. |
| INDIVIDUAL AFFLUENCE | • 100% increase in operations.<br>• Enplaned passengers increased from 208 million (1975) to 800 million.<br>• STOL and Super turbojets. | • From 72% (1970) to 85% of operations at towered airports.<br>• 95% plus of total aircraft. | • Jet: 169% increase to 517 million bbls/yr.<br>• Avgas: 154% increase to 33 million bbls/yr. | • High levels of technology tempered by environmental concerns.<br>• Fewer new aircraft than Scenario 5' |
| EXPANSIVE GROWTH | • 300% increase in operations.<br>• Enplaned passengers increased from 208 million (1975) to 1 billion.<br>• Jet STOL, Super large, and SST aircraft. | • From 72% (1970) to 85% of operations at towered airports.<br>• 95% plus of total aircraft. | • Jet: 342% increase to 850 million bbls/yr.<br>• Avgas: 423% increase to 68 million bbls/yr. | • Rapid development of new aircraft.<br>• Heavy emphasis on R&D. |

*Unless otherwise stated all figures shown are for the year 2000.

## TABLE 3: SUMMARY OF MAJOR FINDINGS* BY SCENARIO

| | AIR TRAFFIC CONTROL TECHNOLOGY | COMPLEMENTARY AND COMPETING MODES | AIR CARGO | AVIATION SAFETY |
|---|---|---|---|---|
| LIMITED GROWTH | • UG3rd installation began in 1985.<br>• NAS rate of growth reduced. | • Auto intercity travel declines.<br>• Shift from auto divided between air, rail and mass transit. | • Low growth (less than 3%) due to weak economic conditions. | • Relatively low demand.<br>• Decline in rates and number of accidents. |
| MUDDLING THROUGH | • Little change in NAS from 1970's. | • Increased telecommunications substituted for travel. | • Low growth (+2%) then decline due to economic conditions. | • Demand less than system capacity, resulting in<br>• Fewer accidents. |
| RESOURCE ALLOCATION | • UG3rd in 1985.<br>• 4th generation ground-based ATCS by 2000. | • Auto intercity travel declines.<br>• High speed ground intercity transit. | • Moderate growth (+4%). | • Relatively low rate of increase in demand, and<br>• Increased use of technology in NAS, results in,<br>• Decline in rates and number of accidents. |
| INDIVIDUAL AFFLUENCE | • UG3rd by 1980.<br>• 4th generation ground-based ATCS by 1990. | • Auto retains major role.<br>• High speed ground intercity transit. | • High growth (+9%).<br>• All-cargo flights increased. | • Technological and procedural advances, but<br>• No decline in numbers of accidents, because of<br>• Heavy increase in aviation activity. |
| EXPANSIVE GROWTH | • Automated air-based ATCS by 1990. | • Auto retains major role.<br>• High speed ground intercity transit. | • Very high growth (+12%).<br>• All cargo airports in 1990's. | • Improved technology and operating procedures.<br>• Number of accidents and fatalities do not decline because of high demand. |

*Unless otherwise stated all figures shown are for the year 2000.

socioeconomic, institutional and political in nature.

## A. Basic Assumptions and Methodologies

It should be understood that the technological forecasts presented in Volume I and the "social forecasting" of the aviation futures, are both "surprise-free" forecasts. The basic assumptions were [1]:

1. No drastic technological breakthroughs
2. No major international conflicts
3. No large scale international depression or monetary catastrophe

These basic assumptions will remain operative throughout this study. Thus, the differences between the constrained (or conditioned) technological forecasts of this chapter and the unconstrained forecasts in Volume I are mainly caused by the different combinations of socioeconomic, political and institutional factors imposed by the three aviation futures.

It should be pointed out that there are no time-proven and quantitative theories for predicting social impact on technological development. However, a qualitative "tracing" approach was taken to hypothesize a reasonable causal relationship between the aviation futures and the technological developments as follows:

1. Identify the fundamental assumptions about the socioeconomic conditions underlying the "unconstrained forecasts"

2. Deduce how these socioeconomic conditions may change in the alternative aviation futures

3. Modify the unconstrained forecasts as functions of the changing socioeconomic conditions

4. Label these modifications as "conditioned forecasts" and relate them to the alternative aviation futures

This four-step procedure will be further explained and applied below.

## B. Crucial Factors Affecting Computer Generation Dynamics

Computers form a giant industry with millions of actual and potential applications in society. The future growth in computer technologies will therefore be practically unaffected by the national aviation system. To the extent that the forecasts of computer technologies are not affected by FAA goals and decisions, the forecasts are exploratory, and not normative, regardless of whether the forecasts are conditioned or not.

The dramatic growth of computer technologies can be attributed to two fundamental and interrelated socioeconomic conditions, which have been tacitly assumed in the previous unconstrained forecasts, namely, vigorous competition, and substantial R&D. Competition includes both domestic and international dimensions; R&D includes both private and public expenditures. Generally speaking, in the computer industry, private R&D is more applied, and is driven more by market competition; whereas public

R&D is more basic, and is driven more by space and defense competition.[3]

The tacit assumptions of socioeconomic conditions underlying the unconstrained computer technology forecasts in Volume I were that the structure (division between private and public, and between domestic and international) and the magnitude (expenditure and trade in percentage of GNP) of competition and R&D in the computer industry would remain approximately the same in the future as in the recent past. However, this may not be the case in the three alternative aviation futures considered.

To modify the unconstrained forecasts while keeping the "surprise-free" assumption intact, a mental model of technological development with an "elastic time scale" was used. This model hypothesizes that technological change will be orderly, but that its speed may be increased or decreased as a function of competitive vigor and R&D expenditure. The orderly change of computer components is considered to be as follows [4]:

| | | |
|---|---|---|
| Generation 0 | Relays and vacuum tubes | Up to 1953 |
| Generation 1 | Vacuum tubes | 1951-1958 |
| Generation 2 | Transistors | 1958-1969 |
| Generation 3 | Integrated circuits | 1967-1974 |
| Generation 4 | MSI and LSI | Present |
| Generation 5 | LSI and GSI (Grand Scale Integration) | |
| Generation 6 | Hybrid GSI and optical (holographic) | |

The escalation of complexity of integrated circuits from small scale integration (SSI) to medium scale (MSI) to large scale (LSI) and eventually to grand scale (GSI) is a natural evolution of technological advances that is impressively rapid but can be generally expected. Optical computing, however, is a quantum jump. Although the basic concept of optical computing has been known for some time, the technology is still embryonic and can evolve in many possible directions at uncertain speeds. (See the IEEE Proceedings special issue on optical computing, January, 1977 for state-of-the-art reference [5].) Optical computing is derived from a scientific base which is distinct from that for semiconductor computer components. The fundamental advantages of optical computing are its parallel data processing in special applications (image processing, two-dimensional Fourier transform, special matrix manipulation, etc.), its extremely compact memory capacity (e.g., holographic memory), and its potential processing at the speed of light. However, many general purpose data processing needs do not lend themselves readily to optical computing. Thus, the sixth generation computers mentioned in the above table are more likely to be hybrid systems involving the combination of coherent optical, electro-optical, solid-state, and digital subsystems, instead of pure optical systems.

Concurrent to computer hardware technology changes, an orderly change of computer software (including computer architecture and networking) is also assumed. In the following, the conditioned forecasts for microcomputers are done with the aforementioned assumptions, but focus particularly on those microcomputer capabilities of speed, size, cost, and weight, which are likely to be the limiting factors in the two types of microcomputer systems described in Volume I.

## III. Variation of Crucial Factors and Generation Dynamics

As pointed out previously, competition and R&D are the crucial factors affecting the rate of technology development. However, every industry, even the computer industry, has its own inertia. It takes time for R&D results to propagate through engineering, marketing, and delivery. Thus, a change in R&D expenditures will have a delayed effect on the acceleration or retardation of the advent of new computer generations. Further, there is, in general, a longer lag between R&D spending and commercial exploitation if the R&D is supported by the public sector rather than the private sector (as the experience in energy R&D has indicated).* The net result of these delayed effects is that the unconstrained forecasts of computer technologies in the previous sections can be converted to conditioned forecasts basically by a "telescoping" process. A "Muddling Through" society will stretch out the unconstrained forecasts, especially the portion corresponding to the distant future (1999-2000). An "Expansive Growth" society will

*The U.S. Energy Research and Development Administration (ERDA) has recognized this factor and has consequently initiated a market-oriented planning system (MOPS) to reduce this longer delay.

compress the unconstrained forecasts, again especially for the period 1990-2000. The short-term forecasts (for 1980) will not be much affected. A shift toward more important government roles (as in the "Individual Affluence" scenario) will also tend to stretch out the unconstrained forecasts. The quantification of this telescoping process will be made specific in this chapter.

A more fine-tuned modification of the unconstrained forecasts will include the changes of the uncertainty band. In general, an acceleration of generation change, such as could be caused by more competition in the computer industry, will increase the uncertainty in the industry's ability to achieve the computer performance target by a particular time, since there will be less time to "get the bugs out" of new technology. This is illustrated by the upper half of Figure 3, which shows that, with more competition, the uncertainty in microcomputer speed will be skewed downward; i.e., the lower bound of the uncertainty band is farther from the mid-curve (the expected performance) than the upper bound. In contrast, an increase of basic R&D expenditure (more likely to accompany a shift toward government R&D) will also increase the uncertainty in the anticipated computer performance, but the uncertainty will be skewed upward; i.e., the upper bound of the uncertainty band is farther from the mid-curve than the lower bound, since there is a higher probability of drastic (or surprising) technological breakthrough resulting from

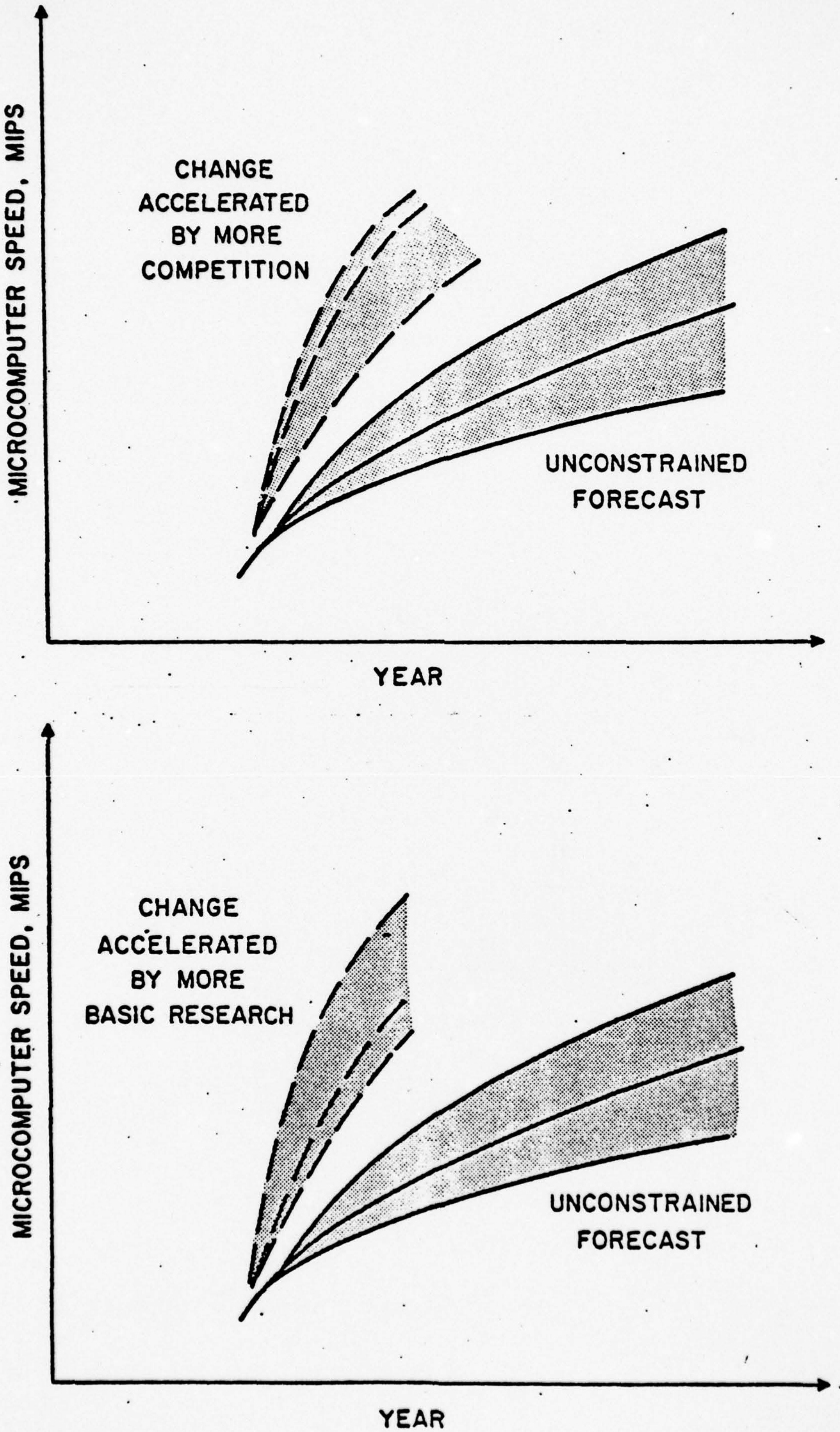



FIGURE 3: UNCONSTRAINED FORECASTS MODIFIED BY COMPETITION AND BASIC RESEARCH (NOTE THE DIFFERENCE IN UNCERTAINTY SKEWS)

more basic research. The lower half of Figure 3 illustrates this latter case.

To relate the modifications of unconstrained forecasts to the three alternative aviation futures, attention will be focused on the competitive vigor and the R&D expenditures in the computer field, although other socio-economic attributes will not be completely ignored. This deduction of relevant socio-economic conditions has been done by:

1. Reading the qualitative scenarios of the alternative futures
2. Looking at certain key quantitative variables (e.g., GNP, federal spending for aeronautical R&D, imports, exports, etc.)
3. Looking at occurrence of key events (e.g., event 96 of the <u>Aviation Futures</u> study - fifty percent of assembly-line production is controlled by computers)

In the end, subjective judgments must be made as to whether the total socio-economic conditions, along with other relevant conditions and events, of a particular aviation future will accelerate or retard microcomputer technology development, and by how much. These judgments on acceleration and retardation in quantitative terms, and their corresponding conditioned forecasts of microcomputer characteristics in terms of speed, size, power, weight, and cost, will be given in the last section of this chapter.

## IV. Relevant Data from Aviation Futures

Data from the continuing work on the aviation futures [2] have been obtained and examined. R&D expenditures and the status of competition are the key factors determining technological innovation of the microcomputer industry. These key factors are primarily described by the "qualitative scenarios" of the aviation futures. Quantitatively, these two key factors are reflected by the values of the following two variables and by the probabilities that the following four events will have occurred by the year 2000. (Each aviation scenario is described quantitatively by a large number of variables and events [2].)

Variables:

1. Federal Spending for Aeronautical R&D (in 1975 dollars)
2. Total of all Government Spending as a Percentage of GNP

Events:

1. R&D spending in the United States increases from 1975 level of 2.5 percent of GNP to 5 percent of GNP.
2. Fifty percent of assembly line production is controlled by computers.
3. Five percent of the work force accomplishes its job functions through the use of electronic computers.
4. Anti-exodus laws are passed penalizing industry for moving outside the United States.

The values of the above two variables are given in Table 4 and the probabilities that the above four events will have occurred by the year 2000 are given in Table 5. Taken as a whole, the data indicate that the "Muddling Through" and "Expansive Growth" scenarios are at the opposite ends (low and high, respectively) of the R&D and competition spectrum, with the "Resource Allocation" in the middle. Thus, if Resource Allocation is taken as the baseline case, microcomputer

TABLE 4: FEDERAL AND NON-DEFENSE AERONAUTICAL RESEARCH AND DEVELOPMENT, MILLIONS OF 1975 DOLLARS

| | Muddling Through | Resource Allocation | Expansive Growth |
|---|---|---|---|
| 1976 | $ 649.2 | $ 649.2 | $ 649.2 |
| 1980 | 812.4 | 900.2 | 904.4 |
| 1985 | 983.9 | 1,183.6 | 1,254.0 |
| 1990 | 1,094.1 | 1,466.8 | 1,724.2 |
| 1995 | 1,213.6 | 1,787.9 | 2,370.5 |
| 2000 | 1,323.1 | 2,160.6 | 3,210.3 |

Source: Reference [2].

TABLE 5: EVENT PROBABILITIES

| EVENT | SCENARIO | MUDDLING THROUGH | | | RESOURCE ALLOCATION | | | EXPANSIVE GROWTH | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | DATE | 1980 | 1990 | 2000 | 1980 | 1990 | 2000 | 1980 | 1990 | 2000 |
| 1. R&D spending in the U.S. increases from 1975 level of 2.5 percent of GNP to 5 percent of GNP | | 0 | 10 | 10 | 15 | 40 | 50 | 20 | 60 | 70 |
| 2. Fifty percent of assembly line production is controlled by computers | | 0 | 10 | 10 | 0 | 20 | 30 | 0 | 40 | 50 |
| 3. Five percent of the work force accomplishes its job functions through the use of electronic computers. | | 0 | 20 | 20 | 0 | 30 | 40 | 0 | 50 | 70 |
| 4. Anti-exodus laws are passed penalizing industry for moving outside the U.S. | | 20 | 60 | 70 | 20 | 30 | 40 | 5 | 10 | 15 |

Source: Reference [2].

technology development would therefore be most retarded in "Muddling Through" and will be most accelerated in "Expansive Growth."

## V. Estimation of Microcomputer Generation Dynamics

The above consideration has led to the choice of the "Resource Allocation" scenario as the baseline case for the sake of easy comparison. Moreover, the socio-economic conditions of this scenario correspond most closely to the assumptions made in Volume I for the unconstrained technological forecasts. The historical data about mainframe computer generation dynamics in Section II (1951 to present) indicated that the time between computer generations has been about six to eight years. In general, microcomputers should be more dynamic than large mainframe computers, for two reasons:

1. It generally takes less time to design a microcomputer system, especially one for instrumentation and control; and

2. Microcomputer technology is younger and can therefore grow faster.

Thus, for the Resource Allocation scenario, the time between microcomputer generations may be taken to be six years, which is near the low end of historical figures for the time between mainframe computer generations.

This six-year span between microcomputer generations will be different for different aviation futures, since as discussed previously, competition and R&D would be different in different aviation futures. The range varies from three years (most optimistic) to twelve years (most pessimistic). This variation by a factor of two appears to be reasonable and was confirmed by a recent study [3]. The social inertia and the lagtime between R&D and commercialization are such that computer technologies will probably not deviate appreciably from the baseline case before 1980, regardless of which aviation future evolves. Beyond 1980, the time between computer generations will be different for different aviation futures. The microcomputer generation times for the three selected aviation futures are thus as follows:

| Aviation Futures | Years Between Generations |
|---|---|
| Expansive Growth | 3 |
| Resource Allocation | 6 |
| Muddling Through | 12 |

## VI. Microcomputer Characteristics Estimation

On the basis of the above generation times, the results of the conditioned forecasts of various microcomputer characteristics (speed, power, etc.) are shown in Table 6 and Figures 4 through 8. To avoid confusion, only the "expected" values are shown and the uncertainty bands are omitted. These values are for typical ground-based data processing microcomputer systems described in Volume I. The characteristics of typical airborne microcomputers are different, as previously discussed in Volume I. The changes in airborne microcomputer systems represent evolutionary, slow improvement and not "generational" changes because functionally airborne

FIGURE 4: CONDITIONED FORECASTS OF MICROCOMPUTER SPEED

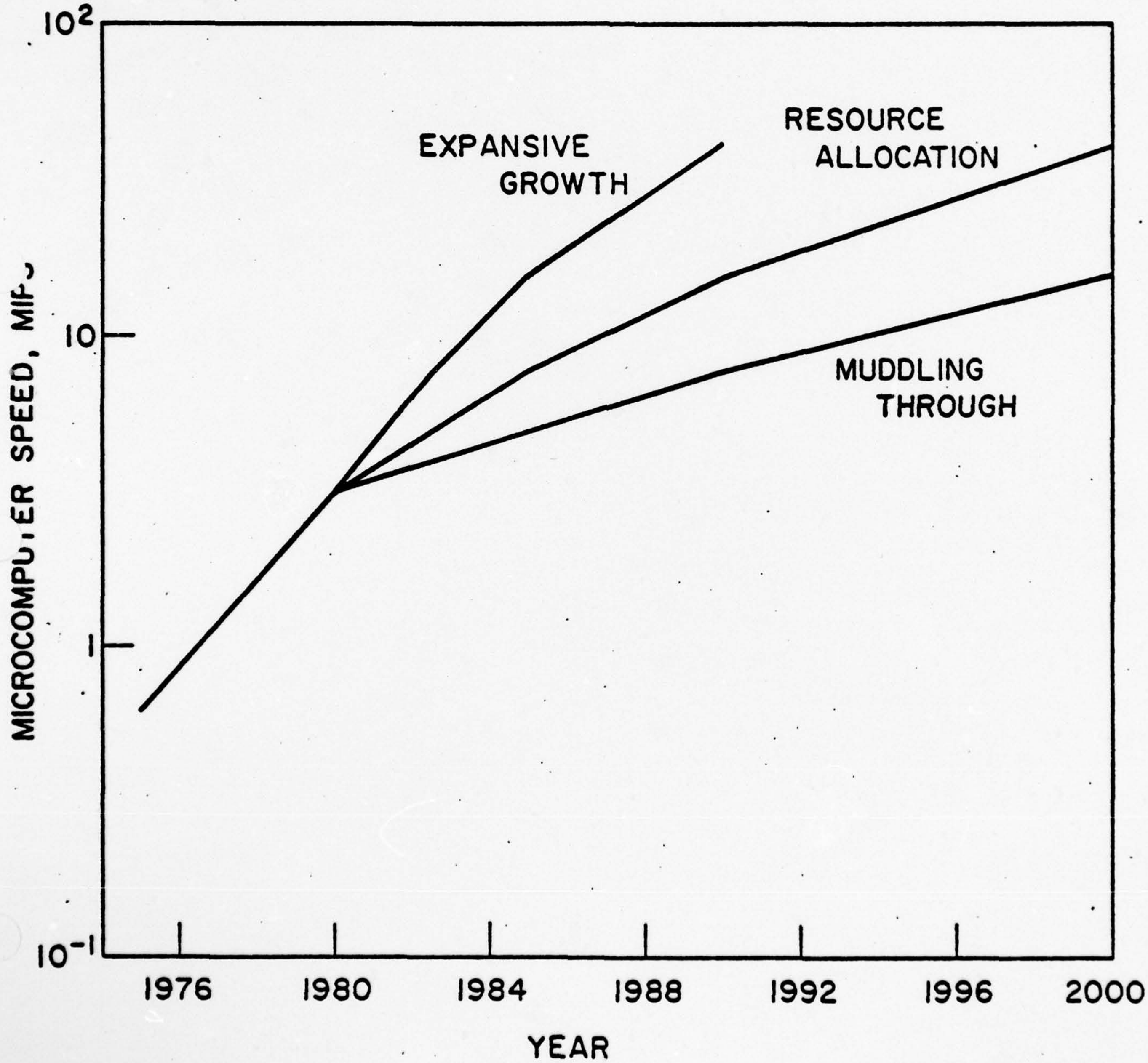


FIGURE 5: CONDITIONED FORECAST OF MICROCOMPUTER POWER

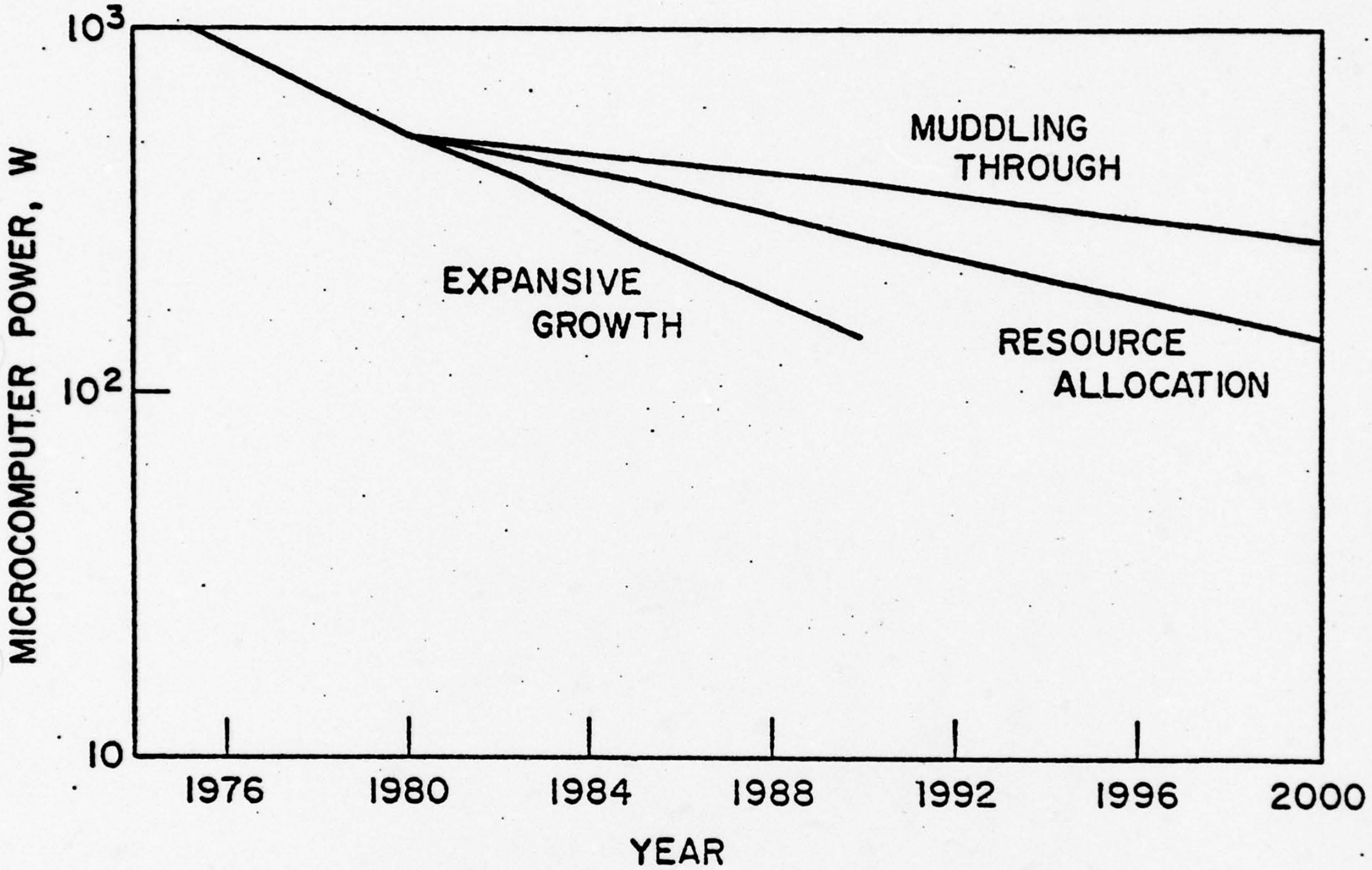


FIGURE 6: CONDITIONED FORECAST OF MICROCOMPUTER SIZE

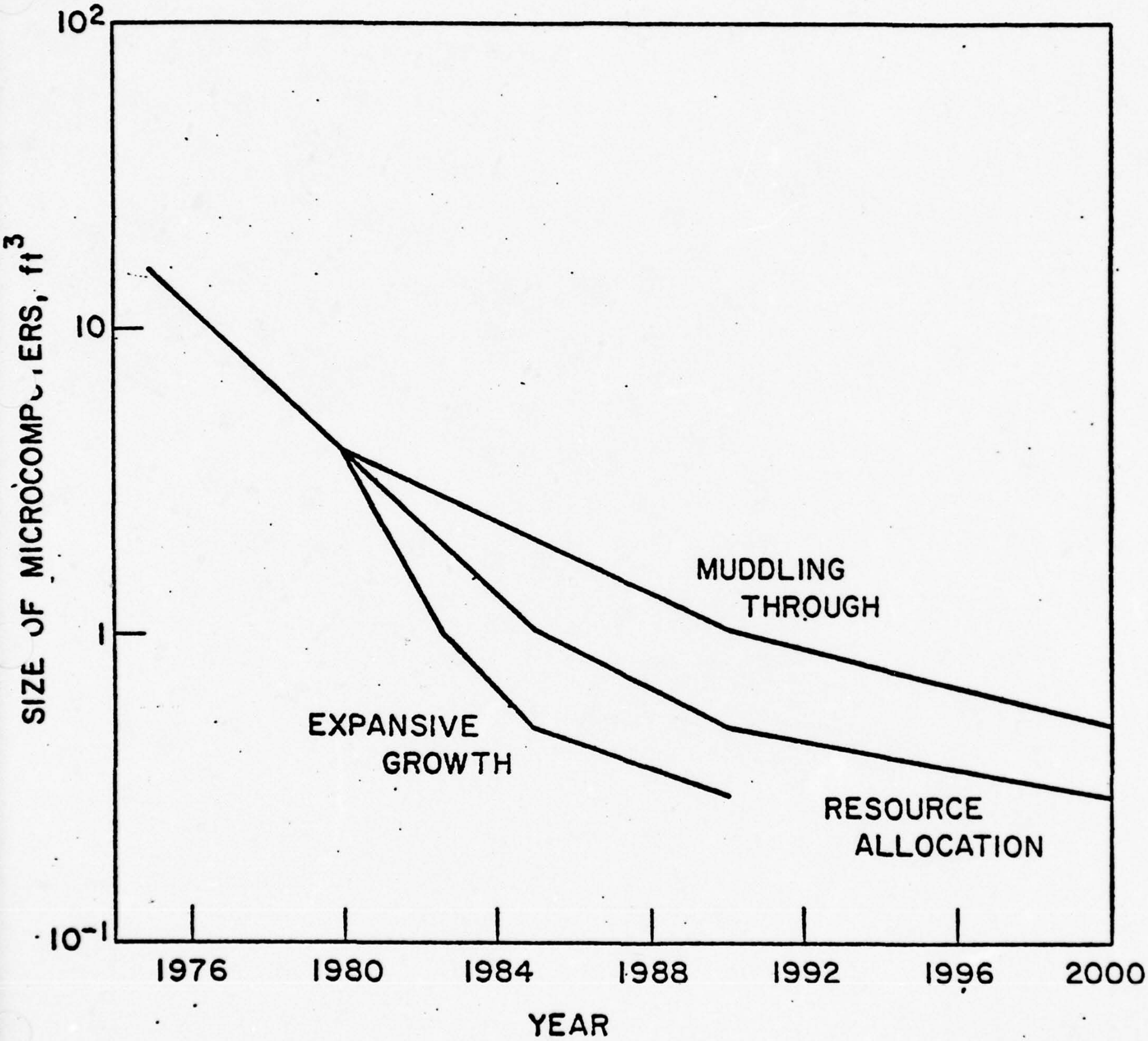


FIGURE 7: CONDITIONED FORECAST OF MICROCOMPUTER WEIGHT

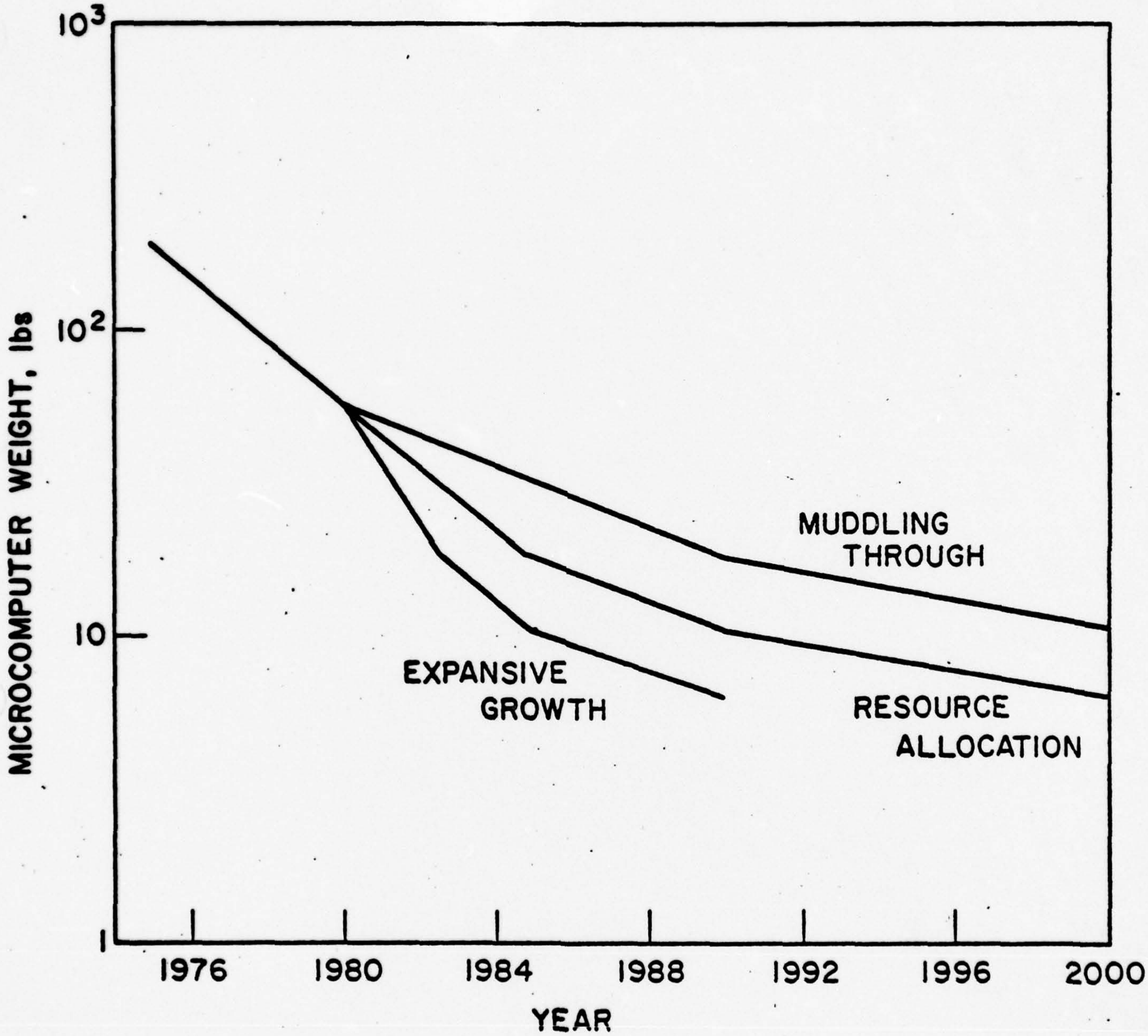
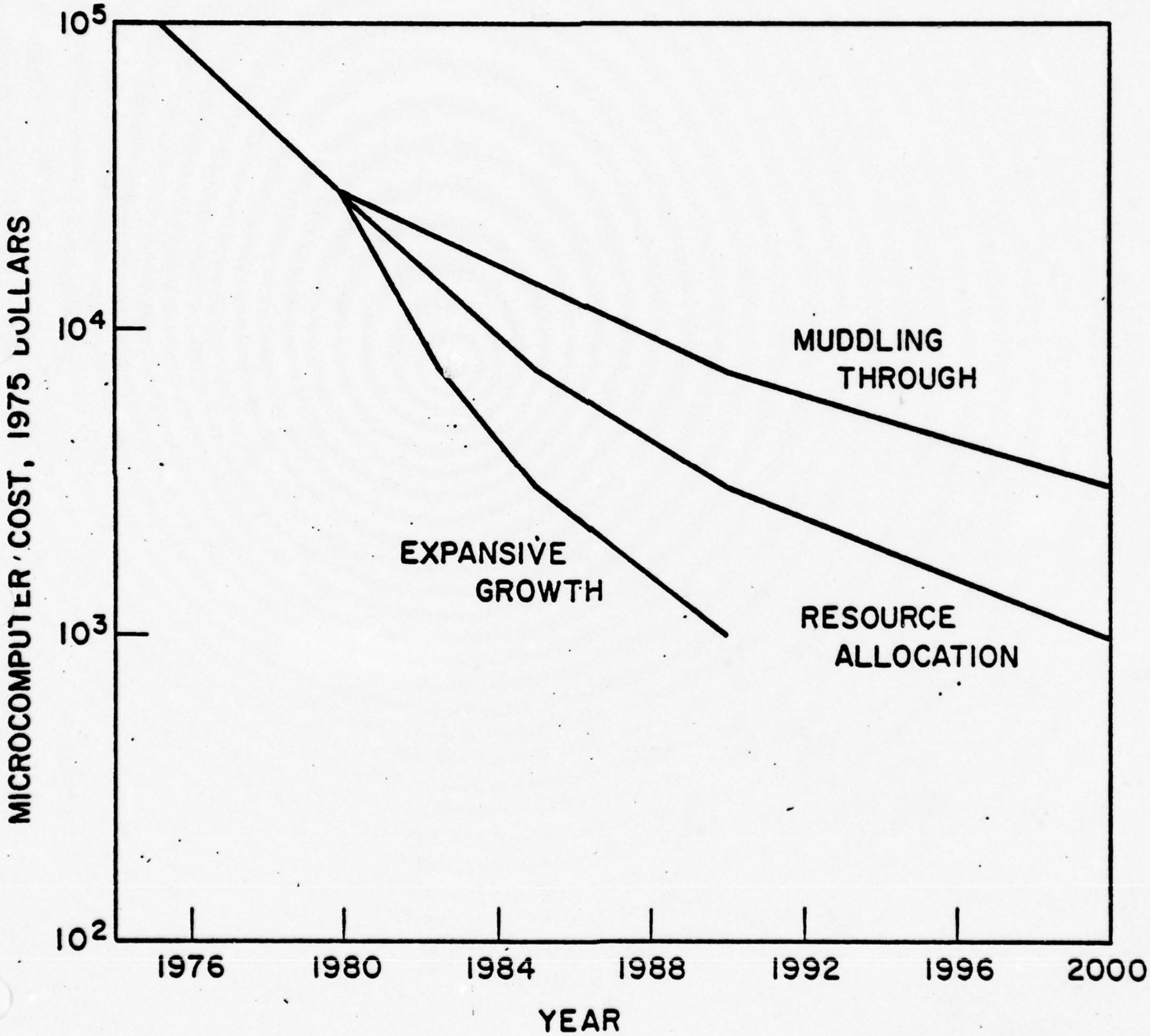


FIGURE 8: CONDITIONED FORECASTS OF
MICROCOMPUTER COST



microcomputers are much less demanding. Moreover, in airborne instrumentation and control systems characteristics are largely determined by peripheral equipment and input/output (I/O) devices. For these reasons, forecasts of ground-base systems only are estimated.

The construction of the forecasted curves has been made according to the following equation. The equation essentially describes quantitatively the "telescoping process" discussed previously in Section III and states that the telescoping process will not begin until after the year 1980. All five microcomputer characteristics should be equally affected by the microcomputer generational gaps, since these characteristics were derived basically from the same forecasts of physical changes in microcomputer hardware, as discussed previously in Volume 1.

$$C_i(t) = C_2[a_i(t-1980) + 1980] \qquad (1)$$

$$\text{for } t \geq 1980$$

C = Microcomputer characteristic (speed, power, etc.)

t = time in year (e.g., 1982)

i = 1 to 3 corresponding to the aviation futures in the following table (e.g., Resource Allocation = 2)

$a_i$ = acceleration factor. The greater $a_i$ is above unity, the faster the microcomputer characteristic grows with time. For Resource Allocation scenario, the baseline case $a_2$ = 1.

The previous judgments made on the years between computer generations can thus be quantified in the following table for acceleration factors:

| Aviation Futures | $i$ | $a_i$ |
|---|---|---|
| Expansive Growth | 1 | 2 |
| Resource Allocation | 2 | 1 |
| Muddling Through | 3 | ½ |

As an illustration, for the "Expansive Growth" Aviation Future, ($i = 1$), the computer speed in million instructions per second (MIPS) in 1986 is forecasted to be:

$$MIPS_1\ (1986) = MIPS_2\ [2\ (1986-1980) + 1980]$$
$$= MIPS_2\ (1992)$$

That is, MIPS in 1986 for "Expansive Growth" Aviation Future is expected to be equal to MIPS in 1992 for Resource Allocation Aviation Future. In other words, Expansive Growth accelerates technological growth as compared to the baseline case. Similarly,

$$MIPS_3\ (1986) = MIPS_2\ [\tfrac{1}{2}\ (1986-1980) + 1980]$$
$$= MIPS_2\ (1983)$$

That is, MIPS for "Muddling Through" Aviation Future is expected to be equal to MIPS in 1983 for Resource Allocation Aviation Future. Thus, "Muddling Through" decelerates technological growth of computers.

Since the "unconstrained forecasts" were made in Volume I for the Resource Allocation Aviation Future as the baseline case, it is easier to find the year in which the computer characteristics in each scenario will reach the forecasted values for the baseline case. Thus, we may go back to equation (1), and solve for t after setting the argument of $C_2$ equal to the grid years of 1985, 1990, and 2000. For example, the question is asked, for the Expansive Growth Scenario, when will the computer characteristics reach those for the baseline case in 1985. Solving for t by using the equation

$$2(t - 1980) + 1980 = 1985$$

and $t = 1982.5$

That is, $C_1\ (1982.5) = C_2\ [a_1\ (1982.5 - 1980) + 1980]$

$$= C_2\ (1985).$$

Repeating the above calculation for all the scenarios and for all the grid years resulted in the conditioned forecasts in Table 6. The left half of Table 6 gives the five points in time. Each horizontal line in the left half of Table 6 essentially describes a "milestone" of the future microcomputer technology. The right half of Table 6 gives the years in which these milestones will be reached by the three alternative aviation futures. As indicated, the first two milestones will be reached in the same years by the three alternative future scenarios because of the near-term momentum and inertia of the computer industry. The last three milestones, however, will be reached in different years by the different scenarios--Expansive Growth being the fastest and Muddling Through the slowest. The year "1982.5" represents the time of late 1982 and early 1983.

These conditioned forecasts are portrayed in Figures 4 through 8 for the computer characteristics of speed, power, size, weight, and cost, respectively. The plots are simply graphic

TABLE 6: MICROCOMPUTER CHARACTERISTICS: CONDITIONED FORECASTS

| CHARACTERISTICS | | | | | SCENARIOS (Year) | | |
|---|---|---|---|---|---|---|---|
| Speed MIPS | Power Watts | Size $ft.^3$ | Weight lbs. | Cost $ | Exp Growth | Res. Alloc. | Muddling Through |
| .63 | 1020 | 16 | 195 | 106,623 | 1975 | 1975 | 1975 |
| 3.13 | 520 | 4.13 | 59 | 28,365 | 1980 | 1980 | 1980 |
| 7.81 | 395 | 1.04 | 18.3 | 7,283 | 1982.5 | 1985 | 1990 |
| 15.63 | 270 | 0.53 | 10.6 | 3,097 | 1985 | 1990 | 2000 |
| 41.67 | 145 | 0.30 | 6.4 | 974 | 1980 | 2000 | 2020 |

displays of Table 6. Each breakpoint in these plots represents the reaching of a milestone. Since the most advanced projected milestone will be reached by the expansive growth scenario in 1980, the plots corresponding to this scenario end before the year 2000. It should be noted that the above algorithm can be applied to the uncertainty bands in the forecasts, although they have been omitted to avoid confusion.

## VII. Summary

This chapter combines the results of technological forecasts and state-of-society assumptions. The five major characteristics of typical ground-based microcomputer systems for aviation applications (microcomputer speed, power, size, weight, and cost) have been forecasted as functions of three alternative aviation futures (expansive growth, resource allocation, and muddling through). These conditioned forecasts will be used as a basis for assessing microcomputer impacts on the National Aviation System and assessing the corresponding FAA policy implications, all in the context of alternative aviation futures.

# CHAPTER III

## IMPACTS OF MICROCOMPUTERS ON THE NATIONAL AVIATION SYSTEM

The purpose of this chapter is to focus on the impacts of micro-computers on the National Aviation System (NAS), and includes both impact identification and analysis. Chapter I of this Volume delineates that the speed of advances in microcomputer technology and the associated specific impacts on the NAS are imbedded within particular alternative future states of society. As specific alternative future states of society differ, so will the specific impacts of microcomputers on the NAS.

Throughout this chapter, three alternative aviation futures, Expansive Growth, Resource Allocation, and Muddling Through, as outlined in Chapter II and Appendix A of this Volume, were used to condition the impacts of microcomputers on the NAS. It is clear from Chapter II and Appendix A that the differences in micro-computer advances and resulting social impacts, as a function of alternative futures, are mainly differences in degree rather than differences in kind. It is expected that the impact of microcomputers on the NAS will differ similarly. The greater the advances of microcomputers, the greater the impact. To simplify the presentation, the Resource Allocation scenario will be used as the reference future scenario from which NAS impacts will be assessed. This approach was taken because the Resource Allocation scenario projects an alternative future bounded, relative to aviation activities and microcomputer development, by the Expansive Growth and Muddling Through scenarios previously mentioned.

## I. Overview of NAS Impacts

Some of the various applications of microcomputers within NAS have been discussed in Chapter VII of Volume I. It is through these and other applications that microcomputers will exert impacts both directly and indirectly on the NAS. In other words, applications of microcomputers within the NAS are the link between general microcomputer technology and areas of impacts on NAS in a causal chain. This causal chain can be lifted from the conceptional structure of microcomputer impact analysis (Figure 1 of Chapter I) as the simple flow diagram shown in Figure 9.

To provide an overview of the impacts on the NAS which could be exerted by the potential use of microcomputer technology through applications within the NAS, a matrix has been constructed (Figure 10), in which the columns delineate major applications within the NAS, and the rows potential impacts on the NAS. The columns consist of the following six main application sectors:

(1) UG3RD and Post-UG3RD ATC

(2) On-board Computers

(3) Remote Monitoring of Federal Aviation Administration (FAA) Equipment

(4) FAA Information Processing

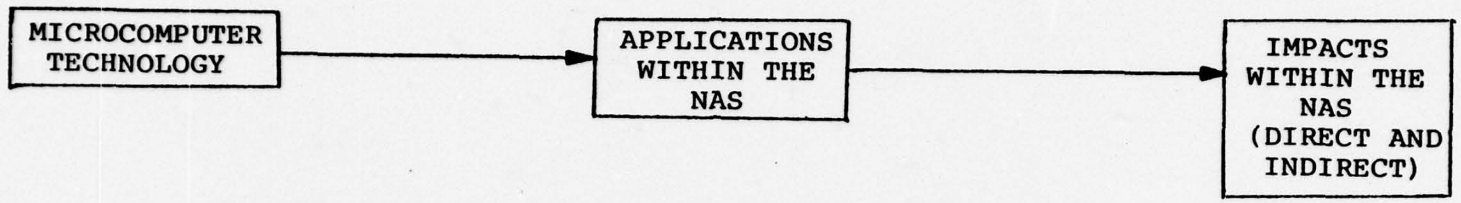



Figure 9

A Simple Flow Diagram for Impact Identification and Analysis

(5) Landside Airport Operations

(6) Simulation Using Computer Technology

As illustrated in Figure 10, the "On-board Computers" sector can be divided into the four application categories of (a) flight monitor, (b) flight control, (c) flight management, and (d) performance computers. The "Landside Airport Operations" sector can be divided into the application categories of (a) passenger processing and (b) baggage and freight handling, for a total of ten application sectors. The potential applications within the NAS for microcomputer technology have been discussed in Chapter VII of Volume I.

There are 59 rows in the matrix (Figure 10), each row corresponding to a potential impact area affecting the NAS. These impact areas were identified as a result of a joint effort between the FAA and The Onyx Corporation project team, after 1) consideration of the many variables in a NAS computer model [1] and, 2) intuitive and preliminary analysis of variables likely to be affected by the application of microcomputer technology, and 3) subsequent selection of those variables impacted which would be of interest to future FAA policy considerations. Most of the variables impacted were quantifiable (units of measurement are indicated in parentheses in figure 10), however, a few impact areas (e.g., ATC operating procedures, and manufacturing processes) could only be described qualitatively.

direct impact / indirect impact

● ● major ○ ○

● minor ○

| IMPACT AREAS | UG3RD and Post -UG3RD ATC | ONBOARD COMPUTER | | | | Remote Monitoring | FAA Information Processing | LANDSIDE AIRPORT OPERATION | | Simulation |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Flight Monitor | Flight Control | Flight Management | Performance | | | Passenger Processing | Baggage Freight | |
| FAA Employment -maintenance (#) | ● ● | | | | | ● ● | ● ● | | | |
| -certification (#) | ● ● | ● ● | ● ● | ● ● | ● ● | ○ | | | | |
| -controllers (#) | ● ● | | | | | | | | | |
| -computer support (#) | ○ | | | | | | ● | | | ● |
| -others (#) | ○ | | | | | ○ | ○ ○ | | | |
| FAA Building Space -hardware (sq. ft.) | ● ● | | | | | ● | ● ● | | | ● |
| -personnel (sq. ft.) | ○ | | | | | ○ | ● | | | ● |
| FAA Computer Investment -ATC ($) | ● ● | | | | | ● | | | | ● |
| -management ($) | | | | | | | ● ● | | | |
| FAA Computer Scrappage -hardware | ● ● | | | | | ● | ● ● | | | |
| -software | ● ● | | | | | ● | ● ● | | | |
| FAA Computer Op. & Maintenance Costs -ATC ($) | ● ● | | | | | ● ● | | | | ● |
| -management ($) | | | | | | | ● ● | | | |
| ATC Equipment Options | ● ● | | ● ● | ● ● | | ● | | | | ○ |
| Enroute & Terminal Capacity Options | ● | | ● | ● | | | | | | ○ |
| ATC Operating Procedures | ● ● | | ● ● | ● ● | | | | | | ● ● |
| Training & Maintenance Requirements | ● ● | ● ● | ● ● | ● ● | | ● ● | ● ● | | | ● |
| Safety - G.A. (accidents/million aircraft mile) | ● | ● | ● | ● | | | | | | ● |
| Safety - Air Carrier (accidents/ million aircraft mile) | ● | ● | ● | ● | | | | | | ● |
| Environmental - Noise (1000 acre -min/day) | ● | | ● | ● | | | | | | ● |
| Environmental - Emissions (1000 lbs. $NO_x$/day) | ● | | ● | ● | | | | | | ● |
| Retrofit of Aircraft with Technology | ● ● | ● ● | ● ● | ● ● | ● ● | | | | | |
| Airline Costs -aircraft ($) | ● | ● | ● | ● | | | | | | |
| -labor ($) | | ● ● | ● ● | ● ● | ● ● | | | ● ● | ● ● | |
| -fuel ($) | | | ● ● | ● ● | ● ● | | | | | ● |
| -maintenance ($) | | ● ● | ● ● | ● ● | ● ● | | | ● | ● | |
| -others ($) | | | | | | | | ● | ● | ● |

FIGURE 10: IMPACT MATRIX

| direct impact | indirect impact |
|---|---|
| • • major | o o |
| • minor | o |

| IMPACT AREAS | | UG3RD and Post -UG3RD ATC | ONBOARD COMPUTER Flight Monitor | Flight Control | Flight Management | Performance | Remote Monitoring | FAA Information Processing | LANDSIDE AIRPORT OPERATION Passenger Processing | Baggage Freight | Simulation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Airline Scheduling and Routing | | • • | | | • • | | | | • | • | |
| Airline Workforce -maintenance (#) | | | • • | | | | | | • | • | |
| -ground operating and reservation (#) | | | • • | • • | • • | • • | | | • • | • • | |
| -airborne operation (#) | | • | • • | • • | • • | • • | | | | | |
| -others (#) | | | | | | | | | • | • | • |
| Airline fuel consumption (millions of barrels/ year) | | • | | • • | • • | • • | | | | | • |
| Airline fleet size | | o | o | o | o | o | | | o | o | |
| Airline fleet age | | o | o | o | o | o | | | | | |
| G.A. Costs | P* | | | | | | | | | | |
| -aircraft ($) | CB* | | • | • | • | • | | | | | |
| G.A. Costs ($) | P* | | • | • | • | • | | | | | |
| -maintenance | CB* | | • • | • • | • • | • • | | | | | |
| G.A. Costs ($) | P* | | • | • | • | • | | | | | |
| -spare parts | CB* | | • • | • • | • • | • • | | | | | |
| G.A. Costs | P* | | | • | • | • | | | | | • |
| -fuel ($) | CB* | | | • • | • • | • • | | | | | • |
| G.A. Costs | P* | | | | | | | | | | • |
| -others ($) | CB* | | | | | | | | | | • |
| G.A. Fuel Consumption | P* | | | • | • | • | | | | | • |
| (millions of barrels/year) | CB* | | | • • | • • | • • | | | | | • |
| G.A. Fleet size | | o | o | o | o | o | | | o | o | o |
| G.A. Fleet age | | o | o | o | o | o | | | o | o | o |
| Pilot Certification | | • • | • • | • • | • • | • • | | | | | • • |
| Baggage & Freight Delay (# pieces lost or delayed/year) | | o o | | | o o | | | | | • • | |
| Baggage & Freight Travel time from plane (average minutes) | | o o | | | o o | | | | | • • | |
| Time spent between entering airport to takeoff or landing (minutes) | | o o | | | o o | | | | • • | • • | |
| Internal traffic & airport access & egress | | o o | | | o o | | | | • • | • • | |
| Manufacturing process | | | • | • | • | • | | | | | |

FIGURE 10: IMPACT MATRIX (CONT'D)

direct impact: ● ● major, ● minor
indirect impact: ○ ○ major, ○ minor

| IMPACT AREAS | UG3RD and Post -UG3RD ATC | ONBOARD COMPUTER | | | | Remote Monitoring | FAA Information Processing | LANDSIDE AIRPORT OPERATION | | Simulation |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Flight Monitor | Flight Control | Flight Management | Performance | | | Passenger Processing | Baggage Freight | |
| Manufacturing Work-force -production (#) | | ● | ● | ● | ● | | | | | |
| -engineering (#) | ● | ● | ● | ● | ● | | | | | |
| -others (#) | | | | | | | | | | ● |
| Manufacturing Supporting Workforce (#) | ● | ● | ● | ● | ● | ● | | ● | ● | ● |

Legend:

\# - Number of employees

$ - Cost in dollars

CB - Commercial business

P - Personal

FIGURE 10: IMPACT MATRIX (CONT'D)

The 590 cells of the matrix each represent the potential impact of a microcomputer technology application within the NAS on an area of the NAS. The intensity of each potential impact was first assessed intuitively. This was a relatively simple process for applications which resulted in direct impacts; e.g., flight control computers used to optimize engine combustion efficiency. However, indirect impacts could be adequately assessed only after tracing through several stages of causal relationships using the "impact tree" method (to be explained later). The results of assessing both direct and indirect impacts, and the associated interactions, are summarized in a coded form in Figure 10. The intensity of each impact is indicated by the number of dots in the cell corresponding to that impact, viz., two dots indicate a major impact and one dot a minor impact. Solid dots represent direct impacts while hollow dots represent indirect impacts. As shown in Figure 10, most impacts are direct, although major indirect impacts do exist.

The matrix in Figure 10 does more than present an overview of the relative impact intensity of potential microcomputer technology uses within the NAS. The use of dots or no dots in each cell as a measure of impact intensity compelled or stimulated imagination and visualization of how the ith application using microcomputer technology could impact, directly or indirectly, the jth area. The matrix was therefore an instrument for applying the morphological approach [2] to impact analysis. Use of the matrix for quantitative analysis is discussed in Appendix B.

While the matrix in Figure 10 is a convenient format to summarize the results of impact analysis, it does not show the rationale used to attain the results, especially the assessment of indirect impacts. For this purpose, "impact trees" were used to augment the results.

Impact trees may be portrayed as flow diagrams, with arrows indicating the direction of successive consequences resulting from initial events (or technological developments) which set the sequence of events in motion. In some cases a dotted line is used to show negative consequences or one event that constrains another event. In this tracing method*, the rationale associated with impact assessment is explicated for group interactions, and facilitates subsequent review and modification(s). In fact, Figure 9 may be considered an impact tree in the most aggregated and simple form, showing a two-stage chain through which microcomputer technology exerts impacts on the NAS. Specifically, Figure 9 should be disaggregated in order to illustrate these microcomputer characteristics which are especially important in leading to selection of the technology for specific NAS applications,

*Impact trees is an important tracing method for technology assessment [3], and was employed as the cardinal principle for impact assessment in the DOT/NASA Intercity Travel Technology Assessment project [4].

which in turn result in specific impacts on the NAS. Figure 11 shows generically a portion of such a disaggregated impact tree, and shows that future microcomputer technological developments would result in components and systems that are smaller, cheaper, more reliable, etc. As acquisition, maintenance, and operation costs of microcomputer systems decrease significantly, increased use of on-board computers, more ATC automation, increased use of simulators for training pilots, etc., should be expected. Such applications would then result in lower fuel consumption, less delay in air traffic flow, and lower training costs.

It should be noted that, if all the possible linkages between all the improvements in microcomputer technology, NAS applications, and the direct and indirect impacts on the NAS were displayed in Figure 11, the diagram would be far too complicated for effective use. For clarity, only segments of the disaggregated tree are presented, each segment corresponding to a cluster of NAS impact areas. Even so, only the most salient linkages will be displayed in each segment of the total impact tree. Before the specific impacts are discussed, it is important to explain how the salient linkages were identified and how the intermediate and final impacts were assessed in terms of their direction and intensity of change. Essentially a great deal of judgement was used in the impact identification and assessment; the procedure combined the following activities:

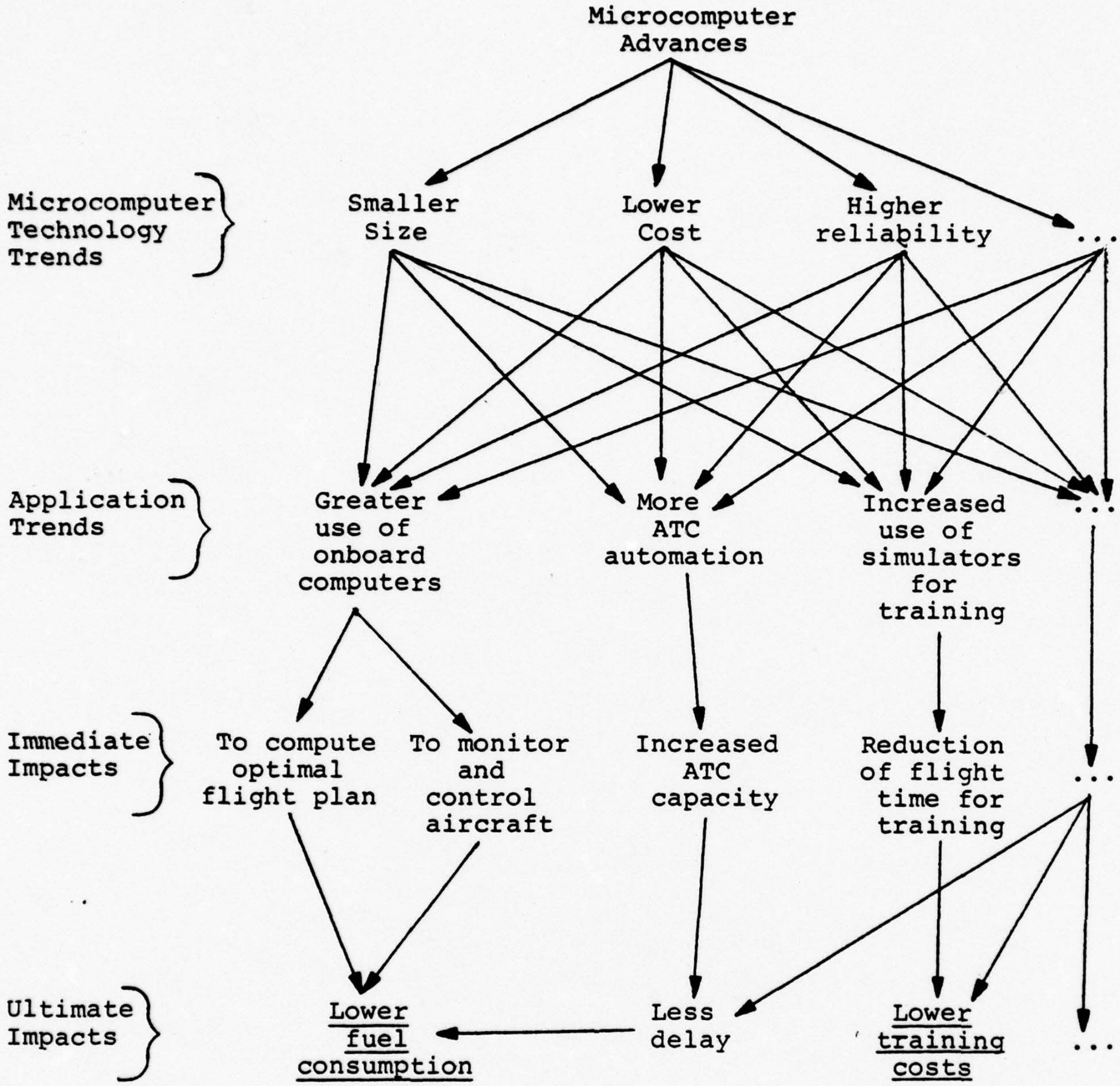



Figure 11

Generic Structure of the Disaggregated Impact Tree

(1) Develop a thorough checklist of relevant considerations

(2) Methodically go through the checklist for each potential impact

(3) Interview a number of knowledgeable people (experts/users/planners)

(4) Study the pertinent literature

The checklist of considerations includes (1) the NAS performance criteria of safety, economy, energy, and environment (S3E), (2) the question of how, how much, when, and under what conditions the specific impacts will be exerted, (3) how society may respond to these impacts, (4) the social value issues which accompany computer developments and applications, and (5) the 59 impact areas identified in Figure 10.

The knowledgeable people interviewed for impact analysis included representatives of various FAA offices (Policy, Facilities, Systems Engineering, R&D, etc.), personnel from DOT, NASA, ERDA, in addition to users and experts such as pilots, air traffic controllers, aircraft industry, and independent research institute experts. A list of interviewees is provided in Appendix D.

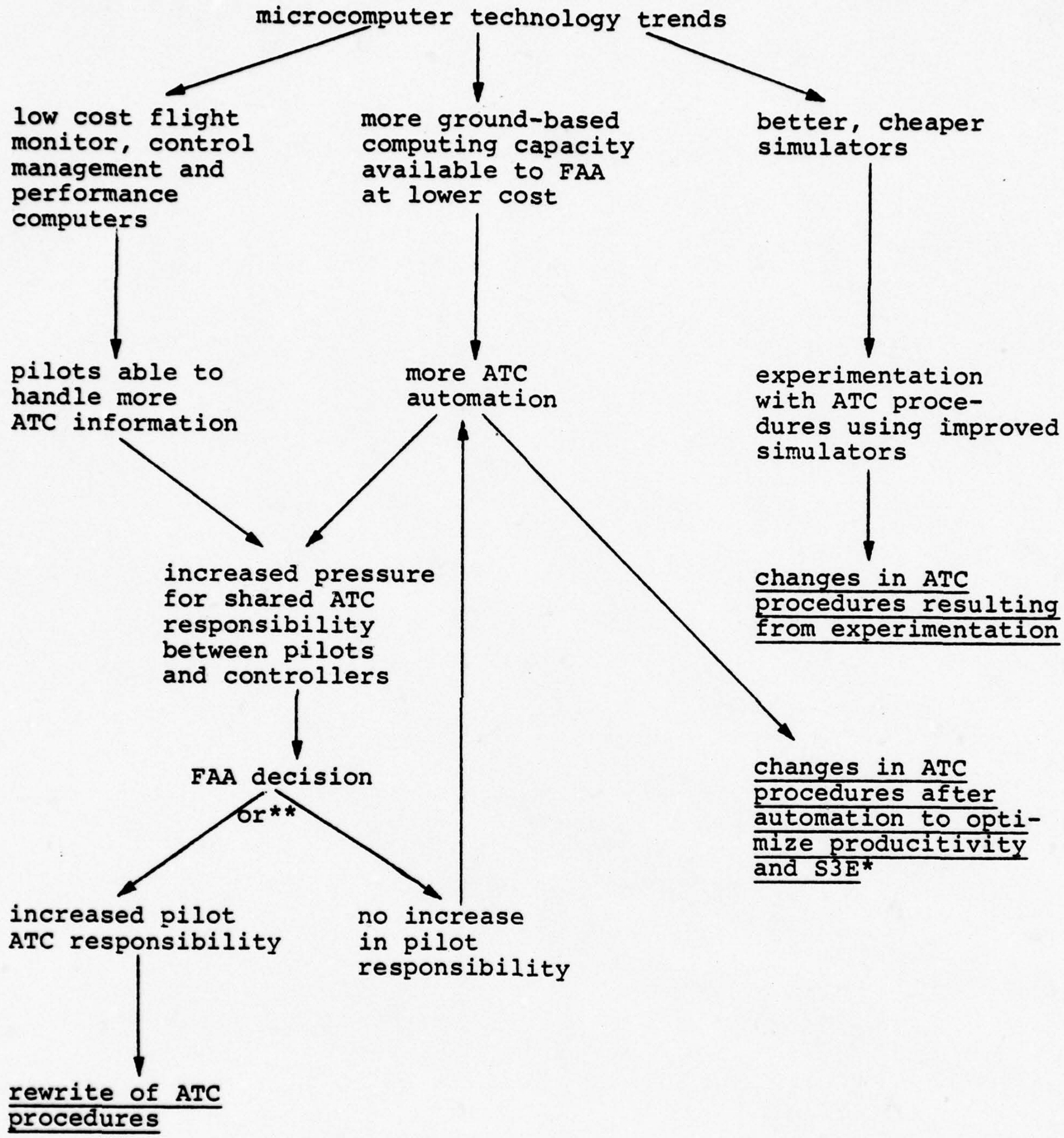
The pertinent literature used for the impact analysis included FAA reports, related technology assessment reports, professional journals, conference proceedings, etc. A bibliography of pertinent literature is provided in Appendix E.

## II. Specific Impacts of Microcomputer Technology on Areas of the NAS

In this section the specific impacts of microcomputer technology on 19 NAS impact areas will be discussed. These 19 areas embrace all 59 rows of the impact matrix (Figure 10). Of the 19 areas, 12 were selected for detailed investigation, and for each, a particular segment of the total NAS impact tree was identified. The 12 impact tree segments are Figures 12-23. Each tree begins with the general trends of microcomputer technology, delineated in Chapter II, viz., cost, speed, weight, size, and ends with specific impacts, which are underlined.

### A. Changes in ATC Operating Procedures

The impacts of microcomputer technology on ATC operating procedures depend upon how microcomputers and associated technologies are incorporated into ATC systems and at what level of sophistication. As Figure 12 shows, changes in ATC operating procedures come about not merely due to one, but many uses of microcomputers. In the Resource Allocation scenario, reductions in size, weight, power requirements and cost of microcomputers should result in low cost on-board flight monitor, control, management and performance computers (see Chapter VII, Volume I). Use of such on-board computers should give pilots increased information processing capability that may be used in air traffic control. On the ground side, reductions in computing costs and increases in computer speed and memory




*S3E - safety, economy, energy and environment

**Decision node - at this point the tree must go one way or the other, it cannot go both ways at the same time.

Figure 12

Changes in ATC Operating Procedures

capabilities should result in increased ATC automation, if the FAA chose to increase the computational capacity of the ATC systems using microcomputer techology advances at lower costs. As the forecasted trends in microcomputer speed, weight, size, power requirements and cost continue, technological barriers to automation will not be hardware, but limitations in input/output devices (throughout) and the development of appropriate software.

Enhanced pilot information processing capabilities and increasing ATC automation could result in increased pressure by pilots on FAA for an airborne ATC system or at least a greater role in ATC. Pilot frustrations over the inability to make use of potentially powerful new technology avionics and on-board computers, and an increasing reluctance to "flying blind," (taking ATC commands from "some machine") should be the driving force for more airborne (cockpit) ATC responsibility. If FAA decides to increase the pilot's role in ATC, ATC procedures would require drastic alterations from the present ground-oriented ATC system. If pilots do not assume some of the controller workload, then even more ATC automation would be necessary to keep up with growing air traffic demands.

The very <u>process</u> of automating certain ATC functions may also result in changes to ATC procedures. The process of analyzing a particular ATC procedure in order to develop the needed supporting software and algorithms may reveal areas where the procedure could be improved upon even more. ATC procedures may also be changed because of the increasing capability of microcomputers to store and process information. Procedures that a human controller would not be able to adequately use because the sheer magnitude of information to be evaluated and acted upon would saturate human capabilities, could be processed by an automated ATC system using advanced microcomputer technology.

The forecasted trends in microcomputer technology could be used to increase the number, level of sophistication, and presentational realism and accuracy of landside simulators at a lower cost. Using sophisticated landside simulators to "experiment" with ATC procedures may bring about new or alternative procedures that normally would not be evaluated and/or exercised because of safety restrictions. Unlike a "real-world" situation, experimentation using simulators run no risk of castastrophe if the procedures being tested prove to be unsafe. Simulators, therefore, could be used to test a number of alternative ATC procedures in a shorter time span than in real-world experiments to determine adequacy, reliability, and applicability.

In the Expansive Growth scenario, the impacts of microcomputer technology should be similar to those of the Resource Allocation scenario because of similarities in microcomputer applications, but should come about sooner. Because of the projected rapid development of microcomputer technology delineated in the Expansive Growth scenario (including cost reductions, utilization of on-board computers) the development of automated ATC procedures, and experimentation with simulators should occur at a faster rate than in the Resource Allocation scenario. The faster rate of microcomputers usage means that the impacts associated with that usage should occur at a faster rate. In the Expansive Growth scenario, pressure for an increased pilot-role in ATC should increase, automation of and the resulting changes in ATC procedures should accelerate, in addition to experimentation, testing, and implementation of new and alternative ATC procedures.

Because of the relatively slow development and utilization of microcomputer technology in the Muddling Through scenario, no great impacts on ATC procedures are seen. Some automation of air traffic control will probably occur but declining levels of air traffic should retard implementation. Better simulators on a limited basis will probably be developed for pilot training, but the declining level of air traffic will probably limit extensive experimentation with ATC procedures. Due to the lower level of microcomputer sophistication and the higher cost of microcomputer systems relative to the Resource Allocation scenario, on-board computers will probably not be as widespread as in the Resource Allocation scenario. Pressure for an increased pilot-role in ATC will probably still exist, but its intensity greatly reduced from the level anticipated in the Resource Allocation scenario.

B. Training and Maintenance Requirements

Utilization of microcomputer technology will result in changes in FAA training and maintenance techniques and procedures. Use of the technology will however depend on the rate at which it is integrated into the NAS and the level of sophistication of that integration. Figure 13 traces the changes in maintenance and training procedures and techniques assuming integration of microcomputer technology. Microcomputers and the associated technologies will be used by the FAA in the NAS regardless of scenario, however, the resulting impacts will vary in intensity not nature and will be due to fundamental differences in the scenarios. In the Resource Allocation scenario, decreasing cost should result in extremely low cost replacement parts. As the unit costs of replacing electronic systems and subsystems decreases, a "throw-away" approach to

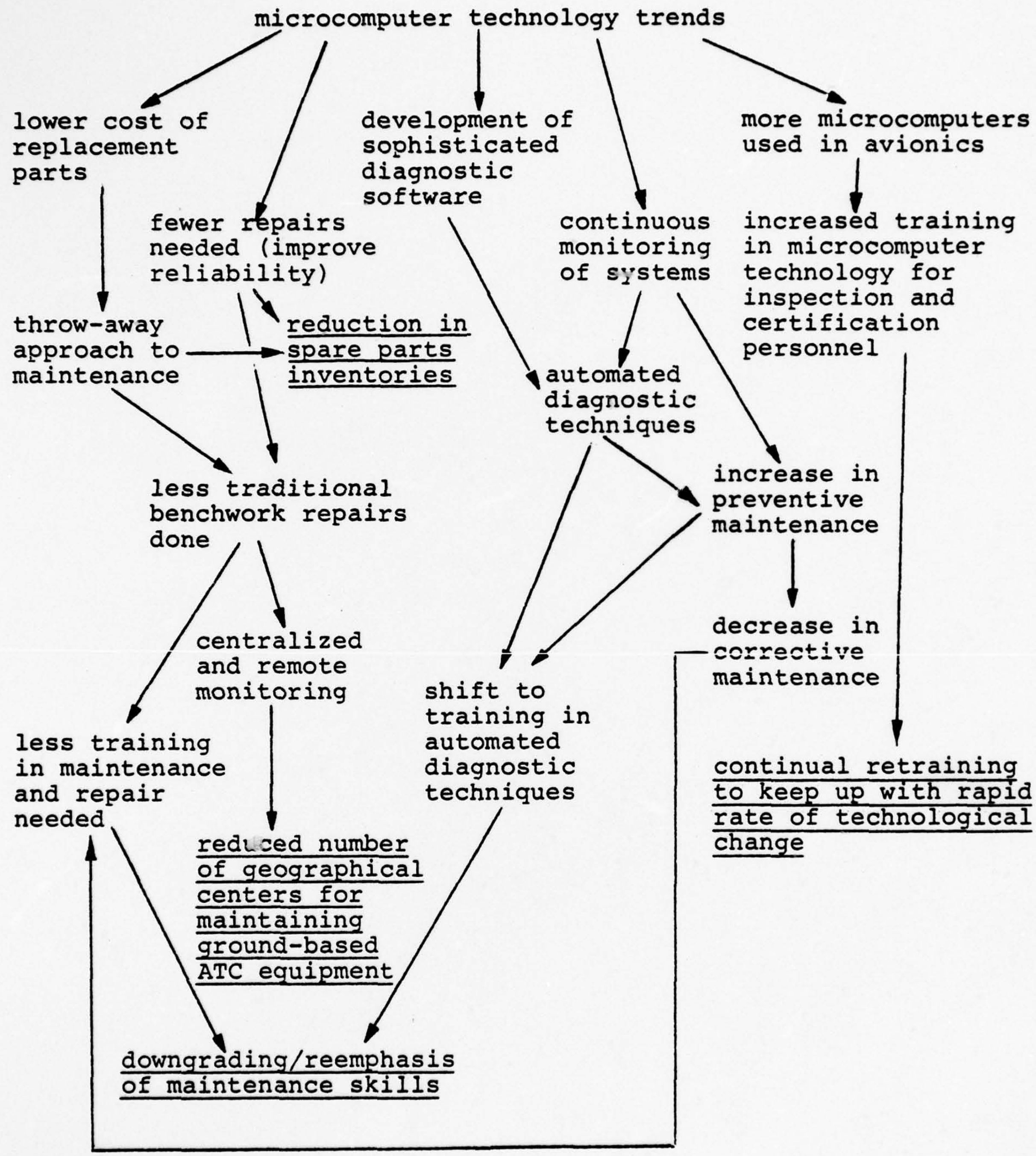



Figure 13

Training and Maintenance Requirements

maintenance should emerge. Rather than correcting a fault by laboriously tracing it to a single component and then replacing or repairing that single part, the fault would be corrected by merely isolating it to a module and/or subsystem and replacing the module in total, similar to replacing a failed vacuum tube.

Additionally, the process of detecting and isolating faults should become simpler. Improved maintenance techniques developed due to the new microcomputer technology, in addition to increased microcomputer speed, memory, storage, diagnostic software/firmware, should facilitate detection and isolation of faults. Such diagnostic software/firmware along with continuous internal and/or remote monitoring of vital primary and back-up system functions and parameters could be visually displayed via CRT and/or advanced technology display providing maintenance personnel with continuous read-out (past and present) of system performance; including warnings of both the existence of a failure and its location.

Automated fault detection and isolation techniques combined with the procedures of throw-away replacement of components and subsystem modules would make routine maintenance as simple as obtaining a read-out (remote or on-site) of a fault location within a system network and on-site replacement on a modular basis. The laborious task of testing and checking circuits by hand and then replacing individual parts that make up traditional electronic "benchwork" repairs would be unnecessary except in unusual cases. Increased reliability of microcomputer circuits, modular system design to allow bypassing of faulty circuits, and system redundancy as well as advanced algorithms to predict mean time between failures to enhance preventative maintenance should also result in less replacement and "benchwork" maintenance. In certain cases, microcomputer circuits might not only be fault detecting but fault correcting as well.

Because of the projected automation enhanced maintenance functions, skills required for repair personnel should shift from the traditional emphasis on "benchwork" expertise, to training in the use of automated diagnostic software/firmware and related equipment. As the emphasis in maintenance shifts to automated diagnosis, the skills required to perform routine on-site maintenance tasks would become less complex. If most fault detection were performed by machine, it would become less important for each maintenance crewmember to have an in depth understanding of the total system. This philosophy in maintenance should result in a shift in work force composition and areas of specialty. Automated diagnostic techniques will probably not be confined to merely electronic systems. With advances in sensor technology, microcomputer "brains" attached to mechanical devices would be able to monitor the vital functions of a mechanical device and quickly pinpoint problems for a technician. Continuous monitoring and recording of the behavior of vital mechanical functions would allow tracing and correction of problems that only show up during actual operations, rather than during maintenance checks; problems that today are difficult to diagnose and correct. Such systems of continual monitoring and recording are currently being tested by the U.S. Navy with good results.

The use of continual system monitoring in both preventive and corrective maintenance coupled with the changing composition of the maintenance work force, should make it both technically feasible and economically desirable to implement remote monitoring of FAA ATC equipment. This concept in maintenance would result in fewer, more geographically centralized maintenance centers (housing both the work force and parts). The crew and the replacement parts could then be dispatched to the remotely located equipment only when there was a need for on-site maintenance.

The increased use of microcomputers should also result in changes in the level of training of FAA personnel responsible for certification of aircraft and aircraft systems. As microcomputers become the "brains" in most avionics, the FAA personnel involved with avionics will need to be trained in microcomputer technology. Given the rate of change forecast for microcomputer technology, this training would need to be on a continual basis in order for FAA personnel to keep up with advances in the technology and upgrading of avionics hardware/software via retrofit.

As is the case with most all of the impacts of microcomputers, the impacts in the Expansive Growth scenario should not differ greatly from the impacts in the Resource Allocation scenario except in speed of occurrence. Continuous monitoring, high reliability, fault detection/correction circuits, sophisticated diagnostic software/firmware and low component replacement costs should accompany the installation of new equipment, as retrofit of older equipment with advanced microcomputer technology features is generally unfeasible, technically and/or economically. With more rapid installation of new equipment, the impacts discussed above should occur more rapidly in the Expansive Growth scenario.

The Muddling Through scenario will probably see little change in maintenance techniques, due to restrained advances in microcomputer technology. Automated diagnostic techniques will probably not be widespread, with "benchwork" maintenance still the rule. Increased training in microcomputer technology for personnel involved in certification and inspection of avionics will probably still be necessary but constant retraining should be less important due to a slower rate of technological change.

C. ATC Equipment Options

Air traffic control equipment options will be impacted by microcomputer technology in both the UG3RD and post-UG3RD ATC systems (see Figure 14). Microcomputer technology is already firmly imbedded within UG3RD. For example, the Microwave Landing System (MLS) and the Wake Vortex Avoidance System (WVAS) are both highly dependent upon microprocessors. In the Resource Allocation scenario, some increase in the utilization of microcomputers should be expected. Usage of low cost microprocessors in UG3RD should increase the level of implementation of UG3RD somewhat. Lower processor costs should result in a better cost/benefit ratio for certain UG3RD deployment configurations. Since processor costs represent only a small factor in the overall system cost, any impact due to microcomputers should be slight. Due to the lead time needed to finalize system design, UG3RD will probably not contain the latest state-of-the-art technology in microcomputers. Those systems and components of UG3RD now scheduled to be implemented in the near future will contain less advanced microprocessor technology than those scheduled to be implemented at some later date. Because

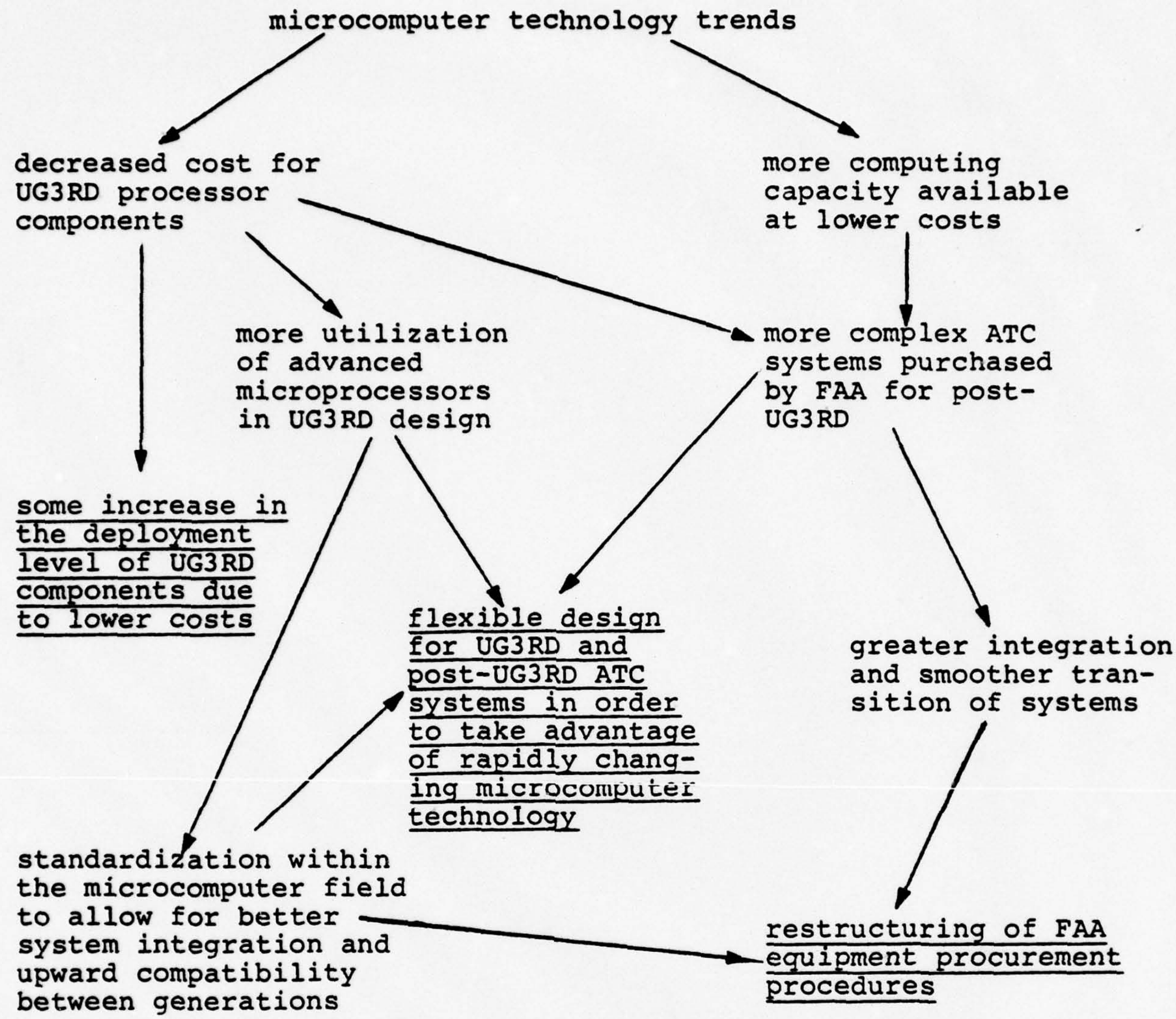



Figure 14

ATC Equipment Options

of the rapid rate of change in microcomputer technology, UG3RD and post-UG3RD need to be designed with emphasis on modularity, distributive processing, redundancy, upward compatibility and flexibility to insure that maximum utilization of the rapidly changing microcomputer technology is achieved on a phased basis. Such versatility in system design would facilitate "minimum impact" upgrading and augmentation of systems using advanced technology microprocessors and associated capabilities as advances in the technology become available and practical for implementation.

Because of trends towards replacement of mainframe computers with microcomputers, any new post-UG3RD system will probably be heavily microcomputer based. With a sufficiently flexible UG3RD design, a new post-UG3RD system could therefore be phased-in to the NAS while keeping the best parts of UG3RD. Flexibility of design to allow for changes in microcomputer technology would also facilitate the smooth integration of the new post-UG3RD with the UG3RD ATC system. Because of the complexity of a post-UG3RD system and the projected rapid rate-of-change in microcomputer technology, increased focus on pre-planned system integration should become necessary to avoid costly gaps and mismatches between components of the upgraded ATC system. In order to accomplish such system integration, a restructuring of

FAA's equipment procurement procedures to take into consideration compatibility of separate system components would probably be necessary. Such a restructuring would allow in-line upgrading and design change as well as upward compatibility. Standardization of certain areas of microcomputer design to enhance hardware/software upward compatibility, universal component replacement, one-for-one module interchange, etc., by hardware manufacturers is highly likely, which will facilitate easier system integration from both a functional and cost standpoint.

The Expansive Growth scenario will probably see less emphasis on the gradual phasing-in of microcomputer advances in UG3RD, as is expected in the Resource Allocation scenario. Replacement of entire ATC subsystems and systems due to technological advances should be the rule. New systems will probably be replaced completely with even newer systems to cope with rapidly growing air traffic, with ATC system designers struggling to keep up with the latest advances in technology. Unless equipment procurement concepts are drastically changed, system component changes would be on a piece-by-piece basis using microprocessors as interfaces between non-compatible equipment.

In the Muddling Through scenario, few advances past the currently planned UG3RD system should be expected.

However, some systems in the UG3RD will probably utilize microcomputers to a greater extent than today. Because of the slow rate of development of microcomputer technology and the gradual decrease in air traffic, no major effort would be place in utilizing state-of-the-art microcomputer technology in air traffic control because current technology can accommodate the projected demands of the scenario.

## D. En Route and Terminal Capacity Options

Microprocessors are currently being used in many areas of UG3RD including the active development of the Discrete Address Beacon System (DABS). In the Resource Allocation scenario, the use of microcomputers should accelerate the trend towards increased positive control of aircraft (i.e., Intermittent Positive Control). As the airborne and ground-based equipment needed for positive control becomes cheaper and more reliable, these systems will be implemented voluntarily or via FAA mandate.

The increase of aircraft (both in percentage and in absolute numbers) under positive control will greatly increase the work load for en route air traffic control centers. Accordingly, communications in and between these centers and, the terminal control centers, should also increase to accommodate the "handoff" of aircraft from one center to another. However, the number of air traffic controllers should remain about the same in spite of the increase in productivity, and it is unlikely that ATC centers will be consolidated. However, more en route ATC equipment would be monitored remotely and serviced less frequently by maintenance crews. The consolidation and centralization of maintenance centers would therefore be quite probable.

Automated (completely unmanned) airport towers are also a strong possibility. Such towers are intended mainly for small and remotely located airports with rather light traffic. Automated towers should become cheaper and more capable due to microcomputer applications. This may very well lead to changed (more lenient) criteria for establishing towers at airports which normally would not be justified as towered airports.

In the Expansive Growth scenario, the above impacts should become more pronounced, due to the rapid increase in air traffic and the rapid development of microcomputers. In the Muddling Through scenario, however, the projected decrease in air traffic and improvement in communications due to microcomputers may result in consolidation of both ATC and maintenance centers.

## E. FAA Employment

Microcomputer technology will have profound impacts throughout the FAA work force. As shown in Figure 15, different applications of microcomputer technology result

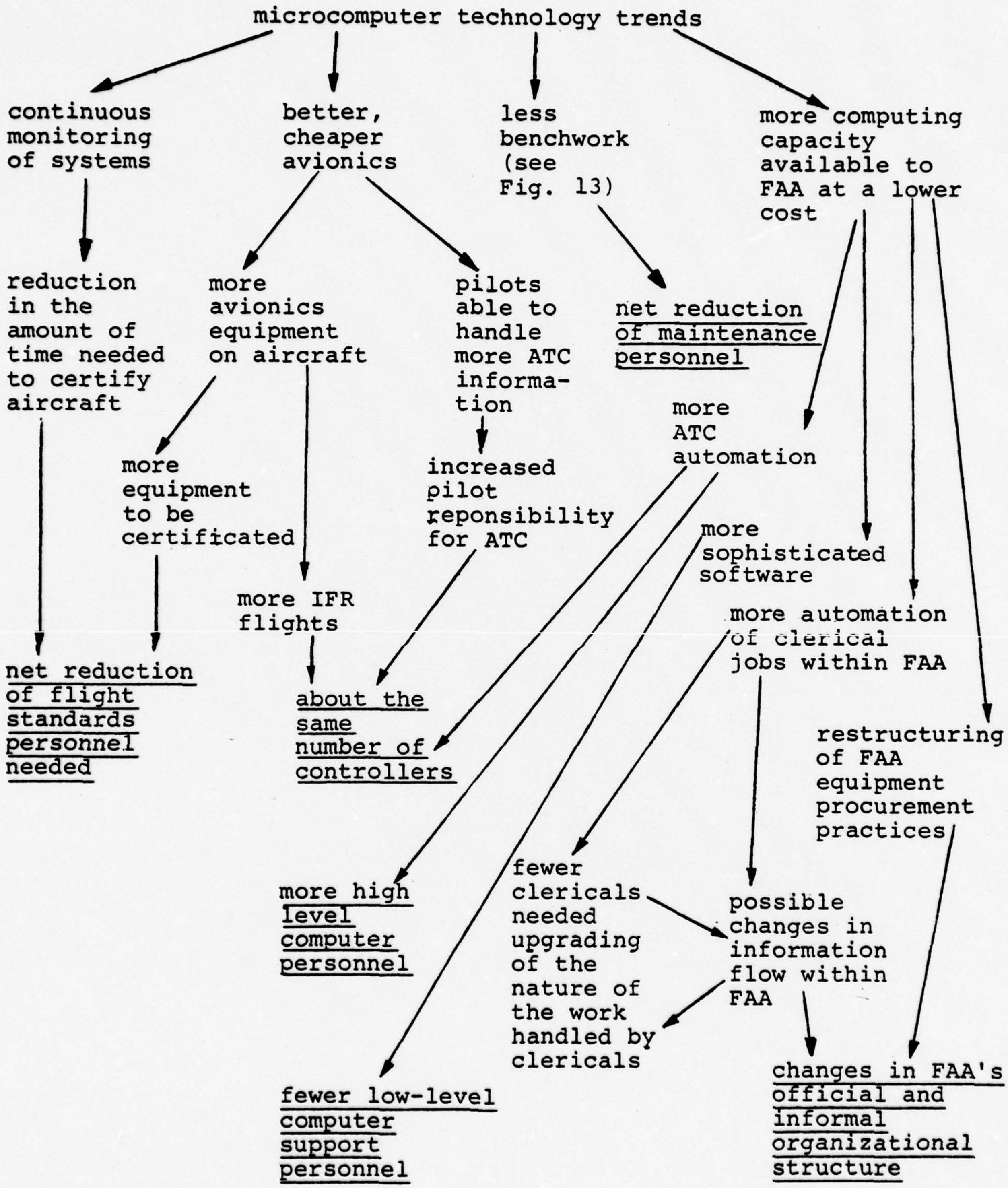



Figure 15

FAA Employment

in impacts on different areas of employment within the FAA. The intensity and direction of impacts will vary from job to job as well as varying according to scenario. The levels of employment in one type of job may decrease over the long-run, while the levels of employment of another type of job may increase.

In the Resource Allocation scenario, one area of dramatic impact should be in the employment level, especially the area of maintenance personnel. As described earlier in this chapter, advances in microcomputer technology will probably result in revolutionary changes in maintenance procedures and concepts. Automated diagnostic techniques, continuous monitoring, throw-away component replacement, increased reliability, etc., should result in a shift in maintenance workload emphasis, and should occur even though the FAA will be purchasing more new equipment for automated ATC. The purchasing of more new equipment should actually accelerate the trend of decreasing maintenance workload emphasis because, as indicated previously, it is the new equipment (with new fault detection and monitoring circuits and modular design allowing low cost throw-away replacement) that will bring about the revolutionary changes in maintenance. Any increases in the workload of maintenance personnel due to increases in the amount of FAA equipment needed for ATC automation should be more than offset by the dramatic savings in labor time resulting from the changes in maintenance techniques outlined earlier. With a decrease in the frequency of maintenance, given the adoption of automated maintenance techniques, the FAA maintenance work force should gradually decrease over time through attrition. A shift in the emphasis of maintenance oriented tasks, for example, more preventative maintenance, may offset any reduction in maintenance workload and work force size due to advanced maintenance techniques and procedures.

With an increase in ATC automation and advances in microcomputer technology, the work force levels of both high-level computer personnel and lower-level computer support personnel should change. Because of the trend towards hardware replacing software, increasing modularity of hardware systems design and software, task-oriented structured programming languages, higher level easier to use languages, and increasing software reliability (see Chapter VI, Volume I), a decrease in the number of personnel required for lower-level support tasks, such as program debugging, should be expected. However, as microcomputers reduce the technological barriers to automation, there will probably be a greater drive to automate more and more complex ATC functions. With both the number and the complexity of the tasks involved in automating ATC increasing, the number of high-level personnel involved in the development and construction of suitable algorithms needed to automate ATC functions would also increase. The rate at which the high-level computer related work force increases depends upon the rate at which FAA elects to automate ATC. In the Resource Allocation scenario, a gradual trend towards ATC automation should be expected. Therefore, the level of the high-level computer work force should increase somewhat initially, but level off over the long-run as ATC functions are automated sequentially; personnel will be switching from task to task, rather than simultaneously, with a large number of personnel working on many tasks at the same time. While more personnel would be needed, the actual FAA payroll may not necessarily increase. Much of the high-level system research, design and development could be done by contractors and consultants outside of FAA. Many complex tasks, such as compiler and firmware development would be done by outside contractors, supported by manufacturers, rather than done by users such as the FAA. However, the professional competence of the in-house personnel must be commensurate in order to plan, monitor, and appropriately utilize the work done outside. While outside personnel could be used to keep FAA employment levels from increasing, the number of personnel being supported outside the FAA budget for computer-related work should increase.

Any increase in the amount of ATC automation should also have an impact on the number of air traffic control and flight service specialists employed by FAA. Even with the increasing volume of air traffic and with controlled General Aviation (GA) flights resulting from better and cheaper avionics available to (or imposed on) GA, it is unlikely that the size of the controller work force would change appreciably, due to the gains in productivity contributed by ATC automation. Automation of the flight service station (FSS) function, however, will probably be more complete and should come about sooner than any other ATC function to be automated. Use of microcomputer-based "smart" terminals for pilot self-briefings and microcomputer-enhanced information storage and retrieval systems (see Chapter VII, Volume I) should lead to almost total automation of FSS operations. Remotely located FSS operations may be closed completely. Thus, FAA should be able to decrease the size of the flight service specialists work force over time through attrition.

As mentioned in Section IIB, Training and Maintenance requirements, advances in microcomputer technology should result in the added capability to continuously monitor both mechanical and electronic aircraft systems. Widespread use of a monitoring capability should drastically reduce the amount of time now spent by FAA flight inspection personnel in the certification of aircraft. Continuous monitoring and recording of aircraft systems would allow instantaneous inspection, including examination of recorded past performance of a system during actual operations. Spot check inspections performed by FAA may become merely reading a computer printout. This should increase the time required between inspections and reduce the total amount of time required for certification. While the amount, sophistication and complexity of avionics in aircraft needing inspection will probably increase due to better, cheaper microcomputer-based avionics coming on the market at a faster rate, the overall effect of microcomputers will probably be to reduce the number of flight inspection personnel. FAA may then choose to reduce the size of the work force involved in certification of aircraft through attrition due to reduced time needed to inspect a unit.

In addition to the impacts on FAA through utilization of microcomputers in aviation systems, the Resource Allocation scenario will also probably see a number of impacts due to microcomputer uses in word processing and information systems. Advanced word processing systems, using microcomputer-based terminals and bubble memories will almost surely replace many conventional typewriters. Voice-actuated typewriters/terminals are also a strong possibility. Computer storage files may replace paper in the office of the future with instant access to information via a terminal and visual display. Many computer companies are presently working on the idea of the paperless office of the future. Such advances in word processing brought about by improved micro-computer technology should have a dramatic impact on those FAA employees involved in clerical work. Any resistance to the introduction of advanced word processing systems should decline as these systems become common. Thus, clerical personnel would find their jobs drastically changed. Constant development of new office machines would call for constant retraining of office personnel. The ratio of professional staff to clerical support personnel should increase, due to the dramatic increase in the productivity of clericals brought about by advanced word processing systems. The administrative duties of clerical positions will probably increase. Fewer purely clerical personnel should be needed, resulting in a reduction of the FAA clerical positions and widespread use of distributed information processing systems made possible by microcomputers may change the way in which information flows throughout the FAA. This in turn will probably result in changes in the formal and informal organizational structure of the FAA. Those who are familiar with and can master the new information system are likely to assume more de facto authority and responsibility.

The impacts of microcomputer technology on the employment level of the FAA work force in the Expansive Growth scenario should differ only in the magnitude of impacts from that of the Resource Allocation scenario. The rapid increase in the number of new and/or advanced systems requiring maintenance, projected in the Expansive Growth scenario, is unlikely to be of sufficient magnitude to offset the anticipated decrease in the time required for both preventive and corrective maintenance projected as a result of the revolutionary advances in maintenance concepts and techniques implemented resulting from the use of microcomputers and associated technology. Therefore, the employment level of the FAA maintenance work force should decrease in both the Expansive Growth or Resource Allocation scenarios. The increased need for high-level computer personnel should be even greater in the Expansive Growth scenario than in the Resource Allocation scenario, at least in the near term. Because of the more rapid development of microcomputer technology in the Expansive Growth scenario, the push for automation should be greater and, therefore, the need for high-level computer personnel should be greater than in the Resource Allocation scenario. As the level of automation peaks, the number of high-level computer personnel engaged in the task of automating ATC should begin to decline. In the areas of flight inspection and air traffic control, the number of personnel required will probably increase in the Expansive Growth scenario rather than decrease as in the Resource Allocation scenario. The extremely rapid increase in air traffic in the Expansive Growth scenario would be more than enough to offset any gains in controller productivity attained by ATC automation, even with the use of advanced microcomputer technology. The increase in air traffic will probably be too fast for automation to hold the number of controllers down. Increased numbers of aircraft along with greatly increased use of better, cheaper avionics due to low-cost microcomputers would also be too great to be offset by advances in continuous monitoring. A reduction in the time required to inspect an aircraft should still be dramatic, but the explosive growth in both the number of aircraft and the amount of equipment will probably force an increase in the amount of flight inspection personnel in order to keep up with the growing demand. The number of flight service specialists should decline, however, because of the relative ease of FSS automation implementation. Other areas of ATC automation may prove to be difficult and should retard implementation. The capability resulting from automation of the FSS should be more than enough to offset the explosive growth of the Expansive Growth scenario. The reduction in the clerical support staff projected in the Expansive Growth scenario should be more pronounced than in the Resource Allocation scenario. The development of the "automated office" of the future which will be stimulated by growth projected in the Expansive Growth scenario and the reduced role of government in aviation should result in a reduced clerical support work force. Changes in the FAA organizational structure due to an emphasis on the relative reduction of government activity, as projected in the Expansive Growth scenario, should facilitate formal and informal restructuring of FAA to accommodate new information flow patterns brought about by an advanced microcomputer-based information system.

In the Muddling Through scenario, the impacts of microcomputer technology should be rather subdued compared to the Expansive Growth and Resource Allocation scenarios. Due to slow advances in microcomputer technology, slow adoption of the new technology by FAA, and continued reliance on old equipment, the size of the FAA maintenance work force should not be expected to decrease. Little new equipment should be purchased and the new equipment that is purchased should not contain the advances in technology needed to facilitate changes in maintenance techniques. The number of high-level computer personnel needed should not increase in the Muddling

Through scenario due to a low emphasis on ATC automation, which will be practically non-existent, with the exception of some automation done in the early 1980's. The number of low-level computer support personnel may increase slightly in the short run due to continued reliance on older software and computer systems. In the long run, however, even the low-level computer support work force should decrease as the level of air traffic decreases. As a result of the decreasing volume of air traffic, the number of flight inspection personnel, flight service specialists, and air traffic control specialists should decrease slowly through attrition. The relatively slow rate of technological advancement will additionally result in little impact on FAA's clerical support staff and organizational structure. The size of the FAA clerical support work force will probably increase in the Muddling Through scenario rather than decrease as in the Expansive Growth and Resource Allocation scenarios due to the increase in paperwork stimulated by the government struggle to cope with growing social problems.

## F. FAA Building Space

Total building space required for computer systems consists of space for both the computer hardware (system, support spaces, inventory, etc.) and space for computer support personnel. As Figure 16 shows, the trends of these two components of total building space branch in

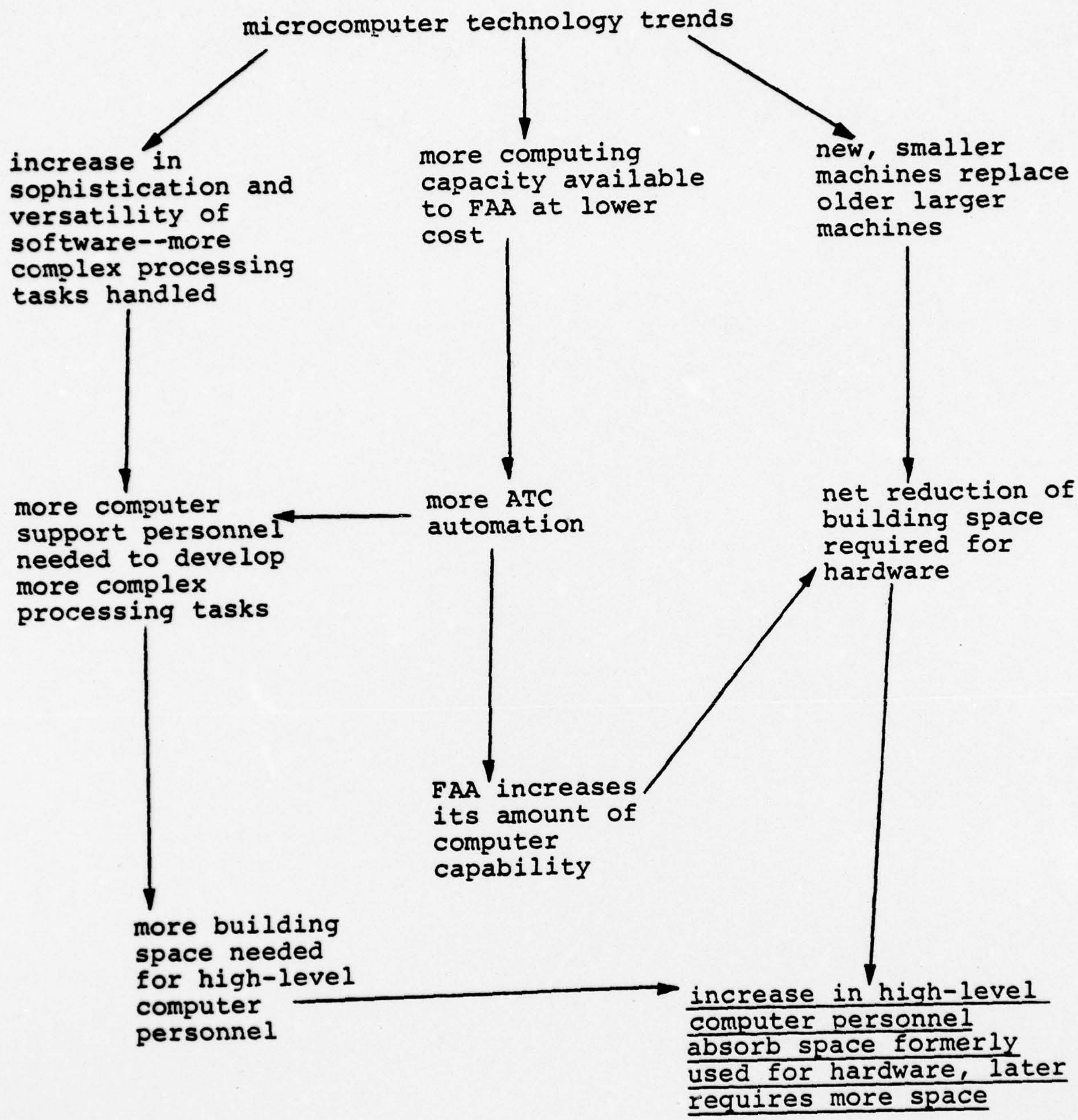



Figure 16

FAA Building Space

opposite directions. In the Resource Allocation scenario, the space requirements for high-level computer personnel will probably increase as the number of personnel needed increases due to factors mentioned earlier. While space required for computer related personnel increases, space required for the computer hardware is rapidly decreasing due to dramatic reductions in computer size. According to forecasts of system size (see Table 6), a computer requiring an area of 16 cubic feet today, would require a third of a cubic foot in the year 2000. Total space savings on hardware should be even greater. The size figures given previously do not include space savings attributable to reductions in air conditioning hardware because of reduced component heat dissipation or reductions in space for connectors and wire bundles resulting from compact computer designs. Assuming the FAA will purchase new computer hardware in order to facilitate an increase in the level of ATC automation, and should, in the long run, replace older, larger equipment, a decrease in the total space occupied by FAA computer hardware should be expected because new equipment will be greatly reduced in size. As the size of computer hardware decreases, space formerly used for hardware can be used to house the increasing number of personnel. The amount of space that could be gained by the replacing older hardware with new hardware is obviously constrained by the area currently being allocated for such hardware.

The gains in area could possibly be insufficient to accommodate the number of computer personnel projected and thus additional building space would be required. A gradual increase in the level of the computer related work force would probably not require the addition of any new building space until the 1990's or beyond. Any increased need for actual FAA building space could also be slowed or eliminated by the use of contractor supplied computer related personnel. Space for contractor personnel is still an FAA budget item in the form of contractor overhead. Increases in the personnel level in non-computer related areas of FAA, however, may absorb any space vacated by shrinking computer hardware area requirements.

In the Expansive Growth scenario, however, the increase in the computer support work force will probably be rapid as FAA quickly moves towards more ATC automation. The increase in the computer related work force will likely be rapid enough to quickly take over all the space made available by hardware size reduction and require even more. Because of the emphasis on the private sector within the Expansive Growth scenario, much of the increase in the computer related work force could probably be absorbed by outside private research and development firms, thereby alleviating some of the need for a commitment by the FAA to its own building space.

In the Muddling Through scenario there should be no need for the FAA to increase building space. While advances in microcomputer technology will probably be slow, hardware size will decrease and some replacement of older, larger machines with newer, smaller equipment is likely. There should, however, be little if any increase in the number of computer related employees as the decreasing volume of air traffic reduces the need for more ATC automation. Any space gained by the reduction in hardware size would not be totally absorbed by increases in the computer related work force. Among the three alternative aviation futures, only the Muddling Through scenario should contain an actual increase in the amount of unused building space available to FAA computer operations.

## G. FAA Computer Investment and Operating Costs

Total FAA costs for both the initial investment for computer systems and for ongoing operation and maintenance are the result of many different factors. As Figure 17 shows, total FAA computer investment costs depend on both the cost of the hardware and the amount of hardware acquired, while changes in operation and maintenance costs would result from changes in maintenance techniques, personnel levels, hardware and maintenance reliability, and energy requirements. As mentioned earlier, the Resource Allocation scenario should see a

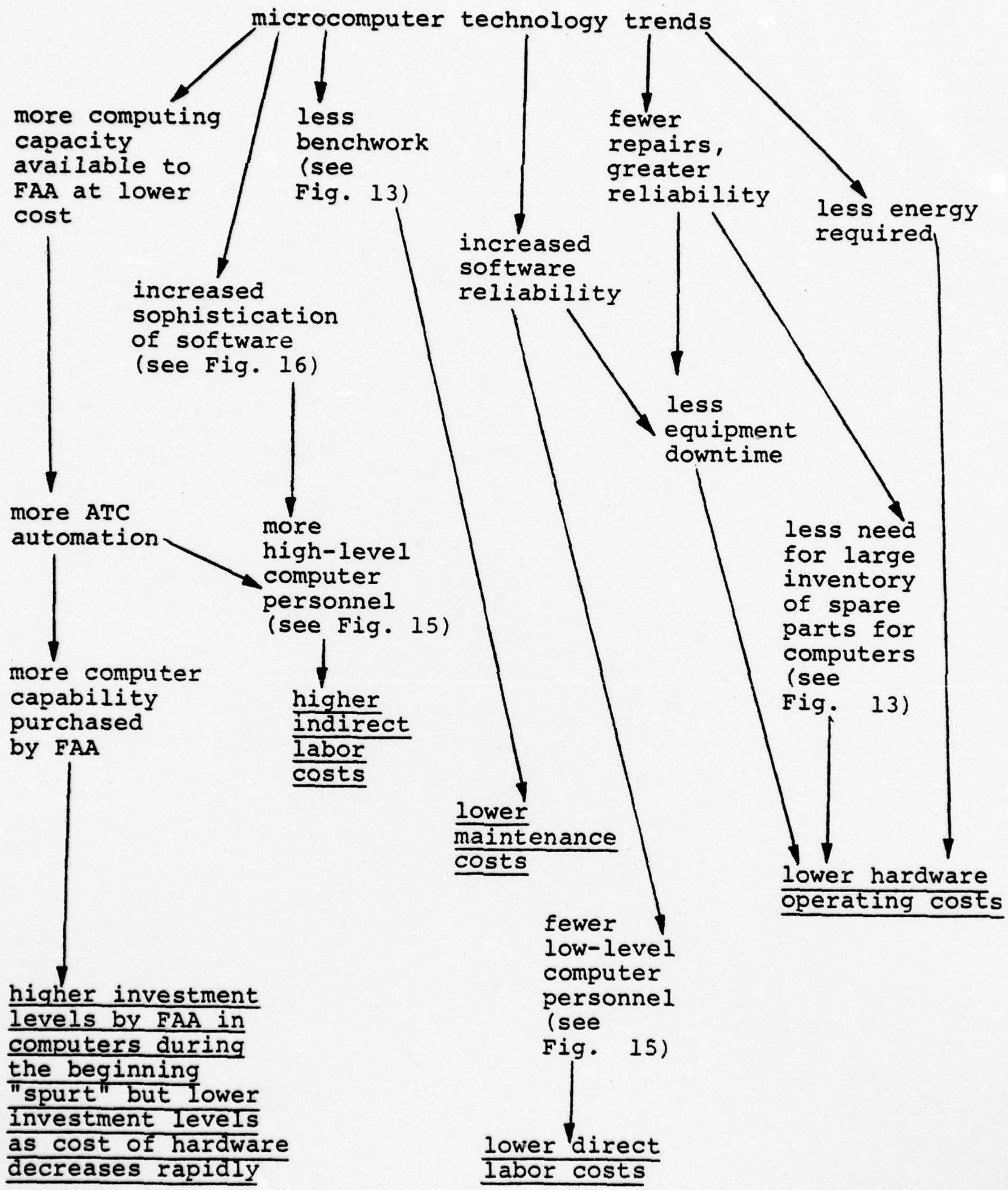



Figure 17

FAA Computer Investment and Operating Costs gradual increase in the level of ATC automation and an increase in the number of computer systems purchased by FAA. The purchase of more computer systems would be required in order to provide the increased computing capability necessary to accomplish ATC automation. As earlier forecast (see Chapter II), advances in microcomputer technology should result in greatly expanded computing capabilities at a lower cost. In the short run, the requirement for greatly increased computing capacity due to ATC automation may result in higher investment levels. The long-run trend, however, should be a reduction in the level of FAA investment in computer systems as technological advances result in the availability of even greater computing capacity at lower costs and the FAA gradually reaches the point where it no longer needs to expand to accommodate NAS growth.

Different areas of FAA computer operations costs should be affected by microcomputer technology in a variety of ways. The increase in high-level computer personnel could result in an increase in labor costs. While the cost of high-level computer personnel may not be considered by some as a direct computer operating cost, it is computer related. A decrease in the number of low-level computer personnel due to increased software reliability and versatility should result in a decrease in direct labor costs. Improved software versatility

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THE IMPACT OF MICROCOMPUTERS ON AVIATION: A TECHNOLOGY FORECAST--ETC(U)

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and reliability should result in less equipment downtime. Improved hardware reliability should reduce the need for large spare part inventories. Reducing the inventories of computer spare parts should help reduce operating costs by reducing the amount of capital tied up in non-productive inventories. Improved hardware reliability and advanced maintenance techniques should reduce overall maintenance costs. Reduced energy requirements realized with new computer systems (see Volume I) due to reduced air conditioning needs and system power consumption should result in lower costs for electricity, or at least a reduction in the rate of cost increase assuming electricity prices increase. On the other hand, increased centralization of maintenance for ground-based ATC equipment may absorb savings gained due to the increased energy costs associated with dispatching maintenance personnel to remotely located ATC equipment from regional centers.

The rapid growth in FAA purchases of greater computing capacity in the Expansive Growth scenario should cause a rapid growth in the level of FAA computer investments. The general economic prosperity as well as the specific demand for more, newer ATC equipment to handle more air traffic should result in greater pressure for an increase in the FAA budget for computer hardware investment. Also, as indicated in Chapter II, the time between computer generation changes will be shorter in the Expansive Growth scenario. Investment levels should therefore remain high as FAA continuously upgrades its computer hardware with the latest state-of-the-art. In the long run, microcomputer cost reductions should decrease the magnitude of the investment. Trends in operation costs should be relatively the same as in the Resource Allocation scenario except that the rate of change should be faster. Indirect labor costs should increase faster as increased numbers of high-level computer personnel are hired. System reliability should increase faster, and maintenance and energy costs should decrease faster due to advances in both microcomputer technology and energy production technology. Spare part inventories will probably not decrease as much, however, due to the increase in the number of FAA computer systems at various generation levels of computer technology development.

In the Muddling Through scenario, computer investments by FAA should decrease due to a lack of need to expand computing capacity because of decreasing air traffic. Operating costs should increase as the reliance an older, less efficient and reliable machines force maintenance, lower-level computer support, and energy costs up. Some operating cost reductions will probably be achieved but the slow rate of advances within microcomputer technology and the even slower rate at which those advances are utilized should severely limit any attempts to reduce operating costs and level-of-effort.

H. FAA Software and Hardware Scrappage

There is nothing inherent in microcomputer technology that would require the replacement of present day software in order to make a microcomputer function. Software currently running on FAA's mainframe computer should be transferable (with minor compilation adaptations) to future mainframes built using microcomputer technology. No major software changes are anticipated. However, to take full advantage of the increased computational capabilities, compiler efficiency, expanded use of firmware, and distributed processing potentials of microcomputer technology, FAA may opt to modify and/or replace existing software. Because of the strong desire to conserve resources, the Resource Allocation scenari will probably see a low level of software scrappage. N systems and software will probably be phased-in rather than replacing existing systems entirely and/or frequently. Software will probably only be replaced when it is clearly shown to be (1) inadequate, (2) unworkable, (3) inefficient, or (4) incompatible. With advances in technology proceeding rapidly, all of the FAA software may fall into one of these four categories by the year 2000 and be replaced. In many cases, a substantial amount of existing software would be replaced totally or partially with firmware rather than new software.

The rate of scrappage of computer hardware will be determined by (1) the adequacy of existing equipment to do a particular job (either existing or new), (2) the cost of investing in new equipment versus the cost of maintaining and operating the old equipment, and (3) the availability and cost of maintaining adequate spare inventories. Concern over maximum usage of resources in the Resource Allocation scenario should promote a modular approach toward system design, acquisition and replacement. Old components of a system would be modified (as economically feasible) to function with newer parts and systems, and would not be replaced or scrapped until maintenance and operation costs become excessive. Getting the most out of older systems would be of great concern.

Because of its fast moving nature, the Expansive Growth scenario should see the greatest amount of both hardware and software replacement. The trend will probably be to replace entire systems with the concern over meeting rapidly growing demand taking precedent over replacement and scrappage costs. Today's hardware will probably be replaced in the near future with new hardware containing yesterday's software with a combination of firmware and enhanced new software.

Because of anticipated slow rates of acquisition of new systems, the Muddling Through scenario should contain the least amount of hardware and software scrappage. A slower rate of development of microcomputer technology along with the decrease in air traffic should make any major effort to scrap existing hardware and software unnecessary. Some firmware will probably replace software in an attempt to reduce costs but overall the level of scrappage should be low.

## I. Safety

Increased use of microcomputer technology should result in an increase in the safety of the entire National Aviation System (NAS). In the Resource Allocation scenario, many different uses of microcomputers should contribute to increased NAS safety. Low cost microcomputers could sufficiently reduce the price of collision avoidance systems and other safety oriented avionics enough to justify an FAA mandate for use in general aviation (GA) as well as air carriers. Widespread use of lower cost microcomputers as the prime components in RNAV avionics systems should facilitate routing aircraft around highly congested areas (terminal approaches as well as en route airways), thereby further reducing the already small number of mid-air collisions. On-board avionics computers may be used as pilot back-up systems to reduce human error. An example of one such pilot back-up system already in use is the ground proximity warning system. On-board continuous monitoring and recording systems with capabilities far exceeding current flight data recorders should provide valuable information to investigators about situations resulting in accidents, in addition to being available for collective evaluation to prevent future accidents. Reduced costs of microcomputer-based flight data recorders may facilitate the use of such equipment on G.A. aircraft. The use of simulators for training should help reduce accidents through increased training of both pilots and controllers at reduced intervals. Advances in maintenance technology, especially the ability to detect and repair faults that may otherwise go unnoticed until total system failure occurs, should result in fewer accidents. Expanded ATC capacity due to microcomputer-based ATC automation should also help reduce the number of accidents and near accidents. While usage of microcomputer technology may reduce the accident rate, whether or not the impact will be great enough to offset the rise in air traffic and produce an actual decrease in the number of accidents is unclear.

The extent to which microcomputer technology applications will increase aviation safety is determined by the extent to which microcomputers are used (airside and landside). The impact of microcomputers on safety should be greater in the Expansive Growth scenario than in the Resource Allocation scenario due to the faster development and usage of the technology. Because of the rapid increase in air traffic in the Expansive Growth scenario, the use of microcomputer technology should result only in a reduction in the accident rate not the absolute number of accidents.

In the Muddling Through scenario, the number of aviation accidents should decline primarily due to a decrease in the volume of air traffic. The use of microcomputer advances should account for some of the reduction but not a significant amount because of the slow rate of development of microcomputer technology.

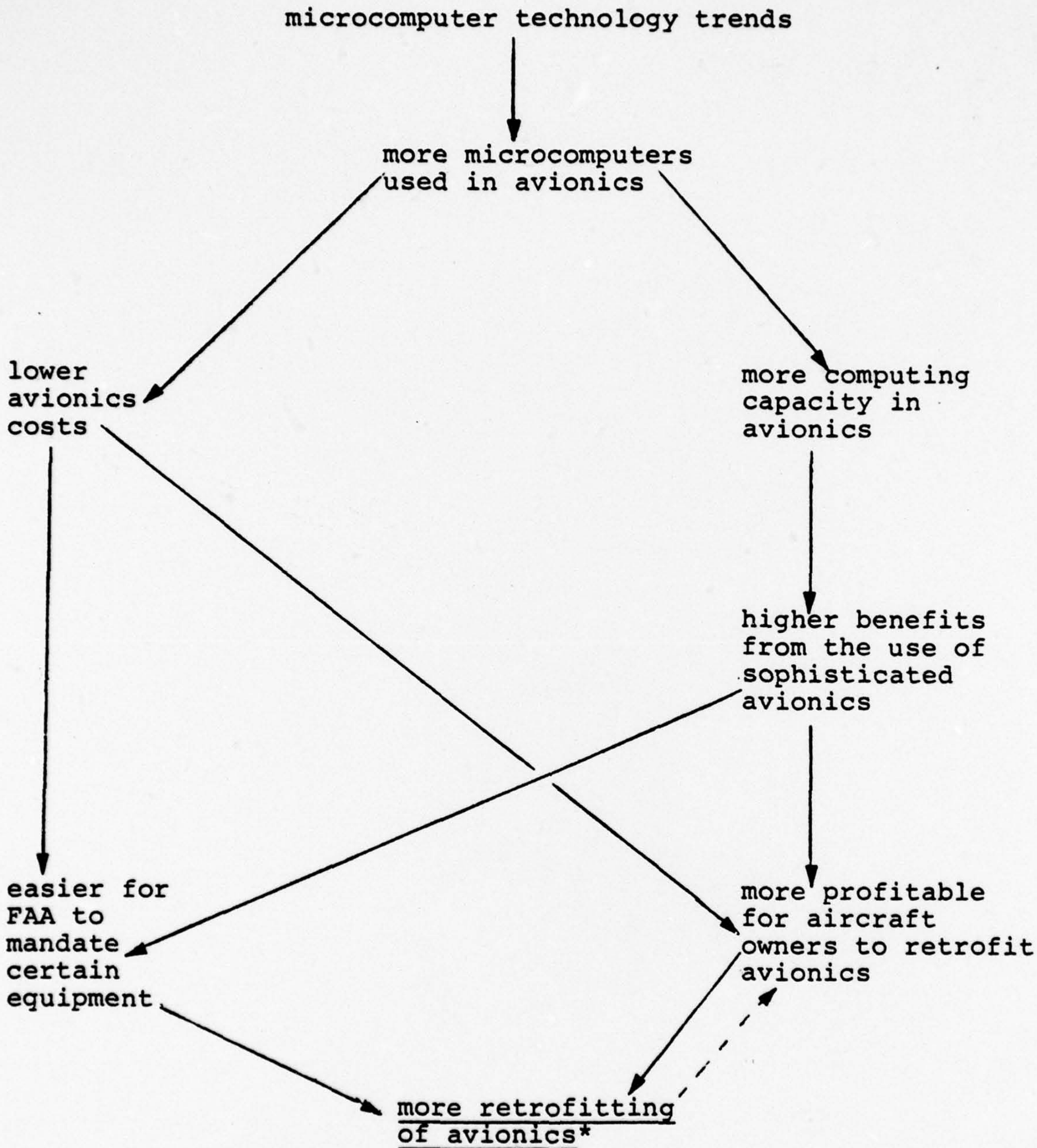
## J. Environmental Degradation

Microcomputer technology should help to reduce potential environmental degradation by decreasing both emission and noise. In the Resource Allocation scenario, the use of on-board computers to control and monitor engine performance to achieve more complete combustion should result in both reductions in aircraft emissions and noise problems. On-board computers will probably be used to plot and track high altitude "straight-in" approaches in conjunction with automated ATC microwave landing systems. Such approaches should help to reduce ambient noise. On-board computers capable of computing the short/ efficient flight paths will reduce air time, and thus reduce emissions and fuel consumption. The use of simulators to train both pilots and controllers should facilitate advanced training in techniques which would minimize environmental damage. Expanded ATC capacity due to microcomputer-based automated ATC and on-board computers should reduce delay and therefore reduce emissions, fuel consumption and ambient noise. It is also possible that specially designed advanced aircraft, which drastically reduce fuel consumption (drastically reducing emissions) and/or reduce noise, would require active controls to achieve flight stability and maneuverability. Such active controls could only be practically implemented with versatile and reliable redundant systems using microcomputers that are cheap, compact, and light. As is the case with safety impacts, the extent to which microcomputers would be able to reduce the actual level of emissions and ambient noise is unclear due to the increasing level of air traffic. Other factors, such as cleaner, quieter engines would have a much greater impact.

The Expansive Growth scenario should see a greater reduction in environmental degradation resulting from microcomputers because of more rapid development and utilization of the technology than in the Resource Allocation scenario. However, the level of environmental degradation due to noise and emissions, because of an increase in air traffic, would be reduced more by retrofitting aircraft with cleaner, quieter engines. The Muddling Through scenario should see little improvement in environmental degradation due to microcomputer technology. Developments in microcomputer technology will probably not be fast enough to make a significant difference. Noise and emission problems should decrease, however, due primarily to the decrease in air traffic.

K. <u>Retrofit</u>

The development of microcomputer technology is only one factor in the decision to retrofit an aircraft with a microcomputer enhanced avionics system (see Figure 18). As the capital cost of microcomputer avionics systems continues to decline, the labor cost of installing a new piece of equipment rather than the actual cost of the system will become more and more the major barrier to retrofit. Overall cost incentives for retrofitting will therefore be determined by the interplay between decreasing system costs, rising labor costs and perceived benefits of the new equipment. In the Resource Allocation scenario, systems that produce clearcut resource savings will probably be accepted, i.e., the perceived benefits to both the airline companies and society should be high enough to offset costs. Retrofitting aircraft with microcomputer enhanced avionics systems would be either done voluntarily by the air carriers or mandated by FAA. Mandatory retrofit for fuel conservation would require new legislation. Presently the FAA has the authority to only mandate aircraft changes for safety reasons. Other systems




*Dotted line indicates possible negative effect. Increased retrofit may cause slight short-term labor shortage, driving labor costs up and reducing the profitability of retrofit.

Figure 18

Retrofit

that do not have as high a perceived level of benefit will be regarded as not worth the total cost and the revenue loss resulting from idling of the aircraft during retrofit. Extensive retrofitting of highly beneficial systems may result in a slight short-run shortage of labor, thereby driving the total cost of retrofit up. With increased total costs, the benefits may not be high enough to justify the retrofit, slowing down the rate of retrofit. This situation would occur only if airlines where forced to go outside of their own labor force to accomplish the retrofit (i.e., if retrofit were not completely voluntary, and/or initiated as a result of an FAA mandate which specified a retrofit completion date).

The situation for general aviation is similar to that of the air carriers. While labor costs should be less and lost revenues due to ground time not a concern (especially for the personal class of GA), perceived benefits of new systems are much lower for general aviation than air carriers. The balance between cost and benefit for general aviation, therefore, should work out the same as for air carriers. In the case of clear-cut resource savings,retrofit should occur, but at a much slower rate than for air carriers. Especially popular should be anything that helps reduce fuel consumption because of the need to conserve energy. General aviation aircraft owners will probably remain skeptical about the value of retrofitting other avionics systems, however. The corporate or business class of general aviation is the exception to the general rule, as perceived benefits are usually very high (near those of air carriers) while relative costs of installation are rather low. This combination along with any decrease in systems cost makes the corporate and business general aviation class much more willing to retrofit existing aircraft with new avionics systems without a mandated requirement.

In the Expansive Growth scenario, the cost to air carriers of retrofitting an aircraft (labor and lost revenues) will probably not increase rapidly enough, given the dramatic decrease in projected system costs, to outweigh the perceived benefits. The personal class of general aviation will probably resist retrofit primarily because of cost. However, the extremely low cost of avionics together with increased affluence should result in the rate of retrofit being much higher than in the Resource Allocation scenario. Corporate/ business class of general aviation should continue to lead all others in retrofit of new systems.

The Muddling Through scenario will probably see the opposite of the Expansive Growth scenario--a slow rate of system cost reduction coupled with rising labor costs, and the weak financial status of the airlines, making retrofit on any large scale impractical. Any retrofit of major systems would have to be mandated by the FAA. The rate of retrofit should be lower for the personal class of general aviation, although some retro-fitting of systems that help reduce costs, i.e., systems to reduce fuel consumption, should take place. Only in the corporate/business class of general aviation would retrofit be common. While fewer of this class of aircraft would exist in the Muddling Through scenario due to the general economic stagnation, those that are should be more willing to retrofit aircraft with new avionics than any other class of aircraft owner. Because of very high operating costs in the Muddling Through scenario, those companies that can still afford to operate an aircraft should be able to afford the retrofit costs.

## L. Air Carrier Costs and Employment

The greatest impacts on air carriers resulting from microcomputer technology, as Figure 19 shows, should come in the area of fuel, labor, maintenance costs, and utilization of equipment. In the Resource Allocation scenario, changes in microcomputer technology should not result in major changes in the cost of aircraft. Avionics and other systems that are likely to be affected by microcomputers make up only a small portion of the total cost of civil aircraft. Increased reliability of electronic components and advances in maintenance techniques and the use of continuous monitoring, should result in less equipment downtime due to failures. Increased utilization of equipment, less need for back-up equipment and a greater return on the investment per unit could be obtained. Higher component

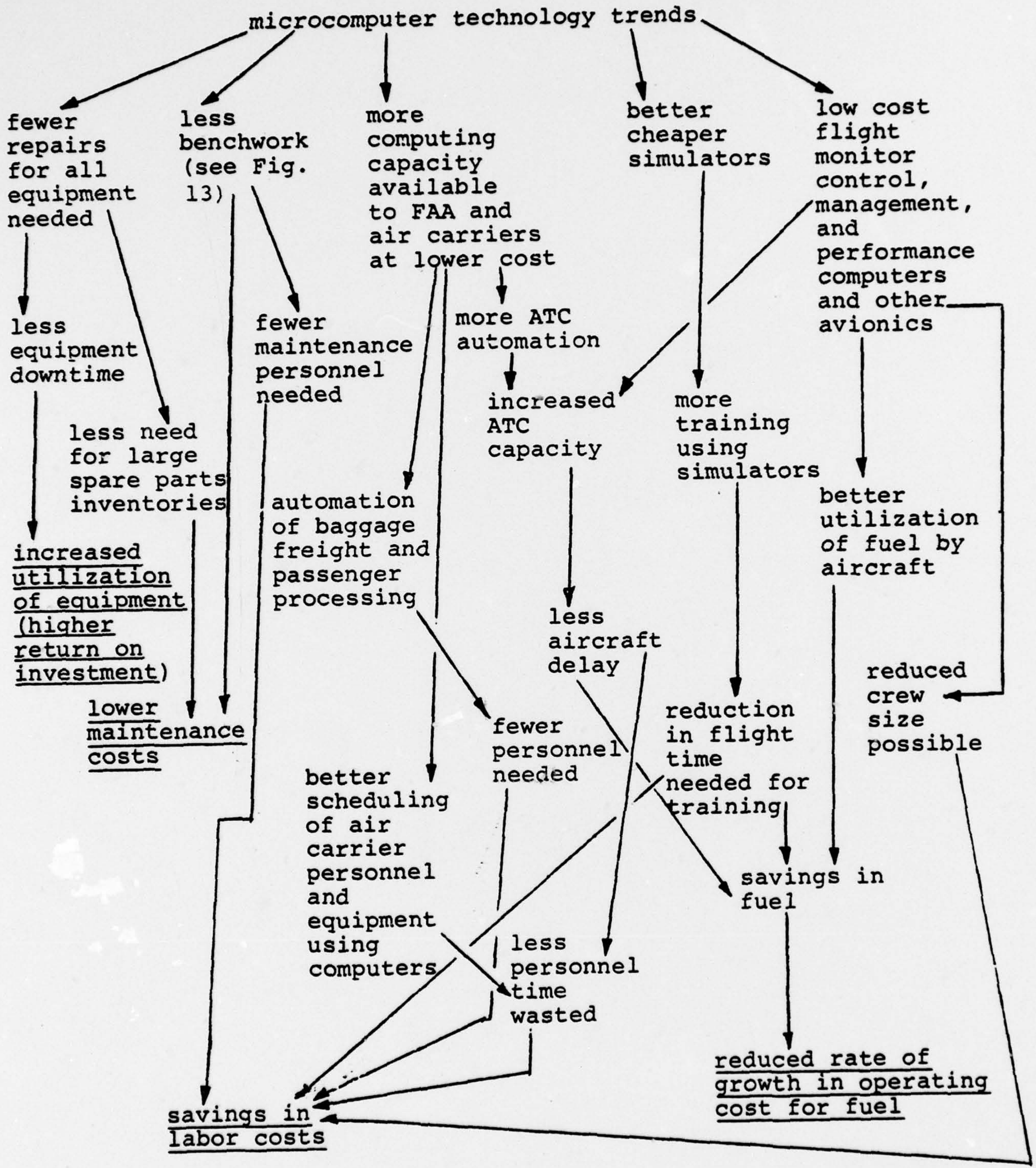



Figure 19

Air Carrier Costs and Employment

reliability and advanced maintenance techniques should also lead to reduced spare part inventories and lower maintenance costs as well as a reduction in the size of the maintenance work force required for avionics repairs. While advances in maintenance techniques should result in dramatic savings in the level and cost of manpower, the growth of air carrier equipment inventories in the Resource Allocation scenario should be moderate. The net result expected is a gradual reduction in overtime for the air carrier maintenance work force involved in avionics maintenance. While diagnosis of mechanical aircraft system failures may be automated, the actual repair of such systems should still require traditional benchwork rather than the "throw-away" approach used for electronic systems. Thus, the mechanical systems maintenance work force should not be expected to decrease.

Savings in manpower levels and costs should also occur in a number of other areas. The increased capabilities and decreases in the cost and size of microcomputers should bring about passenger self-processing and automated baggage and freight handling systems. Such automation would greatly reduce the number of ground personnel used. The moderate increase in passenger traffic expected in the Resource Allocation scenario should not be enough to offset the dramatic savings in manpower levels and costs due to automation. Air carriers should therefore be able to gradually reduce their ground operating work force. The quickest advances in automation should occur in the passenger self-processing area, since much of passenger processing is already partially automated. This trend would be accelerated by faster implementation of electronic funds transfer systems (EFTS). Baggage and freight handling automation will probably advance much more slowly. Sensor technology to allow automated baggage and freight handling systems is less advanced than microcomputer technology, and the cost of mechanical systems for baggage and freight handling should not decrease significantly, thereby hindering the utilization of the microcomputer technology. Airborne flight monitor, control, management and performance computers could result in a reduction of crew size, although many other factors would be involved. Some airlines are already using two-man instead of three-man crews. Piedmont Airlines, for example, uses a two-man crew in its 737's. Besides direct savings in labor costs due to work force reductions, higher working efficiency should result in lower labor costs. Expanded ATC capacity due to microcomputer-based ATC automation and on-board computers should reduce delay and increase work force efficiency (both airside and landside). The use of microcomputers by air carriers to better schedule personnel and equipment should improve work force efficiency.

Savings in fuel is another area where microcomputer technology should have an impact on air carrier costs. Use of on-board computers to monitor and control engine performance (sometimes known as "performance computers") should result in greater fuel efficiency. Advanced maintenance techniques and continuous monitoring to keep engines running at peak performance levels should also help reduce fuel waste. Expanded ATC capacity due to microcomputer-based ATC automation and air carrier use of on-board computers should result in fuel savings by reducing delay and allowing aircraft to fly optimal fuel-efficient routes, both vertically and horizontally. Use of on-board computers in active control technology (ACT) aircraft (see Chapter VII, Volume I) is probable but more likely in the Expansive Growth scenario. Such aircraft are inherently more fuel efficient than current aircraft. Development of cheaper, and more sophisticated simulators for procedures, part-task and mission training purposes should result in fewer training flights, thereby saving fuel and manpower. Savings in fuel should manifest itself in reduced fuel consumption and lower costs as fuel prices stabilize.

In the Expansive Growth scenario, savings in maintenance costs and greater productivity due to reduced equipment failures should be as great if not greater than in the Resource Allocation scenario, even with the explosive growth in air traffic. The advances in the areas of maintenance and component/system reliability should be so great as to totally offset increases in the airline equipment inventory. Similar savings should be realized in labor costs to support personnel used in passenger processing, baggage and freight handling. Even though the volume of passenger and freight traffic would be growing explosively in the Expansive Growth scenario, automation should be able to keep up. Once the software for automating passenger, baggage and freight processing has been developed, the decreasing cost of microcomputers and their modular design should make it more profitable for air carriers, as passenger demand increases, to install more automated systems rather than hire more people. The good financial conditions expected to accompany Expansive Growth should allow air carriers to make the capital outlays required for increased automation. Only in the area of reducing ATC delay and crew size should microcomputers not result in lowering total labor costs. The increase in air traffic should result in more crews, thereby offsetting any cost savings due to reductions in crew size. Fuel savings resulting from microcomputer controlled aircraft systems should not be great enough to offset the rapid rise in total fuel consumption due to the increased volume of air traffic. All microcomputer controlled aircraft systems could do is to slow down the rate of increase of fuel consumption.

Falling fuel prices however, may result in some actual reduction in total fuel costs.

Use of microcomputers in the Muddling Through scenario should result in a holding action against ever rising operating and maintenance costs. The rate of utilization of microcomputers by the airlines to control costs, however, will probably be rather slow. Sluggish advances in microcomputer technology should also result in little impact on airline costs and employment. Microcomputers may be used to increase productivity, but it is extremely unlikely that any productivity increases would result in changes in employment levels. Likewise, microcomputers maybe used to offset reduced fuel consumption. Due to the air carriers' inability or unwillingness to retrofit with fuel saving technologies and rising fuel prices, the impact of microcomputers on overall fuel costs should be slight.

## M. Air Carrier Scheduling and Routing

Several uses of microcomputer technology may allow air-carriers greater freedom in routing and scheduling aircraft. Achieving optimal allocation and scheduling of aircraft and personnel with the use of microcomputer technology depends not only on the availability of the technology but also on the regulatory and ATC environment in which the aircraft operates. In the Resource Allocation scenario, the drive for an optimal resource mix in both the government and the airlines should create the environment needed for use of the technology. Increased ATC capacity resulting from microcomputer-based ATC automation and on-board computers should facilitate both reduced aircraft separation standards and less airside and landside delay. Tighter scheduling of flights would then be possible. The use of on-board computers for area navigation (RNAV) and a RNAV compatible automated ATC system would allow the air carriers to fly direct routes, assuming the RNAV concept is consistent with ATC regulations. Availability of more computing capacity at a lower cost should result in greater use of computers for airline allocation problems, resulting in more flexible scheduling, routing and allocation of airline resources. Data links between airline landside computers and aircraft computers would provide the communications necessary to readjust schedules and routes to deal with such problems as foul weather, congestions, delays, and other contingencies. Such a data link has been developed by Aeronautical Radio, Inc. and should be in use by early 1978. Advances in maintenance techniques and continuous monitoring of aircraft systems as mentioned earlier should result in a reduction in the time required for aircraft maintenance and inspection. Increased utilization and improved scheduling of air carrier fleet resources may result.

In the Expansive Growth scenario, the desire for less government regulation and control, coupled with a rapid rate of technological advance and acceptance of retrofit should result in greater usage of microcomputer technology. The airlines should possess even greater freedom and technological capability for optimizing schedules and routes than in the Resource Allocation scenario. It is unlikely, however, that either the technology or the operating environment needed to make use of the technology will exist in the Muddling Through scenario. The slow growth of microcomputer technology, advancement and counter-productive government and airline procedures should result in minimal impacts on scheduling and routing resulting from microcomputer technology.

## N. Air Carrier Fleet Size and Age

Airline fleet size and age should not be greatly affected by microcomputer technology. Fleet size and age is determined, for the most part, by demand for air travel and aircraft profitability. While microcomputers may increase the viability and longevity of older aircraft in the Resource Allocation scenario, it is doubtful these enhanced older planes could compete in resource savings with newer aircraft. The replacement of aircraft will probably be determined more by advances in aviation rather than microcomputer technology. There is a greater possibility that the use of microcomputers technology will have an impact on air carrier fleet size and age in the Expansive Growth scenario. Development of active control technology (ACT) aircraft made possible by microcomputers may result in a high level of investment by the air carriers in new ACT aircraft, which would alter the fleet size and average age. Other factors, such as the demand for air travel, are much more important in the decision to purchase new aircraft than the development of a new aircraft type. In the Muddling Through scenario, the use of microcomputer technology may result in increased aircraft longevity by increasing functional viability. However, the determining factor is dependent on many complex factors, of which the impacts of microcomputers is minor.

O. General Aviation Costs and Fuel Consumption

The impacts of microcomputer technology on general aviation (GA) costs and fuel consumption should be much the same as the impacts on air carriers only on a much smaller scale (see Figure 20). The main difference would be the kind of driving force affecting a causal chain of events. For air carriers and corporate/business GA, the changes are likely to be voluntary and driven by economic incentives. For pleasure GA, the changes might have to be imposed by FAA mandates. In the Resource Allocation scenario, most impacts should be identical to those for air carriers. Lower maintenance costs could result from advances in

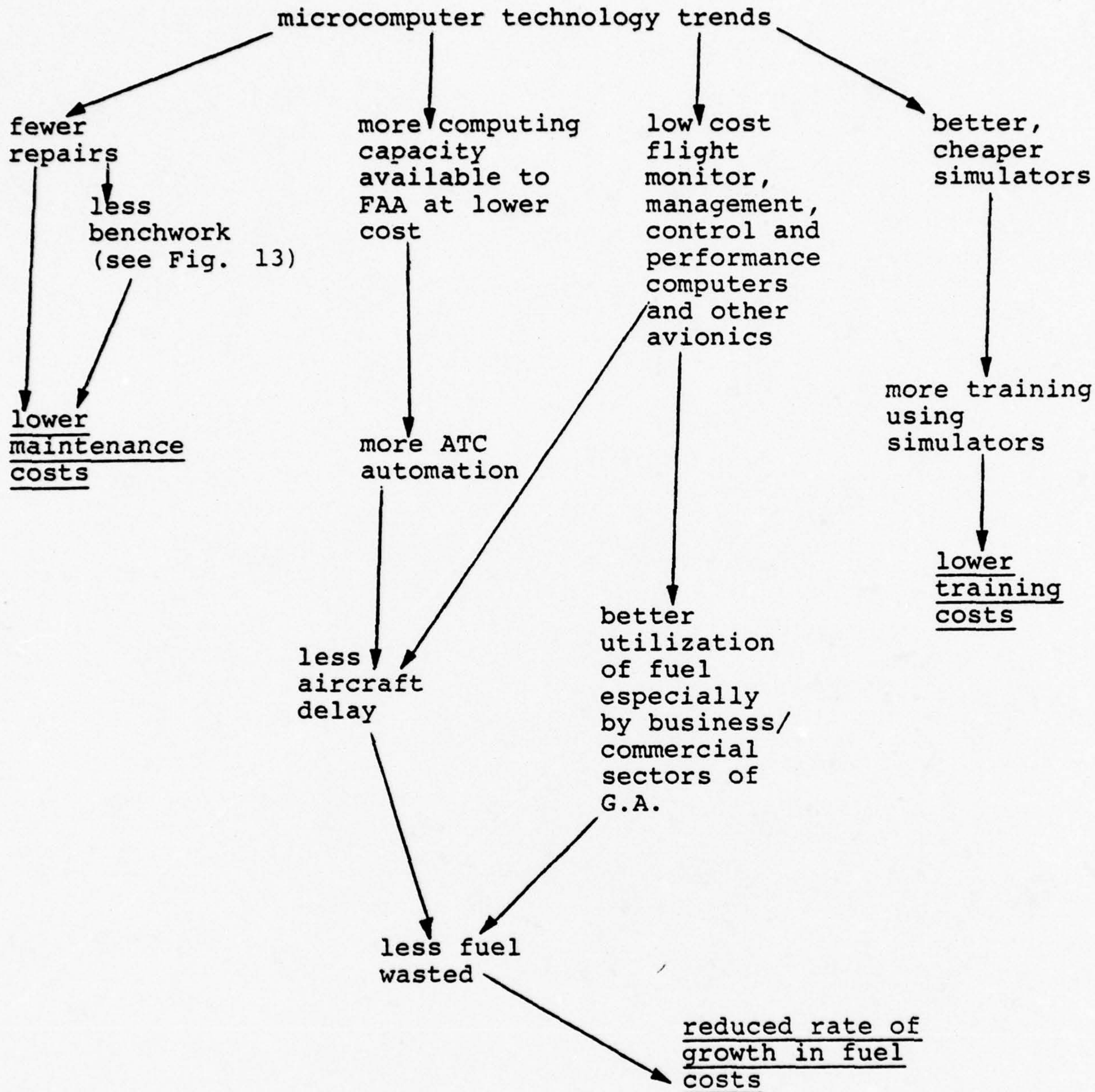



Figure 20

General Aviation Costs

maintenance techniques. Decreased ATC delay due to ATC automation and on-board computers should lower fuel consumption. Utilization of on-board computers to control engine performance especially by corporate/business GA should also reduce fuel consumption. Because fewer microcomputer-based systems are expected to be used by GA per aircraft as compared to the air carriers, fewer impacts should be expected. The exception to this is the corporate/business class which should have a much higher rate of microcomputer utilization. One area of microcomputer usage that should affect general aviation greater than air carriers is the development of better, cheaper simulators. The use of simulators by the public for training could bring the cost of flying lessons for the general aviation pilot down somewhat.

The Expansive Growth scenario should see the same basic types of impacts as in the Resource Allocation scenario. The impacts should, however, be more dramatic due to the greater rate of both microcomputer development and utilization. In the Muddling Through scenario, the impacts should be minimal for just the same reason. Both utilization and development of microcomputer technology should be rather slow in the Muddling Through scenario. The fewer microcomputer systems used, the less of an impact microcomputer technology has.

## P. GA Fleet Size and Age

Similar to the air carrier it is doubtful that the utilization of microcomputer technology will have an impact on GA fleet size and age. An increase in fleet size and a decrease in fleet age may be expected in the Expansive Growth scenario, as on-board computers make flying much less complicated and cheaper.

## Q. Airman Certification

Changes in the certification procedures as a result of microcomputer technology will depend upon how the technology is used and the rate at which the technology appears (see Figure 21). Changes in ATC procedures in the Resource Allocation scenario, discussed earlier in this chapter, would result in changes in what a pilot would need to know. The requirements for certification would require changes to incorporate new procedures.

The availability of more simulators for training at a lower cost may result in changes in training requirements, i.e., less actual flight time and more simulated flight time. The development of new avionics systems using microcomputer advances should result in major changes in pilot certification and re-certification requirements. As new avionic systems are developed and mandated, certification requirements for those flying aircraft equipped with new equipment would require changes and periodic updating of re-certification requirements. The crucial impact due to increased avionics is

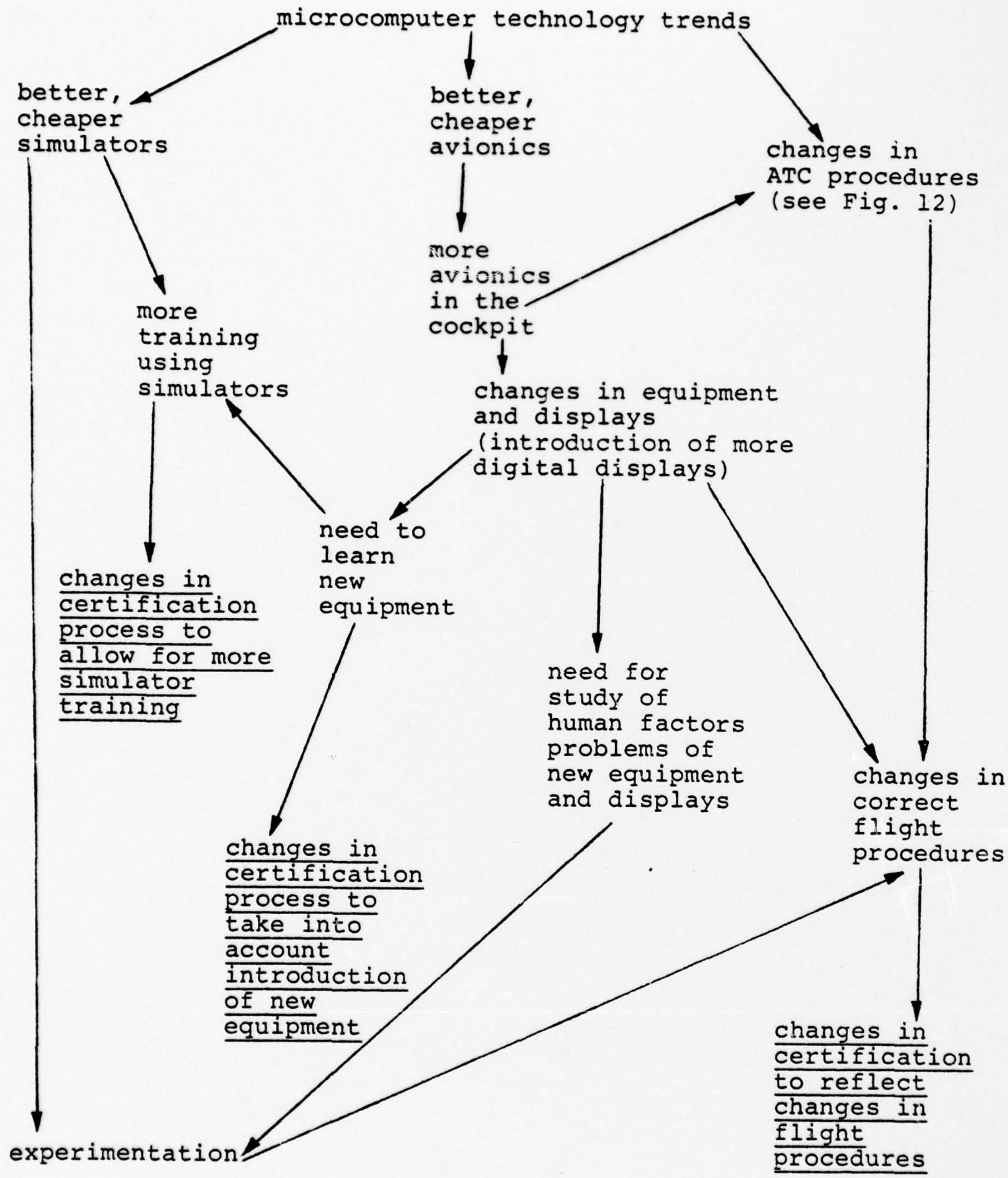



Figure 21

Airman Certification

one of timing. Today the time between a new system is development and its appearance in the cockpit is about 10 years. Due to the increasing rate of technological change, the time between development and implementation should be shortened, and should vary for all types of avionics. As mentioned under section K. Retrofit, those systems which are clearly involved in resource savings will probably be retrofitted while others may be placed in the cockpit of the next generation aircraft. Because of the retrofit of new equipment, pilot certification requirements may be constantly changing. In order to cope with this rapid change, increased flexibility in the certification process may be required. Use of simulators to train and retrain pilots on the uses of the latest equipment may become common. Additionally, as avionics are added to a cockpit and changes made to the instrument panel, many human factors problems emerge. Overcrowding of a cockpit with instrumentation and changing layouts may result in pilot confusion. The use of digital readouts and displays, and voice output systems rather than traditional analog indicators may accelerate the need for the use of simulators in the certification process, in addition to providing a tool for human factors problem evaluation and correction.

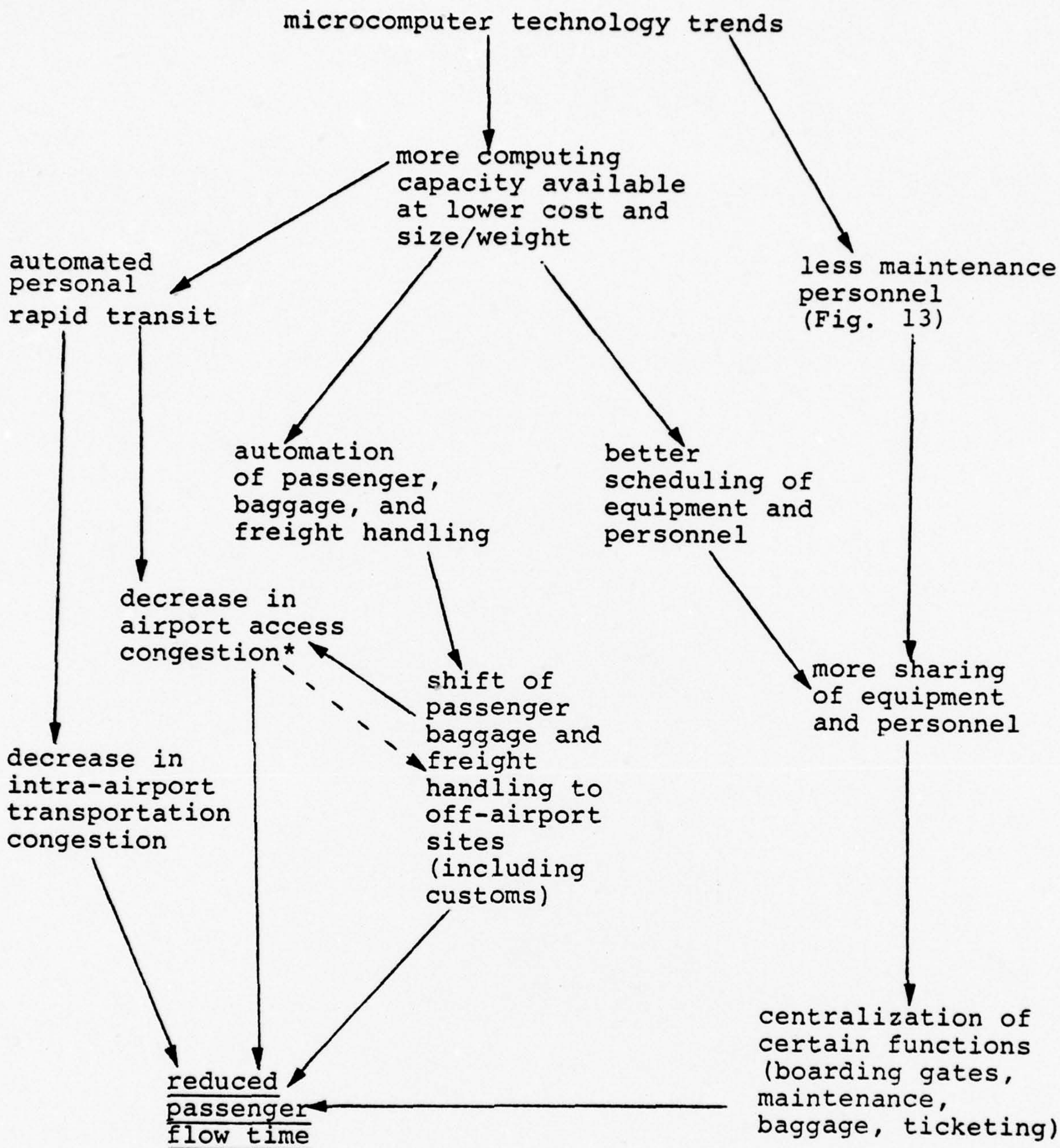
In the Expansive Growth scenario, changes in ATC procedures, increased use of simulators and avionics systems should occur more rapidly than in the Resource

Allocation scenario. Lead time for some types of avionics will probably be greatly shortened. Because of this rapid rate of technological change and utilization, the need for a flexible certification and training process should become even more acute. Human factors problems will probably also become more pronounced due to the rapid rate of change.

In the Muddling Through scenario, little impact on airman certification should be expected. Although some new microcomputer-based avionics will probably be developed, the slow rate of development and utilization of microcomputer technology in general should result in no major frequent changes in the certification procedure.

R. Airport Operations

Advances in microcomputer technology may result in dramatic changes in airport operations including such areas as baggage and freight handling, passenger processing and boarding, maintenance, and airport access and egress as shown in Figure 22. In the Resource Allocation scenario, the availability of increased computing capabilities at a relatively low cost should result in increased automation of many airport functions. Use of "smart" terminals and decentralized processing to create passenger self-processing stations either inside or outside the airport is one such possibility. With such a system, passengers would simply go to a terminal connected to




*Dotted line indicates a negative effect. Decrease in airport access congestion would result in a slowing of the shift of services to off-airport site.

Figure 22

Airport Operations

the system, insert a credit card or Electronic Funds Transfer (EFT) card, type in their desired departure and arrival points, what time they wish to leave and/or arrive and the terminal would issue the ticket. American Airlines has already conducted a joint experiment with IBM on a passenger self-processing system at Chicago's O'Hare Airport. Such systems should become widespread. The lack of an Electronic Funds Transfer (EFT) system may hinder the development of passenger self-processing, however. Automated baggage and freight systems should also be widespread. Newer airports would be designed and built to include such automated systems. Such a system using electric carts and automated guideways has already been installed at the Dallas/Fort Worth Airport in Texas. The major constraint to the use of automated baggage and freight handling currently is the lack of suitable sensors and the expense of a mechanical conveyor system, not a lack of computing capability. With the combination of passenger self-processing and automated baggage and freight handling, passenger processing functions may be shifted to off-airport areas such as hotel lobbies and downtown airline and travel agency offices. The Transportation Workshop at MIT addressed such a possibility in 1967 in their report entitled <u>Air Transportation 1975 and Beyond: A Systems Approach</u>. Passenger-processing satellites combining baggage checking, security and, if needed, customs checks before departure, located within and close to urban complexes, along with passenger self-processing using terminals at travel agencies, airline offices or even at home, would substantially reduce terminal congestion problems, both inside the airport and going to and from the airport. [5] Automated Personal Rapid Transit (PRT) systems should also help reduce traffic access and egress problems. A decrease in airport congestion due to automated PRT may, however, reduce the need or desire for off-airport passenger and baggage processing. If off-airport passenger and baggage processing becomes widespread, airports would have less need for classical terminal passenger facilities such as ticket counters and concessions. New airports may be designed with fewer of these features, and the financing of airport operations would have to take into account the reduced revenue that is normally expected from concessions. Some passenger services would need to remain on-airport to handle passenger on connecting flights. PRT should result in less parking spaces required for automobiles. The decrease in airport congestion from both PRT and off-airport processing should reduce door-to-door passenger travel time and increase the convenience of air travel. The reduction in door-to-door travel time should greatly increase competitive standing of air travel with regards to other modes of transportation.

Increased computing capability at a reduced cost should also result in greater usage of computers to schedule both personnel and equipment. As passenger-processing functions move off-airport, baggage and freight handling are automated and maintenance manpower requirements for an individual aircraft decrease, greater sharing of both personnel and equipment between airlines may become common. Shared boarding gates, maintenance facilities and the like, using computers to solve complex scheduling problems would help improve manpower utilization and promote efficiency. Sharing of facilities, less automobile parking required and the moving of many functions off-airport should allow some of the valuable airport space formerly used for these functions to be used for runways and taxiways to increase aircraft landing, takeoff and maneuvering capabilities and capacities. Older airports would, therefore, be able to increase their airside capacity without adding more land and newer airports could be designed with a higher percentage of land devoted to aircraft support.

In the Expansive Growth scenario, passenger self-processing using home or office computers should be common along with downtown or neighborhood baggage drop-off stations. Due to the extremely high volume of air travel, these measures will probably not result in any reduction in passenger travel time although automating these functions should result in an increase in the convenience of air travel while increasing the competitive standing of air travel with regards to other modes of transportation. Shared use of personnel and equipment will probably be unheard of, although airlines may use components to help schedule their own personnel and equipment.

The Muddling Through scenario should see little use of microcomputers to help increase convenience or decrease travel time. Some passenger self-processing will probably exist but because of the decreasing volume of air traffic and slow development of sensor and microcomputer technologies, automated baggage and freight handling would be nonexistent. For the same reasons, sharing of equipment and personnel would also not be practical or feasible.

S. Aircraft Manufacturing Process

Adoption of microcomputer technology within the aircraft itself should not greatly increase the complexity of the aircraft production process, as Figure 23 shows. The use of microcomputer technology to automate the production process will have a major impact. In the Resource Allocation scenario, an increase in the amount of avionics in the aircraft should result in the addition of a few intermediate manufacturing steps to facilitate installation and checkout of the new equipment; basically the process should remain the same. Some small increase in

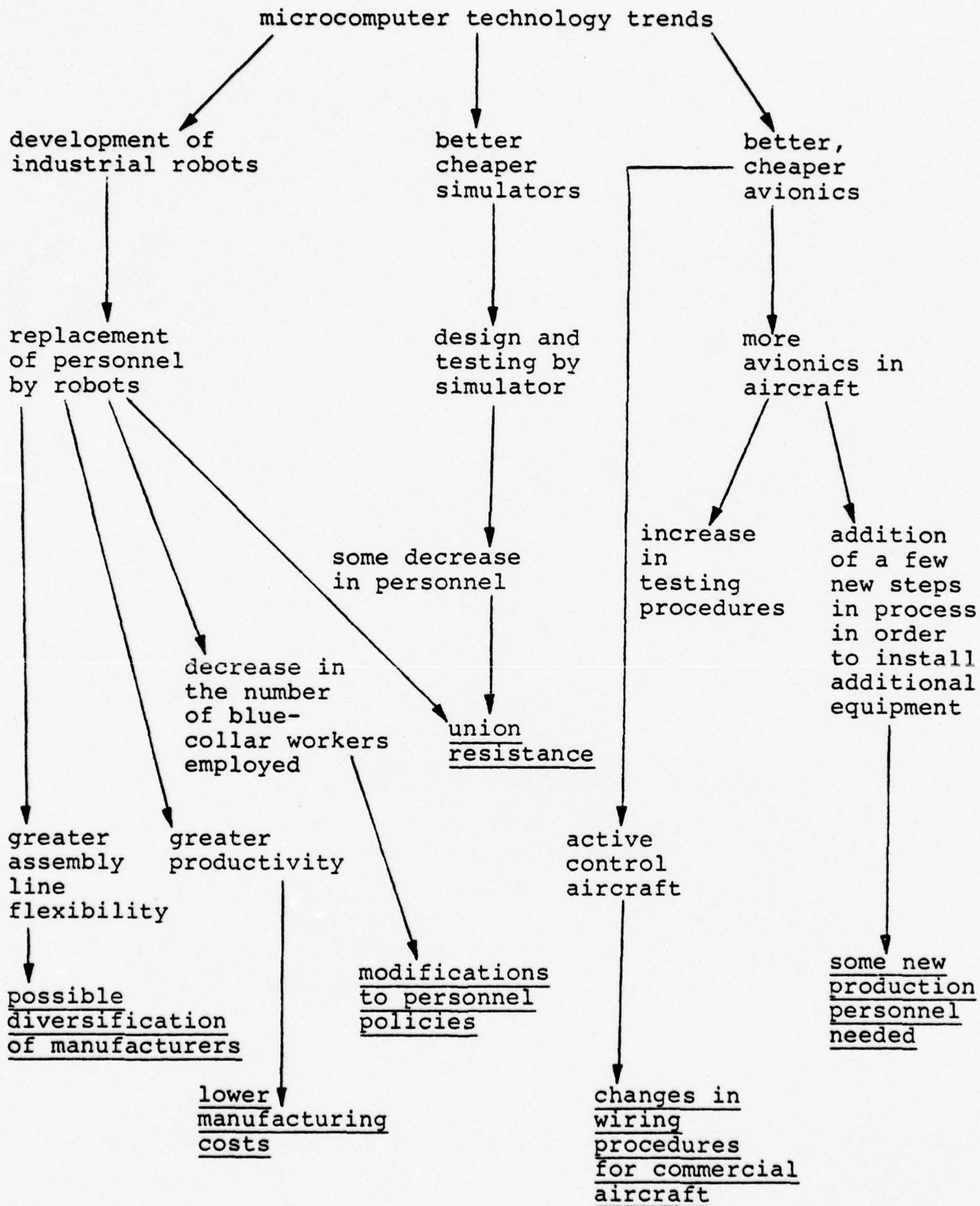



Figure 23

Aircraft Manufacturing Process

the number of production workers could result. Some changes in specialization of personnel and testing procedures should also result due to the introduction of more avionics. However, these changes should be minor.

The decreasing cost, size and weight and increasing computing capabilities of microcomputers used in the actual manufacturing process, however, could result in dramatic changes. The development of microcomputer-based robots would allow almost total automation of the aircraft production process. Industrial robots, which combine artifical intelligence, pattern recognition, and automatic control, will probably replace many of the personnel now engaged in the actual assembly of aircraft. Greater productivity and lower manufacturing costs should result. Whether this reduction in costs will lead to a reduction in the price of aircraft is unclear because a number of other very important factors such as material and engineering costs, which have not been the object of this study, are involved. The replacement of personnel by robots should also result in a decrease in the number of blue-collar workers employed by aircraft manufacturers. This should have a large impact on personnel and management procedures which are mostly based on the assumption of a large number of blue-collar workers. Use of robots and computers may also allow better scheduling and greater flexibility of the assembly line. It may become possible to use the same assembly line to construct a number of different aircraft types through multiple programmed robots and computer scheduling of parts. This may result in a great diversification of aircraft companies. The use of microcomputers in simulators for design and testing may also result in a decrease in the number of engineering personnel needed. Needless to say, the replacement of personnel with robots and simulators will probably be hotly contested by all parties concerned.

In the Expansive Growth scenario, the impacts due to the development of robots should be even greater than in the Resource Allocation scenario. The willingness of aircraft manufacturers to invest capital and the availability of highly sophisticated robots in this scenario should result in an extremely high level of automation. Because of the booming economy and its ability to absorb displaced workers, union resistance, while still extremely vocal, should not be as great as in the Resource Allocation scenario. The development of active control aircraft due to advances in microcomputer technology may also result in actual changes in the aircraft assembly procedure, especially in steps concerned with electrical wiring.

In the Muddling Through scenario, little change should be expected. The slow rate of development and utilization of microcomputer technology along with decreasing demand for aircraft should result in only a slight, if any, impact on the aircraft manufacturing process due to microcomputers.

## III. Conclusion

As this report has pointed out, the impacts of microcomputers on the NAS are indeed multifaceted and pervasive. In this chapter an attempt has been made to point out the important impacts on the NAS resulting from the utilization of microcomputers and associated technologies. While an attempt has been made to be as thorough as possible, time and resource constraints were such that an exhaustive study was not possible. Many important impacts were not explored in great depth, others were only touched upon briefly. Therefore, this study should be regarded as a mini-technology assessment rather than a full scale technology assessment (see Chapter I of this Volume).

While this study may not be exhaustive, it does point out a number of important potential impacts that deserve further exploration. The effect of changes in maintenance procedures due to advances in microcomputer technology is one area of great importance. Automation of ATC and the resulting changes in ATC procedures is another. The possibilities of greatly expanded computing capabilities within the cockpit and a greater sharing of ATC responsibilities between pilot and controller should be explored further. Increased system complexity and what that means to the FAA procurement procedures also deserves further clarification. Automation within all parts of the NAS and how it relates to work force levels should be of great concern. Strategies for the use of microcomputers to enhance the safety, economy, energy and environmental (S3E) goals of a FAA should be looked into in greater detail.

Trade-offs between the increasing rate of acquisition of more computer systems by the FAA and the declining cost and size of individual computer systems should be addressed in greater detail and where possible quantified (see Appendix C). The possibilities of advanced industrial robots and the resulting changes in the aircraft manufacturing industry are of great importance. Changes in airport design and operation are also important. These are but a few of the major impacts that should result in great changes within the NAS.

One important area of any technology assessment that could not be addressed within the scope of this mini-technology assessment is the question of affected parties. Not all of the impacts described in this report will affect or will be greeted by all sectors of the NAS alike. While one group of individuals may welcome increased ATC automation or changes in maintenance techniques, another group may bitterly oppose it. Therefore, in order to truly understand the impacts of microcomputers on the NAS, the many different viewpoints should be included. While this has not been possible within the scope of this project, we have tried to clearly outline how specific areas of NAS would be affected so that the viewpoint of individuals within those areas could be solicited.

The microcomputer has been called the third major cultural invention in the American technological society, following the television and the automobile. [6] As this report has shown, the impacts of microcomputer technology are indeed far reaching. This report, a technology forecast and mini-technology assessment of microcomputers, was intended to explore where microcomputer technology is heading and what will be the effects on the National Aviation System. Clearly microcomputers will exert significant impacts on the NAS, the FAA S3E goals, and the quality of aviation services, which includes benefits to the users, producers, and regulators of these services. However, these benefits cannot be achieved without some transitional social and economic costs, as have been pointed out in this Chapter. The extent to which and the speed at which these contributions can be achieved will depend on various factors within the NAS and on the broad social context in which the NAS will be embedded. In this report, both the rapidly changing world of microcomputers and the consequent changes within the NAS have been discussed and analyzed. Many of these changes have profound policy implications. In order to cope with these changes, it is important that the FAA have a clearer picture of possible future developments in and impacts of microcomputer technology than what has previously been available. The study was conducted to provide the FAA with a tool to better plan for, rather than react to, revolutionary changes forecast in microcomputers technology and the resulting effects on aviation.

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# APPENDIX A*

## SOCIAL IMPACTS OF THE MICROCOMPUTER

## (A MICRO-TA)

As explained in Chapter I, before focusing on the impacts of microcomputers on the National Aviation System the broad impacts of microcomputers on society should first be evaluated as a micro-TA. A micro-TA is a comprehensive scanning process using the assessors' intuitions to identify the major areas of impact. It is a quick once-through analysis which gives the assessors a clearer picture of the assessment as a whole. This holistic viewpoint is extremely important in the latter stages of an assessment, for without it, consideration of the vast interrelationships that make up the "impact space" becomes difficult if not impossible. A brief micro-TA allows the team to realistically bound the study and focus on important aspects of the impact space. Without this, a study may grope blindly, never being able to get a clear grasp of the direction the study should take. It was with the goal of better understanding the impact space that a micro-TA of the impacts of microcomputers on society was undertaken.

The effects of microcomputers on society in general, rather than the National Aviation System in specific, was the focus of this micro-TA, because, as The Futures Group study pointed out, the NAS does not exist in a vacuum.

*References cited in this Appendix may be found on page 130-131.

> The future of the NAS is likely to be influenced by as many, or more, factors than other areas which traditionally have exploited advanced technology. In the past, growth in air transportation was largely determined by capabilities in aviation system technology. But, recent developments have indicated that future aviation system developments will largely be influenced also by concern for environmental effects, social legislation, and economic developments, and with changing attitudes about life styles, both here and abroad [1].

Descriptions of the NAS derived from possible future states of society are therefore more valid than projections of possible futures of the NAS done directly. Deriving values for the parameters of the NAS from possible future states of society gives one a much better insight as to the relationship between society and the NAS and the alternative futures facing the NAS.

Of the five scenarios describing possible future states of society developed by The Futures Group, as mentioned in Chapter One, three were selected. The data suggest that of the five scenarios, the Muddling Through and the Expansive Growth scenarios have the lowest and highest respective values for aviation activity with the Resource Allocation scenario in the middle. Resource Allocation was taken, therefore, as the baseline case with microcomputer usage being more widespread in Expansive Growth and less so in Muddling Through.

## I. A Structured Brainstorming Procedure for Micro-TA

The micro-TA was done in a structured brainstorming mode. The use of brainstorming was chosen since the uninhibited flow of ideas generated in brainstorming lends itself to the needs of a micro-TA. Being a once-through, top-of-the-head analysis, a micro-TA relies heavily on intuition which brainstorming is best able to capture. The term "structured" brainstorming may appear to be self-contradictory, as brainstorming is supposed to be uninhibited and unstructured. However, entirely unstructured brainstorming is often unproductive. Cross fertilization in brainstorming seems to work at its best when some clear objectives and general procedures are specified [2].

The structure used to aid in brainstorming in this study was a multiple taxonomy system of impact areas. These impact areas under 6 taxonomies are listed below:

1. Substantive aspects

    Environment and natural resources (energy, minerals, water, air, etc.)
    Economic
    Technological
    Social & cultural
    Political
    Psychological
        Individual
        Social
    Legal
    Defense/security
        External/national security
        Internal/crime control
        Espionage/intelligence
    International
        Political
        Ideological
        Trade & production

2. Life support functions

    Food
    Clothing
    Shelter
    Transportation
    Health

3. Institutions

   Marriage & family
   Property/ownership
   Corporations
   Public interest groups
   Unions
   Universities
   International organizations
   Government
     - Federal
     - State
     - Local
     - Regional

4. Social values

   Privacy
   Community
   Justice (distribution)
   Survival
   Rationality
   Materialistic prosperity
   Equity
   Freedom

5. Life activities

   Work
     - Home
     - Factory
     - Office
     - Service
     - Government
     - Households

   Leisure
     - Individual
     - Group

   Learning

6. Maslovian hierarchy of human needs

   Survival
   Security
   Belongingness
   Esteem
   Self-actualization

The last taxonomy listed comes directly from Maslow's theory that human needs are arranged in a hierarchical fashion, with survival the lowest level need and self-actualization the highest. The other needs of security, belongingness and esteem are arranged in correct order in the list of taxonomies above. According to Maslow, when an individual satisfies one level of need, they then begin working to satisfy the next higher level of needs, i.e., when the need of security is satisfied a person then becomes concerned with belongingness [3].

A multiple taxonomy system was used in order to capture most if not all of the major impacts. A multiple taxonomy system, unlike a single taxonomy system, can be used to explore many dimensions of the impact space simultaneously. Such a system acts as a series of nets, each one catching what escapes the others.

In applying the multiple taxonomy system to structured brainstorming, each team member was asked to describe one major impact for each impact area in the taxonomies for each scenario. For example, each team member would describe one impact on privacy for the case of Resource Allocation, one for Muddling Through, and one for Expansive Growth. This process generated many possible impacts in each of the three scenarios.

To avoid "not seeing the forest for the trees," each team member was asked near the end of the exercise to describe holistically the impact of microcomputers for each of the six different future scenarios. The six scenarios included the three descriptive ones mentioned before; Resource Allocation, Muddling Through, and Expansive Growth, along with three new normative ones; "Technetronic Society" as described by Zbigniew Brzezinski [4], "Person-Centered Society," as described by Willis Harman [5], and the "Fourth Kingdom" as described by William Sauber [6].

In the Technetronic Society, the world has become a global city--a nervous, agitated, tense and fragmented web of interdependent relations. Society is shaped culturally, psychologically, socially, and economically by the impact of technology and electronics, particularly in the areas of computers and communications. New social patterns emerge including a shift to a more service oriented economy. Increasingly, man lives in man-made and man-altered environments. Knowledge rather than wealth becomes power with information overload a serious problem. Instant participation in events due to increased communications leads to a greater sense of uncertainty as the old ways of doing things no longer seem to work. The United States is the major force for social change due to its exportation of the "technetronic society" to the rest of the world. Anticipatory planning becomes a necessity but in the form of coordination rather than centralization, viz: participatory pluralism. Science and technology become subordinate to social ends as rational humanism, the synthesis of scientific innovation with humanistic world-view, becomes dominant. Reason, belief and values interact intensely, putting a premium on the explicit definition of social purpose.

The Person-Centered Society is dominated by the view that man is a part of nature and not master over it and that the proper end of all individual experience is the further growth in individual awareness and the evolutionary development of the human species. Coupled with this is the concept of supraconscious choice, one's sense of a "higher self" exerting behind-the-scene guidance. The search for knowledge and the application of that knowledge--science and technology--become subservient to this world view. The new science actively assists society in formulating new dominant goals for the whole culture. The "central project" of society--the dominant theme of a society--becomes promoting individual growth, evolving social institutions to accelerate such growth, and further the evolution of the human species. This implies a learning and planning society replacing the work ethic with a work-play-learn ethic. Science, technology and all institutions reflect and support the goals of individual growth.

In the Fourth Kingdom Society, the central project is not human growth but colonization of space. Technology exists to insure the perpetuation of life. In order to assure the perpetuation of life mankind must free itself from the confines of earth. Mankind must cast its seeds into space to insure its survival. All of society's actions are guided by the principle of survival and growth and all of society's activities are bent towards the goal of space colonization. The conquest of space becomes society's major concern, its central project. As a prelude to the external growth into outer space, mankind will invest heavily (as much as 10% of their goods and services) in high technologies, including fusion power, bionics, cybernation, as well as space programs. Practically all the technologies described in science fictions will be developed and used at an accelerating speed.

The procedure for brainstorming in this micro-TA was unlike that of what is considered 'normal' brainstorming. Rather than meetings and sessions, ideas were exchanged via computer conferencing. Team members in both Ann Arbor, Michigan and Washington, D. C. entered their impact ideas into the computer in the form of items to be read by all other team members. An example of an item is as follows:

```
Item=55     14:29:54  03-05-77    Lines=4    Prime=  Next=
Jarboe, Kenan Patrick
Impact - Social and Cultural

(M) MC used in entertainment (home video) as a major
    cultural and social force
(R) MC used to monitor resource depletion, driving
    home the death of the 'throw-away ethic'
(E) MC used in telecommunications which becomes a major
    cultural medium

    Ref to items
```

Votes/Feelings

MC Continue "Throw-away" Approach to High Technology

(MC=Microcomputers; M=Muddling Through; R=Resource Allocation; E=Expansive Growth)

The ideas generated by the structured brainstorming were then pulled together to create complete scenarios for each of the three major scenarios: Resource Allocation, Muddling Through, and Expansive Growth. The remainder of this chapter deals with the substance of these three scenarios.

## II. Impacts of the Microcomputer in a Resource Allocation Society

> Resources, particularly energy resources, were in short supply. Groups of nations, functioning essentially as cartels, unilaterally established resource prices and continually threatened to withhold supply unless consuming nations met requirements established by the suppliers. Throughout the world, tension built and ebbed. The exporting nations remained reluctant to repatriate capital in ways which were useful and productive to the importing nations. Once a year, one or the other of the cartels would withhold supplies for a period of several weeks, and the importing countries coped as best they could. As supply fluctuated, so did prices. Inevitably, the response was a dynamic move toward self-sufficiency--to reduce the demand for critical imports. Political and intellectual energy was focused on how to grow given these resource constraints. The answers were: to develop indigenous resources, to allocate stringently, to recycle, to plan [7].

The use of microcomputers increased significantly as a means for carrying out society's goal of optimal allocation of resources.* As their cost decreased dramatically, microcomputer usage became widespread in areas of recycling and resource management. Microcomputers were used to make better

*The past tense is used throughout these impact descriptions, to be consistent with The Futures Group's approach to the construction of societal scenarios as "future histories."

use of resources both directly and indirectly. Spin-off uses of microcomputers were encouraged but only where they fit into the goal of resource allocation.

Telecommunications was one major user of microcomputers. As its potential grew and costs decreased, telecommunciations gradually increased its role in every day life. Global communication systems were expanded and improved to handle the increased flow of information. Telecommunications became a substitute for transportation as strict allocation of resources, especially energy, cut transportation capabilities and microcomputers increased the capability of two-way CATV, computer-conferencing and other electronic communication techniques.

Education was greatly affected by microcomputers. Educational instruction at home via telecommunications networks increased the popularity of the open university and "class-room without walls" concepts of education, increasing the opportunities for education for those previously unable to complete a formal on-campus program of study. Increased educational opportunities gave rise to a higher cultural standard of living. With physical growth restricted by resource constraints, growth in knowledge became highly prized. The ease at which education became available lead to a blurring of work and learning. Education became a life-long process rather than something confined to a person's youth. Career counseling and on-going job counseling enhanced by microcomputers allowed individuals to make better decisions as to how to best use the educational resources available to them. Microcomputers also found great use in learning/ teaching machines to augment human teachers.

Medicine was another area affected by microcomputers. Telecommunications became a useful tool in diagnosing and treating patients. Paramedics and others equipped with microcomputer controlled sensors and telecommunications network links increased the ability of an individual to receive medical attention. Bioengineering devices provided low-cost artificial organs for those who could afford them or those who could get government subsidies.

The impact on the legal profession was substantial, as judge, jury, and opposing lawyers made use of the increased capability for information processing and analysis brought about by microcomputers. Telecommunications made it possible for trials to be separated geographically, with witnesses, juries, judges, and lawyers situated in different parts of the country, tied together by telecommunication networks. Microcomputers were also used in law enforcement areas, making it increasingly difficult for criminal activities to go undetected.

Politics and government changed as telecommunications increased the direct participation of the public in government. Electronic voting became widespread with major issues being decided by the electorate in the form of electronic general referendums. The use of improved information processing techniques lead some political candidates to try to optimize their appeal to the voters by taking calculated stands on the issues, while other candidates used the information processing techniques to strengthen their personal stand on an issue. The increase in the need for information gave those in control of valuable information greater political clout. Those who controlled lines of communications and information flow held power over those who did not. Control over information flow was hard to maintain, however, as microcomputers made equal access to information easier. Political control, therefore, became a shifting quantity, resting temporarily with those who controlled vital information at a given moment.

The increase in the flow and access of information allowed for more successful planning. Earth resource satellites and other sensing devices equipped with microcomputers generated more accurate information in greater volume than before. Microcomputers in "smart" terminals, word processing units, distributed processing systems and telecommunication networks increased man's ability to handle the increasing flood of information. Government took real leadership in the nation, using microcomputers not only for information processing, but in decision making as well. Microcomputers greatly increased the level of sophistication of analysis done by decision makers. Linear programming, computer simulation modeling, risk analysis, decision analysis and other quantitative analytical techniques became more and more popular in government. Due to earlier experiences with such techniques, qualitative descriptive techniques were merged with the quantitative analytical techniques. Microcomputer controlled information processing and telecommunication units made both qualitative and quantitative information available to decision makers.

As microcomputers were used to reach optimal policies, both private and public decisions became increasingly rational. The exercise of rational thinking in the entire populace increased, due to the fact that rationality was considered a requisite for resource allocation. Because of the increase in information flow due to microcomputers in telecommunications, rationality was applied broadly in terms of social goals with more input from diverse social groups. Decision making became increasingly decentralized as all levels of the decision process and most impacted parties used microcomputers to increase the level of sophistication of analysis.

As information became more valuable, the right of equal access to information became a major social right. Due to the widespread use of microcomputers and nation-wide telecommunications networks, facilitating instantaneous information sharing, easy access to information became available to most all individuals. Legal and governmental safeguards of the right of access to information were carefully drawn up, balancing the right to information against the right to privacy. In some cases, the definition of privacy was changed as the right of information took precedent. Ownership also changed as in most cases, information became public instead of private property.

Since growth in most areas of the economy was constrained due to lack of resources, two major areas of growth emerged. The first area of growth was in industries directly connected with microcomputer technology. This included new industries created by the spin-off uses of microcomputers. Microcomputers were used increasingly in monitoring many tasks to achieve resource savings. Many industrial processes such as assembly lines became automated with microcomputers used to control most tasks. Energy controls using microcomputers became commonplace in many buildings. Consumer hard-goods such as ovens, refrigerators, washers, dryers, etc., used microcomputers in their instrumentation. Misplacement in employment caused by automation was absorbed by the growth in other areas. Automation itself led to an increase in productivity and some growth in resource constrained industries.

The second area of growth was in the information or knowledge industries. As knowledge became prized in itself and information became increasingly important, the area of knowledge and information generation grew dramatically. One outcome of this growth was the merging of think-tanks into universities as interdisciplinary teaching and research was emphasized.

A new type of elite emerged. Those who had the know-how to use microcomputers to increase their store of knowledge and information gained in power vis-a-vis those who did not. The knowledge of the technology of information processing and and generation became as important as access to the information. Social interactions were enhanced for those at ease with the technology while a new class of powerless was formed, made up of those lacking skills needed to use the technology. This group remained relatively small, however, as the necessary skills were emphasized in the educational system.

Social interactions changed due to the nature of telecommunications and the blurring of work and leisure. Exposure to a great variety of cultures and interests served to widen the horizons of most of the society. The sense of community (including the feeling of global community) increased as communications and understanding increased and the use of microcomputer-based automation allowed individuals more time for social interactions.

Most people operated on the higher levels of Maslow's hierarchy of human needs. Microcomputers helped link people together with common interests to develop a sense of belonging. Microcomputers also helped provide a diversity of activities, ideas, and options to an individual so that almost all individuals could find some area in which they could be creative in their own way.

The United States, because of its self-sufficiency and domestic stability, maintained a cooperative posture with the other nations of the world. Military uses of microcomputers in intelligence gathering and analysis systems and in sophisticated weapon systems kept the U. S. in a superpower position. The exportation of microcomputer technology and the output of our knowledge industries became our biggest export item, creating a balance of payments surplus.

Microcomputers, by the end of the century, had become a major factor in the United State's economy and way of life. Because of the emphasis on rational decision making, resource allocation and planning, microcomputers filled an important position in society, helping it to reach its goals. America looked forward to the 21st century with increasing confidence in its ability to cope with major social problems.

## III. Impacts of the Microcomputer in a Muddling Through Society

> Things went downhill from the 1970's. The United States never seemed to be able to "get it all together." When it tried to repair inflation recessions followed; when recession was the target, inflation accelerated. Muddling through was the norm. Cohesive policies which lasted beyond the presidential term were very unusual. The result, inevitably, was frustration. Who was at fault? Industry, said government; government, said industry; the public faulted both; and government and industry claimed the public did not understand. Large corporations were nationalized. Regional authorities were established. And the people were insecure and searching for a better

> reality. For several reasons, the last quarter century was not a repeat of the depression years of the 1930's. In the later part of the century, the nation was more organized, federal programs had reduced unemployment rates, large-scale quasi-public corporations functioned with adequate but reduced efficiency. But the feeling of depressions was inescapable. This was the modern depression--and it was long-lasting [8].

As the general feeling of frustration grew, society turned both towards technology as a hope of solving social problems and away from technology as technological fixes to social problems failed. Society's love-hate relationship with technology in general also characterized society's relationship to microcomputers. The growth in the usage of microcomputers was slow with a lengthy gap between computer generations. Changes and uses of microcomputers occurred a relatively long time after the need for such changes and uses arose. Microcomputers did spark some development of other technologies, but there was little synergism. Advances in one technology were used in other technologies after a period of time, but there was no anticipatory exploration across technologies for possible spin-off uses.

One major use of microcomputers was in automation and control systems. Manufacturers turned increasingly towards microcomputers to automate factories in an attempt to achieve better economies of scale and to increase productivity. A union backlash resulted, as workers feared the loss of their jobs. Featherbedding became common as industry tried to overcome workers fears, wiping out any gains in productivity due to the use of microcomputers. The power of unions increased as more and more individuals felt threatened by microcomputers and automation in general.

The use of microcomputers in some control and automation functions was accepted, however. Microcomputers were used in homes and factories to monitor and control energy uses. Closed control systems for reducing pollution in both transportation and manufacturing became common. Microcomputers were used in automobiles in an attempt to improve gas mileage and reduce emissions. In some cases, microcomputers completely controlled automobiles, taking over all driver functions.

As crime and other social problems increased, more and more of the sophisticated military uses of microcomputers resulted in spin-offs in the domestic market. Microcomputers were used, for example, in advanced communication systems for police and other security units, and in highly sophisticated building security systems.

Microcomputers became increasingly popular at home. Home computers were regarded as the latest play thing, performing such exotic tasks as reminding people of appointments and errands, filing letters, documents, and recipes, computing income taxes, and keeping children amused with television games. Home entertainment centers, including TV games, and home video and telecommunication systems, dominated family life, much like television and the CB craze of the

70's. Alienation among family members increased as each member tended to spend more and more time with the entertainment centers and less time with each other. As society became more addicted to this form of entertainment as a source of escape from reality, leisure became more of a passive activity. Electronic entertainment became a major social and cultural force, replacing, for the most part, family and schools as the major value-shaping institution of the society.

Due to the power of electronic entertainment to shape values, control of the electronic medium meant control of the society. As society's dependence on the electronic medium increased, so did the power of those in control of the medium. Those who knew how to use and control the technology gained in relative power vis-a-vis those who did not. Due to enhancement by microcomputers, the electronic medium's potential as a tool for political repression increased.

As frustration increased, society, using this newly enhanced tool, turned more and more to political repression as the solution to social problems. Microcomputers became a tool in society's "holding action" to maintain the status quo. Government was largely inept, however. Microcomputers were used to gather and analyze data, but no real information, knowledge or wisdom was distilled from the data. As government and others, in a desperate attempt to find solutions to social problems, used the increased power of microcomputers to process and analyze data, information overloading increased. This in turn resulted in the increase in the level of frustration rather than a decrease.

Technological fixes were tried and failed. Central planning was emphasized but poorly done. Microcomputers were used to help cope with problems in a crisis-responding mode, with little or no positive effects. Solutions to social problems were generally characterized as too little--too late. The resulting depression lead some in society to blame microcomputers and over-rationality in general as the root cause of social problems.

The increased power of telecommunications and microcomputers in general had a large impact on an individual sense of community. Sense of community was reduced in part by the encouragement of man-machine interaction, thus reducing the time for human interaction. Yet, the sense of community was increased as home telecommunication systems facilitated interaction among persons not in the same location at the same time. Some people reacted to this trend and to society in general with deliberate efforts to interact with people in the same local community, with or without the aid of microcomputers. More and more people turned away from technology completely, advocating a return to "the good old days." Even with a high level of anti-technology feelings within the society, microcomputer usage continued to grow as many saw microcomputers as the last hope for a technological solution.

The level of hostility toward technology continued to increase within the society. Paradoxically, microcomputers were used to prepare the case against technology, revealing society's dependency on technology. Most of society operated on the survival and security level of Maslow's hierarchy of human needs. On one hand, microcomputers and technology in general were blamed for keeping society from progressing toward, meeting, or obtaining higher human needs. On the other hand, microcomputers became valuable tools in helping society meet survival and security needs.

World tensions continued to mount as the domestic depression of the United States was reflected in its foreign policy. Microcomputer usage in military applications increased as the world's superpowers continued to create sophisticated weapon systems. Microcomputer technologies used in military and other applications dominated the export sector of the U. S. economy.

Frustration and depression were the dominant moods within society at the turn of the century. Microcomputers served as a ray of hope, but also as a source of frustration as the gap between utilization of microcomputers and their potential continued to widen. Over-expectations of what microcomputers could do for society lead to a frustrating collision of expectation with reality. The United States at the end of the twentieth century, faced a gloomy and uncertain future, with little prospect for improvement.

## IV. Impacts of the Microcomputer in an Expansive Growth Society

> The United States confronted the problems which inhibited its development--attacked them vigorously--and solved them with the old "American Spirit." The nation found it possible to create images of what might be, and then put into place policies to achieve its end. Technology still worked, and the means of achieving the technological solutions were through free enterprise. As the private sector grew in vitality, the public sector--government--reduced its relative size and propensity to intervene and control. The emphasis was on individualism; on corporate achievement [9].

As society grew at an enormous rate, microcomputer usage also grew. Time between microcomputer generations shortened dramatically and software became obsolete soon after development. Cost for hardware became trivial, as the only barrier to a particular use of a microcomputer was software. Modernization was society's password, and modernization meant automation. Microcomputers were used in automation and control systems everywhere and anywhere. Some uses were integrated with other uses; some were not. Microcomputer and other technologies stimulated and multiplied each other's growth. Sophisticated pollution control systems, energy generation systems, and world-wide weather and resource sensor systems using microcomputers helped society to overcome past social problems.

One main area of microcomputer usage was in home computers. Among other things, home computers using telecommunication networks helped consumers do their shopping at home, along with suggestions as to the planning of meals based on one's diet, taste, recent meals, etc. The same home computer would also control the kitchen and cook the meals automatically. Other items besides food were also purchased using one's home computer, which also dispensed helpful consumer and fashion information. Home computers also controlled the houses' climate and security control systems. Entertainment systems using home computers to control TV games, home video systems, and the like became common.

Medical care became easily accessible to most all via home computer and telecommunication links. Using microcomputers, high risk patients could be continually monitored even outside of the hospital. Bio-engineering made great use of microcomputers in such areas as artificial limbs, sensory aids, and monitoring of weak organs.

High-speed personalized automated transportation systems relied heavily on microcomputers. Total automation of factories became common. Advanced synthetics and non-conventional processing techniques grew out of increased use of microcomputers in the textile industry. Microcomputers were used to create completely controlled indoor environments, enabling food to be grown in automated food factories.

In manufacturing, the use of microcomputers facilitated increased flexibility for workers.

The greatest impact, however, came in the usage of microcomputers in artificial intelligence systems and robots. Robots, with microcomputer brains, took over many dangerous and boring jobs. Mining of resources, such as deep-shaft coal mining, was done solely by robots. Construction work, assembly-line jobs, and other manual labor jobs became automated through the use of robots. Robots were extremely important in the exploration and colonization of the moon, the planets, and outer space. Other uses of microcomputers, such as in spaceship control systems, also became important in space exploration.

Microcomputers also enhanced the capabilities of information processing and telecommunication systems. Intelligent components, such as voice-activated terminals, helped overcome many of the man-machine interface problems.

The direction of technological growth was multi-directional, uncontrolled by social goals and purposes. Much of the growth in the technological and materialistic areas were spurred by rigorous competition in the private sector. Government took essentially a laissez-faire attitude toward microcomputers and technology in general, content to follow and assist private industry rather than lead. As automation increased, service industries flourished. A diversity of new services sprung up, supporting many new, small companies. Entrepreneurship attracted the brightest minds of the society with many entrepreneurs becoming millionaires.

The use of microcomputers in decision making on all levels increased. This, combined with increased telecommunciation capabilities and the demands of strong competition, forced corporations and other planning units to decentralize in an effort to increase innovation. Following the trend for decentralization, population patterns continued to sprawl. Decentralization also meant an increase in the ability of individuals to influence decision making. Unions and other special interest groups who were able to take advantage of the decentralization trend increased in influence. Clashes between groups became less violent, however, as the economy's ever-expanding pie resulted in enough for all. Those who had knowledge or influence over microcomputer technology, such as microcomputer industry unions and information processing specialists, gained in relative power vis-a-vis those who did not. This inequality decreased somewhat as the use of microcomputers became simplified.

In politics, microcomputers and telecommunication systems made electronic voting and referendums possible complete with electronic ballot box stuffing. National Delphi surveys were used as a means of determining political positions. Politicians rapidly adopted microcomputers as an aid in communications and information analysis. Some political candidates used microcomputers to help optimize their stands on major issues.

Legal definitions of privacy and ownership changed as the value of information increased thereby increasing the need for access to information. Decentralized trials, with judge, jury, and opposing lawyers in different areas of the country tied together via telecommunication systems, became common. Microcomputers became a necessary supporting tool for lawyers in the courtroom. Break-throughs in law enforcement due to microcomputers helped keep crime under control.

The expansive growth of the United States had a spill-over effect on the rest of the Western world. As microcomputer-enhanced telecommunication systems grew, the information flow between nations increased, easing world tensions. International trade flourished, supported by microcomputers in data analysis and telecommunication systems. Wars became electronic as remote sensing and automated weapons systems made up the bulk of the world's military hardware.

Knowledge, not only material goods, became important assets to possess. By helping to store information, microcomputers fostered greater creation of technical knowledge, thereby increasing the technological areas dominated by university activities. Interdisciplinary activities were emphasized, revolving around microcomputers and other technologies.

Telecommunications became a major cultural and social force. Microcomputers and telecommunication systems helped certain individuals (those familiar with the technologies) to build new personal networks with others at remote locations. The increased social contact outside the family that resulted, including extramarital experiences, threatened the stability of the nuclear family. Privacy could be obtained only occasionally by flight from the "civilized world" or by pathetic self-imposed isolation. Microcomputers both reduced the sense of community by encouraging man-machine interaction, thus reducing time for human interaction, and increased the sense of community by facilitating interactions among persons not in the same location at the same time. The ability to communicate over time and space became increasingly important as population patterns became more decentralized.

A positive attitude toward technology existed within the society. As microcomputers were used more and more in the decision making process, rational thinking in the entire population increased. Rationality and competition came to be viewed as the basic values that fuel expansive growth. Holistic thinking also increased, as microcomputer information processing allowing for a greater diversity of data to be collected and analyzed.

Concerns about inequity were uncommon since most of the society was better off materialistically, in spite of the actual increase of inequality of income and wealth distribution. The increased use of robots created more leisure, allowing individuals to increase consumption. Leisure became basically a group activity. As long as there existed some activity to keep people occupied and happy, no major social unrest occurred.

Most individuals operated at the higher levels of Maslovian human needs. Microcomputers were used to link people with common interests to develop a sense of belongingness. Microcomputers also helped provide diversity of activities, ideas, and options, so that almost anyone could find some area in which to excel and be creative, thereby attaining esteem. This process was not, however, free of frustration. Microcomputers allowed individuals greater control over their lives but also forced people to become more dependent upon technology for survival.

By the end of the twentieth century, the United States was a growing, dynamic society. The problems of the past had been solved and the promise of the future lay ahead. Society welcomed the future, confident in its ability to cope with any problems that might arise.

# APPENDIX B

## IMPACT MATRIX

Chapter III of this report uses a matrix to show an overview of the affects of particular applications of microcomputers within the National Aviation System (NAS) on certain NAS impact areas. This matrix, Figure A, can also be used as a quantitative analytical tool as well as a morphological tool. If percent changes in an impact area due to an application could be found for each individual cell of the matrix, rather than merely using dots to signify intensity (Figure 10), then matrix algebra techniques could be used to calculate the total percentage changes in specific impact areas due to a number of microcomputer applications.

As an example of how this matrix approach could be used, take the two impact areas of air carrier fuel consumption; measured in millions of barrels of jet fuel, and noise pollution, measured in thousands of acre-minutes per average day nationally. These two areas were picked because each has been forecasted by the Futures Group* for each of the scenarios without taking into consideration specific impacts of microcomputers. The general matrix, Figure 10, shows that these two impact areas are affected by the application areas of UG3RD, on-board computers and simulation. A closer examination reveals that of all the specific

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*H. S. Becker, E. Fein, T. J. Gordon, F. Kropp, D. Tagoff, Alternative Future Scenarios for the National Aviation System. The Futures Group, Final Report, August 1975.

microcomputer applications within UG3RD, five separate areas--precision landing applications, navigation applications, automated ATC applications, wake vortex wind shear (WV/WS) detection applications, and airport surface traffic controls applications (ASTC)--have an impact on air carrier fuel consumption and noise pollution. Similarly, the specific uses of microcomputers in the on-board computer applications of control of the aircraft and monitoring of aircraft systems are the most important on-board applications. The matrix now has eight application areas and two impact areas.

For the sake of this example, the matrix is reconstructed using the eight application areas and two impact areas. In each cell of the matrix a hypothetical but realistic figure is entered for the percent change of an impact area due to the 100 percent implementation of an application. The matrix with hypothetical figures added is labeled [R] and is shown below.

Impacts

applications

| | | | | | | |
|---|---|---|---|---|---|---|
| -.01 | -.04 | -.02 | -.02 | -.08 | -.005 | -.009 |
| -.05 | 0 | -.1 | .1 | -.02 | -.02 | 0 |

For example, the figure in the first cell of the matrix, -.01, states that the use of microcomputers in precision landing equipment should, hypothetically, help reduce air carrier fuel consumption by 1 percent.

Since each cell of the matrix [R] shows what the impact would be at 100 percent implementation, a second matrix called [A] must be created to show the percent of implementation at each application at each year for each scenario. Each cell represents the levels of implementation of each application at each given year. The three [A] matrices are shown on the following page.

For example, the second line of the first matrix shows that in the Expansive Growth scenario the implementation level of micro-computer based navigation equipment was assumed to be about five percent in 1975 and that by 1990 the implementation level was 100 percent (for this example 100 percent implementation means all air carrier and executive/business and commercial general aviation aircraft equipped with microcomputer based navigation equipment). By multipling the [R] matrix by the [A] matrix using matrix algebra, it is possible to find the extent of the composite impact on the impact areas of all the applications at each application implementation level for that year.

The multiplication procedure, using a 1 x 2 [R] matrix and a 2 x 2 [A] matrix as an example, is as follows:

$$RA = \begin{matrix} & j_1 & j_2 \\ i_1 & [a & b] \end{matrix} \times \begin{matrix} & t_1 & t_2 \\ j_1 & [c & d \\ j_2 & e & f] \end{matrix} = \begin{matrix} & t_1 & t_2 \\ i_1 & [ac + eb & ad + fb] \end{matrix}$$

The percent change of $i_1$ due to 100 percent implementation of $j_1$ (a) times the level of implementation of $j_1$ at $t_1$(c) plus the percent change of $i_1$ due to 100 percent implementation of $j_2$(b) times the level of implementation of $j_2$ at $t_i$(e) is the percent change in $i_1$ due to both $j_1$ and $j_2$ at $t_i$(ac + be). The same process is undertaken for $t_2$.

## [A] MATRICES

### Expansive Growth

time

| Applications | 75 | 80 | 85 | 90 | 95 | 00 | |
|---|---|---|---|---|---|---|---|
| | 0 | .1 | .3 | .7 | 1.0 | 1.0 | Precision Landing |
| | .05 | .2 | .8 | 1.0 | 1.0 | 1.0 | Navigation |
| | 0 | .01 | .1 | .4 | .8 | 1.0 | Automatic ATC |
| | 0 | 0 | .05 | .5 | 1.0 | 1.0 | WV/WS |
| | 0 | .1 | .35 | .7 | 1.0 | 1.0 | Control Computer |
| | 0 | .1 | .3 | .7 | 1.0 | 1.0 | Monitoring Computer |
| | .05 | .2 | .6 | 1.0 | 1.0 | 1.0 | Simulation |
| | 0 | .05 | .2 | .6 | 1.0 | 1.0 | ASTC |

### Muddling Through

| | | | | | |
|---|---|---|---|---|---|
| 0 | .05 | .15 | .17 | .2 | .2 |
| .05 | .1 | .4 | .42 | .45 | .45 |
| 0 | 0 | .05 | .05 | .07 | .07 |
| 0 | 0 | 0 | .02 | .05 | .1 |
| 0 | .05 | .1 | .1 | .1 | .1 |
| 0 | .1 | .25 | .3 | .32 | .35 |
| .05 | .1 | .2 | .25 | .25 | .25 |
| 0 | .5 | .1 | .15 | .17 | .2 |

### Resource Allocation

| | | | | | |
|---|---|---|---|---|---|
| 0 | .07 | .15 | .35 | .6 | .8 |
| .05 | .2 | .8 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | .05 | .2 | .3 | .5 |
| 0 | 0 | 0 | .05 | .2 | .5 |
| 0 | .1 | .4 | .8 | 1.0 | 1.0 |
| 0 | .25 | .5 | .8 | 1.0 | 1.0 |
| .05 | .15 | .30 | .5 | .7 | 1.0 |
| 0 | .05 | .2 | .5 | .7 | 1.0 |

For the hypothetical [R] and [A] matrices described earlier, the results of this process are given below.

Expansive Growth

Percent Change in Impacts Over Time

| 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | |
|---|---|---|---|---|---|---|
| -0.00 | -0.03 | -0.09 | -0.19 | -0.26 | -0.26 | AC Fuel |
| -0.00 | -0.01 | -0.05 | -0.07 | -0.09 | -0.11 | Noise |

Resource Allocation

Percent Change in Impacts Over Time

| 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | |
|---|---|---|---|---|---|---|
| -0.00 | -0.04 | -0.11 | -0.18 | -0.23 | -0.24 | AC Fuel |
| -0.00 | -0.01 | -0.04 | -0.07 | -0.09 | -0.10 | Noise |

Muddling Through

Percent Change in Impacts Over Time

| 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | |
|---|---|---|---|---|---|---|
| -0.00 | -0.02 | -0.05 | -0.05 | -0.06 | -0.06 | AC Fuel |
| -0.00 | -0.01 | -0.02 | -0.02 | -0.03 | -0.02 | Noise |

Each cell of the output matrices represent the percent change of the particular impact area at each particular year due to the combined affects of all the application areas. In the Expansive Growth scenario, for example, there is no change in the impact areas in 1975 because there was hardly any implementation of the applications. However, by 2000 the total change in air carrier fuel consumption due to all applications was a decrease of 26 percent.

By taking the product matrix [RA] , adding 1 to all the cells and multipling times a matrix [M] which contains the actual level of the impact area for each year as forecasted by The Futures Group, new levels for the impact areas, taking the impact of microcomputers into consideration, can be arrived at. The [M] matrices for each scenario, as forecasted by The Futures Group, are given below.

Expansive Growth

| | | | | | | |
|---|---|---|---|---|---|---|
| 177.00 | 242.00 | 321.00 | 434.00 | 584.00 | 755.00 | AC Fuel |
| 7100.00 | 6030.00 | 5480.00 | 5050.00 | 7150.00 | 9390.00 | Noise |

Muddling Through

| | | | | | | |
|---|---|---|---|---|---|---|
| 177.00 | 189.00 | 176.00 | 173.00 | 167.00 | 162.00 | AC Fuel |
| 7100.00 | 5530.00 | 3780.00 | 3080.00 | 2670.00 | 2150.00 | Noise |

Resource Allocation

| | | | | | | |
|---|---|---|---|---|---|---|
| 177.00 | 218.00 | 245.00 | 275.00 | 289.00 | 294.00 | AC Fuel |
| 7100.00 | 4240.00 | 4380.00 | 3850.00 | 2990.00 | 2520.00 | Noise |

The output of the final calculation [RA + 1]*[M] , is given below.

Expansive Growth

Change in Impacts Over Time

| 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | |
|---|---|---|---|---|---|---|
| 176.60 | 235.55 | 290.57 | 352.67 | 432.16 | 555.68 | AC Fuel |
| 7092.90 | 5945.58 | 5233.40 | 4681.35 | 6506.50 | 8357.10 | Noise |

Resource Allocation

Change in Impacts Over Time

| 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | |
|---|---|---|---|---|---|---|
| 176.60 | 209.74 | 218.10 | 224.54 | 223.74 | 222.85 | AC Fuel |
| 7092.90 | 4182.76 | 4220.13 | 3563.18 | 2708.94 | 2268.00 | Noise |

Muddling Through

Change in Impacts Over Time

| 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | |
|---|---|---|---|---|---|---|
| 176.60 | 185.70 | 167.48 | 163.57 | 157.18 | 151.88 | AC Fuel |
| 7092.90 | 5488.52 | 3691.17 | 3004.54 | 2602.18 | 2104.85 | Noise |

While the theory behind using the matrix as an analytical tool is rather straightforward and simple, difficulties in the practical application of this technique made it impossible to use during this study. The data required to construct the [R] matrix was next to impossible to obtain.

The matrix is merely a method of aggregating specific affects determined earlier. For each possible application and impact area the following question must be asked: "What percent change in impact area X would occur due to a certain level of implementation, defined as 100 percent, of application Y?" In order to answer that question a great deal of preliminary analysis is required, much more than this study was able to undertake.

Other problems also hinder the use of the matrix approach. First of all, it is static. It assumes that the only thing that changes over time is the amount of implementation of a certain application.

The relationships between the impact and application areas remain unchanged. A second problem is that not all impact areas can be meaningfully quantified. For example the changes in ATC procedures due to on-board microcomputer navigation systems cannot meaningfully be expressed in numbers. Even with the problems outlined above, the matrix technique described in this section can be a useful tool in aggregating specific affects. By allowing the intensity of separate impacts to vary differently over time, the influences of separate parts can be studied. This tool, however, should not be expected to be useful in analyzing specific impacts. It is merely a way to aggregate an impact once the specific impact has been found. Used in this manner, the matrix concept can be very helpful in the analysis of technological impacts.

## APPENDIX C

## QSIM MODEL

One of the key factors that must be taken into consideration in an analysis of the impacts of microcomputers on the National Aviation System (NAS) is the dynamic nature of both the field of microcomputer technology and the entire NAS. As can be seen in Volume I of this study, microcomputer technology is rapidly changing. The NAS also constitutes a very dynamic system. Key factors such as the demand for air travel, the volume of air traffic, the financial condition of the airline industry and the demand for general aviation aircraft are dynamic in nature rather than static. Any analysis of the impacts of microcomputers on the NAS must take into account the changing nature of both the field of microcomputer technology and the NAS.

One way to undertake an analysis of a dynamic system is through the use of simulation models. QSIM (Quick Interactive Simulation Model) is a simulation modeling program that allows the relatively easy construction of simulation models for use in the analysis of dynamic systems. For a further description of QSIM see Wayne Wakeland's article, "QSIM II: A Low Budget Heuristic Approach to Modeling and Forecasting," Technology Forecasting and Social Change, Vol. 9, #1/2. Unfortunately the time and resource constraints of this study significantly reduced substantive use of QSIM. The following is an example of how

QSIM could be used in some future study to analyze certain quantifiable areas of the NAS. The example chosen was the analysis of FAA building space required for computer hardware. This NAS impact area was used because of the ability of key factors to be quantified and the availability of data. The possible future use of QSIM in other areas may be hampered for both of these reasons.

In order to understand how QSIM was used in this specific example it is important that the reader be familiar with the general use of QSIM. Those readers unfamiliar with QSIM are urged to first read the Wakeland article.

The following is a list of variables and their symbols.

B = SPAC - Building space required for computer hardware (thousands of sq.ft.)

C = COMP - FAA computer hardware (1 unit represents the 1975 level)

T = TIME (T=0 is 1975)

R = REPL - The percentage rate at which FAA replaces its existing computers with new computers (.01 = 1% units per year)

E = EXPN - The percentage rate at which FAA expands and purchases more computers (units per year)

N = NEWS - The space required for each unit of new computers (thousands of sq.ft.)

X = DBDT - rate of change of B (SPAC) over time

Y = DCDT - rate of change of C(COMP) over time

The variables B, C, and T are state variables with the following characteristics:

B, initial value - 300 (FAA currently uses about 300,000 sq. ft. for computer hardware at ARTCC's)

base rate of change - 0

C, initial value - 1

base rate of change - 0

T, initial value - 0

base rate of change - 1

The variables R, E and N are auxiliary variables with one term, T. Each of these variables are functions of the time variable, T and are entered as table functions of T. The use of the table function capabilities of QSIM allow the input of predetermined curves as a function of a time variable. Therefore the rates of computer replacement and expansion are allowed to vary drastically over time as each scenario changes. The rate of expansion for each scenario was set equal to the rate at which the number of aircraft operations grows, as forecasted by The Futures Group*. The replacement rate for each scenario was based upon what levels of replacement would seem appropriate for each scenario.

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* H. S. Becker, E. Fein, T. J. Gordon, F. Kropp, D. Tagoff, <u>Alternative Future Scenarios for the National Aviation System</u>, The Futures Group, Final Report, August 1975.

The rates for both R and E by scenario are given below.

Muddling Through

| | | | |
|---|---|---|---|
| when | T = 0 | E = .06 | R = .05 (5%) |
| | 5 | .06 | .05 |
| | 10 | 0 | .02 |
| | 25 | 0 | .02 |

Resource Allocation

| | | | |
|---|---|---|---|
| when | T = 0 | E = .06 | R = .05 |
| | 5 | .06 | .05 |
| | 10 | .045 | .1 |
| | 15 | .04 | -- |
| | 20 | .04 | -- |
| | 25 | .035 | .1 |

Expansive Growth

| | | | |
|---|---|---|---|
| when | T = 0 | E = .15 | R = .05 |
| | 5 | .18 | .1 |
| | 10 | .3 | .1 |
| | 12.5 | -- | .2 |
| | 15 | .5 | -- |
| | 20 | .15 | .2 |
| | 25 | .1 | .2 |

In the case of N, space required for new computers, this curve was a modification of the forecast for system volume in Chapter II. The microcomputer-based system used in Chapter II occupies approximately 16 $ft^3$. A comparable mainframe computer system takes up approximately 6500 $ft^3$. Assuming that the reduction in floor space is directly proportional to the reduction in volume, the mainframe systems that today need 300,000 sq. ft. would only use about 735 sq. ft. if they were microcomputer based. The amount of reduction between 300,000 sq. ft and 735 sq. ft. is directly proportional to the reduction from 6500 $ft^3$ to 16 $ft^3$. Further reductions in floor space were calculated in a like manner using the forecasted data for volume reductions given in Chapter II and are given below.

Muddling Through

| | | |
|---|---|---|
| when | T = 0 | N = .735 (thousands sq. ft) |
| | 5 | .18 |
| | 15 | .04 |
| | 25 | .02 |

Resource Allocation

| | | |
|---|---|---|
| when | T = 0 | N = .735 |
| | 5 | .18 |
| | 10 | .04 |
| | 15 | .02 |
| | 25 | .01 |

Expansive Growth

| | | |
|---|---|---|
| when | T = 0 | N = .735 |
| | 5 | .18 |
| | 7.5 | .04 |
| | 10 | .02 |
| | 15 | .01 |

The variables X(db/dt) and Y(dc/dt) are also auxiliary variables which express the following equations:

(1) $X = ECN + RCN - RB$

(2) $Y = EC$

Equation (2) indicates that the rate of change of C over time or the number of computer units added is equal to the rate of expansion, E times the current number of computer units, C. For example if in 1980 (T = 5) FAA had 2 units of computer equipment, C = 2 (twice as much as in 1975) and was adding at a rate of 10% per year, E = .1 then the number of units to be added would be 2 x .1 or .2 units. By using the interaction matrix to set the rate of change of C equal to X, equation (2) becomes the growth equation for the amount of computer hardware using the 1975 level as a base.

Equation (1) gives the actual growth in building space required. The first term, ECN, tells us how much additional space is required for new computer systems bought to expand FAA's computer capability. For example if in 1980 FAA had 2 units of computer systems, C = 2, was expanding at 10% per year, E = .1 and each unit took up 180 sq. ft., N = .18, then the amount of floor space needed for the computer expansion would be 2 x .1 x .18 or 36 sq. ft. The second term, RCN, tells us how much space would be needed for the computers used to replace older computers. The logic behind it is the same as for the first term. The third term, - RB, tells us how much floor space is being vacated by replacing of older computers. For example, if the floor space used for FAA's computer hardware in 1980 is 100,000 sq. ft., B = 100, and FAA is replacing older equipment at a rate of 5% per year, R = .05, then the amount of space formerly used by that 5% but that will be empty is .05 x 300 or 15 thousand sq. ft.

Combining all three terms tells us that the rate of change of B or the amount of building space needed to be added for computer hardware is the amount of space needed for new systems purchased for expansion plus the amount of space need for new systems purchased to replace older systems minus the space vacated by getting rid of the older equipment. Using the figures in the examples above db/dt = x = 2 x .1 x .18 + 2 x .05 x .18 - .05 x 100 or -14.946. This shows that even though FAA is adding 10% to its computer capabilities, because it is replacing 5% of its current computer capability with newer, smaller systems there is a net gain of 14,946 sq. ft. Again the interaction matrix is used to set the actual rate of change of B equal to the value of X, the calculated rate of change of B. Equation (1) therefore becomes the equation of the growth of building space needed for computer hardware.

In order to set $\dot{C}$ (dc/dt) equal to Y and $\dot{B}$ (db/dt) equal to X, these relationships should describe straight lines through the origin (0,0) with a slope of 1. The actual tables used are as follows:

when $X = -100$, $\dot{B} = -100$

0, 0

100, 100

when $Y = -10$, $\dot{C} = -10$

0 0

10 10

Using the QSIM Model described above, three computer runs were made, one for each scenario with the appropriate values for E, R and N used. The output for each of the runs, in both table and graph form is given below.

Muddling Through

| TIME | spac | comp | time | repl | expn | news | dbdt | dcdt |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 300.0 | 1.0 | 0.0 | 0.1 | 0.1 | 0.7 | -14.9 | 0.1 |
| 1.0 | 285.1 | 1.1 | 1.0 | 0.1 | 0.1 | 0.6 | -14.2 | 0.1 |
| 2.0 | 270.9 | 1.1 | 2.0 | 0.1 | 0.1 | 0.5 | -13.5 | 0.1 |
| 3.0 | 257.4 | 1.2 | 3.0 | 0.1 | 0.1 | 0.4 | -12.8 | 0.1 |
| 4.0 | 244.6 | 1.3 | 4.0 | 0.1 | 0.1 | 0.3 | -12.2 | 0.1 |
| 5.0 | 232.4 | 1.3 | 5.0 | 0.1 | 0.1 | 0.2 | -11.6 | 0.1 |
| 6.0 | 220.8 | 1.4 | 6.0 | 0.0 | 0.0 | 0.2 | -9.7 | 0.1 |
| 7.0 | 211.1 | 1.5 | 7.0 | 0.0 | 0.0 | 0.2 | -8.0 | 0.1 |
| 8.0 | 203.1 | 1.5 | 8.0 | 0.0 | 0.0 | 0.1 | -6.5 | 0.0 |
| 9.0 | 196.6 | 1.6 | 9.0 | 0.0 | 0.0 | 0.1 | -5.1 | 0.0 |
| 10.0 | 191.5 | 1.6 | 10.0 | 0.0 | 0.0 | 0.1 | -3.8 | 0.0 |
| 11.0 | 187.7 | 1.6 | 11.0 | 0.0 | 0.0 | 0.1 | -3.8 | 0.0 |
| 12.0 | 183.9 | 1.6 | 12.0 | 0.0 | 0.0 | 0.1 | -3.7 | 0.0 |
| 13.0 | 180.3 | 1.6 | 13.0 | 0.0 | 0.0 | 0.1 | -3.6 | 0.0 |
| 14.0 | 176.7 | 1.6 | 14.0 | 0.0 | 0.0 | 0.1 | -3.5 | 0.0 |
| 15.0 | 173.1 | 1.6 | 15.0 | 0.0 | 0.0 | 0.0 | -3.5 | 0.0 |
| 16.0 | 169.7 | 1.6 | 16.0 | 0.0 | 0.0 | 0.0 | -3.4 | 0.0 |
| 17.0 | 166.3 | 1.6 | 17.0 | 0.0 | 0.0 | 0.0 | -3.3 | 0.0 |
| 18.0 | 163.0 | 1.6 | 18.0 | 0.0 | 0.0 | 0.0 | -3.3 | 0.0 |
| 19.0 | 159.7 | 1.6 | 19.0 | 0.0 | 0.0 | 0.0 | -3.2 | 0.0 |
| 20.0 | 156.5 | 1.6 | 20.0 | 0.0 | 0.0 | 0.0 | -3.1 | 0.0 |
| 21.0 | 153.4 | 1.6 | 21.0 | 0.0 | 0.0 | 0.0 | -3.1 | 0.0 |
| 22.0 | 150.3 | 1.6 | 22.0 | 0.0 | 0.0 | 0.0 | -3.0 | 0.0 |
| 23.0 | 147.3 | 1.6 | 23.0 | 0.0 | 0.0 | 0.0 | -2.9 | 0.0 |
| 24.0 | 144.4 | 1.6 | 24.0 | 0.0 | 0.0 | 0.0 | -2.9 | 0.0 |
| 25.0 | 141.5 | 1.6 | 25.0 | 0.0 | 0.0 | 0.0 | -2.8 | 0.0 |

```
spac=b, comp=c, time=t, repl=r, expn=e, news=n, dbdt=x, dcdt=y,
(b     ).0        60.00      120.00      180.00      240.00      300.00
(c     ).0         0.40        0.80        1.20        1.60        2.00
(er    ).0         0.02        0.04        0.06        0.08        0.10
TIME-------------------------------------------------------------------
 0.0    .           .           .    rc    e.           .           b
 1.0    .           .           .    r c   e.           .        b  .
 2.0    .           .           .    r   c e.           .     b     .
 3.0    .           .           .    r     e.           .  b        .
 4.0    .           .           .    r     e.c          b           .
 5.0    .           .           .    r     e.   c     b .           .
 6.0    .           .           . r e       .     c b   .           .
 7.0    .           .        er .           .     b c   .           .
 8.0    .           . e    r    .           .   b     c .           .
 9.0    .      e    .  r        .           .  b       c.           .
10.0    e           r           .           . b        c.           .
11.0    e          r.           .           .b         c.           .
12.0    e          r.           .           b          c.           .
13.0    e          r.           .           b          c.           .
14.0    e          r.           .          b.          c.           .
15.0    e          r.           .         b .          c.           .
16.0    e          r.           .        b  .          c.           .
17.0    e          r.           .        b  .          c.           .
18.0    e          r.           .       b   .          c.           .
19.0    e          r.           .      b    .          c.           .
20.0    e          r.           .      b    .          c.           .
21.0    e          r.           .     b     .          c.           .
22.0    e          r.           .     b     .          c.           .
23.0    e          r.           .    b      .          c.           .
24.0    e          r.           .   b       .          c.           .
25.0    e          r.           .   b       .          c.           .
```

Resource Allocation

| TIME | SPAC | COMP | TIME | REPL | EXPN | NEWS | DBDT | DCDT |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 300.0 | 1.0 | 0.0 | 0.1 | 0.1 | 0.7 | -14.9 | 0.1 |
| 1.0 | 285.1 | 1.1 | 1.0 | 0.1 | 0.1 | 0.6 | -14.2 | 0.1 |
| 2.0 | 270.9 | 1.1 | 2.0 | 0.1 | 0.1 | 0.5 | -13.5 | 0.1 |
| 3.0 | 257.4 | 1.2 | 3.0 | 0.1 | 0.1 | 0.4 | -12.8 | 0.1 |
| 4.0 | 244.6 | 1.3 | 4.0 | 0.1 | 0.1 | 0.3 | -12.2 | 0.1 |
| 5.0 | 232.4 | 1.3 | 5.0 | 0.1 | 0.1 | 0.2 | -11.6 | 0.1 |
| 6.0 | 220.8 | 1.4 | 6.0 | 0.1 | 0.1 | 0.2 | -13.2 | 0.1 |
| 7.0 | 207.6 | 1.5 | 7.0 | 0.1 | 0.1 | 0.1 | -14.5 | 0.1 |
| 8.0 | 193.1 | 1.6 | 8.0 | 0.1 | 0.1 | 0.1 | -15.4 | 0.1 |
| 9.0 | 177.7 | 1.7 | 9.0 | 0.1 | 0.0 | 0.1 | -16.0 | 0.1 |
| 10.0 | 161.7 | 1.7 | 10.0 | 0.1 | 0.0 | 0.0 | -16.2 | 0.1 |
| 11.0 | 145.5 | 1.8 | 11.0 | 0.1 | 0.0 | 0.0 | -14.5 | 0.1 |
| 12.0 | 131.0 | 1.9 | 12.0 | 0.1 | 0.0 | 0.0 | -13.1 | 0.1 |
| 13.0 | 117.9 | 2.0 | 13.0 | 0.1 | 0.0 | 0.0 | -11.8 | 0.1 |
| 14.0 | 106.1 | 2.1 | 14.0 | 0.1 | 0.0 | 0.0 | -10.6 | 0.1 |
| 15.0 | 95.5 | 2.1 | 15.0 | 0.1 | 0.0 | 0.0 | -9.5 | 0.1 |
| 16.0 | 86.0 | 2.2 | 16.0 | 0.1 | 0.0 | 0.0 | -8.6 | 0.1 |
| 17.0 | 77.4 | 2.3 | 17.0 | 0.1 | 0.0 | 0.0 | -7.7 | 0.1 |
| 18.0 | 69.6 | 2.4 | 18.0 | 0.1 | 0.0 | 0.0 | -7.0 | 0.1 |
| 19.0 | 62.7 | 2.5 | 19.0 | 0.1 | 0.0 | 0.0 | -6.3 | 0.1 |
| 20.0 | 56.4 | 2.6 | 20.0 | 0.1 | 0.0 | 0.0 | -5.6 | 0.1 |
| 21.0 | 50.8 | 2.7 | 21.0 | 0.1 | 0.0 | 0.0 | -5.1 | 0.1 |
| 22.0 | 45.7 | 2.8 | 22.0 | 0.1 | 0.0 | 0.0 | -4.6 | 0.1 |
| 23.0 | 41.1 | 2.9 | 23.0 | 0.1 | 0.0 | 0.0 | -4.1 | 0.1 |
| 24.0 | 37.0 | 3.0 | 24.0 | 0.1 | 0.0 | 0.0 | -3.7 | 0.1 |
| 25.0 | 33.3 | 3.1 | 25.0 | 0.1 | 0.0 | 0.0 | -3.3 | 0.1 |

Resource Allocation

```
SPAC=B, COMP=C, TIME=T, REPL=R, EXPN=E, NEWS=N, DBDT=X, DCDT=Y,
(B     ).0        60.00      120.00      180.00      240.00      300.00
(C     ).0         0.80        1.60        2.40        3.20        4.00
(RE    ).0         0.02        0.04        0.06        0.08        0.10
TIME-------------------------------------------------------------------
 0.0    .           .  C        .    R     E.           .           B
 1.0    .           .  C        .    R     E.           .         B .
 2.0    .           .   C       .    R     E.           .     B     .
 3.0    .           .    C      .    R     E.           .  B        .
 4.0    .           .     C     .    R     E.           B           .
 5.0    .           .       C   .    R     E.         B .           .
 6.0    .           .        C  .         ER.       B   .           .
 7.0    .           .         C .       E   .    R      .           .

 8.0    .           .          C.     E     . B        R.           .
 9.0    .           .           C   E      B.           .    R      .
10.0    .           .           . CE    B   .           .          R.
11.0    .           .           . EC B      .           .          R.
12.0    .           .           .EB C       .           .          R.
13.0    .           .          B.E   C      .           .          R.
14.0    .           .        B  E     C     .           .          R.
15.0    .           .      B   E.       C   .           .          R.
16.0    .           .    B     E.        C  .           .          R.
17.0    .           .  B       E.         C .           .          R.
18.0    .           .B         E.           C           .          R.
19.0    .           B          E.           .C          .          R.
20.0    .          B.          E.           .  C        .          R.
21.0    .         B .          E.           .   C       .          R.
22.0    .        B  .         E .           .     C     .          R.
23.0    .       B   .         E .           .      C    .          R.
24.0    .      B    .        E  .           .        C  .          R.
25.0    .     B     .       E   .           .          C.          R.
```

Expansive Growth

| TIME | SPAC | COMP | TIME | REPL | EXPN | NEWS | DBDT | DCDT |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 300.0 | 1.0 | 0.0 | 0.1 | 0.1 | 0.7 | -14.9 | 0.2 |
| 1.0 | 285.1 | 1.1 | 1.0 | 0.1 | 0.2 | 0.6 | -17.0 | 0.2 |
| 2.0 | 268.2 | 1.3 | 2.0 | 0.1 | 0.2 | 0.5 | -18.6 | 0.2 |
| 3.0 | 249.6 | 1.5 | 3.0 | 0.1 | 0.2 | 0.4 | -19.8 | 0.3 |
| 4.0 | 229.8 | 1.8 | 4.0 | 0.1 | 0.2 | 0.3 | -20.5 | 0.3 |
| 5.0 | 209.2 | 2.1 | 5.0 | 0.1 | 0.2 | 0.2 | -20.8 | 0.4 |
| 6.0 | 188.4 | 2.5 | 6.0 | 0.1 | 0.2 | 0.1 | -18.7 | 0.5 |
| 7.0 | 169.7 | 3.0 | 7.0 | 0.1 | 0.2 | 0.1 | -16.9 | 0.7 |
| 8.0 | 152.8 | 3.7 | 8.0 | 0.1 | 0.3 | 0.0 | -15.2 | 0.9 |
| 9.0 | 137.5 | 4.6 | 9.0 | 0.1 | 0.3 | 0.0 | -13.7 | 1.3 |
| 10.0 | 123.8 | 5.9 | 10.0 | 0.1 | 0.3 | 0.0 | -12.3 | 1.8 |
| 11.0 | 111.5 | 7.7 | 11.0 | 0.1 | 0.3 | 0.0 | -15.5 | 2.6 |
| 12.0 | 96.0 | 10.3 | 12.0 | 0.2 | 0.4 | 0.0 | -17.2 | 3.9 |
| 13.0 | 78.8 | 14.2 | 13.0 | 0.2 | 0.4 | 0.0 | -15.6 | 6.0 |
| 14.0 | 63.1 | 20.2 | 14.0 | 0.2 | 0.5 | 0.0 | -12.5 | 9.3 |
| 15.0 | 50.7 | 29.4 | 15.0 | 0.2 | 0.5 | 0.0 | -9.9 | 14.7 |
| 16.0 | 40.7 | 44.1 | 16.0 | 0.2 | 0.4 | 0.0 | -7.9 | 19.0 |
| 17.0 | 32.8 | 63.1 | 17.0 | 0.2 | 0.4 | 0.0 | -6.4 | 22.7 |
| 18.0 | 26.5 | 85.8 | 18.0 | 0.2 | 0.3 | 0.0 | -5.1 | 24.9 |
| 19.0 | 21.3 | 110.7 | 19.0 | 0.2 | 0.2 | 0.0 | -4.2 | 24.4 |
| 20.0 | 17.2 | 135.1 | 20.0 | 0.2 | 0.2 | 0.0 | -3.4 | 20.3 |
| 21.0 | 13.7 | 155.4 | 21.0 | 0.2 | 0.1 | -0.0 | -2.9 | 21.7 |
| 22.0 | 10.9 | 177.1 | 22.0 | 0.2 | 0.1 | -0.0 | -2.4 | 23.0 |
| 23.0 | 8.5 | 200.1 | 23.0 | 0.2 | 0.1 | -0.0 | -2.1 | 24.0 |
| 24.0 | 6.4 | 224.1 | 24.0 | 0.2 | 0.1 | -0.0 | -1.8 | 24.7 |
| 25.0 | 4.6 | 248.8 | 25.0 | 0.2 | 0.1 | -0.0 | -1.7 | 24.9 |

## Expansive Growth

```
SPAC=B, COMP=C, TIME=T, REPL=R, EXPN=E, NEWS=N, DBDT=X, DCDT=Y,
(B     ).0        60.00      120.00      180.00      240.00      300.00
(C     ).0        50.00      100.00      150.00      200.00      250.00
(ER    ).0         0.20        0.40        0.60        0.80        1.00
TIME-------------------------------------------------------------------
 0.0    C  R    E   .           .           .           .           B
 1.0    C  R     E  .           .           .           .        B  .
 2.0    C   R    E  .           .           .           .    B      .
 3.0    C   R     E .           .           .           .B          .
 4.0    C    R    E .           .           .        B  .           .
 5.0    C    R    E .           .           .    B      .           .
 6.0    C     R     E           .           .B          .           .
 7.0    C     R     .E          .        B  .           .           .
 8.0    C     R     .  E        .     B     .           .           .
 9.0    .C    R     .   E       .  B        .           .           .
10.0    .C    R     .    E      B           .           .           .
11.0    .C      R   .       E B .           .           .           .
12.0    . C       R .      B  E .           .           .           .
13.0    .  C       R.  B        .E          .           .           .
14.0    .   C      RB           .  E        .           .           .
15.0    .      C  BR.           .    E      .           .           .
16.0    .       B CR.           .E          .           .           .
17.0    .     B    R.  C     E  .           .           .           .
18.0    .    B     R.    E  C   .           .           .           .
19.0    .   B      R.E          . C         .           .           .
20.0    .  B     E R.           .       C   .           .           .
21.0    . B     E  R.           .           .C          .           .
22.0    . B    E   R.           .           .     C     .           .
23.0    .B     E   R.           .           .           C           .
24.0    .B    E    R.           .           .           .    C      .
25.0    B     E    R.           .           .           .          C.
```

The results of the three runs show the value of QSIM as an analytical tool. An analysis of the runs confirm what was said about FAA building space for computer hardware in Chapter IV. The amount of building space needed for computer hardware decreases rapidly in all three scenarios. Even the explosive increase in the amount of computer hardware in the Expansive Growth scenario (C = 248 by the year 2000) is not enough to offset the decrease in computer system size.

The model also raises new questions. For example, is the decrease in building space more the result of replacement of old mainframe computers with today's state-of-the-art microcomputer system or the result of the decrease in the size of future microcomputer systems? Further analysis using these and other models would prove to be useful.

# APPENDIX D

## INTERVIEWS

The following is a list of individuals interviewed by the assessment team during the technology assessment portion of the study.

Bailey, David, Air Transport System Division, MITRE

Carson, C. Wesley, Chief, Policy Development Division, Office of Aviation Policy, Federal Aviation Administration

Etgen, James R., Assistant Division Chief, Maintenance Program Division, Airway Facilities Service, Federal Aviation Administration

Evans, Ted, Data Systems Specialist, Detroit Metropolitan Airport

Fisher, Charles, Passenger Services, Air Traffic Conference of America

Flavin, John W., Chief, Avionics Staff, Air Carrier Division, Flight Standards Service, Federal Aviation Administration

Flax, Bennett, Enroute Automation Branch, Automation Branch, Airway Flacilities Service, Federal Aviation Administration

Gray, Kenneth, Technical Advisor, Systems Research and Development Branch, Federal Aviation Administration

Gumina, Leo, Windshear/WVAS, Airport Division, Systems Research and Development Service, Federal Aviation Administration

Harris, Ken, Senior Policy Analyst, System Concepts Branch, Policy Development Division, Office of Aviation Policy, Federal Aviation Administration

Harris, R. Mike, Air Transport System Division, MITRE

Hodgkins, Phillip O., Chief (Acting), DABS-IPC Branch, Systems Research and Development Service, Federal Aviation Administration

Holliday, Gerald, Chief, Avionics Staff, General Aviation Division, Flight Standards Service, Federal Aviation Administration

Israel, David, Assistant Administrator, Field Operations, Energy Research and Development Administration

Jackson, Lynn, Chief, System Concepts Branch, Policy Development Division, Office of Aviation Policy, Federal Aviation Administration

Kye, Mitchell, Data Systems Officer, Detroit Metropolitan Airport

McIntire, Owen E., Chief, CAS/PWI Section, Systems Research and Development Service, Federal Aviation Administration

Meer, Ahmed, Applications System Analysis Office, Goddard Space Administration

Pierson, Harold, Air Transport System Division, MITRE

Roche, Robert J., Chief, Flight Service Station Branch, Systems Research and Development Service, Federal Aviation Administration

Rucker, Richard, Air Transport System Division, MITRE

Russell, William, Air Transport Association of America

Selrig, George, Assistant Chief, Air Traffic Controller Crew, Detroit Metropolitan Airport

Simolunas, Arthur, Chief, Enroute Navigation Branch, Systems Research and Development Service, Federal Aviation Administration

Sinha, Agam, Air Transport System Division, MITRE

Sutton, S. Scott, Director (Acting), Office of Aviation Policy, Federal Aviation Administration

Tracy, James, Coordination Staff, Microwave Landing System Division, Systems Research and Development Service, Federal Aviation Administration

Ward, Jerry D., Director, Office of Research and Development Policy, Department of Transportation

Zellweger, Andres G., Advanced Concepts Staff, Office of Systems Engineering Management, Federal Aviation Administration

## APPENDIX E

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UNCLASSIFIED OTSD-77-609-9-2 NL

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