COPY 1

Report No. FAA-EM-76-1

COST ANALYSIS OF AIRBORNE COLLISION AVOIDANCE SYSTEMS (CAS) CONCEPTS

FINAL REPORT

WAFIC
LIBRARY
APR 14 '76

Stanley Kowalski
J. Kent Haspert
James Witt

December 1975

PREPARED FOR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Systems Engineering Management
Washington, D. C. 20591

Technical Report Documentation Page

1. Report No. FAA-EM-76-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: Cost Analysis of Airborne Collision Avoidance Systems (CAS) Concepts		5. Report Date: December 1975
		6. Performing Organization Code: 1306-01-1-1479
7. Author(s): Stanley Kowalski, J. Kent Haspert, James Witt		8. Performing Organization Report No.
9. Performing Organization Name and Address: ARINC Research Corporation, A Subsidiary of Aeronautical Radio, Inc., 2441 Riva Road, Annapolis, Md. 21401		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOT-FA74WA-3506
12. Sponsoring Agency Name and Address: Department of Transportation, Federal Aviation Administration, Office of Systems Engineering Management, Washington, D.C. 20591		13. Type of Report and Period Covered: Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report presents the results of the cost and operational evaluations developed for three CAS Concepts: the Honeywell AVOIDS, the McDonnell Douglas EROS, and the RCA SECANT. To provide a basis for assessing the economic impact of CAS on the various aviation communities, separate cost evaluations have also been developed for general aviation, commercial aviation, and the military.

This report presents the expected cost of ownership to the individual aircraft owner and the cumulative life-cycle costs to the user communities, based on the competing manufacturers' data and independently developed electronics and installation cost data.

17. Key Words: CAS, AVOIDS, EROS, SECANT	18. Distribution Statement: Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	282	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

Throughout the Cost of Airborne Collision Avoidance Systems study, ARINC Research received enthusiastic and invaluable support from the management and engineering departments of the CAS manufacturers. The Federal Aviation Administration furnished the overall guidance for the study, while the manufacturers supplied the basic data necessary for an independent evaluation of the concepts.

While space does not permit listing the names of all those who contributed to the study, we are pleased to acknowledge our indebtedness to the following persons for their assistance: Ron Erickson and Charles P. Harman of Honeywell; L.J. Robertson, M. Borrok, and Walter Weiss of McDonnell Douglas Electronics Company; Peter B. Korda and James R. Hall of RCA.

SUMMARY

ARINC Research orporation is under contract to the Federal Aviation Administration (Contract DOT-FA74WA-3506) to provide assistance in the development and evaluation of cost and operational factors that will affect the FAA policy regarding Collision Avoidance Systems (CAS) as a national standard.

Cost and operational evaluations have been developed for the Honeywell AVOIDS CAS, the McDonnell Douglas EROS CAS, and the RCA SECANT CAS concepts. To provide a basis for assessing the economic impact of CAS on the various aviation communities, separate cost evaluations have also been developed for general aviation, commercial aviation, and the military.

The classes of equipment studied have been limited to a full-capability CAS (i.e., one based on ANTC 117 vertical threat logic for commercial air carriers and other high-performance aircraft), referred to as a Type I CAS; and a limited-capability CAS intended for general-aviation aircraft, referred to as a Type II CAS. This was done in an attempt to bound the problem by pricing out the most expensive (air carrier Type I) and the least expensive (general aviation Type II) electronics. In addition, the three manufacturers were also asked to submit data on a collision avoidance device that provides no collision-avoidance protection itself but allows other CAS-equipped aircraft to execute collision avoidance with aircraft carrying this device. Because only RCA proposed such a device, known as a remitter or CAD, the cost impact was treated as a special case in the overall analysis.

To develop the costs associated with implementing each of the three CAS concepts, it was assumed that CAS implementation would begin in 1978. The number of CAS units to be installed each year was estimated and CAS life cycle costs were developed from 1978 through 1988. The costs to be borne by the commercial carrier, military, and general-aviation user communities were developed. The cost analyses required the development of detailed cost and reliability data peculiar to each of the CAS systems and the three CAS concepts. System costs based on these data were evaluated with the aid of an economic cost model.

The cost and reliability data describing each of the three system concepts provided the basis for the economic comparison of the three systems. These data were critical to the overall success of the study and were therefore developed with extreme care. Two sources for these data were used. First, the three manufacturers were requested to provide detailed cost and reliability data on their proposed system. Several successive data submissions, each providing more detailed data, were made by each of the manufacturers; at the end of this process very detailed system cost and reliability data were available. An independent system cost and reliability analyses were conducted based on the supplied designs to provide a comparison between the manufacturer-supplied data and to provide an independent data upon which additional comparative CAS economic analyses could be based. The equipment cost based on the independent evaluations is presented in Table S-1.

Factors such as aircraft installation costs, equipment distribution costs, and the numbers of aircraft installing CAS on a year-by-year basis were assumed to apply equally to each CAS concept. They were developed so that the total cost of CAS implementation could be determined. These factors produced virtually identical effects on the predicted costs associated with the three CAS concepts.

The individual aircraft costs and the combined user community costs of CAS implementation were developed using both the manufacturer-supplied data and the independently derived system cost and reliability data. A summary of the CAS Cost Analysis based on the independent evaluation is presented in Table S-2. These cost analyses showed that the Honeywell CAS concept is the least costly to implement, the McDonnell Douglas CAS falls in the middle, and the RCA CAS concept is the most costly. This relative ranking was maintained even when a number of the basic assumptions and data inputs were varied. However, for the special case in which the RCA remitter was included in the aircraft scenario, the RCA system costs were reduced below those of the McDonnell Douglas systems, but remained higher than those of the Honeywell systems. The remitter case was not subjected to an independent evaluation, and therefore is not included in Table S-2. Table S-3 presents the total life-cycle costs to the entire aviation community for each of the three CAS concepts at the three annual inflation rates used in the study.

Table S-1. CAS COST OF EQUIPMENT (INDEPENDENTLY DEVELOPED DATA ONLY)

Unit	AVOIDS			EROS			SECANT		
	Type I	Type II Without Encoder	Type II With Encoder	Type I	Type II Without Encoder	Type II With Encoder	Type I	Type II Without Encoder	Type II With Encoder
Principal Electronics*	$4012	$565	$703	$4694	$998	$1138	$5501	$1148	$1296
Indicator	1092	0	0	1092	0	0	1092	0	0
Antenna	63	13	13	63	13	13	63	13	13
Control	0	0	0	0	0	0	127	0	0

*Costs are manufacturers' estimated OEM prices, without mark-up for distribution.

Type I equipment is for commercial aviation and other high performance military and general aviation aircraft.
Type II equipment is intended for the limited performance (less than 250 knots) military and general aviation aircraft.

Table S-2. SUMMARY OF CAS COST ANALYSIS (INDEPENDENTLY DEVELOPED DATA)

COST CATEGORY	COMMERCIAL AVIATION			MILITARY AVIATION			GENERAL AVIATION		
	AVOIDS	EROS	SECANT	AVOIDS	EROS	SECANT	AVOIDS	EROS	SECANT
Cost of Acquiring and Installing CAS in a Single Aircraft. (ZERO Percent Inflation)	$ 10549	$ 11231	$ 12165	$ 14574	$ 15256	$ 16189	$ 1156 1377	$ 1823 2060	$ 2076 2312
Anticipated 11-Year Life Cycle Cost for a Single Aircraft. (ZERO Percent Inflation)	14382	14730	16286	18374	19007	20064	1407 1632	2253 2489	2425 2665
Total Life Cycle Cost for the Entire User Community (ZERO Percent Inflation Rate)	46.9M	48.3M	53.5M	219.8M	237.2M	247.8M	411.9M 464.1M	602.2M 650.6M	658.8M 708.1M
Total Life Cycle Cost for the Entire User Community (Six Percent Inflation Rate	67.5M	68.8M	76.3M	316.1M	338.5M	357.4M	598.2M 709.7M	873.9M 993.1M	975.9M 1081.9M
Total Life Cycle Cost for the Entire User Community (Ten Percent Inflation Rate)	82.6M	83.8M	93.4M	395.4M	429.0M	438.5M	829.4M 934.2M	1218.4M 1316.0M	1280.9M 1420.5M

NOTES:

1. The underlined values represent the costs of CAS when altitude encoding is included in the general aviation community. (It is assumed that CA and MIL already are equipped with encoders.)

2. The individual aircraft data for the military apply to high performance aircraft which is the major category of military aircraft. The user community life cycle costs include the combination of high and low performance aircraft.

3. The individual aircraft data for general-aviation apply to the low performance aircraft which the major category of general aviation aircraft. The user community life-cycle costs include the combination of high and low performance aircraft.

4. Life cycle costs for the users of EROS systems do not include the cost of the minimum of five mandatory ground stations required for system synchronization. Depending upon the actual number of ground stations that would be required, this could represent a major increase in the EROS costs.

5. The aircraft statistics forecasts are based on FAA-provided data.

Table S-3. TOTAL COST OF CAS IMPLEMENTATION [1] (Independently Developed Data)			
	AVOIDS	EROS	SECANT
Total Life Cycle Cost for the Aviation Community (ZERO Percent Inflation)	$ 678.6M 730.8M	$ 887.7M 936.1M	$ 960.1M 1009.4M
Total Life-Cycle Cost for the Aviation Community (Six Percent Inflation)	981.8M 1094.1M	1281.2M 1396.8M	1409.6M 1506.0M
Total Life-Cycle Cost for the Aviation Community (Ten Percent Inflation)	1307.4M 1412.2M	1731.2M 1828.8M	1812.8M 1952.4M

[1] The underlined values represent the total costs of implementing CAS including altitude encoding in the entire general aviation community.

A separate evaluation of the operability features of the three CAS concepts was also performed to determine the operational problems (i.e., undetected system failures) that would result from the inevitable failures of avionics equipments. Failures were grouped into two categories, immediately detectable and undetectable until a routine equipment checkout is performed, and the undetectable failures were used as a basis for an operability ranking of the CAS concepts. As a result of its extensive built-in test capability, the McDonnell Douglas CAS concept was found to have the fewest undetected system failures.

TABLE OF CONTENTS

	Page
Summary	v
Chapter One - INTRODUCTION	1-1
1.1 Background	1-1
1.2 Contract Objectives	1-2
1.3 Scope	1-2
1.4 Report Organization	1-2
Chapter Two - ANALYSIS APPROACH	2-1
2.1 Development of Ground Rules for the CAS Cost Analysis	2-3
2.2 Development of the Economic Analysis Model (EAM)	2-4
2.3 System Data Elements	2-4
2.4 Common Data Elements	2-5
2.5 Approach Summary	2-6
Chapter Three - CAS EQUIPMENT COST AND RELIABILITY DEVELOPMENT	3-1
3.1 System Descriptions	3-1
3.2 Summary of Manufacturer-Supplied Cost and Reliability Data	3-4
3.3 Independently Derived Data	3-9
Chapter Four - CAS INSTALLATION DATA	4-1
4.1 Cost of CAS-Related Electronics Components	4-1
4.2 Distribution Costs	4-4
4.3 Aircraft Configurations	4-5
4.4 Installation Costs	4-7
4.5 Aircraft Scenarios	4-12
Chapter Five - INDIVIDUAL AIRCRAFT AND FLEET COSTS FOR CAS IMPLEMENTATION	5-1
5.1 Cost Model	5-1
5.2 Additional Inputs Required by the Model	5-2
5.3 Results of Applying the Life-Cycle Cost Model	5-2

TABLE OF CONTENTS
(continued)

		Page
Chapter Six -	SENSITIVITY OF THE CAS COST ANALYSES TO PARAMETER VARIATIONS AND ALTERNATIVE ASSUMPTIONS	6-1
6.1	Sensitivity of Life-Cycle Cost to MTBF Variations	6-1
6.2	The Effect of Various Mixes of CAS in the Military Fleet	6-4
6.3	The Effect of Including Amortization of Manufacturer Start-Up Costs	6-4
6.4	The Cost Impact of the Remitter	6-12
6.5	The Effect of Providing Redundant Electronics in the Commercial Air Carrier Community	6-14
Chapter Seven -	CAS OPERABILITY EVALUATION	7-1
7.1	Relationship of CAS to the ATC System	7-2
7.2	CAS Failures and Failure Detection Methods	7-4
7.3	Examination of Failures in the Three Candidate CAS Concepts	7-6
7.4	Formulation of the Operability Analysis Equations	7-12
7.5	Analytical Assessment of Candidate CAS Operability	7-16
7.6	Overall CAS Operability	7-20
Chapter Eight -	THE COST OF ALTITUDE ENCODERS FOR THE GENERAL-AVIATION COMMUNITY	8-1
8.1	Altitude Encoding	8-1
8.2	The Honeywell Blind Encoder	8-2
8.3	Honeywell Encoder Cost Development	8-2
8.4	NARCO Blind Encoder	8-6
8.5	NARCO Encoder Cost Development	8-6
8.6	Application of Encoders to the CAS Concepts	8-7
8.7	Encoder Reliability and Maintainability	8-8
8.8	Cost of Ownership and Life-Cycle Costs	8-9
Chapter Nine -	RESULTS AND CONCLUSIONS OF CAS COST AND OPERABILITY ANALYSES	9-1
9.1	Review of the CAS Cost Analyses	9-1
9.2	Discussion of the Sensitivity Analyses	9-3
9.3	Discussion of the Operability Analyses	9-4
9.4	Discussion of the Altitude Encoders For General-Aviation	9-5
9.5	Relation of the CAS Cost and Operability Analyses to the Development of a National CAS Standard	9-5

TABLE OF CONTENTS
(continued)

		Page
Appendix A -	Uniform Ground Rules	A-1
Appendix B -	Manufacturers' Data	B-1
Appendix C -	Independently Developed Cost and Reliability	C-1
Appendix D -	Life-Cycle-Cost Model	D-1
Appendix E -	Common Parameters Affecting Life Cycle Costs	E-1
Appendix F -	Results of GA Installation Facilities Response to Questionnaire	F-1

LIST OF TABLES

Table 3-1	Main CAS Parameters and Design Features	3-2
3-2	Manufacturer's Cost and Reliability Data (Honeywell)	3-5
3-3	Manufacturer's Cost and Reliability Data (McDonnell Douglas)	3-6
3-4	Manufacturer's Cost and Reliability Data (RCA)	3-7
3-5	Honeywell AVOIDS I Parts Breakdown (Type I)	3-11
3-6	McDonnell Douglas EROS Parts Breakdown (Type II)	3-12
3-7	RCA SECANT Parts Breakdown (Type I)	3-13
3-8	Honeywell AVOIDS I System Cost Development (Type I)	3-14
3-9	McDonnell Douglas EROS II System Cost Development (Type I)	3-15
3-10	RCA SECANT System Cost Development (Type I)	3-16
3-11	ARINC Research Cost and Reliability Data - Honeywell	3-18
3-12	ARINC Research Cost and Reliability Data - MDEC	3-19
3-13	ARINC Research Cost and Reliability Data - RCA	3-20
3-14	GENAVE 1978 System Costs (in 1975 Dollars)	3-22
3-15	NARCO 1978 System Costs (in 1975 Dollars)	3-23
3-16	GENAVE System Reliability (Type II)	3-24
3-17	NARCO System Reliability (Type II)	3-25
4-1	CAS Equipment Cost	4-3
4-2	Expected Selling Price of Electronics (General-Aviation)	4-4
4-3	Summary of Installation Costs (Per Aircraft)	4-12
4-4	Commercial-Carrier Aircraft Statistics	4-14
4-5	CONUS Military Aircraft Statistics	4-14
4-6	General-Aviation Aircraft Statistics	4-15
5-1	Commercial Aviation Cost Data Comparison (Per Aircraft) (Zero Percent Inflation Rate)	5-5
5-2	Military Aviation (High Performance) Cost Data Comparison (Per Aircraft) (Zero Percent Inflation Rate)	5-6
5-3	Military Aviation (Limited Performance) Cost Data Comparison (Per Aircraft) (Zero Percent Inflation Rate)	5-6
5-4	General Aviation (High Performance) Cost Data Comparison (Per Aircraft) (Zero Percent Inflation Rate)	5-7

LIST OF TABLES
(continued)

		Page
Table 5-5	General Aviation (Limited Performance) Cost Data Comparison (Per Aircraft) (Zero Percent Inflation Rate)	5-8
5-6	Life-Cycle Costs for Total Aviation Community (in Millions of Dollars) (Zero Percent Inflation Rate)	5-11
6-1	Amortization Costs, Manufacturers' Data	6-6
6-2	Commercial Aviation Cost Data Comparison-Dual Systems (Per Aircraft-Retrofit) (Zero Percent Inflation Rate)	6-15
7-1	Aircraft by Type and Altitude in the 1982 Los Angeles Basin Model	7-6
7-2	ACAS System Mix by Category of Aircraft	7-7
7-3	Preliminary CAS Failure Assessment	7-8
7-4	Failure Rates Required in the Operability Evaluations	7-13
8-1	Honeywell Encoder Parts Breakdown	8-4
8-2	NARCO Encoder Parts Breakdown	8-7
8-3	Per Aircraft Cost of Equipment Including Altitude Encoders from Independently Developed Data (General Aviation-Low Performance)	8-8
8-4	General Aviation (Limited Performance) Cost Data Comparison Including Altitude Encoding (Per Aircraft) (Zero Percent Inflation Rate)	8-9
9-1	Summary of CAS Cost Analysis	9-2

LIST OF ILLUSTRATIONS

FIGURE		PAGE
2-1	CAS Economic Analysis Approach	2-2
3-1	Typical General-Aviation Packaging	3-3
4-1	CAS/IVSI Command Indicator	4-2
5-1	Cumulative CAS Cost From Manufacturers' Data (Commercial Aviation) (Zero Percent Inflation Rate)	5-14
5-2	Cumulative CAS Cost From Manufacturers' Data (Commercial Aviation) (Six Percent Inflation Rate)	5-15
5-3	Cumulative CAS Cost From Manufacturers' Data (Commercial Aviation) (Ten Percent Inflation Rate)	5-16
5-4	Cumulative CAS Cost From Manufacturers' Data (Military Aviation) (Zero Percent Inflation Rate)	5-17
5-5	Cumulative CAS Cost From Manufacturers' Data (Military Aviation) (Six Percent Inflation Rate)	5-18
5-6	Cumulative CAS Cost From Manufacturers' Data (Military Aviation) (Ten Percent Inflation Rate)	5-19
5-7	Cumulative CAS Cost From Manufacturers' Data (General Aviation) (Zero Percent Inflation Rate)	5-20
5-8	Cumulative CAS Cost From Manufacturers' Data (General Aviation) (Six Percent Inflation)	5-21
5-9	Cumulative CAS Cost From Manufacturers' Data (General Aviation) (Ten Percent Inflation)	5-22
5-10	Cumulative CAS Cost From Manufacturers' Data (Total Aviation Community) (Zero Percent Inflation Rate)	5-23
5-11	Cumulative CAS Cost From Manufacturers' Data (Total Aviation Community) (Six Percent Inflation Rate)	5-24
5-12	Cumulative CAS Cost From Manufacturers' Data Total Aviation Community) (Ten Percent Inflation Rate)	5-25

LIST OF ILLUSTRATIONS
(continued)

FIGURE		PAGE
5-13	Cumulative CAS Cost From Independently Developed Data (Commercial Aviation) (Zero Percent Inflation Rate)	5-14
5-14	Cumulative CAS Cost From Independently Developed Data (Commercial Aviation) (Six Percent Inflation Rate)	5-15
5-15	Cumulative CAS Cost From Independently Developed Data (Commercial Aviation) (Ten Percent Inflation Rate)	5-16
5-16	Cumulative CAS Cost From Independently Developed Data (Military Aviation) (Zero Percent Inflation Rate)	5-17
5-17	Cumulative CAS Cost From Independently Developed Data (Military Aviation) (Six Percent Inflation Rate)	5-18
5-18	Cumulative CAS Cost From Independently Developed Data (Military Aviation) (Ten Percent Inflation Rate)	5-19
5-19	Cumulative CAS Cost From Independently Developed Data (General Aviation) (Zero Percent Inflation Rate)	5-20
5-20	Cumulative CAS Cost From Independently Developed Data (General Aviation) (Six Percent Inflation Rate)	5-21
5-21	Cumulative CAS Cost From Independently Developed Data (General Aviation) (Ten Percent Inflation Rate)	5-22
5-22	Cumulative CAS Cost From Independently Developed Data (Total Aviation Community) (Zero Percent Inflation Rate)	5-23
5-23	Cumulative CAS Cost From Independently Developed Data (Total Aviation Community) (Six Percent Inflation Rate)	5-24
5-24	Cumulative CAS Cost From Independently Developed Data (Total Aviation Community) (Ten Percent Inflation Rate)	5-25

LIST OF ILLUSTRATIONS
(continued)

FIGURE		PAGE
6-1	Life-Cycle Costs as a Function of CAS Electronics MTBF (Commercial Aviation) (Zero Percent Inflation Rate)	6-2
6-2	Life-Cycle Costs as a Function of CAS Electronics MTBF (Military Aviation) (Zero Percent Inflation Rate)	6-3
6-3	Life-Cycle Costs as a Function of CAS Electronics MTBF (General Aviation) (Zero Percent Inflation Rate)	6-5
6-4	Life-Cycle Costs as a Function of Percent of Type I CAS Implemented (Military Aviation) (Zero Percent Inflation Rate)	6-6
6-5	Cumulative CAS Cost From Manufacturers' Data (Commercial Aviation), Including Amortization (Zero Percent Inflation Rate)	6-8
6-6	Cumulative CAS Cost From Manufacturers' Data (Military Aviation), Including Amortization (Zero Percent Inflation Rate)	6-9
6-7	Cumulative CAS Cost From Manufacturers' Data (General Aviation, Including Amortization	6-10
6-8	Cumulative CAS Cost From Manufacturers' Data (Total Aviation Community, Including Amortization (Zero Percent Inflation Rate)	6-11
6-9	Cumulative CAS Cost From Manufacturers' Data Remitter (General Aviation) (Zero Percent Inflation Rate)	6-13
6-10	Cumulative CAS Cost from Manufacturers' Data - Dual Systems (Commercial Aviation) (Zero Percent Inflation Rate)	6-17
6-11	Cumulative CAS Cost from Manufacturers' Data - Dual Systems (Commercial Aviation) (Six Percent Inflation Rate)	6-18
6-12	Cumulative CAS Cost from Manufacturers' Data - Dual Systems (Commercial Aviation) (Zero Percent Inflation Rate)	6-19
6-13	Cumulative CAS Cost from Independently Developed Data - Dual Systems (Commercial Aviation) (Zero Percent Inflation Rate)	6-17
6-14	Cumulative CAS Cost from Independently Developed Data - Dual Systems (Commercial Aviation) (Six Percent Inflation Rate)	6-18
6-15	Cumulative CAS Cost from Independently Developed Data - Dual Systems (Commercial Aviation) (Ten Percent Inflation Rate)	6-19

LIST OF ILLUSTRATIONS
(continued)

FIGURE		Page
7-1	Probability of an Undected Failure Using Pre-Takeoff Confidence Testing and Periodic Bench Check	7-17
7-2	Percentage of Undetected CAS Failures as a Function of the Bench Checking Interval	7-18
8-1	Honeywell Altitude Encoder Block Diagram	8-3
8-2	Cumulative CAS Cost from Independently Developed Data, Including Altitude Encoders (General Aviation)(Zero Percent Inflation Rate)	8-11
8-3	Cumulative CAS Cost from Independently Developed Data, Including Altitude Encoders (General Aviation)(Six Percent Inflation Rate)	8-12
8-4	Cumulative CAS Cost from Independently Developed Data, Including Altitude Encoders (General Aviation)(Ten Percent Inflation Rate)	8-13

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Federal Aviation Administration (FAA) has been engaged in an intensive evaluation of three Collision Avoidance System (CAS) concepts.* These efforts will culminate in a recommendation to the Congress, by the end of 1975, on which of these concepts, if any, would be suitable for adoption as a national standard for independent airborne CAS. Each of the concepts has been subjected to an exhaustive technical examination to ensure that the approaches are technically sound and feasible. Flight-test programs have been conducted with prototype hardware embodying each concept that would be used in a commercial or high-performance military environment, and a general-aviation environment. These flights have shown that all of the systems are capable of providing aircraft collision-avoidance protection.

However, recommendation of a national policy for CAS cannot be based solely on technical factors but must also take into consideration the operational and economic aspects of each alternative. Therefore, the FAA initiated this study to provide the necessary additional data essential to the formulation of a policy decision on the three CAS concepts. The work is being performed by ARINC Research Corporation under FAA Contract DOT-FA74WA-3506. This report presents the results of the analysis of the three concepts in terms of expected cost of ownership to an individual aircraft owner and total life-cycle costs (LCC) to the entire using community, i.e., commercial aviation, general aviation, and military aviation. The report also presents an evaluation of the operational features associated with each of the concepts.

* These concepts are the Minneapolis-Honeywell AVOIDS, McDonnell Douglas EROS, and RCA SECANT.

1.2 CONTRACT OBJECTIVES

The primary objective of the contract effort is to develop and evaluate detailed cost data for the Honeywell, McDonnell Douglas, and RCA CAS concepts. A second objective is to define the operability considerations for each concept (e.g., the need for and the means of obtaining periodic system checks).

The costs associated with the acquisition, installation, and operation/support of each of the proposed CAS equipments have been addressed in this study and have been combined to establish the total cost of ownership to both the individual operator and the entire using community. As a result, separate cost data have been developed for general aviation, the military, and commercial air carriers. The operability evaluations have focused on the operational consequences of implementing CAS in a representative mix of commercial, military, and general aviation aircraft.

1.3 SCOPE

To provide fair and expeditious cost evaluations, the contract has required extensive participation of the three competing manufacturers. These companies were asked to provide detailed equipment cost, reliability, maintainability, and design data on their system concepts based on the design techniques that would be used if CAS installations were to begin in 1978. Cost of implementation and life-cycle costs of ownership were then computed for each concept in each using community for the period 1978-1988; FAA-supplied aircraft population data and mutually agreed upon aircraft retrofit schedules were used in these computations.

The manufacturer-supplied data also were used by ARINC Research and selected general-aviation equipment manufacturers as the basis for independent assessments of the unit costs and reliabilities. Cost-of-ownership and LCC estimates were derived for these independent assessments and compared with the values derived from the manufacturers' data.

1.4 REPORT ORGANIZATION

This report consists of nine chapters, describing the technical approach followed, data acquired, analyses conducted, and results and conclusions obtained. The appendixes present supporting detailed data and results.

Chapter Two describes the overall approach to developing the economic evaluations, the assumptions and constraints employed, and the modeling methodology used in obtaining the desired cost-of-implementation and LCC of ownership values for each concept.

Chapter Three presents the specific cost, reliability, maintainability, and design data obtained from the three companies for both the commercial and general-aviation CAS concepts. This chapter also presents the results

of the independent examinations of the accuracy of these data. The independent examinations compare the cost and reliability data provided by each manufacturer with estimates developed by ARINC Research and, in the case of the general-aviation versions, with estimates developed independently by two leading general-aviation avionics manufacturers. On the basis of these comparisons, alternative data sets characterizing each of the system concepts are provided for subsequent evaluation.

The implementation cost of each of the CAS concepts requires the development of certain data that are common to all three concepts. These data include installation costs, aircraft population statistics, and equipment configurations reflecting the practices and trends of the specific user communities that would ultimately be participants in a national collision-avoidance system. These common data are presented in Chapter Four.

In Chapter Five, the development and exercise of the economic-analysis model are presented. The model is exercised for both the manufacturers' data and the independently developed alternative data sets. Acquisition, installation, and maintenance support costs of the various CAS equipments and user populations are evaluated and summarized for the individual aircraft and for the total user communities. These costs are also combined to provide total life-cycle costs for the defined 11-year period.

In anticipation of potential differences of opinion over some of the assumptions and parameter values used in the model exercises, a number of additional evaluations were developed in which certain input parameters and assumptions were varied in order to determine the sensitivity of the projected life-cycle costs to these parameters. The results of these special cases are presented in Chapter Six.

Chapter Seven investigates the impact of introducing the three CAS concepts into the national airspace. Scenarios for aircraft densities, average flight durations, and special handling of failed CAS units are developed and evaluated for each of the CAS candidate systems. The effects of special monitoring and built-in-test equipment incorporated into the proposed designs are evaluated to determine the suitability of each system in an operational environment and the impact on the existing air traffic control system.

Chapter Eight presents a refinement in the overall CAS cost analysis to include the cost of providing altitude encoding data to all aircraft. Without a mandatory requirement, only the commercial aircraft, the military aircraft, and a portion of the general aviation fleet are likely to be equipped with altitude encoding equipment. Therefore, as a separate refinement in the overall cost analysis, ARINC Research has incorporated a modified, built-in-altitude-encoding version of the Type II CAS for use in general aviation aircraft that lack an altitude-encoding system. These modified Type II systems have little effect on the cost differences because they represent a modification to the designs originally proposed by the three manufacturers and are an almost constant increment in cost for all three systems.

Chapter Nine provides a summary of the results obtained from the investigation and presents specific conclusions resulting from the economic analyses performed for the three concepts and the conclusions reached from the independent assessment of the projected unit costs and reliabilities.

CHAPTER TWO

ANALYSIS APPROACH

The majority of the present report is concerned wtih the economic analysis of the three CAS concepts, and this Chapter discusses the approach used in these economic analyses. The development of detailed and accurate cost analyses for three avionics concepts that currently exist only in prototype form posed a number of formidable problems, including the following:

- Establishing a Common Basis For Evaluating The Three Concepts. The system concepts are in different stages of evolution and employ different technology levels. Evaluation criteria that take into account these differences and are fair to each of the concepts are needed to ensure that the study results will provide an objective evaluation of each concept.

- Obtaining Accurate and Comparable Cost and Design Data. The three CAS manufacturers have made claims regarding the costs of their systems, but little detailed justification of these costs was provided. Therefore, it has been necessary in this study to develop procedures for obtaining or developing detailed data that would justify the costs associated with the three system concepts. Potential sources of these improved data are independent investigations and the three CAS proponents themselves.

- Developing the Necessary Additional Data Required for a Comprehensive Cost Analysis. Although the development of data (such as aircraft fleet sizes) that apply equally to all three CAS concepts is of the lowest criticality in the comparative cost evaluation of the three CAS concepts, it is extremely important in developing accurate overall total costs of implementation.

The general approach followed by ARINC Research Corporation in resolving these problems and obtaining the comparative economic evaluations of the three competing CAS concepts is illustrated in Figure 2-1. Initially, the basic

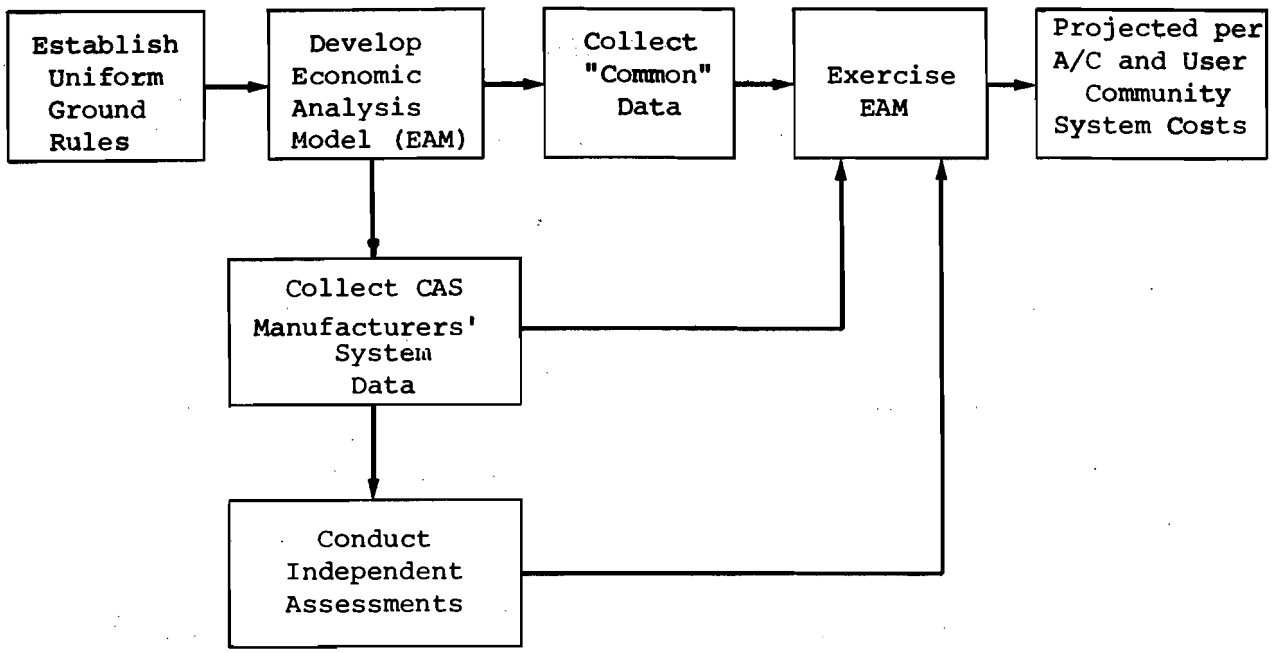


Figure 2-1. CAS ECONOMIC ANALYSIS APPROACH

criteria for evaluation of the concepts were established through a set of Uniform Ground Rules for the analysis (.e.g, all systems would utilize LSI technology projected for 1978) and agreed upon by all participants. An existing ARINC Research life-cycle-cost model was then tailored to represent the CAS evaluation environment and the established criteria. Parallel data-collection efforts were then initiated to obtain the common and system-peculiar input data needed to exercise the model. The common data such as aircraft populations, installation costs, maintenance scenarios, etc., were developed or obtained from the FAA and representative commercial, general, and military aviation users. The specific systems' data were obtained directly from the three CAS manufacturers. These latter values provided the bases for the initial exercises of the Economic Analysis Model (EAM). The manufacturers' data were also used as the starting point of the independent unit cost and reliability assessments by ARINC Research and several general-aviation equipment manufacturers. These assessments produced an alternative set of system data for which the model was exercised. In addition, the model was exercised for several key parameter-variation cases in order to investigate sensitivity of the results obtained to the input data and assumptions employed in the analysis. The outputs of each model exercise were the resultant acquisition, installation, support, and total costs, on a per aircraft and total user community basis, for each year and cumulative over the 1978-1988 time period.

The remaining sections of this chapter give details of how these steps were accomplished, how the key problems enumerated above were addressed, and also present the important assumptions that underlie the entire study.

2.1 DEVELOPMENT OF GROUND RULES FOR THE CAS COST ANALYSIS

To perform the study objectively, without favoring or penalizing any of the competitors, it was necessary to define a set of Uniform Ground Rules. The development of the Rules was discussed at several meetings with the FAA and subsequently at a conference with each of the principal manufacturers to assure concurrence and acceptance before the evaluation started. The key aspects of the ground rules involve the classes of equipment, technology levels, production quantities, and time periods.

The classes of equipment were limited to a full CAS (i.e., one based on ANTC 117* vertical threat logic intended for commercial air carriers and other high-performance aircraft), a limited-capability CAS intended for general aviation aircraft, and a remitter that would provide an aircraft no collision-avoidance protection by itself but would allow CAS-equipped aircraft to avoid the remitter-equipped aircraft. For study purposes, it was assumed that military aircraft would carry either the full CAS or limited-capability CAS equipments appropriate to aircraft performance, and that no military-peculiar equipment would be considered in the evaluation.

Technology levels and quality levels of components (e.g., present commercial practice in the selection of components) were identified, and the total production quantity for each of the manufacturers was assumed to be 3000 CAS units of the commercial-carrier equipment and 10,000 CAS units of the general-aviation equipment. These quantities were chosen in accordance with the normal industry experience with new avionic equipment in which the production by any one manufacturer is limited to approximately one-third of the total quantity required by commercial carriers. It was also assumed that the bulk of the general-aviation units will be manufactured by specialized general-aviation avionics companies, with only a limited quantity being manufactured by the full-CAS manufacturers.

It was assumed that CAS implementation would begin in 1978 and would be completed in four years for commercial carriers and eight years for general and military aviation. These implementation periods, chosen after consultation with industry leaders, are consistent with the past

**Statement of Airline Policy and Requirements and a Technical Description of the System, Airborne Collision Avoidance System,* issued by the Air Navigation/Traffic Control Division, Air Transport Association of America, as ANTC Report No. 117.

experience of the aviation industry in introducing new equipment. The equipment designs were to reflect the level of technology that would be readily available in 1978.

The Uniform Ground Rules also contain the proposed ARINC Research approach for defining equipment costs, installation costs, maintenance philosophies, preflight and in-flight performance checks, and operating scenarios.

The final version of the Rules, incorporating all comments of the interested parties, is included as Appendix A to this report.

2.2 DEVELOPMENT OF THE ECONOMIC ANALYSIS MODEL (EAM)

The specific means of assessing the projected costs associated with each of the three CAS concepts was through the development and exercise of a computer-based cost model. This model determines the annual and cumulative costs associated with each combination of CAS system type and user category and tabulates these costs on a per aircraft and a total user community basis. The model was developed by tailoring an existing ARINC Research cost model to the specific characteristics of the CAS concepts and the three categories of users (i.e., commercial, military, and general aviation).

The input data to the EAM consist of two types: data that are unique to the particular CAS concept being evaluated, and data that are common to all three concepts being evaluated. The specific requirements for each type of data were defined concurrently with the development of the model, and a data-collection effort was initiated.

Upon completion of the data collection efforts, the model was exercised for each system concept in each user community. These exercises were conducted for both the CAS manufacturer-provided and independently derived system data sets. In addition, the EAM was exercised to determine the sensitivity of the results obtained to variations in key parameters (e.g., MTBF) or assumptions (e.g., amortization).

2.3 SYSTEM DATA ELEMENTS

On the basis of the data requirements specified during the model development, detailed cost and system performance data were sought from each of the CAS manufacturers. These data included information, for both the full- and limited-capability equipments, concerning their physical descriptions and their costs, reliabilities, and maintainabilities down to the lowest replaceable assemblies. Chapter Three describes the specific data obtained from the manufacturers during this collection effort.

In addition to obtaining specific input data from the manufacturers necessary to exercise the model, detailed design data, performance specifications, and system diagrams were obtained in order to provide a basis for conducting an independent assessment of the predicted unit costs and reliabilities. This independent assessment, which is descrebed in detail in Chapter Three, had two general objectives: (1) to determine if comparable technology levels and design assumptions were made for each concept, and (2) to determine if the designs would be simplified in production by specialized general-aviation avionics manufacturers, thereby reducing the unit costs and improving reliability. The result of these assessments was the generation of an alternate system data set (cost and reliability) to by evaluated for each CAS concept by means of the EAM.

2.4 COMMON DATA ELEMENTS

The data common to all three system concepts consist of four basic types: (1) installation costs, (2) aircraft fleet size projections, (3) aircraft equipment configurations, and (4) user community operation and support parameters (e.g., average flying hours per month, labor rates, pipeline times). Chapter Four describes the specific approach to the development of these data and presents the data obtained.

The slight variation in installation costs among the three systems was neglected and it was assumed that equal installation costs would apply to all three CAS consepts. Estimates for installing CAS equipments on commercial air carriers were derived from experiences by two carriers, United Airlines and Piedmont Airlines, in actually installing an early version of CAS in two different types of aircraft. The general-aviation installation costs were developed through a questionnaire survey of all general-aviation certified radio repair shops. The shops were asked to estimate the costs of installing a CAS in single- and twin-engine aircraft. These estimates were based upon quotes for installing a system similar to the CAS in complexity and functions-- a modern general-aviation DME. Military aircraft installation costs were developed by the avionics installation agencies of each of the branches of the military and presented to the FAA by the Department of Defense (DOD).

Aircraft fleet size projections for the commercial, military and general aviation communities were obtained directly from the U. S. Department of Transportation, FAA, Office of Aviation Policy, Aviation Forecast Branch for the period 1975-1985. These data were linearly extrapolated through 1988 to complete the coverage of the time period of interest.

Estimates of the common data elements which were peculiar to the individual user communities were developed from contacts with representative users within each category, consultation with the FAA and the CAS manufacturers. and ARINC Research personnel's prior knowledge gained from similar studies of these aviation user environments.

2.5 APPROACH SUMMARY

The preceding sections have provided an overview to the technical approach used in the study; generally outlined how the Economic Analysis Model was used; and identified the general types and sources of data to be used in the evaluation. The succeeding chapters of this report describe in detail the data obtained, the characteristics of the EAM, and the specific results obtained from the study.

CHAPTER THREE

CAS EQUIPMENT COST AND RELIABILITY DEVELOPMENT

The equipment cost and reliability data developed in this chapter provide the basis for the economic comparison of the three competing CAS concepts. Careful development of these data was thus an essential step in the overall economic analysis of the CAS concepts. The development procedure used was to obtain detailed cost and reliability data from the competing CAS manufacturers and then perform an independent data critique.

The manufacturers supplied data in response to an initial data request, followed by numerous requests for additional or clarifying data. The result of this data-collection effort was a thorough investigation by the manufacturers of their proposed system designs. They produced system parts counts, module designs, and system schematic diagrams, to serve as a basis for their cost and reliability estimates.

The data supplied by the manufacturers were evaluated by means of independent cost and reliability analyses. ARINC Research conducted the independent analysis of the commercial-aviation (Type I) versions of the three CAS concepts, and two general-aviation equipment manufacturers (NARCO and GENAVE) provided independent analyses of the general-aviation (Type II) versions of the systems.

3.1 SYSTEM DESCRIPTIONS

System costs and reliabilities are functions of the complexities of the system designs, and the complexities of the three systems are related to the system design parameters. Table 3-1 was developed to provide the reader with a general appreciation of the various techniques used in the three CAS concepts. It shows only the most important CAS parameters (from a cost-analysis point of view). A more detailed description of the CAS design data is presented in Appendix B, which includes the manufacturers' estimated unit costs, module partitioning, reliabilities, repair-time estimates, repair-material-cost estimates, and technical parameters. Detailed parts lists, logic partitioning for LSI development, and schematic diagrams are available but not included, since they are considered proprietary to the manufacturers.

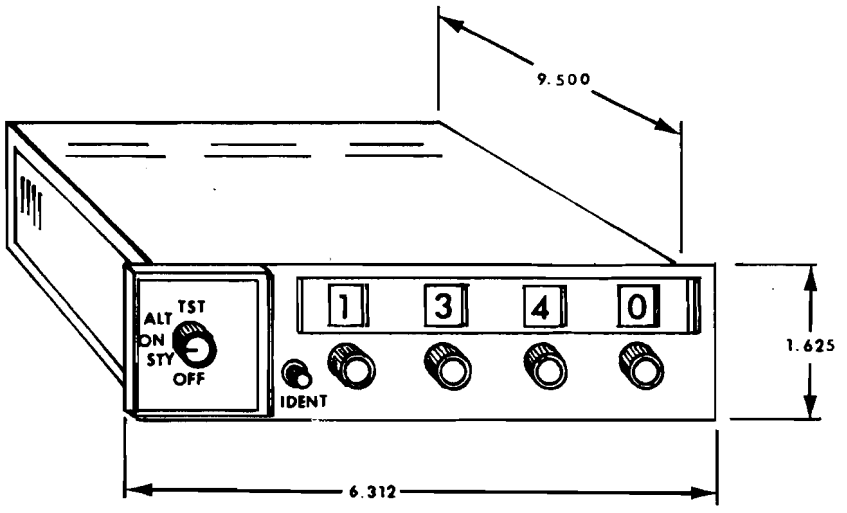
Table 3-1. MAIN CAS PARAMETERS AND DESIGN FEATURES

SYSTEM PARAMETER	AVOIDS	EROS II	SECANT
OPERATIONAL REQUIREMENTS			
Transmission Format	100 nsec pulse, 2 pulse pair	200 μsec range pulse, 25 μsec altitude pulse	1 μsec pulse, 1 pulse pair
Epoch duration	3.2 sec	3 sec	5.1 sec
Maximum transmissions per epoch	166	1*	2274
Minimum transmissions per epoch	4	1	450
COMMUNICATIONS			
Frequencies	1	4	24
Frequencies used per epoch	1	4	Up to 24
Ranging Technique	Query/ Response	Time/ Synchronization	Query/ Response
Altitude Encoding Technique	Pulse Position Modulation	Pulse Position Modulation	Pulse Position Modulation
Power	200-800 W	100-1000 W	16-25 W
Effective Range	45 n mi.	>45 n mi.	15 n mi.
Receivers	2 (One redundant)	1	2
CONSTRUCTION			
Transmitter	Cavity Oscillator	Tube Exciter/ Power Amp	Transistor Exciter/Power Amp
Receiver	Logarithmic	Logarithmic	Linear
Logic**	9 LSI; 20 MSI; 7 IC	8 LSI; 9 MSI; 9 IC	42 LSI; 1 IC
Power Supply	1 module (high and low voltage)	2 modules (one high, one low voltage)	1 module (low voltage)

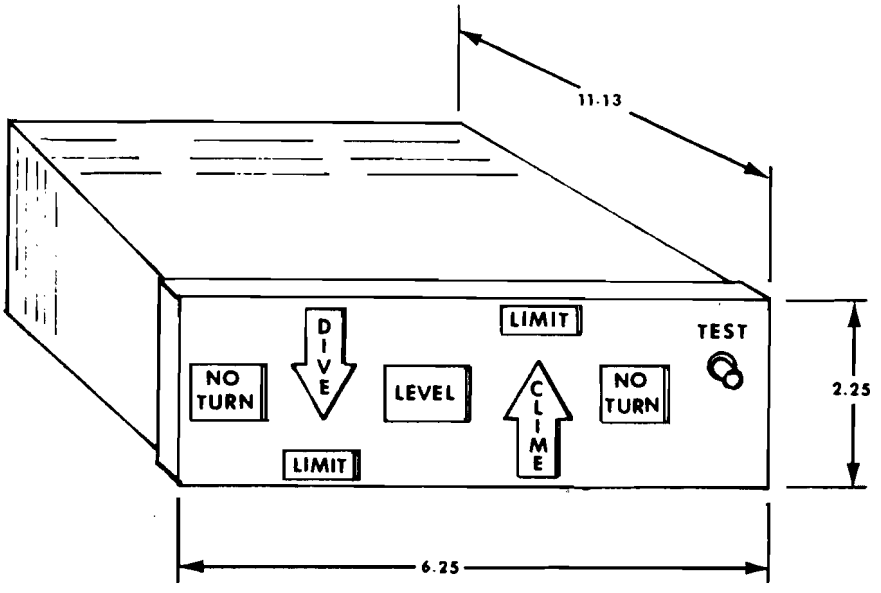
* Up to 2000 synchronization triads may also be transmitted during an epoch.

** Custom LSIs required for each system.

Equipment intended for commercial carriers and other high performance aircraft is designed to the form-fit-function characteristics of ARINC specifications, while the general aviation version intended for the limited performance aircraft conforms to the practice of unresticted packaging common in the general-aviation community. Figure 3-1 presents a typical package profile of CAS expected to be produced by general-aviation manufacturers, with a profile of an existing ATCRBS transponder for comparison of size and clarity of functional details.



TRANSPONDER



TYPE II CAS

FIGURE 3-1. TYPICAL GENERAL-AVIATION PACKAGING

3.2 SUMMARY OF MANUFACTURER-SUPPLIED COST AND RELIABILITY DATA

Tables 3-2, 3-3, and 3-4 list the system and module data provided by the CAS manufacturers.* The reliability data include the equipment failure rates and the costs and times involved in repairing the units. The costs shown are projected costs for 1978 production, but in 1975 dollars.

The unit costs represent the costs at which the manufacturer would be prepared to sell the equipment to a large-volume customer (e.g., a commercial airline, the military, a general-aviation distributor). The advertised price on the units would be substantially higher (probably 80- to 100-percent higher). While the single-aircraft owner would not be able to purchase equipments for this factory selling price, he would be equally unlikely to pay the full advertised price. The true system acquisition cost to the single-aircraft owner would be the factory selling price paid by the avionics distributor plus the distributor's handling charge and profit. Therefore, the factory selling price represents a common expense borne by any CAS purchaser. In the life-cycle-cost analyses of Chapter Five the distribution costs have been included as appropriate for each class of users.

3.2.1 Relation of System Costs to System Design Parameters

This subsection presents a brief discussion of the relative system costs for the commercial-aviation (Type I) CAS units, followed by a general discussion of the costs of the general-aviation (Type II) units in comparison with the full Type I units. The unique elements of each system are the RF sections, the logic circuitry, and the power supplies for which cost and reliability data are summarized in Tables 3-2 to 3-4.

3.2.1.1 RF Sections

The three RF sections described vary in degree of complexity from the single-frequency AVOIDS to the 24-frequency SECANT, and the resultant cost difference is reflected in the relative costs proposed by the manufacturers. The AVOIDS and EROS techniques are well established, utilizing existing hardware and packaging concepts such as cavity oscillators and tube-type power amplifiers. The SECANT system employs the latest state-of-the-art packaging and components (i.e., microwave transistorized transmitter module), which may require a careful manufacturing process to minimize RF interference.

The system costs presented by the manufacturers appear to be consistent with the complexities encountered and justified based on the buying potential and typical labor rates of large corporations.

---

* For common data items (e.g., antennas) the same cost and reliability values representing a consensus of the manufacturers are shown for all three concepts.

Table 3-2. MANUFACTURERS' COST AND RELIABILITY DATA (Honeywell)

Unit	System Cost (Dollars)	Subsystem Cost (Dollars)	MTBF (Hours)	Mean Time To Isolate A Failure (Hours)	MTTR (Hours)	Expected Materiel Cost Per Repair (Dollars)
Honeywell AVOIDS I (Commercial Aviation Unit)						
Indicator	1,092		7,500			
Antenna	63		50,000			
Principal Electronics	4,016		2,051	1.0		
Transmitter		452	3,230		1.0	97.36
Receiver		1,315	17,677		1.2	12.28
Chassis		982	33,036		2.0	15.58
Logic		952	14,029		1.7	11.40
Power Supply		315	50,787		1.2	1.50
Honeywell AVOIDS II (General Aviation Unit)						
Antenna	13		50,000			
Principal Electronics	591		3,194	0.1		
RF and Power Supply		169	13,400		1.2	10.58
Cavity (TX)		55	5,000		1.0	28.55
Logic		367	26,001		1.0	10.58

Table 3-3. MANUFACTURERS' COST AND RELIABILITY DATA (McDonnell Douglas)

Unit	System Cost (Dollars)	Subsystem Cost (Dollars)	MTBF (Hours)	Mean Time To Isolate A Failure (Hours)	MTTR (Hours)	Expected Materiel Cost Per Repair (Dollars)
McDonnell Douglas EROS II (Commercial Aviation Unit)						
Indicator	1,092		7,500			
Antenna	63		50,000			
Principal Electronics	4,683		1,882	0.08		
Transmitter		1,171	5,265		1.0	18.85
Receiver		234	14,768		1.0	1.47
RF Front End		1,639	47,736		1.5	12.59
Exciter		374	15,083		1.0	2.18
Oscillator		140	100,000		0.5	50.38
Logic		936	7,086		1.0	1.68
Power Supply		187	28,377		1.0	2.10
McDonnell Douglas EROS II GA (General Aviation Unit)						
Antenna	13		50,000			
Principal Elect.	1,215		3,100	0.08		
Transmitter		231	19,991		1.0	20.99
Receiver		36	25,713		1.0	1.47
RF Front End		268	47,736		1.0	12.59
Exciter		97	16,436		1.0	2.10
Oscillator		97	100,000		0.5	50.38
Logic		364	10,918		1.0	2.10
Power Supply		122	34,276		1.0	2.10
Miscellaneous			47,356			

Table 3-4. MANUFACTURERS' COST AND RELIABILITY DATA (RCA)

Unit	System Cost (Dollars)	Subsystem Cost (Dollars)	MTBF (Hours)	Mean Time To Isolate A Failure (Hours)	MTTR (Hours)	Expected Material Cost Per Repair (Dollars)
RCA SECANT (Commercial Aviation Unit)						
Indicator	1,092		7,500			
Antenna	63		50,000			
Control	127		10,000			
Principal Electronics	5,141		3,000	0.1		
Microwave Unit		2,966	16,800*		3.0	26.87
Detector		478	24,000*		1.5	20.99
Housing		421	31,200*		1.0	5.04
Miscellaneous		51				
Logic:						
Control		211	24,000*		1.3	12.59
Threat		211	24,000*		1.3	12.59
Track & Data		242	24,000*		1.3	12.59
Track Exp.		242	24,000*		1.3	12.59
Power Supply		319	24,000*		1.5	Replacement Cost
RCA SECANT GA (General Aviation Unit)						
Indicator	53		10,000			
Antenna	13		50,000			
Principal Electronics	1,547		4,000	0.08		
Microwave Unit		635	19,600*		2.5	20.99
Detector		159	28,000*		1.5	20.99
Housing		159	36,400*		0.9	504
Miscellaneous		6				
Logic						
Control		130	28,000*		1.3	12.59
Threat		130	28,000*		1.3	12.59
Track & Date		176	28,000*		1.3	12.59
Power Supply		159	28,000*		1.3	Replacement Cost

* Manufacturer's Recommended Proportioning of System MTBF

3.2.1.2 Logic Sections

The associated costs of materials required for the logic section are based on the use of large-scale integration (LSI) circuitry. The degree of utilization of LSI technology in the systems varies from total application in the SECANT system to the more conservative usage in the AVOIDS system. The associated costs of the systems reflect the variations in the extent of LSI application.

The manufacturers were requested to provide LSI materials costs and LSI development costs separately. Anticipated LSI development costs were submitted by Honeywell and McDonnell Douglas, and overall manufacturing start-up costs (which presumably include LSI development) were submitted by RCA. In Chapter Six the study considers the sensitivity of the relative CAS cost analyses to the system development costs. The introduction of LSIs permits the detailed differences in the logic designs to be ignored in the cost analyses. Once the LSI circuits are developed, the effect of logic complexity on system cost is related only to the number of LSI circuits included in the system design.

3.2.1.3 Power Supplies

The regulated power supplies required by each of the competing systems are similar in that they require multiple low-voltage outputs to drive the various logic or RF stages. The supplies are packaged in modules suitable for easy replacement and testing. The proposed costs have been confirmed through quotations from the proposed suppliers and, in the case of AVOIDS, through a review of the parts costs and assembly rates.

3.2.1.4 Comparison of Type I and Type II Versions

The design and manufacturing approach used by all three competitive manufacturers in the proposed production of the general-aviation equipment is consistent with the relative complexity and cost of the commercial-aviation units. Lower RF power, simplified logic, less stringent power-supply requirement, and packaging consistent with the general aviation requirements and practices, all contribute to the lower equipment costs. The use of a cavity oscillator as a transmitter in the AVOIDS II contributes greatly to the reduced cost of the system. The proportional costs of the three systems appear to be justified on the basis of the data presented.

3.2.2 Review of System Reliability and Repair Data

System reliability data (i.e., the mean time between failures, or MTBF) is the subject of a subsequent section 3.3.2,in which reliability is linked directly to system design; that discussion will not be repeated in this subsection.

The maintenance time data are not discussed in detail because there appeared to be little basis for conducting an independent analysis of system MTTRs. (However, independent analyses of the material cost associated with repair are developed in the following section). As a result, these manufacturer-supplied data have been used directly throughout the study. While an independent review of these paraments was not practical, a superficial examination of the parameters suggests they are reasonable on the basis of the maintenance of present-day avionics and in light of the fact that built-in test and special test equipment should be provided as a part of the overall CAS implementation. In fact, Honeywell and McDonnell Douglas submitted conceptual approaches to their proposed built-in test and test equipment, and these plans are consistent with their predicted maintenance times.

3.3 INDEPENDENTLY DERIVED DATA

The data presented by the manufacturers were reviewed and evaluated by ARINC Research. The detailed system material costs and manufacturing assembly costs were considered sufficient to confirm the proposed unit costs, especially on a relative basis, for the commercial-aviation version of the equipment.

The general-aviation version of each proposed system was evaluated by ARINC Research and further subjected to cost and reliability evaluations by independent general-aviation manufacturers. It has been assumed that, in the event of system implementation, the majority of the units required by general aviation would be manufactured by companies other than the CAS competitors. The results of the independent evaluations of the Type II CAS designs are presented in Section 3.3.3.

3.3.1 ARINC Research Critique of Commercial-Aviation CAS Costs

ARINC Research obtained sufficiently detailed design and assembly data from each competing manufacturer to permit direct initial-cost estimating of each system. The component costs were compared with present advertised costs and allowances made for volume purchasing, common to corporations of the size of the competitors. Where modules (e.g., power supplies or cavities) were to be provided by other than the prime competitors, the potential suppliers were contacted and their costs verified.

The costs of the commercial-aviation equipment assembly and packaging were reviewed on the basis of the data provided and corrected for learning effects, as outlined in the Uniform Ground Rules. The labor hours and rates were reviewed and compared with published data on similar components. Although each of the three manufacturers has a rate and burden structure peculiar to itself, the independent analysis assumed typical rate and burden structures for the industry. As a result, exact agreement with the manufacturer-proposed costs was not expected; but the independent analysis did confirm that the manufacturers' prices were realistic.

The uniform pricing evaluation of the three Type I equipments began with a review of the parts lists of each system, and the cost of each component was determined. Although the evaluation considered each component by part number and type, a summary of the parts by function is presented for each module of a system in Tables 3-5 through 3-7. The relative complexity of each module can be appreciated by comparison of the parts density required by the module. However, cost of material should not and cannot be averaged, since any grouping may include wide-range cost items--e.g., a $20 micro network digital-to-analog converter and a $.70 buffer/converter are both listed under MSIs for the EROS logic. The exact parts costs are presented in Appendix C. The material costs shown in Tables 3-5 through 3-7 represent true costs of the components shown for each module. Where a module was identified by the manufacturer as scheduled for purchase from outside sources, only the confirmed costs of the module is presented.

The factory cost for each module was developed by applying cost factors for material-handling, labor and burden, inspection, and engineering. The direct cost of manufacture is identified in Tables 3-8 through 3-10 as the Factory Cost. A 20-percent general and administrative cost and a 15-percent profit were added to the factory costs of each system to establish the true minimum selling price of the modules or systems. This selling price would be the acquisition cost borne by a commercial air carrier, the military, or an avionics distributor that re-sells these systems to the small percentage of general-aviation users requiring a Type I CAS unit.

The approach was uniform for each module and each system. The results are very close to the quotations provided by the competing manufacturers except for the modules involving specially purchased subassemblies.* In these cases, cost adjustments to allow for different cost accounting for purchased subassemblies were made, and better agreement between the manufacturer and the ARINC Research-estimated costs was obtained. The independent costs shown in the tables were used in the cost analyses of Chapter Five.

In the case of the specially purchased $504 McDonnell Douglas RF front end, the material-handling charge could be omitted and the proportional engineering and QC could be reduced to 10 percent on the premise that normal design engineering is not required on an assembled item. As a result, the cost of the RF front end and housing would be reduced to within five percent of the manufacturer's quoted price. A similar argument can be made for the specially purchased $210 power supply of the RCA SECANT, which would reduce the cost to within four percent of the manufacturer's quoted price.

There is, however, a discrepancy between the independent cost evaluation and the manufacturer's data for the SECANT system that could not be explained. This discrepancy occurred between the independent cost-evaluation results and the manufacturer's data for the SECANT logic. Efforts to resolve this problem were unsuccessful. The impact of this increased cost is considered in Chapter Five in the life-cycle-cost analysis of the RCA system.

* The McDonnell Douglas RF front end section, oscillator modules, and the RCA power supply.

Table 3-5. HONEYWELL AVOIDS I PARTS BREAKDOWN (TYPE I)

Parts (ea.) \ Module	TRANSMITTER		RECEIVER		LOGIC		POWER SUPPLY		HOUSING		TOTAL	
	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST
LSIs	-	-	-	-	9*	100.91	-	-			9	100.91
MSIs	-	-	-	-	20	198.34	-	-			20	198.34
ICs	3	3.53	12	10.90	7	11.99	6	8.41			28	34.75
Transistors	5	10.41	8	7.10	2	2.00	6	5.31			21	24.81
Diodes	7	2.22	16	.80	20	.60	12	5.73			55	9.35
Resistors	17	2.26	84	7.15	25	13.89	8	3.48			134	26.78
Capacitors	10	4.68	64	14.71	14	5.10	12	10.92			100	35.41
Crystals	-	-	-	-	1	5.00	-	-			1	5.00
Potentiometers	3	19.49	-	-	-	-	1	3.64			4	23.13
Inductors	3	1.31	-	-	-	-	2	1.00			5	2.31
Transformers	1	.50	-	-	-	-	2	1.10			3	1.60
Power Amplifiers	1	100.00	-	-	-	-	-	-			1	99.92
Printed Circuits	1	10.00	1	11.99	2	49.96	1	9.99			5	81.93
Misc.Electrical	-	-	1	424.64	-	-	-	-			1	424.64
Misc.Hardware	6	.81	2	6.69	4	11.99	3	9.62	1 lot	$176.32	Lot	205.03
Material Cost	$155		$484		$400		$59		$176		$1274	

* Custom Component

Table 3-6. McDONNELL DOUGLAS EROS PARTS BREAKDOWN (TYPE I)

Module / Parts (ea.)	TRANSMITTER		RECEIVER		LOGIC		POWER SUPPLY		EXCITER		TOTAL	
	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST
LSIs	-	-	-	-	8*	134.34	-	-	-	-	8	134.34
MSIs	-	-	6	2.94	18	122.71	-	-	-	-	24	125.65
ICs	8	25.12	3	3.57	3	1.51	-	-	4	12.76	18	42.96
Transistors	24	30.52	5	5.58	21	6.76	3	2.52	12	5.64	65	51.02
Diodes	33	8.63	13	4.45	18	.76	24	3.78	14	27.54	102	45.16
Resistors	74	13.69	53	.67	58	.73	13	2.52	58	.73	256	18.34
Capacitors	35	34.16	63	5.63	22	.70	17	12.47	40	1.78	177	54.74
Crystals	-	-	-	-	-	-	-	-	8	13.43	8	13.43
Potentiometers	3	23.72	4	3.82	-	-	-	-	3	.88	10	28.42
Inductors	-	-	13	4.91	-	-	-	-	15	4.45	28	9.36
Transformers	4	32.75	2	.08	-	-	3	36.10	-	-	9	68.93
Power Amplifiers	3	133.50	-	-	-	-	-	-	-	-	3	133.50
Printed Circuits	-	-	1	6.72	2	11.75	1	2.52	1	4.20	5	25.19
Misc. Electrical	3	.76	13	21.16	-	-	-	-	1	16.79	17	38.71
Misc. Hardware	9	62.76	2	5.12	2	5.88	3	7.64	6	20.99	22	102.39
Material Cost	$365.		$65.		$285.		$67		$109		$892.	

* Custom Component
** Outside Purchase: Oscillator - $50. RF Front End - $504.
Chassis and Hardware - $401 Lot

Table 3-7. RCA SECANT PARTS BREAKDOWN (TYPE I)

Parts (ea) \ Module	MICROWAVE		IF DETECTOR		LOGIC		POWER SUPPLY		HOUSING		TOTAL	
	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST
LSIs	-	-	-	-	42*	533.20					42	533.20
MSIs	-	-	8*	16.93	-	-					8	16.93
ICs	36	24.98	-	-	1	.35					37	25.33
Transistors	57	43.64	-	-	1	2.38					58	46.02
Diodes	9	5.81	-	-	-	-					9	5.84
Resistors	210	3.33	-	-	10	.16					220	3.49
Capacitors	481	31.16	44	6.56	10	.53					535	38.25
Crystals	12	12.70	-	-	1	1.06					13	13.76
Potentiometers	3	1.11	8	2.96	-	-					.11	4.07
Inductors	111	7.04	24	20.31	-	-					135	27.35
Transformers	-	-	-	-	-	-					-	-
Power Amplifiers	3	202.07	-	-	-	-					3	202.07
Printed Circuits	2	10.58	10	5.29	4	21.16					16	37.03
Misc. Electrical	27	193.28	8	33.85	-	-	1 unit	$210.00**			Lot	437.13
Misc. Hardware	5	371.34	14	11.64	4	14.81			1 lot	169.61	Lot	567.40
Material Cost	$907		$97		$574		$210		$170		$1958	

* Custom Component
** Outside Purchase

Table 3.8 HONEYWELL AVOIDS I SYSTEM COST DEVELOPMENT (TYPE I)

COST \ MODULE	TRANSMITTER (Dollars)	RECEIVER (Dollars)	LOGIC (Dollars)	POWER SUPPLY (Dollars)	HOUSING (Dollars)	TOTAL (OEM) (Dollars)
Material	155.00	484.00	400.00	59.00	176.00	1274.00
Handling @ 25% of Material	38.75	121.00	100.00	14.75	44.00	318.50
Labor @ $11 plus 135% burden	76.32	136.43	81.52	96.37	307.96	698.60
Inspection @ 5% of labor	3.82	6.82	4.08	4.82	15.40	34.94
SUBTOTAL	273.89	748.25	585.60	174.94	543.36	2326.04
Engineering and Quality Control @ 25%	68.47	187.06	146.40	43.74	135.84	581.51
FACTORY COST	342.36	935.32	731.99	218.68	679.20	2907.55
General and Administrative @ 20%	668.47	187.06	146.40	43.74	135.84	581.51
TOTAL COST	410.83	1122.38	878.39	262.41	815.04	3489.05
Profit @ 15%	61.62	168.36	131.76	39.36	122.26	523.36
Selling Price	472.46	1290.74	1010.15	301.77	937.29	4012.41
System Cost						
Adjusted Cost	-	-	-	-	-	-
Independently Derived Cost	472.46	1290.74	1010.15	301.77	937.29	4012.41
Manufacturer Provided Cost	451.72	1314.86	952.14	314.86	981.53	4015.95

Table 3-9. McDONNELL DOUGLAS EROS II SYSTEM COST DEVELOPMENT (TYPE I)

COST \ MODULE	TRANSMITTER	RECEIVER	EXCITER	RF AND HOUSING	OSCILLATOR	LOGIC	POWER SUPPLY	TOTAL
Material	365.00	65.00	109.00	905.00	50.00	285.00	67.00	1846.00
Handling @ 25% of Mat'l.	91.25	16.25	27.25	226.25	12.50	71.25	16.75	461.50
Labor @ $11 + 135% burden	217.77	67.30	63.77	85.93	12.83	98.37	39.83	585.80
Inspection @ 5% of labor	10.89	3.37	3.19	4.30	.64	4.92	1.99	29.29
SUBTOTAL	684.91	151.92	203.21	1221.47	75.97	459.54	125.57	2922.59
Engineering and Quality Control @ 25%	171.23	37.98	50.80	305.37	18.99	114.88	31.39	730.65
FACTORY COST	856.14	189.90	254.01	1526.84	94.96	574.42	188.36	3653.24
General and Administrative @ 20%	171.23	37.98	50.80	305.37	18.99	114.88	31.39	730.65
TOTAL COST	1027.37	227.88	304.81	1832.21	113.96	689.31	188.36	4383.89
Profit @ 15%	154.11	34.18	45.72	274.83	17.09	103.40	28.25	657.58
Selling	1181.48	262.06	350.53	2107.04	131.05	792.71	216.61	5041.47
System Cost								5041.47
Adjusted Cost				1785.89	104.95			
Independently Derived Cost	1181.48	262.06	350.53	1785.89	104.95	792.71	216.61	4694.23
Manufacturer Provided Cost	1171.00	234.00	374.00	1639.00	140.00	936.00	187.00	4683.00

Table 3-10. RCA SECANT SYSTEM COST DEVELOPMENT (TYPE I)

COST \ MODULE	MICROWAVE (Dollars)	DETECTOR (Dollars)	LOGIC (Dollars)	POWER SUPPLY (Dollars)	HOUSING (Dollars)	TOTAL (OEM) (Dollars)
Material	907.00	97.00	574.00	210.00	170.00	1958.00
Handling @ 25% of Material	226.75	24.25	143.50	52.50	42.50	489.50
Labor @ $11 plus 135% burden	536.52	141.21	40.84	12.83	50.09	781.49
Inspection @ 5% of labor	26.83	7.06	2.04	.64	2.50	39.07
SUBTOTAL	1697.10	269.52	760.38	275.97	265.09	3268.06
Engineering and Quality Control @ 25%	424.28	67.38	190.10	68.99	66.27	817.02
FACTORY COST	2121.38	336.90	950.48	344.96	331.36	4085.08
General and Administrative @ 20%	424.28	67.38	190.10	68.99	66.27	817.02
TOTAL COST	2545.28	404.28	1140.58	413.95	397.63	4902.10
Profit @ 15%	381.85	60.64	171.09	62.09	59.65	735.32
Selling Price	2927.51	464.92	1311.07	476.04	457.28	5637.42
System Cost	-	-	-	-	-	5637.42
Adjusted Cost	-	-	-	339.23	-	-
Independently Derived Cost	2927.51	464.92	1311.07	339.23	457.28	5500.61
Manufacturer Provided Cost	2966.00	478.00	906.00	319.00	421.00	5141.00

With the above exception for the RCA logic section, the proposed equipment costs correlate to within 1% (overall system development cost) on the basis of the quantities considered in the study. Some cost reductions could be realized by each of the manufacturers through either greater utilization of LSIs or in-house manufacturing of subassemblies currently scheduled for outside procurement. However, it was not the purpose of this study to identify areas of potential cost savings, but rather to substantiate the costs proposed by the manufacturers.

3.3.2 ARINC Research Critique of Reliability and Maintainability

The reliability of each of the systems was reviewed and evaluated. The manufacturers provided sufficiently detailed parts lists to permit application of the MIL-217* reliability-prediction technique in the determination of system or module MTBF by component failure rate. However, since a detailed circuit analysis was not practical, and insufficient data were provided by RCA and Honeywell on junction temperatures, stress ratios, and environmental conditions within the electronic package, a uniform approach to system reliability was chosen for all three systems to insure a comparable basis for analysis.

When the MIL-217 reliability-prediction technique is used, it is necessary to make assumptions regarding key system operating parameters. For example, the operating ambient was chosen at 40°C. The stress ratios for components was assumed to be 0.5 unless specifically identified by the manufacturer as other than 0.5. Junction temperatures used were those listed in D.A.T.A. Reference Standards for Industry, as applicable to the semiconductor class. Critical transistors, e.g., modulators or final amplifier, were evaluated to establish the normalized junction temperature (T_n), and failure rates were derived from the curves and data tables of MIL-217A. The appropriate K-factor for airborne application was used.

Additional failure rate data used in the evaluation were the TRI-Service and NASA FARADA** data; these failure rates are computed on the basis of actual experience in given environments.

The reliability evaluations of the systems considered all electronic components in the circuits of the systems. A failure of any component was treated as causing a failure of the system. The determination of the module and system reliabilities is presented in Appendix C.

The resultant data, as evaluated by ARINC Research, are presented in Tables 3-11 through 3-13. The manufacturers' reliability data that are accepted directly are for those items not manufactured by the prime CAS competitors --i.e., the cavity for AVOIDS or the oscillators for the EROS. The estimated reliability proposed by these outside suppliers was considered to be valid for this study because of their experience with their components.

---

* *Military Standardization Handbook, Reliability Stress and Failure Rate Data for Electronic Equipment*, MIL-HDBK-217A, 1 December 1965.

** *Failure Rate Data (FARADA)*, Fleet Missile Systems Analysis and Evaluation Group Annex, Naval Weapons Station, Seal Beach, Corona, California.

Table 3-11. ARINC RESEARCH COST AND RELIABILITY DATA

Unit	MTBF (Hours)	Mean Time To Isolate A Failure	MTTR (Hours)	Expected Material Cost Per Repair (Dollars)
Honeywell AVOIDS I				
Principal Electronics	2138	*		
Transmitter	3522		*	88.30
Receiver	18137		*	.39
Chassis	20177		*	4.20
Logic	28332		*	2.63
Power Supply	22843		*	1.71
Honeywell AVOIDS II				
Principal Electronics	3101	*		
R.F. and Power Supply	10182		*	.85
Cavity	*		*	16.64
Logic	41293		*	9.04

* Indicates concurrence with manufacturer's estimate. (see section 3.2.2 for rationale justifying concurrence)

Table 3-12. ARINC RESEARCH COST AND RELIABILITY DATA

Unit	MTBF (Hours)	Mean Time To Isolate A Failure	MTTR (Hours)	Expected Material Cost Per Repair (Dollars)
McDonnell Douglas EROS II				
Principal Electronics	1,813	*		
Transmitter	4,207		*	18.85
Receiver	11,121		*	.45
R.F. Front End	27,526		*	*
Exciter	15,727		*	.48
Oscillator	*		*	*
Logic	12,807		*	2.05
Power Supply	27,822		*	2.82
McDonnell Douglas EROS II GA				
Principal Electronics	3,631	*		
Transmitter	19,991		*	20.99
Receiver	27,526		*	.31
R.F. Front End	*		*	*
Exciter	12,299		*	1.23
Oscillator	*		*	*
Logic	24,604		*	1.96
Power Supply	27,685		*	.78

* Indicates concurrence with manufacturer's estimate.

Table 3-13. ARINC RESEARCH COST AND RELIABILITY DATA

Unit	MTBF (Hours)	Mean Time To Isolate A Failure	MTTR (Hours)	Expected Material Cost Per Repair (Dollars)
RCA SECANT				
Principal Electronics	2,475	*		
Microwave Unit	3,728		*	9.61
Detector	16,183		*	1.04
Housing	*		*	*
Logic:				
Control	115,088		*	5.69
Threat	277,778		*	12.59
Track & Data	208,333		*	12.59
Track Expansion	208,333		*	12.59
Power Supply	50,000		*	Replacement Cost
RCA SECANT GA				
Principal Electronics	3,227	*		
Microwave Unit	4,652		*	2.90
Detector	31,694		*	1.86
Housing	*		*	
Logic:				
Control	115,088		*	5.69
Threat	416,667		*	12.59
Track & Data	208,333		*	12.59
Power Supply	50,000		*	Replacement Cost

* Indicates concurrence with manufacturer's estimate.

Although the general-aviation equipment manufacturers were asked to provide reliability estimates on their designs (see Section 3.3.4) to permit independent cost analysis of their designs, the tables also show the application of the MIL-217A and FARADA techniques to the Type II equipments. While the Type II reliability values shown in Tables 3-11 through 3-13 have not been used in the cost analyses, they do provide a basis for judging the accuracy of the manufacturer-supplied reliabilities for the limited version equipment .

The average maintenance times presented by the CAS manufacturers were accepted directly. The average material costs determined independently by ARINC Research were lower than the average material costs for repair presented by the manufacturers. Efforts to resolve these material-cost values with the manufacturers proved to be unsuccessful, and these independently developed material costs were included in the cost analyses of Chapter Five.

3.3.3 GENAVE/NARCO Critique of Cost

The general-aviation (Type II) version of each of the three systems was subjected to a uniform pricing evaluation by two independent general-aviation manufacturers. The information provided by ARINC Research to these manufacturers included system description, block diagrams, parts lists, and technical parameters such as duty cycles, power outputs, receiver sensitivity, system stability, bandwidths, number of frequencies, and packaging. The details of logic operation were intentionally omitted, and only the number and types of LSI or discrete components were identified. It was desired to obtain cost information based on the system design complexities consistent with the experience and capabilities of the general-aviation manufacturers and not a technical evaluation of the techniques used in threat detection. The general-aviation manufacturers' reports on their investigation are contained in Appendix C.

This section presents the results of the evaluation of the three systems by General Aviation Electronics (GENAVE) and the National Radio Company (NARCO), as well as the techniques used by each GA manufacturer in establishing the system costs. The system costs generated by NARCO and GENAVE have been specified in terms of 1975 dollars for systems to be delivered in 1978, making these readily comparable to all other cost data in this chapter.

3.3.3.1 GENAVE Cost Evaluation

GENAVE evaluated each system cost on the basis of parts costs, labor, anticipated cost of logic components in 1978, and the company's normal overhead and profit in today's market. Their experience in both the RF and microwave fields was utilized in establishing the RF-section costs of each system; this experience reflects their present capability in manufacturing the required components for any of the systems. The material and labor costs associated with the power supply, packaging,assembly, and testing are included.

Table 3-14 summarizes the cost data developed by GENAVE. The total development of costs by module for each system is contained in the GENAVE report, which is presented in Appendix C to this study.

Table 3-14. GENAVE 1978 SYSTEM COSTS (in 1975 Dollars)

SYSTEM	LSI COSTS	OTHER COSTS	TOTAL COSTS	FACTORY SELLING PRICE	LIST PRICE
AVOIDS II	164.66	214.32	378.98	629.00	1,258.00
EROS II GA	47.99	704.73	752.72	1,250.00	2,500.00
SECANT GA	97.20	678.05	775.25	1,287.00	2,574.00

The data submitted by GENAVE were reviewed by ARINC Research and modified slightly after additional discussions with GENAVE engineering. The proposed cost of the oscillator required by the EROS II GA system was found to be in error. The unit estimated by GENAVE has a stability specification greater than currently required by the EROS system, and this resulted in an additional material cost of $100. With the concurrence of GENAVE engineering, the factory cost of the EROS-II GA system was reduced by $166.00 (1975 dollars) to the price shown in Table 3-14.

GENAVE's consensus of the systems can be best summarized in the following statement from their report: "None of the systems, in our opinion, could be called unfeasible even with today's technology. Some of the borderline approaches, such as the surface acoustic wave filters [in the RCA design], will likely be quite suitable by 1978".

3.3.3.2 NARCO Cost Evaluation

NARCO established the cost of each system by comparing the proposed CAS equipment with similar NARCO equipments and establishing proportional complexity and cost variations between the CAS and NARCO systems.

NARCO made the assumption that the logic sections for any of these systems under evaluation would represent equivalent costs. Similarly, the power supplies were considered cost-comparable, as well as the logarithmic IF sections and the packaging. The small variation in physical size that might be required by the SECANT-GA to house the SAW filters represents a very nominal cost increase that would not affect the overall unit cost. The major cost difference is represented by the complexities in the RF sections. NARCO engineers addressed themselves to these variations and established a differential cost for the increased complexities relative to their basic unit.

The basic unit cost was developed by comparison of the systems under evaluation with standard manufactured systems. The similarity of the AVOIDS packaging, operating frequency, and power requirements to the NARCO AT-50 air traffic control transponder permitted the NARCO engineers to establish

a price of the AVOIDS based on actual costs of the transponder. Allowances were made for the cost of the logic components and the additional labor required to assemble and test the AVOIDS unit. The estimated factory selling price of the AVOIDS II system (in 1975 dollars) was quoted to be $500 per unit.

NARCO's evaluation of the EROS II GA identified the system as requiring seven more crystals, with the associated oscillator and multiplier networks, for a differential of $170; and one more power-output tube, for a differential of $60. The remainder of the system was considered comparable to the AVOIDS. The quoted factory selling price of the EROS II GA system (in 1975 dollars) was $730 per unit.

THE SECANT-GA system was compared with the AVOIDS to establish variations in operating parameters. The 24 frequencies required by the SECANT system resulted in an anticipated cost increase of $290. The required second IF of the SECANT caused a differential of $20, and the introduction of eight SAW filters was estimated at a differential of $80. The increased cost of a transistorized final power amplifier resulted in a differential of $120. The total increase in the cost of the SECANT-GA over the base-unit AVOIDS was estimated by NARCO to be $510 for a quoted factory selling price of the SECANT-GA system (in 1975 dollars) of $1010 per unit. Table 3-15 summarizes the NARCO evaluation, showing the base unit price, increases caused by complexities, factory selling prices, and the normal advertised list price for each of these evaluated systems. The NARCO report on the evaluation is included in Appendix C to this study.

Table 3-15. NARCO 1978 SYSTEM COSTS (in 1975 Dollars)

SYSTEM	BASE COST	COST FOR COMPLEXITY	FACTORY SELLING PRICE	LIST PRICE
AVOIDS	$ 500.	-	$ 500.	$ 1,000.
EROS II GA	500.	+ $ 230.	730.	1,460.
SECANT GA	500.	+ 510.	1010.	2,020.

3.3.4 GENAVE/NARCO Critique of Reliability

The general-aviation manufacturers reviewed the proposed designs and compared them with the systems or modules of existing production units to establish estimates of the system reliabilities. The methods employed by the manufacturers differed sufficiently to justify presentation and qualification of the results.

3.3.4.1 GENAVE Reliability Evaluation

GENAVE maintains detailed repair records on equipment manufactured by their plant and has managed to establish an average relationship between system electronic parts count and system reliability. The technique appears to be justified, since it is based on field experience of long standing by GENAVE and presents a uniform evaluation of the three proposed systems. The technique is also recognized and used as a "rapid reliability prediction" by MIL-217A advocates. The results of the GENAVE reliability predictions are presented in Table 3-16.

Table 3-16. GENAVE SYSTEM RELIABILITY (TYPE II)

SYSTEM	TOTAL ELECTRONIC COMPONENTS	FREQUENCY OF REPAIR	COST PER REPAIR CYCLE
AVOIDS II	181	3860 hours	$100.00
EROS II GA	340	2050 hours	150.00
SECANT GA	325	2150 hours	150.00

The reliability data presented include the average cost of repair of a unit and reflect multiple corrective actions during a repair cycle. While the actual system MTBFs based on a single component failure would result in lower reliability figures than those presented, these additional data were not provided by GENAVE.

3.3.4.2 NARCO Reliability Evaluation

NARCO established reliability data on the three systems by comparing CAS module components with similar modules manufactured by NARCO for which the reliability is known. The evaluation established a reliability for the AVOIDS unit by direct comparison with the AT-50 transponder. The dominant factor controlling the AVOIDS reliability was considered to be the cavity oscillator.

The EROS system was considered equivalent in complexity to the AVOIDS for reliability prediction, except for the addition of a second power amplifier tube and the added frequency generation. The failure rate on the PA tubes was identified from standard industrial handbooks to be 2.5 percent per 1000 hours of operation. The resultant reliability of the EROS system decreased in proportion to the complexity difference to the MTBF specified.

The SECANT system logic, power supplies, and indicator reliabilities were considered equivalent to the AVOIDS and EROS systems. The use of a transistorized final amplifier increased the system reliability, reflecting the advantage of solid-state components, but the complexity of the frequency generation in the use of 24 frequencies offset the advantages gained. The resultant reliabilities predicted for each of the three systems are presented in Table 3-17.

Table 3-17. NARCO SYSTEM RELIABILITY (TYPE II)

SYSTEM	BASE UNIT FAILURE RATE (% per 1000 hours)	INCREASE IN FAILURE RATE (% per 1000 hours)	CALCULATED MTBF	EXPECTED MTBF
AVOIDS II	20.4%		4900	1500.
EROS II GA	20.4%	+ 9.0%	3400	1200.
SECANT GA	20.4%	+ 5.9%	3800	1500.

3.3.4.3 System Reliability Used in Study

The experience of the general-aviation manufacturers with repair of failed units produced by their plants was considered as indicative of the expected reliability of CAS if produced by these manufacturers and used by the general-aviation community. The general-aviation aircraft is frequently subjected to inclement weather, unsheltered storage, and minimum preventative maintenance resulting in reduced reliability of the avionics of the aircraft as evidenced by the failure data of the manufacturers. Therefore in the independent evaluation this study has used the expected reliability data provided by the manufacturers for the CAS concepts to provide a realistic evaluation of the cost of ownership of the CAS. The reliabilities used are; 1500 hours for AVOIDS and SECANT, and 1200 hours for EROS.

CHAPTER FOUR

CAS INSTALLATION DATA

This chapter addresses the development of those data items which are employed in the economic analysis and represent common cost factors to all three CAS concepts. The data items include the specific CAS-equipment configurations for each category of user, the costs of command indicators, antennas, the estimated installation costs of CAS for each category of user (including distribution costs), and aircraft population projections within each user category. In addition,a review and summary of electronics costs developed in chapter three is presented for ready comparison of the equipment required for implementing CAS.

There are many other data items that are common to the type of system but peculiar to the specific user category (e.g., labor rates, pipeline times, training cost). These additional data items are defined in Appendix E and the values of these items used for the analyses are presented. These latter values were established through contact with representative user organizations, ARINC Research prior experience, and consultation with the FAA and the three principal manufacturers. The developed values were included as a part of the Uniform Ground Rules established at the beginning of the study.

4.1 COST OF CAS-RELATED ELECTRONICS COMPONENTS

The classes of equipment studied have been limited to the Type I CAS (i.e., one based on ANTC-117 vertical threat logic, intended for commercial air carriers and other high-performance aircraft) and the less expensive, limited-capability Type II CAS, intended for the general-aviation aircraft. Each system will provide the owner with collision-avoidance protection when an intruder equipped with either version of CAS is encountered.

Chapter Three established the cost of both classes of equipment as proposed by the principal manufactueres and as independently developed by ARINC Research based on typical avionic manufacturing practices. Emphasis was placed on the manufacturing costs of the "block-box" electronics without regard to the costs of the antennas or indicators necessary for CAS operation. This section identifies these additional costs and summarizes the overall equipment costs associated with a completely-installed CAS system.

4.1.1 Antennas

Each of the CAS concepts operates in the L-Band region and requires identical antennas. The antennas are similar to those presently used for ATCRBS transponder operation, except that the radiators are designed for the higher L-Band frequencies. The antennas required by the high performance aircraft are either the blade or flush mount type. This study reflects the cost of the blade antenna and assumes the cost to be the same as those for the transponder antenna (i.e., $63.00 per antenna). These costs have been confirmed through contacts with Collins Radio on their model 237Z-1 antenna and TRANSCO Products, Inc. on their type-T25 CAS antenna. The limited performance CAS systems require the less expensive quarter-wavelength stub antenna which retails for an average price of $13.

4.1.2 Command Indicators

Figure 4-1 shows the combined vertical speed and CAS indicator proposed by McDonnel-Douglas and used by each of the CAS concepts. The cost of the proposed indicator has been substantiated by quotations to McDonnell Douglas by Teledyne Avionics, a potential manufacturer of the CAS/IVSI indicator. The cost, estimated at $1092 per unit, reflects an increase of approximately $300 over the cost of a vertical speed indicator. However, Teledyne Avionics has informed McDonnell Douglas that a modification of the existing VSI instruments would be economically impractical. Therefore, this study has assumed that a new indicator would be required for each aircraft retrofitted with high performance CAS equipment.

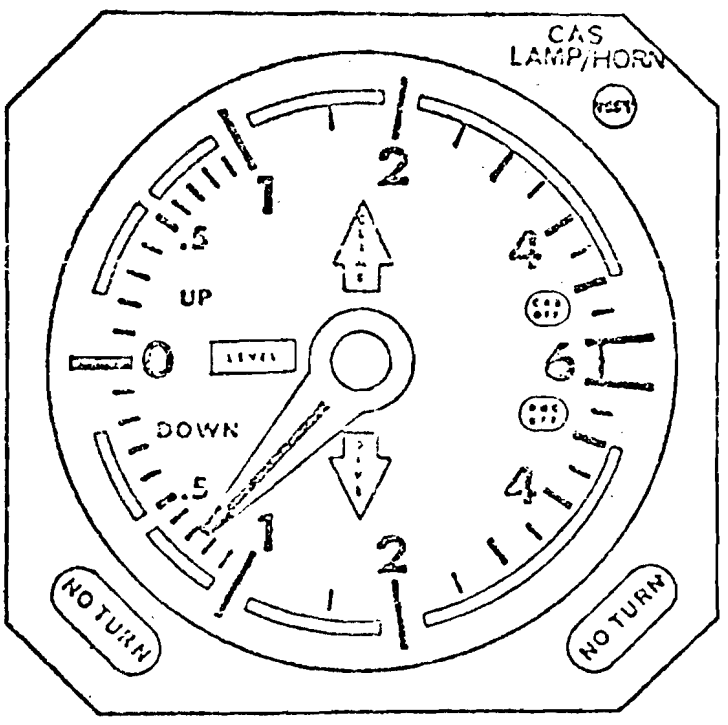


Figure 4-1. CAS/IVSI COMMAND INDICATOR

The indicators used in the general-aviation low performance versions of CAS would be built-in as part of the electronics box. A typical maneuver command indicator is shown on the front panel of the CAS presented in Chapter Three. The cost of this indicator is included in the developed costs of the equipment reported in Chapter Three.

4.1.3 Summary of Electronics Costs

The common and unique CAS cost elements associated with each concept are presented in Table 4-1. Both the manufacturer's suggested costs and the independently developed costs from Chapter Three are presented for easy comparison. The principal electronics costs are the suggested OEM (factory selling) price without allowances for distribution costs. The effect of distribution is identified in the following section.

TABLE 4-1. CAS EQUIPMENT COST

	MANUFACTURERS DATA			INDEPENDENTLY DEVELOPED DATA		
	AVOIDS	EROS	SECANT	AVOIDS	EROS	SECANT
HIGH PERFORMANCE TYPE I CAS						
ELECTRONICS*	4016	4683	5141	4012	4694	5501
INDICATOR	1092	1092	1092	1092	1092	1092
ANTENNA	63	63	63	63	63	63
CONTROL	0	0	127	0	0	127
LIMITED PERFORMANCE TYPE II CAS						
ELECTRONICS*	591	1215	1547	565	990	1148
INDICATOR	0	0	53	0	0	0
ANTENNA	13	13	13	13	13	13

*MANUFACTURER'S EXPECTED OEM PRICES WITHOUT MARK-UP FOR DISTRIBUTION

4.2 DISTRIBUTION COST

In Chapter Three, emphasis was placed on the identification of the factory selling price for the CAS equipments; as a result, no allowance was made for the distribution cost associated with marketing the CAS units to the general public. It is common practice that the commercial airlines and the military will obtain CAS equipments directly from the CAS manufacturers, but that the general-aviation community will have to pay additional money to avionics distributors as a part of the acquisition cost for the CAS units. To account for this added expense, a 100 percent mark-up of the factory selling price for Type II units has been followed in the study to determine the list price. However, many distributors who are not engaged in equipment installations advertise discounts nationally on new factory warranted equipment. The advertised discounts vary depending on demand and availability but are generally between 10 and 30 percent. A 20 percent discount of the list price has been applied to the Type II equipment evaluated in this study, reflecting the mean of the advertised discounting practice in the general-aviation community when a unit is purchased separately (installation would then appear as an additional expense to this user).

A 30 percent mark-up of Type I units was applied to the full capability units installed in general-aviation aircraft. These values are representative of the distribution costs found in the general-aviation community and were considered acceptable by the three CAS manufacturers. The addition of these costs to the acquisition costs of each of the three concepts has not affected the relative cost evaluation of the three concepts. Table 4-2 presents the expected cost of equipment to the general-aviation community when distribution costs are included.

TABLE 4-2. EXPECTED SELLING PRICE OF ELECTRONICS-(GENERAL-AVIATION)

	MANUFACTURERS DATA			INDEPENDENTLY DEVELOPED DATA		
	AVOIDS	EROS	SECANT	AVOIDS	EROS	SECANT
HIGH PERFORMANCE TYPE I CAS						
ELECTRONICS	5221	6088	6683	5216	6102	7151
INDICATOR*	1092	1092	1092	1092	1092	1092
ANTENNA	63	63	63	63	63	63
CONTROL	0	0	165	0	0	165
LIMITED PERFORMANCE TYPE II CAS						
ELECTRONICS	946	1944	2475	904	1584	1837
INDICATOR	0	0	85	0	0	0
ANTENNA	13	13	13	13	13	13

*THE CAS/IVSI INDICATOR HAS BEEN QUOTED AT THE EXPECTED SELLING PRICE, THEREFORE NOT SUBJECT TO DISTRIBUTION MARK-UP
**INCLUDES 30% MARK-UP
***INCLUDES A 100% MARK-UPS FOLLOWED BY A 20% DISCOUNT

Distribution costs were also considered as a logistic support cost factor associated with the replacement of modules or component parts. The distribution costs of the individual replacement parts were computed as a percentage of the components' cost, with a distribution cost of 30 percent of cost of Type I components and 60 percent of the cost of Type II components.

4.3 AIRCRAFT CONFIGURATIONS

The complement of equipment to be installed by each of the users depends on individual needs, the probable flight profiles, the required reliabilities that affect aircraft availability (especially for the air carriers), and the anticipated or required flight crews for special classes of aircraft.

This section identifies the probable CAS aircraft configurations for each class of user based on existing practices in the aviation community concerning flight-critical avionic equipment.

4.3.1 Commercial Aviation

The air-carrier practive of achieving high operational availability through system standardization is assumed to be applicable to the CAS implementation. Therefore, all certified commercial air carriers are assumed to require the following complements of CAS avionics:

- 1 set of CAS electronics (Type I)
- 2 antennas (top and bottom)
- 2 CAS/IVSI indicators (pilot and co-pilot)
- 1 set of control and switching equipment

The elctronics will be located in the normal avionics bay of the aircraft, and the indicators will replace the currently installed vertical speed indicators in the flight console. The switching and control systems will be tailored to the specific air frame and the system chosen for implementation. A single set of CAS electronics has been assumed for commercial air carriers to be consistent with the installation decisions generally made for other important avionics such as transponders. It is recognized that some air carrier aircraft may be equipped with dual installations, and the economic impact of such a decision is addressed in Chapter Six.

4.3.2 Military Aviation

It is assumed that the military will participate in a National CAS program primarily to fly in the National Air Space and not to satisfy any special military requirements. Thus the military is expected to employ the minimum of required equipment consistent with the level of performance and number of pilot positions. Therefore, the configuration considered in the study for high-performance military aircraft (i.e., aircraft capable of speeds in excess of 250 knots) was the following:

- 1 set of CAS electronics (Type I)
- 2 antennas (top and bottom)
- 2 CAS/IVSI indicators (1 for single seat aircraft)
- 1 set of control equipment

The single set of CAS electronics was selected since the equipment is assumed to be not military-essential and thus represents the minimum requirement. However, the Type I CAS was chosen in order to be able to meet the protection requirements of the high-performance aircraft. The electronics will be located in the normal avionics bay, and the indicators will replace the existing vertical speed indicators in the flight console.

The lower-performance military aircraft considered in the study will use the proposed Type II version of CAS with built-in indicators, and these units will be located in the flight console of the cockpit. The equipment configuration will consist of the following for these types of military aircraft:

- 1 set of electronics (Type II)
- 1 antenna (top) (MDEC OR RCA)
- 2 antennas (top and bottom) (Honeywell)

The study considers only the inexpensive Type II system available for this class of equipment. However, each of the three candidate manufacturers has indicated that remote indicators can be incorporated into the system on the basis of the user's requirements. Some of the military piston-engine aircraft may need remote installations with dual indicators; this variation will be available, but it is not evaluated in this study.

4.3.3 General Aviation

The private aircraft owner is usually cost-conscious, carrying the minimum avionics required consistent with flight regulations and safety. Therefore, it has been assumed in this study that almost all (95 percent) private aircraft owners will prefer to install the least expensive CAS. The assumed installation consists of a single set of electronics with built-in indicators intended for installation in the flight console of the aircraft. The equipment required for this 95 percent of the population will thus be the same as that already specified for the lower-performance military aircraft.

The remaining five percent of the general-aviation aircraft are assumed to be in the high-performance class, requiring the Type I CAS equipment. This study considers the minumum required equipment and recommends a single system for each of the general-aviation users. The equipment will be installed either in the avionics bays of the large airframes or at remote locations peculiar to the particular aircraft type. A single indicator will be required, replacing the vertical speed indicator at the pilot's position. The minimum equipment required by each of the high-performance aircraft will consist of the following:

- 1 set of electronics (Type I)
- 1 CAS/IVSI Indicator (pilot only)
- 2 antennas (top and bottom)

The particular needs of some larger general-aviation aircraft (e.g., cargo or executive jets) requiring additional indicators or redundant systems can be satisfied at additional expense to the owners, but these are not considered in this study in determining the implementation costs of mandatory CAS.

4.4 INSTALLATION COSTS

The cost of equipment installation considered in this study falls into two categories: (1) retrofit of the existing fleet, and (2) implementation in new aircraft. Installation costs have been developed for each of these two categories for the various user categories and general classes of aircraft, i.e., the high-performance aircraft capable of speeds greater than 250 knots, and the low-performance aircraft with speeds lower than 250 knots. For purposes of the analysis, it was assumed that the installation costs in new commercial carrier and general-aviation aircraft were 60 percent of the estimated retrofit installation costs. The installation costs for new military aircraft are discussed in section 4.4.2. The costs developed reflect the equipment configurations identified in section 4.3.

4.4.1 Commercial-Aviation Installation Costs

The development of CAS installation cost estimates for the commercial carriers was based on the experience gained by United Airlines and Piedmont Airlines in their test and evaluation exercise with the McDonnell Douglas EROS system. These airlines retrofitted a B-727 and B-737, respectively, with collision-avoidance equipment, and, although the equipment was not identical to the proposed production versions, the concepts were sufficiently similar to utilize the data on labor, materials, engineering, and space availability. Considerations were given to the prototype installations, and the results presented in this report have the concurrence of the airline individuals involved in the retrofit program.

The installation costs presented are the expected average costs per aircraft with single system implementation. No allowances have been made for variations in system packaging. The large new aircraft have adequate space to accommodate any of the systems. Some of the smaller commercial aircraft, e.g., the F-227 operated by Piedmont, have no space left in the electronics bay and will require expansion of the present areas. At the same time, some aircraft have been produced with provisions for the installation of CAS (e.g., plates that are intended to be removed and replaced with a CAS antenna). Therefore, the costs shown have been assumed to be the average costs for any of the commercial aircraft.

The cost breakdown for system retrofit in the commercial-aviation case is as follows:

Installation Factor	Time Required	Cost
Shelf Fabrication and Installation	48 hours	$1,067
Antenna Installation	12 hours	267
Indicator Replacement	4 hours	89
On-Aircraft Cabling	100 hours	2,222
Engineering (300 hours ÷ fleet size of 100)	3 hours	66
Material (Lot)	--	516
TOTALS	167 hours	$4,227

4.4.2 Military-Aviation Installation Costs

The military fleet has been divided into the two performance classes on the basis of aircraft speed as previously discussed. All aircraft of the turbine class, except helicopters, are considered to be high performance and will require a single Type I CAS. The piston aircraft and helicopters were assumed to be candidates for the Type II CAS.

Installation costs for the military aircraft have been based on data provided by the Department of Defense (DOD) and represent the weighted average of each cost category associated with installations; these costs are governed by the types and numbers of aircraft in the military community. Each of the military branches was directed by DOD to develop costs associated with the implementation of CAS in existing and new aircraft scheduled to remain in the military inventory beyond 1985. The data prepared by the installation facilities of each branch of the services reflect the costs to retrofit the existing fleet, by aircraft type, and the costs to add a CAS to new aircraft during production. The cost categories considered by the installation facilities included: (1) the acquisition of the CAS electronics, antennas, indicators, and control; (2) the labor hours converted to dollars for installation on the aircraft; (3) the materials required to support the installation (Group A); and (4) the non-recurring logistic support costs. The latter include:

- Engineering - design of the installation, EMI/ECM testing, prototype testing on each type of airframe, and continuing support engineering during the eight year retrofit period.
- Initial Spares - Introduction of spare parts into inventory.
- Technical Data - including system technical orders (TO) and aircraft manual modifications.
- Test Equipment - special or peculiar support test equipment required to maintain a CAS.
- Training - the cost of training personnel at each installation and maintenance facility to repair and operate the CAS.
- Reprocurement - Data the cost of manufacturing drawings and system details required to permit reprocurement of an identical system from different manufacturers.

The treatment of each element within the non-recurring category varies between the services and reflects the operating procedures of each branch of service. For example, spares provisioning varies from a percentage of the acquisition cost to provisioning based on the number of repair facilities. The procedures for computing training costs vary from personnel training at depot facilities (NAVY), to training at intermediate facilities with no depot training (ARMY), to personnel training at a rate of one man per each aircraft in the inventory (AIR FORCE). The non-recurring costs, other than engineering, provided by the DOD have been carefully reviewed to insure that each category is properly included and evaluated by the Economic Analysis Model used in this study. Therefore, these specific costs have not been averaged and included in the installation costs presented in this section. The impact of non-recurring costs on a per-aircraft and fleet basis is evaluated and presented in Chapter Five.

The cost breakdown for system implementation in the military high-performance case, based on the weighted average of the data presented by the three branches of the service, is as follows:

INSTALLATION FACTOR	PER AIRCRAFT RETROFIT	(HIGH PERFORMANCE) NEW
MATERIAL ACQUISITION (GROUP A)	$2062	$1301
INSTALLATION (LABOR)	5976	9840
ENGINEERING (DESIGN AND TEST)	214	0
TOTAL	$8252	$11,141

It should be noted that different organizations within the military prepared the installation cost estimates for the new and retrofit aircraft.

The low-performance military aircraft will use the Type-II CAS System. This study considers the CAS equipment as proposed by the design manufacturers and reflects the costs of the equipment (Group B) as developed in Chapter Three. The military, however, believe that certain changes in equipment configurations will be required for installation on the military low-performance aircraft. For example, the ARMY helicopter fleet will require a single Type II CAS but with two remotely mounted indicators. The AIR FORCE low-performance aircraft will use the Type II CAS but indications will be provided by the Type I CAS/IVSI indicator, at each pilot position. The NAVY has used a combination of equipment and displays. In order to provide the true expected costs of system installation, the data obtained from DOD reflecting the cost of installing the modified versions of equipment has been used in this study. The per aircraft data has been averaged over the total low-performance military fleet and the results (i.e. the weighted averages) are as follows:

INSTALLATION FACTOR	Per Aircraft (Low-Performance) RETROFIT	NEW
Material Acquisition (Group A)	$788.	$ 270.
Installation (Labor)	875.	2042.
Engineering (Design and Test)	816.	403.
	$2479.	$2715.

4.4.3 General Aviation

The installation costs for the high-performance general-aviation aircraft have been developed from the experience of Piedmont Airlines (Piedmont does engage in the maintenance and retrofit of avionic equipment for corporate aircraft). The resultant costs have been averaged to reflect the various classes and configurations anticipated in the high-performance general-aviation aircraft.

The following data identify the estimated costs to install the CAS system in a high-performance general-aviation aircraft:

Installation Factor	Time Required	Cost
CAS Unit Installation	24 hours	$ 430
Antenna Installation	12 hours	215
Indicator Replacement	2 hours	36
Cabling	40 hours	715
Material (Lot)		529
TOTALS	78 hours	$1,925

The installation costs for the single-engine and light twin-engine aircraft were developed through a survey of the maintenance facilities supporting the general aviation community. All FAA-certified repair facilities were requested to provide an estimate on the installation of a NARCO DME-190. The DME-190 was chosen as being similar in size and complexity to the proposed Type II CAS; requiring similar cabling, antenna, and power. The questionnaire further requested a breakdown in hours of the effort required for unit installation, antenna installation, cabling, average material cost, and installation and repair labor rates. The replies received reflect more than 25 percent of the repair facilities and are considered representative of the entire general-aviation community. A summary of the questionnaire replies is contained in Appendix F.

The following data are the results of the survey. The installation costs are the average of the information received and reflect the variety of airframes encountered by the responding facilities. A complexity factor has been used on the cabling estimate to allow for the additional labor for connecting the encoding altimeter, assumed to be a part of the existing aircraft avionics.

The following data identify the costs to install any of the three proposed Type II CAS systems in general-aviation aircraft*:

Installation Factor	Time Required	Cost
GA Unit Installation	4.89 hours	$ 31
Antenna Installation	2.50 hours	41
Cabling	5.00 hours	81
Material (Lot)		23
TOTALS	12.39 hours	$226

* It was assumed that this cost will apply to all three Type II CAS designs, even though the Honeywell unit requires two antennas and the others require only a single antenna. While the requirement for a second antenna in the Honeywell installation tends to increase the installation costs, the fact that the Honeywell boxes should be smaller and lighter tends to reduce the installation costs. For purposes of this study, these two effects were assumed to cancel each other.

4.4.4 Installation Cost Summary

Table 4.3 presents a summary of the installation costs developed in this section and used in the life-cycle cost evaluation of Chapter Five. The data for new aircraft installation are those provided by the military for their aircraft and the expected ratio to the retrofit costs for Commercial and General Aviation aircraft.

Table 4-3

SUMMARY OF INSTALLATION COSTS (PER AIRCRAFT)			
	COMMERCIAL AVIATION	MILITARY AVIATION	GENERAL AVIATION
RETROFIT INSTALLATIONS			
HIGH PERFORMANCE	$4227.	$8252.	$1925.
LIMITED PERFORMANCE	0	2479.	226.
NEW AIRCRAFT INSTALLATIONS			
HIGH PERFORMANCE	2536.	11141.	1155.
LIMITED PERFORMANCE	0	2715.	136.

4.5 AIRCRAFT SCENARIOS

System implementation has been assumed to begin in 1978. The three-year time period allowed before the start of CAS implementation would be required to pass the necessary legislation, develop the necessary regulations, finalize the development of the selected CAS concept, and begin the production process.

The retrofit period for the entire aviation community has been assumed for purposes of this study to be eight years with the commercial carriers completing the retrofit after four years. The CAS installation program has been assumed to affect only those aircraft not scheduled for retirement during the retrofit period. For all user categories, the number of retrofits has been assumed to be linear, with all existing aircraft being equipped with CAS by the end of 1985. All new aircraft delivered in 1978 and in later years would have the CAS implemented as part of the original required avionic equipment.

All aircraft registered in the continental United States, except experimental aircraft, gliders, balloons, and nonmilitary rotocraft, have been assumed to require the installation of a CAS. In reality, many other types of aircraft may not be required to operate CAS equipments, but their inclusion or omission from the assumed general-aviation population should not affect the decision regarding which of the three CAS concepts is most attractive to general aviation from a cost point of view.

The aircraft fleet population projections used in this study have been based on available information developed in 1974 by the U. S. Department of Transportation, FAA-Office of Aviation Policy, Aviation Forecast Branch.

4.4.1 Commercial Aviation

It is assumed that the air carriers' retrofit period will be four years, and all aircraft not scheduled for retirement within the first four years will be retrofitted with the Type I version of CAS. Table 4-4 identifies the projected fleet of commercial-carrier equipment, with planned expansions and retirements that were used in the analysis.

4.5.2 Military Aviation

The military-aviation community considered by this study includes all U. S. based military aircraft operated by the active Armed Forces, the reserves, and the National Guard.

The retrofit period for the military was assumed to be linear over the entire eight years. As for the commercial category, any aircraft scheduled for retirement during the retrofit period was not considered in the cost analysis. All new aircraft scheduled for delivery in 1978 or later were assumed to have CAS incorporated in the basic avionics at the factory. Table 4-5 identifies the assumed fleet of military aircraft considered in this study. All jet and turbine aircraft are assumed to fall in the high-performance category while all piston and helicopter aircraft are assumed to fall into the low-performance category.

Table 4-4. COMMERCIAL-CARRIER AIRCRAFT STATISTICS

Year	Existing	New	Retirements	Total
1978	2,848	133	50	2,931
1979	2,931	157	69	3,019
1980	3,019	142	67	3,094
1981	3,094	180	102	3.172
1982	3,172	149	78	3,243
1983	3,243	142	69	3,316
1984	3,316	130	63	3,383
1985	3,383	119	53	3,449
1986	3,449	65	0	3,514
1987	3,514	64	0	3,578
1988	3,578	65	0	3,643
TOTALS		1,346	551	

Table 4-5. CONUS MILITARY AIRCRAFT STATISTICS

Year	Jet and Turbine (High)			Piston (Low)			Helicopter (Low)			Total
	Existing	New	Ret	Existing	New	Ret	Existing	New	Ret	
1978	10,882	143	53	1,542	0	154	7,553	13	18	19,908
1979	10,972	84	4	1,388	0	170	7,548	61	5	19,874
1980	11,052	117	5	1,218	0	102	7,604	52	1	19,935
1981	11,164	204	35	1,116	0	65	7,655	118	3	20,154
1982	11,333	32	1	1,051	0	5	7,770	72	0	20,252
1983	11,364	15	11	1,046	0	0	7,842	0	0	20,256
1984	11,368	0	0	1,046	0	0	7,842	0	0	20,256
1985	11,368	0	0	1,046	0	0	7,842	0	0	20,256
1986	11,368	0	0	1,046	0	0	7,842	0	0	20,256
1987	11,368	0	0	1,046	0	0	7,842	0	0	20,256
1988	11,368	0	0	1,046	0	0	7,842	0	0	20,256
Totals		595	109		0	496		316	27	

4.5.3 General Aviation

The largest and fastest-growing element of the aviation community is general aviation. The population extends from the large, pure-jet cargo fleets, through executive and corporate aircraft, to the air-taxis and the privately owned pleasure aircraft. The sizes and types of aircraft are as numerous as the variety of uses to which they are subjected. The latest FAA statistics for 1974 list more than 150,000 registered aircraft in the general-aviation community. The general-aviation community has also been divided into high- and low-performance categories. For purposes of this study, and on the basis of sampled data on new aircraft production, 10 percent of the multi-engine aircraft were assumed to be in the high-performance category. All single-engine aircraft were assumed to be in the low-performance category and all turbine aircraft were assumed to be in the high-performance category. An eight-year linear retrofit of general-aviation aircraft has been assumed for the analysis.

Table 4-6 GENERAL-AVIATION AIRCRAFT STATISTICS *

	SINGLE ENGINE		MULTI ENGINE		TURBINE			
Year	Existing	New	Existing	New	Existing	New	Total New	TOTAL
1978	140,300	4,200	22,600	1,100	4,900	400	5,700	173,500
1979	144,500	4,000	23,700	1,200	5,300	600	5,800	179,300
1980	148,500	4,100	24,900	1,100	5,900	500	5,700	185,000
1981	152,600	5,100	26,000	1,200	6,400	400	6,700	191,700
1982	157,700	4,900	27,200	1,200	6,800	600	6,700	198,400
1983	162,600	4,800	28,400	1,300	7,400	600	6,700	205,100
1984	167,400	4,500	29,700	1,600	8,000	700	6,800	211,900
1985	171,900	5,500	31,300	800	8,700	300	6,600	218,500
1986	177,400	5,500	32,100	800	9,000	300	6,600	225,100
1987	182,900	5,500	32,900	800	9,300	300	6,600	231,700
1988	188,400	5,500	33,700	800	9,600	300	6,600	238,300
TOTALS		53,600		11,900		5,000	70,500	

Table 4-6 presents the projected general-aviation population data on the existing and predicted expansion of the community, by engine configuration and totals for the period considered in the life cycle of the study. The eight-year retrofit program identifies the quantities of both types of CAS equipment that will be required to satisfy the needs of the community and represents the 5-percent Type I and 95 percent Type II CAS deployment dictated by performance.

* These statistics do not include gliders, experimental aircraft, rotorcraft, etc.

CHAPTER FIVE

INDIVIDUAL AIRCRAFT AND FLEET COSTS FOR CAS IMPLEMENTATION

The cost of implementing the Honeywell, McDonnell Douglas, and RCA CAS concepts for the various users of the national airspace are presented in this chapter. The economic analyses are based on the data developed in Chapters Three and Four and are performed with the assistance of an economic cost model. Implementation-cost data are shown on an individual aircraft and a total fleet basis for two sets of data: the manufacturer-supplied cost and reliability data, and the revised cost and reliability data resulting from the critique of the manufacturers' data.

5.1 COST MODEL

ARINC Research Corporations' Economic Analysis Model* (EAM) has been adapted to evaluate the economic impact of proposed collision-avoidance systems and to provide a basis for cost comparison among the several competing CAS concepts currently under development.

The model evaluates the economic impact and provides a basis for cost comparison in three different user environments: Commercial Aviation, General Aviation, and Military Aviation. Further, within each user category and system, the model considers three levels of CAS: full (commercial aviation) capability, limited (general aviation) capability, and remitter (cooperative transponder without threat-detection logic) capability.** The distribution of these three CAS levels within a specific user category is specified by the input data to the model.

The model has been programmed in FORTRAN for use with a computer time-sharing system. It computes the expected annual and cumulative acquisition, installation, and logistic support costs for each concept/user combination desired. The program is flexible so that data changes can be readily implemented, sensitivity evaluations performed, or additional data outputs obtained.

---

* Developed for cost analysis of a Proposed Defense Navigation Satellite System Receiver, prepared for USAF Space and Missile Systems Organization under Contract F09603-73-A-0933-TB01 by ARINC Research Corporation.

** The results of the remitter cost evalution are presented in Chapter Six.

The program features and mathematical formulation of the EAM are documented in Appendix D to this report.

5.2 ADDITIONAL INPUTS REQUIRED BY THE MODEL

The information provided by the manufacturers on costs and reliabilities, together with the statistical data developed in Chapter Four, constitute only a portion of the data required to compare systems or establish the cost of implementation.

Many parameters contributing to the evaluation of the systems and life-cycle costs are dictated by the user communities. For example, the average hours flown by a user vary from 17.3 hours per month for the general-aviation equipment to 238 hours per month for the air-carrier equipment. These data were developed as were other parameters required by the model, through contact with the user community, (e.g., United and Piedmont Airlines, AOPA*, and ATA**) research work completed through other contracts within the corporation, and information furnished by the FAA.

A complete listing of the parameters influencing the evaluation is presented in tabulated format for ready comparison in Appendix E to this report. All the parameters considered influential in evaluating the relative costs and reliabilities of the systems have been programmed into the cost model and the maintenance and life-cycle costs determined by the model.

5.3 RESULTS OF APPLYING THE LIFE-CYCLE-COST MODEL

The ARINC Research EAM computes annual and cumulative acquisition, installation, and logistic support costs for each concept/user combination desired. The model was programmed to print out data for three additional years beyond the complete aircraft population retrofit period of 1978 through 1985 to evaluate the effects of new aircraft production without retrofit, and of maintenance and logistics costs after fleet implementation.

This section presents the results derived from the model on the basis of the parametric inputs provided by both the competing manufacturers and independently derived data. The results are presented on a per-aircraft basis to identify separately the costs of acquisition, installation, non-recurring logistics, recurring logistics, and, finally, the eleven-year life-cycle cost expected by an aircraft owner in any of the user categories. Costs are presented in Section 5.3.1 on the basis of both the manufacturers' supplied data and the independently derived data.

The life-cycle cost of system implementation is presented graphically on a year-by-year basis for each user community's fleet of aircraft. To make the graphical presentations easy to interpret, Section 5.3.2 presents the life-cycle costs based on the manufacturers' data, and Section 5.3.3 presents the costs for the independently derived cost and reliability estimates.

---

*Aircraft Owners and Pilots Association (AOPA)
**Air Transport Association (ATA)

5.3.1 Cost of Ownership per Aircraft

The cost of ownership of a collision-avoidance system on a per-aircraft basis consists of the initial acquisition and installation costs, a proportion of the nonrecurring logistic support costs (determined by averaging over the entire user population in the 11-year life cycle), the recurring yearly logistics costs attributed to an aircraft, and the cumulative life-cycle cost of aircraft maintenance during the 11 years. These costs can be combined to provide a competitive evaluation of the systems based on both initial investment and reliability. One cost factor (amortization of manufacturer initial costs) was determined in the data-collection effort but is not included in the cost analyses presented in this chapter because of the uncertainties regarding the effect that the competitive market will have on these costs. However, the possible effects of amortization are considered in Chapter Six.

Acquisition reflects the equipment costs developed in Chapter Three and for aircraft configurations identified in Chapter Four. This section presents the cost of ownership per aircraft for the existing fleet, the majority of the expected aircraft requiring CAS during the 11-year life cycle. New high-performance aircraft introduced into the aviation inventory after 1978 would realize a saving in the acquisition of the single combined CAS/IVSI indicator. An allowance of $800 per unit has been made in the study for the cost of a vertical speed indicator and is reflected in the acquisition cost of new CAS avionics and in the life-cycle costs presented in this chapter.

The logistic support costs are divided into two categories: the nonrecurring costs associated with introduction of a new system, and the recurring costs experienced from normal corrective maintenance of the system. The costs are categorized by the following groupings:

- On-aircraft maintenance
- Off-aircraft maintenance
- Spare parts
- Inventory management
- Support equipment
- Training
- Technical data and failure documentation
- Facilities

The composition and application of any category are complex and require a detailed review of the economic analysis model for proper understanding. However, in identifying those categories influencing the logistic support costs, all categories contribute to the recurring logistics costs and all but the on-and off-aircraft maintenance contribute to the non-recurring logistics cost. For example, spare parts would normally be purchased by a user and introduced into the inventory system. This would result in costs associated with the spares and the costs of inventory set-up, both considered as non-recurring. Upon failure of a unit, spares would be used up and replacement spares reordered, encountering a recurring cost of parts and documentation. The EAM computes these types of cost parameters based on the probability of failures controlled by the system reliabilities.

The logistic support costs for the general-aviation community are limited to the recurring costs of maintenance, i.e., on- and off-aircraft maintenance costs consisting of labor and materials to repair a failed unit. The individual general-aviation owner is not expected to provision either spare parts or test equipment, and consequently does not usually incur the management or facility costs associated with provisioning. These costs are reflected in the general aviation cumulative life-cycle CAS costs, however.

5.3.1.1 Commercial Aviation

Table 5-1 compares the costs of system implementation on a per-aircraft basis for the three competing manufacturers. The table shows the acquisition, installation, and estimated portions of the nonrecurring and recurring logistic costs shown in 1975 dollars, to be incurred for CAS equipment installed in 1978. The first year of ownership, therefore, applies to a 1978 installation. These costs will be greater in subsequent years because of the effect of inflation. The life-cycle cost represents the total cost associated with CAS installations made in 1978 and maintained through 1988. The exact relationship between the first year of ownership costs and the life-cycle costs is complex and based on the life-cycle cost model. However, the life-cycle costs is essentially the first-year cost, plus the cumulative recurring logistic cost, at a zero percent inflation rate.

The manufacturers' data show that the initial investment favors the AVOIDS system, with EROS and SECANT requiring increasing initial costs, respectively. The cost aspects of maintaining the equipment for eleven years (the duration of the assumed life-cycle study) show that the SECANT system enjoys the lowest recurring maintenance cost on the basis of the manufacturers' data. A detailed review of the influencing parameters identified the cause of this effect to the "average material cost per repair" data specified by the manufacturers. The acquisition-cost advantage enjoyed by Honeywell in the use of a simplified RF section, specifically the cavity oscillators, is offset by the high cost of cavity replacement over a typical life-cycle period.

System costs for the independently developed data are also shown in Table 5-1. In the independently derived data, the assumed cost of replacing the AVOIDS cavity is reduced from $97. to $88. with a net effect that the Honeywell system still exhibits the lowest life-cycle costs. The upward variation in the SECANT recurring logistic and life-cycle costs is attributable to the lower MTBF estimated by ARINC Research relative to that proposed by RCA. Based on both the manufacturers' and the independently derived data, the Honeywell CAS is the least expensive throughout the 11-year life cycle.

Table 5-1. COMMERCIAL AVIATION COST DATA COMPARISON
(Per Aircraft-Retrofit) (Zero Percent Inflation Rate)

System / Costs	Manufacturers' Data			Independently Developed Data		
	Honeywell AVOIDS	MDEC EROS	RCA SECANT	Honeywell AVOIDS	MDEC EROS	RCA SECANT
Acquisition*	$6,326	$6,993	$7,578	$6,322	$7,004	$7,938
Installation	4,227	4,227	4,227	4,227	4,227	4,227
Non-Recurring Logistic	141	159	144	103	160	164
Recurring Logistic	356	309	301	337	302	358
1st Year Ownership	11,050	11,688	12,250	10,989	11,693	12,687
Life-Cycle Cost	14,633	14,797	15,278	14,382	14,730	16,286

* Electronics package (1); Antennas (2); Indicators (2); Control Unit (1)

5.3.1.2 Military Aviation

Table 5-2 presents the cost of ownership and life-cycle costs per aircraft for the military high-performance fleet. The initial investment costs, similar to those of the commercial-aviation case, favor the Honeywell AVOIDS system, with the EROS and SECANT sytems requiring higher initial investment. Detailed review of the recurring logistics costs of each system shows that the SECANT experiences the lowest cost, with an anticipated LCC for maintenance of $3,225; the EROS is next, with a system maintenance cost of $3,253; and the AVOIDS requires the highest cost -- $3,478 over the 11-year life cycle. However, the reduced average flight time per aircraft for the military, 80 hours per month versus 238 hours per month for the commercial carriers, results in an overall system cost advantage for the Honeywell AVOIDS. The calculated reduced reliability of the SECANT results in the highest life-cycle maintenance cost for that system based on independently developed data. Table 5-2 presents the results of the independently developed evaluation for comparison.

Table 5-2. MILITARY AVIATION (HIGH PERFORMANCE) COST DATA COMPARISON (Per Aircraft-Retrofit) (Zero Percent Inflation Rate)

System / Costs	Manufacturers' Data			Independently Developed Data		
	Honeywell AVOIDS	MDEC EROS	RCA SECANT	Honeywell AVOIDS	MDEC EROS	RCA SECANT
Acquisition*	$6,326	$6,993	$7,578	$6,322	$7,004	$7,937
Installation	8,252	8,252	8,252	8,252	8,252	8,252
Non-Recurring Logistic	420	519	378	391	514	471
Recurring Logistic	787	768	760	781	767	776
1st Year Ownership	16,085	16,532	16,968	15,746	16,537	17,436
Life-Cycle Cost	18,776	19,017	19,433	18,374	19,007	20,064

*Electronics package (1);Antennas (2); Indicators (2); Control Unit (1)

Table 5-3 presents the results of the evaluation for the limited-performance (Type II) equipment in the military community. The independently developed data used in this case represent an average of the cost and reliability estimates developed by NARCO and GENAVE and presented in Chapter Three. The expected rather than the calculated reliability data were used for the Type II equipment based on the experience and recommendation of the general-aviation manufactureres.

Table 5-3. MILITARY AVIATION (LIMITED PERFORMANCE) COST DATA COMPARISON (Per Aircraft-Retrofit) (Zero Percent Inflation Rate)

System / Costs	Manufacturers' Data			Independently Developed Data		
	Honeywell AVOIDS	MDEC EROS	RCA SECANT	Honeywell AVOIDS	MDEC EROS	RCA SECANT
Acquisition**	$ 617	$1,228	$1,613	$ 591	$1,003	$1,161
Installation	2,479	2,479	2,479	2,479	2,479	2,479
Non-Recurring Logistic	51	143	98	100	208	196
Recurring Logistic	810	809	812	882	952	918
1st Year Ownership	3,906	4,659	5,002	4,052	4,642	4,754
Life-Cycle	5,922	6,635	7,070	6,786	8,051	7,888

* Based on average of data developed by GENAVE and NARCO

** Electronics package, including indicator (1); Antennas (1) MDEC and RCA (2) Honeywell

5.3.1.3 General Aviation

The data in Table 5-4 identify the cost of ownership and the anticipated life-cycle costs for each CAS concept for high-performance GA aircraft. The rationale presented for the cost advantages in AVOIDS for the military high-performance-aircraft costs are equally appropriate to the high-performance-aircraft costs for general aviation. The acquisition costs include the distribution costs expected in a competitive market for the full-capability CAS. Nonrecurring costs (e.g., spares inventory) are not identified since they are considered inappropriate for the private general-aviation owner. The low recurring logistics costs for each system are based on a limited flight-hours-per-month average. For some classes of the high-performance GA community -- e.g., corporate or cargo jet aircraft--these costs will increase considerably. However, the typical aircraft owner equipped with a TYPE I - CAS is expected to experience the indicated maintenance costs on the average. The data are generally confirmed through the independently developed costs shown in the table.

TABLE 5-4. GENERAL AVIATION (HIGH PERFORMANCE) COST DATA COMPARISON (PER AIRCRAFT-RETROFIT) (ZERO PERCENT INFLATION RATE)

COST FACTOR	MANUFACTURERS' DATA			INDEPENDENTLY DEVELOPED DATA		
	HONEYWELL AVOIDS	MDEC EROS	RCA SECANT	HONEYWELL AVOIDS	MDEC EROS	RCA SECANT
ACQUISITION*	$5439	$7306	$8066	$6434	$7320	$8533
INSTALLATION	1925	1925	1925	1925	1925	1925
RECURRING LOGISTIC	23	20	20	22	19	24
1st YEAR OWNERSHIP	8,387	9,251	10,011	8,471	9,264	10,482
LIFE-CYCLE COST	8,621	9,448	10,210	8,691	9,439	10,719

*ELECTRONICS PACKAGE (1); INDICATOR (1); ANTENNAS (2); CONTROL UNIT (1)

Table 5-5 reflects the anticipated costs of ownership for the majority of the general-aviation community (i.e., the owners of limited-performance aircraft). On the basis of information presented by the manufacturers, the cost-of-ownership analysis favors the AVOIDS II system, with EROS II GA and SECANT GA reflecting the higher costs in proportion to the acquisition costs. The maintenance per aircraft is low but reasonable because of the 17.3-hour average flight time per month. The NARCO and GENAVE reliability and maintainability data confirm the low maintenance costs that a private owner can anticipate from CAS implementation. The unconfirmed cost of the RCA Remitter is included to show the expected life-cycle cost of this device based on the manufacturer's data.

TABLE 5-5. GENERAL AVIATION (LIMITED PERFORMANCE) COST DATA COMPARISON (PER AIRCRAFT-RETROFIT) (ZERO PERCENT INFLATION RATE)

COST FACTOR	MANUFACTURERS' DATA				INDEPENDENTLY DEVELOPED DATA		
	HONEYWELL AVOIDS	MDEC EROS	RCA SECANT	RCA REMITTER	HONEYWELL AVOIDS	MDEC EROS	RCA SECANT
ACQUISITION**	$972	$1,957	$2,573	$1,301	$930	$1,597	$1,850
INSTALLATION	226	226	226	226	226	226	226
RECURRING LOGISTIC	6	6	7	5	23	39	32
1st YEAR OWNERSHIP	1,204	2,189	2,806	1,532	1,179	1,862	2,108
LIFE-CYCLE COST	1,267	2,246	2,879	1,582	1,407	2,253	2,425

* BASED ON AVERAGE OF DATA DEVELOPED BY GENAVE AND NARCO.

** ELECTRONICS PACKAGE, INCLUDING INDICATOR (1); ANTENNAS (1) MDEC AND RCA (2) HONEYWELL

5.3.2 Life-Cycle Fleetwide Costs Based on Manufacturers' Data

The per-aircraft costs identified in the preceding section are informative and important to the general-aircraft owner and the small-fleet commercial carriers. However, the commercial air carriers and the military support large fleets of aircraft and are more concerned with the cumulative costs of system implementation which include the total costs of acquisition, installation, recurring, and non-recurring logistics, rather than the proportional costs per aircraft.

The total general-aviation expenditures, as well as the cumulative totals, are presented to identify the cost of a CAS implementation for the entire aviation community.

The cost-model outputs based on data provided by the competing manufacturers are shown in Figures 5-1 through 5-9. The graphs reflect the impact of inflation, assumed to increase at zero, six, and ten percent per year, for the entire life cycle of the study. (All figures are presented at the end of this chapter for ease of comparison. The presentation is organized so that for each user category and inflation rate, CAS costs based on manufacturers' data are juxtaposed with those based on independently developed data.)

5.3.2.1 Commercial-Aviation Costs Based on Manufacturers Data

Figures 5-1 through 5-3 represent the expenditures required to implement each of the three systems in the air-carrier community. The effect of system retrofit in the first four years of implementation is evidently controlled by the acquisition cost of the system.

The logistic support costs required to maintain the systems are the highest for the Honeywell AVOIDS, but the initial cost advantage of the AVOIDS over the other systems is retained through the end of the eleven-year life cycle.

5.3.2.2 Military-Aviation Costs Based on Manufacturers Data

Figures 5-4 through 5-6 identify the total annual cost and the cumulative life-cycle cost to the military population in implementing any of the three systems on CONUS aircraft. The advantage of the lower initial cost of acquisition of the AVOIDS system is maintained throughout the life cycle. The effect of maintenance, i.e., the slope of the curves after acquisition is complete, is not as strong as in the commercial-carrier case because of the lower utilization of the military aircraft. Maintainability is a factor in the EROS and SECANT systems, but insufficient to overcome the lower acquisition cost advantage of the AVOIDS systems.

This study presents results on only the CONUS-based military aircraft as defined in Chapter Four. However, it is recognized that a large number of military aircraft are based overseas and are subject to periodic rotation through the U.S. and the National Air Space. It has been assumed that the military would not operate CAS units in aircraft stationed at overseas bases, but that these aircraft would be modified for a CAS installation when they were restationed in the U.S. (presumably, the CAS units themselves could be exchanged between aircraft being sent overseas and those returned to the U. S.). Unfortunately, ARINC Research was unable to determine the number of aircraft that would fall into this category. Therefore, the following formula is recommended to establish the added installation costs to be borne by the military when the required number of additional aircraft installations is determined:

$$\text{Added Cost} = \sum_{i=1}^{8} \left[\left(\frac{N_1}{8} \right) \left(I_f + E_f \right) + \left(\frac{N_2}{8} \right) \left(I_1 + E_1 \right) \right] (1+\alpha)^{i-1} \qquad (5.1)$$

where N_{1_i} = a total number of military high-performance aircraft stationed overseas in the ith year

N_{2_i} = total number of military limited-performance aircraft stationed overseas in the ith year

I_f = installation cost of Type I-CAS in 1978 -- $8,252*

I_1 = installation cost of Type II-CAS in 1978 -- $2,479*

E_f = cost of CAS/VSI indicator and two antennas -- $1,218*

E_1 = cost of Type II antennas -- $13*

i = year of retrofit, 1 through 8

α = inflation rate

* All cost are shown in 1975 dollars and should be inflated before being used in equation 5.1.

5.3.2.3 General Aviation Costs Based on Manufacturers' Data

Figures 5-7 through 5-9 illustrate the total cumulative life-cycle costs for the general-aviation community to implement any of the three CAS concepts. The primary costs associated with CAS implementation in the general-aviation community are system acquisition and installation, with acquisition costs being the predominant reason for the cost difference among the three concepts. The high reliabilities for each of the CAS equipments and the low average aircraft utilization (e.g., approximately 200 hours per year) combine to result in maintenance costs that are less than five percent of the total life-cycle costs for each of the three concepts.

5.3.2.4 Total Aviation-Community Manufacturers' Data

Figures 5-10 through 5-12 present the cost of system implementation for any of the manufacturers in the entire aviation community for the eleven-year life cycle. The required expenditure for acquisition, installation, and maintenance costs varies from 659.6 million for the Honeywell system to 1067.4 million for the RCA system at a zero rate of inflation. The McDonnell Douglas costs total 905.3 million for the same period. The comparative expenditures for each system are presented in Table 5-6, which identifies the major categories comprising the life-cycle costs. The total aviation life-cycle costs associated with the use of a remitter by 70 percent of the general-aviation aircraft as proposed by RCA are presented. The remitter costs are discussed more completely in Chapter Six.

TABLE 5-6. LIFE-CYCLE COSTS FOR TOTAL AVIATION COMMUNITY (IN MILLIONS OF DOLLARS) (ZERO PERCENT INFLATION RATE)

SYSTEM	ACQUISITION COST	INSTALLATION COST	TOTAL LOGISTIC COST	TOTAL COSTS
MANUFACTURERS DATA				
HONEYWELL	406.2	195.8	57.6	659.6
MCDONNELL-DOUGLAS	651.9	195.8	56.1	903.8
RCA	812.0	195.8	58.8	1065.9
(REMITTER)	610.2	195.8	56.4	862.4
INDEPENDENTLY DEVELOPED DATA				
HONEYWELL	394.8	195.8	87.9	678.5
MCDONNELL-DOUGLAS	571.4	195.8	120.5	887.7
RCA	654.1	195.8	110.3	960.2

5.3.3 Life-Cycle Fleet-Wide Costs Based on Independently Developed Data

The results of Section 5.3.2 were based on data provided by the competing manufacturers. Although the evaluation of their data by ARINC Research showed general agreement, especially in the initial acquisition costs, some variations in system reliability and cost per repair action were identified in Chapter Three. The effect of these variations on the life-cycle costs of each user community is presented in this section.

5.3.3.1 Commercial Aviation Costs Based on Independent Data

Figures 5-13 through 5-15 present the life-cycle costs for the commercial-aviation community. The life-cycle costs for implementing three CAS concepts would result in expenditures of 46.9 million for the AVOIDS, 48.3 million for the EROS, and 53.5 million for the SECANT, assuming a zero rate of inflation. The variations in costs between these data and the manufacturers' provided data are the results of differences in the system acquisition costs and the logistic support costs.

The AVOIDS costs changed primarily because of a slight increase in system reliability and a decrease in the average material cost per repair action. The slight change in the system acquisition reflected in independent cost analysis of Chapter Three produced only a $0.6 million dollar decrease in the system life-cycle costs.

The change in the EROS system costs is uniform over the life cycle and caused by a re-evaluation of the average material costs per repair action. A significant variation in repair costs between the manufacturers' data and ARINC-developed data is noted for the exciter and the receiver. The MTBF of the exciter is calculated at 15,000 hours by both sources, but the cost of material per repair action is quoted at $2.10 by the manufacturer, and only $0.48 by the statistical probability method used by ARINC Research. In the case of the receiver, McDonnell Douglas has quoted a $1.47 cost per repair action. The equivalent cost based on ARINC Research-developed data is only $0.45. These changes result in a decrease in logistic support cost in excess of $0.2 million dollars over the life cycle. The slight change in the system acquisition cost reflected in the independent cost analysis resulted in a $0.3 million decrease in the system life-cycle costs.

As with the other two systems, higher material costs per repair action have been proposed for the SECANT system than can be justified by mathematical analysis. RCA has quoted a material cost of $21 per repair action for the IF Detector. Review of the RCA parts lists identifies the highest cost component in the detector subject to failure to be the SAW filter, estimated by RCA to cost $4.24. ARINC Research evaluation of the detector identifies the probable cost per repair action to be $1.04. A similar variation in cost per repair action is noted for the microwave module, reducing the anticipated cost from the RCA quote of $27 to the mathematically derived cost of $9.61. However, in Chapter Three, significant disagreements with the MTBFs and the logic module costs for the RCA system were identified in the independent data development. The overall system MTBF was changed from 3000 hours to 2475 hours, and the overall system cost was changed from $5,141 to $5,501. These two factors combined to produce the significant increase in life-cycle costs for the SECANT system.

5.3.3.2 Military Aviation Costs Based on Independent Data

Figures 5-16 through 5-18 present the life-cycle costs in the military community based on the parameters calculated by ARINC Research and the GENAVE/NARCO estimates. The life-cycle costs for this community are $219.8 million for the AVOIDS, $237.2 million for the EROS, and $247.8 million for the SECANT. The variations between the manufacturers' data and the independently developed data result in an increase of $4.5 million in the AVOIDS system, an increase of $9.3 million in the EROS, and an increase of $10.9 million in the SECANT life-cycle costs, where zero inflation is considered. The cost changes are a result of the variations in the unit acquisition costs and the reliability and maintainability estimates. The effect of the reliability and maintainability of the Type I CAS is not as evident to the military as in the commercial air carrier community because of the reduced aircraft utilization. However, the effect of the expected reliability of the Type II systems results in the higher predicted life-cycle costs based on the independently developed data. The unit acquisition variations presented in Table 5-3 for the Type II CAS are off-set by the estimated higher costs of maintenance required by the limited version CAS.

5.3.3.3 General Aviation Costs Based on Independent Data

Figures 5-19 through 5-21 present the life-cycle costs based on the independent evaluation of system costs, reliability, and maintainability. The unit cost and reliability figures developed by GENAVE and NARCO have been averaged and used in the cost analysis. The life-cycle costs for implementing these CAS concepts would result in expenditures of $411.9 million for the AVOIDS, $602.2 million for the EROS, and $658.8 million for the SECANT, with zero rate of inflation.

The life-cycle costs for the GA community based on the independently-developed data are lower than the life-cycle costs based on the manufacturer supplied data, due primarily to the lower independently-developed acquisition costs for the Type II CAS equipments reported in Chapter Three. However, the lower expected*reliability proposed by the general-aviation manufacturers has resulted in logistic support costs higher than those based on manufacturers' data, overcoming the lower acquisition cost of the AVOIDS and increasing the AVOIDS life-cycle costs by $16.6 million when compared with data presented in Figure 5-7. The differences for the other two systems revealed cost reductions of $25.2 million for the EROS, and $119.9 million for the SECANT. The lower acquisition costs are the result of the more economic manufacture of the general-aviation products, lower overhead of the general-aviation manufacturers, the utilization of separate existing microwave components, and standard packaging techniques used in the general-aviation market.

5.3.3.4 Total Aviation Community Independent Data

Figures 5-22 through 5-24 present the life-cycle costs to the entire aviation community based on the costs developed by ARINC Research, GENAVE, and NARCO. A comparison of these costs with the manufacturers' data presented in Figure 5-10 shows that overall cost changes ranging from an increase of $18.9 million (AVOIDS) to a decrease of $105.7 million (SECANT) can be expected by the total aviation community. These changes are based on the projected costs of the Type II units as developed by the general-aviation manufacturers.

* As opposed to calculated.

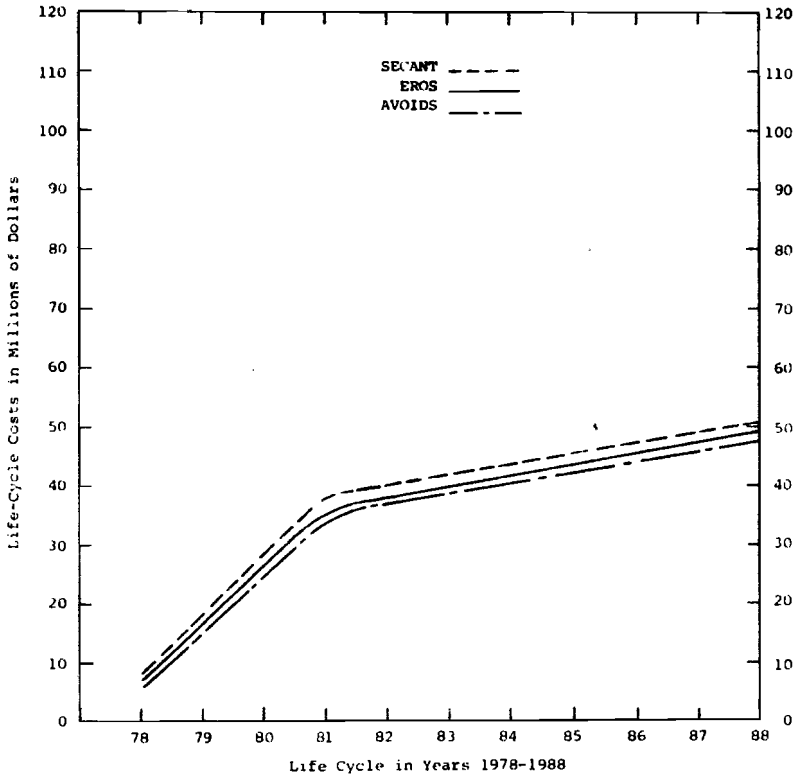


Figure 5-1. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (COMMERCIAL AVIATION, ZERO-PERCENT INFLATION RATE)

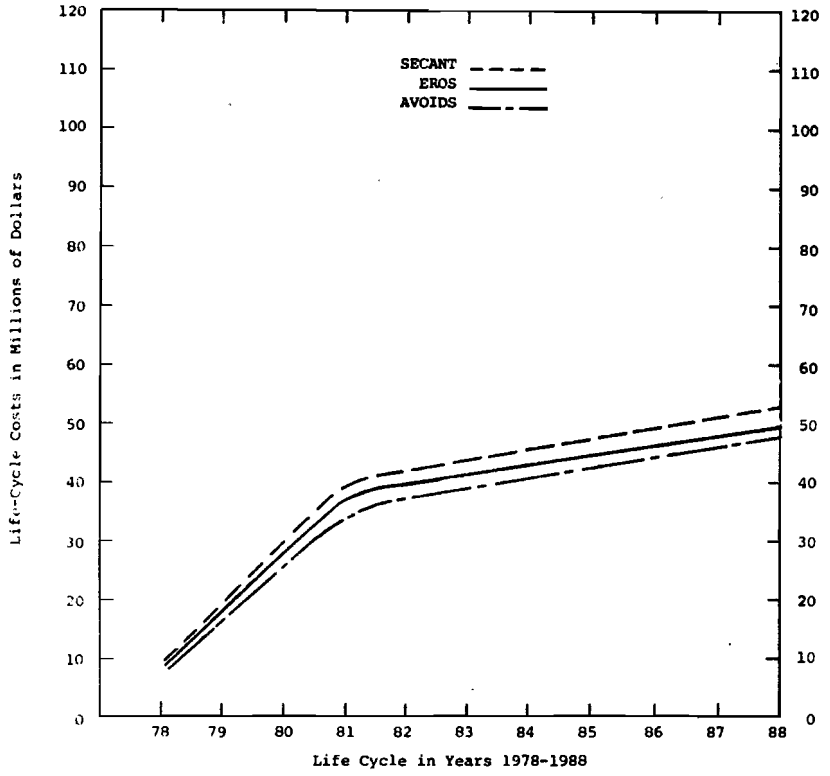


Figure 5-13. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (COMMERCIAL AVIATION, ZERO-PERCENT INFLATION RATE)

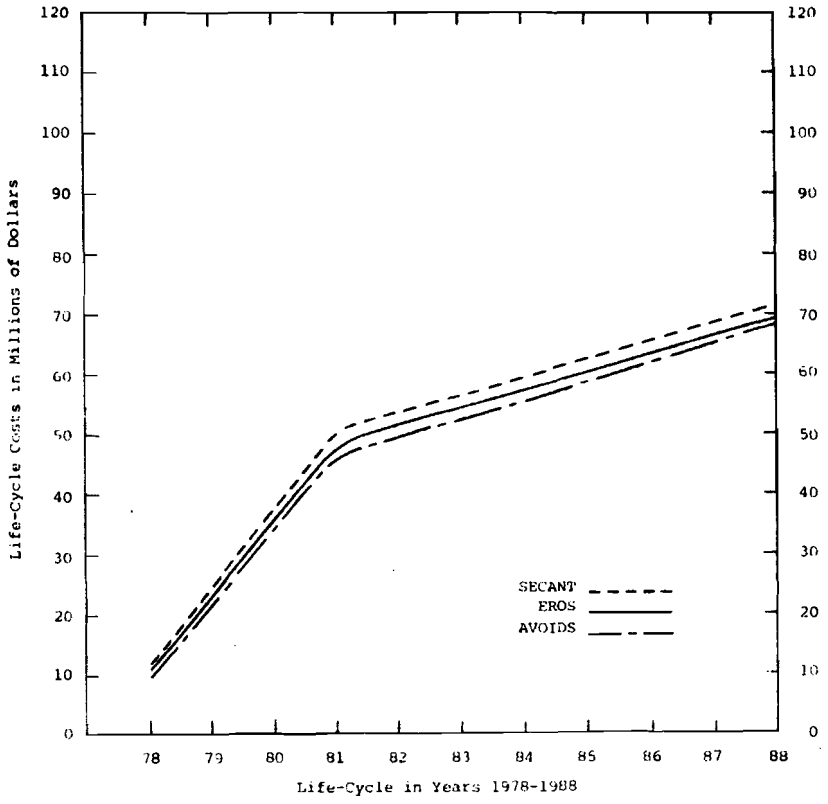


Figure 5-2. CUMULATIVE CAS COSTS FROM MANUFACTURERS' DATA (COMMERCIAL AVIATION, SIX-PERCENT INFLATION RATE)

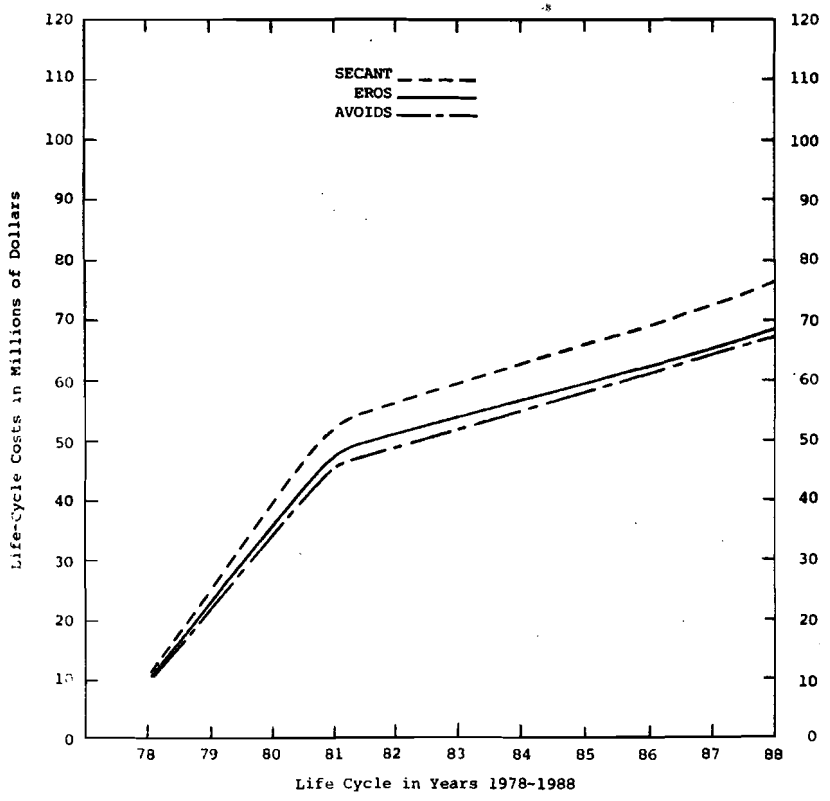


Figure 5-14. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (COMMERCIAL AVIATION, SIX-PERCENT INFLATION RATE)

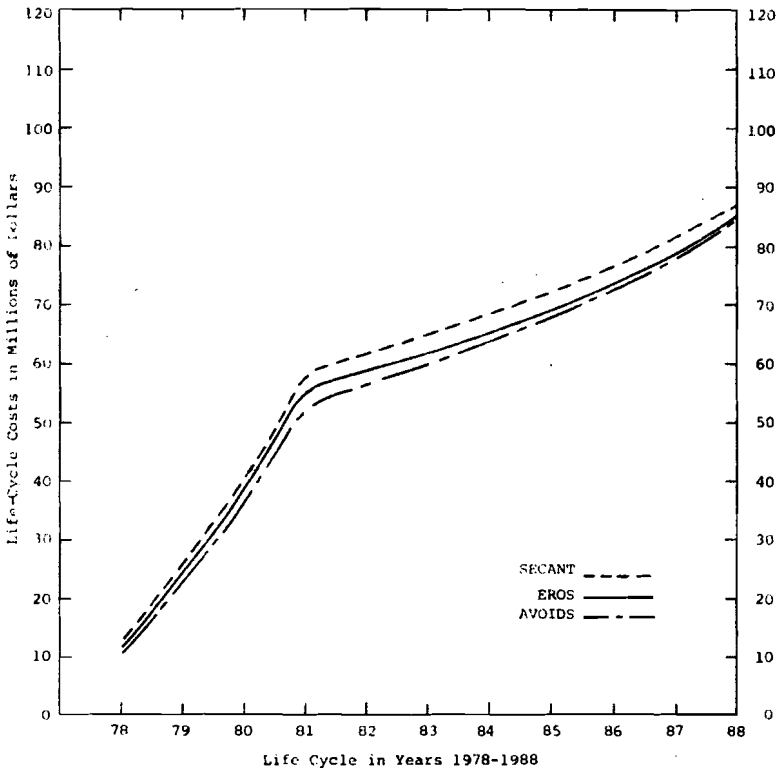


Figure 5-14. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (COMMERCIAL AVIATION, TEN-PERCENT INFLATION RATE)

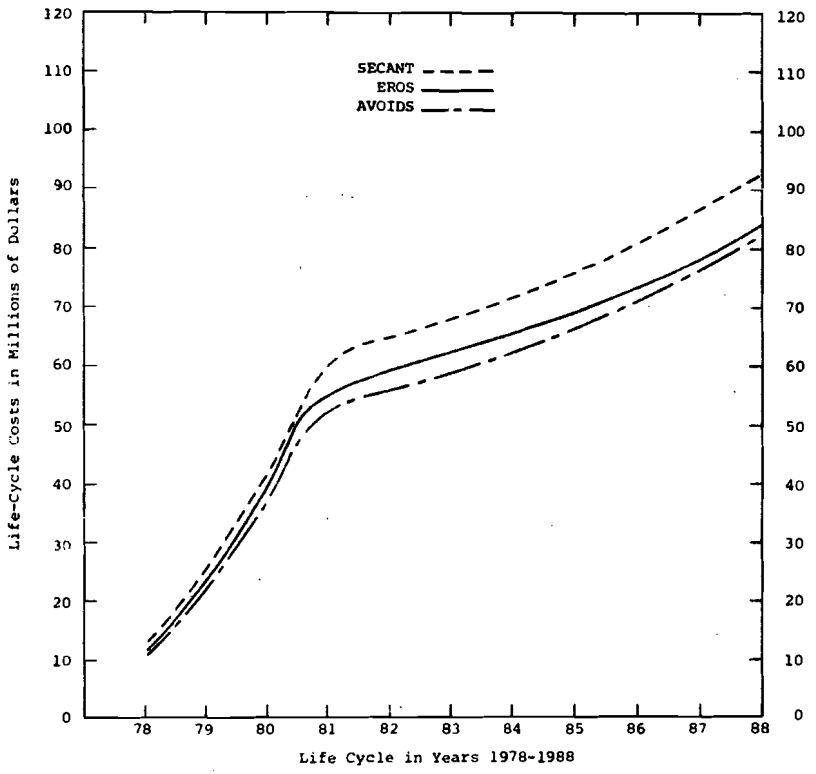


Figure 5-15. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (COMMERCIAL AVIATION, TEN-PERCENT INFLATION RATE)

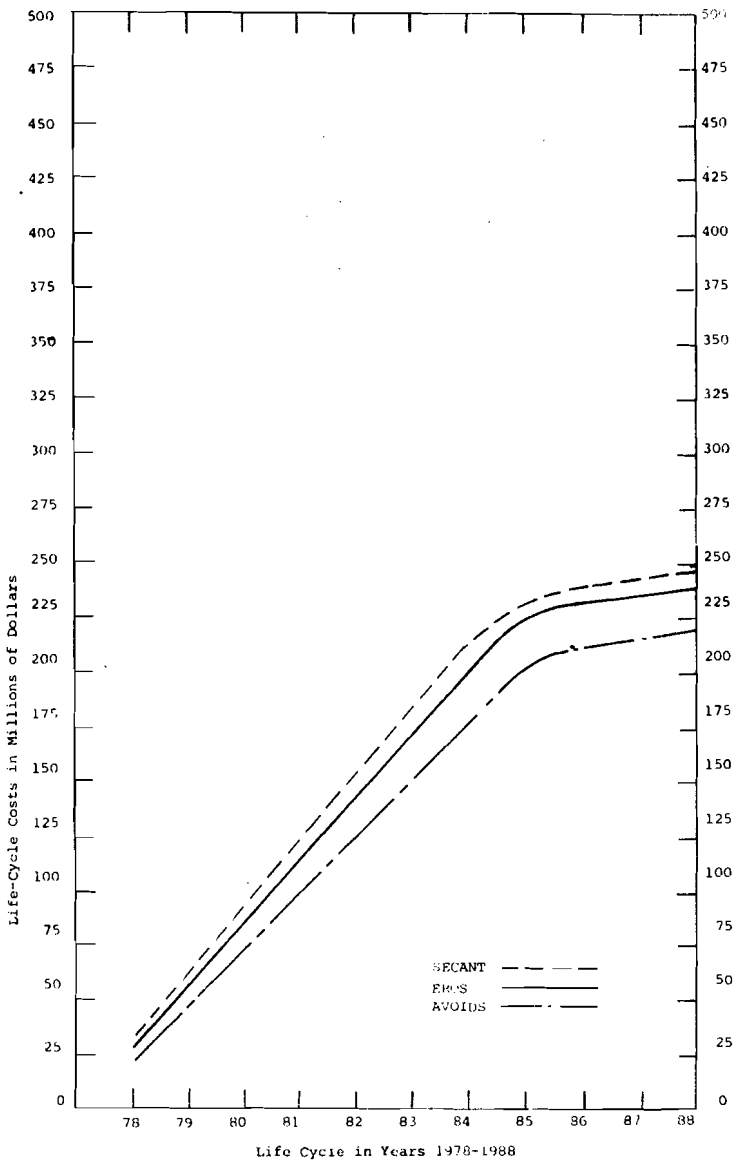


FIGURE 5-4 CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (MILITARY AVIATION, ZERO-PERCENT INFLATION RATE)

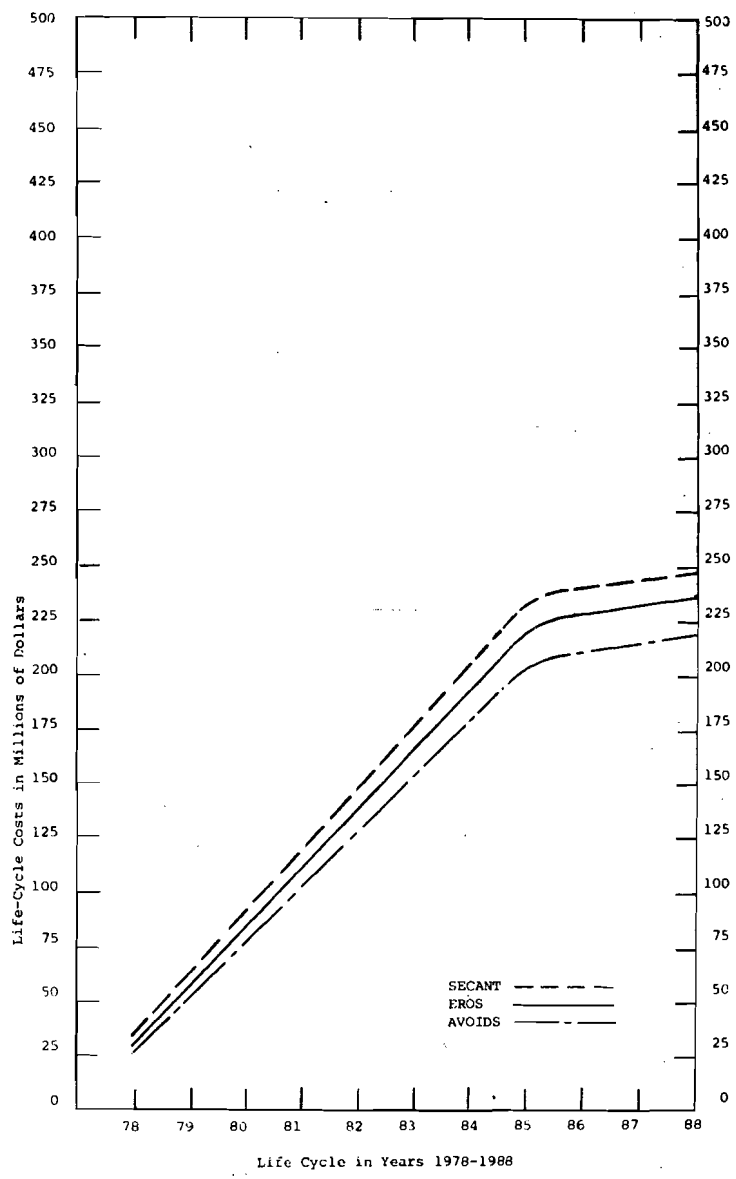


FIGURE 5-16 CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (MILITARY AVIATION, ZERO-PERCENT INFLATION RATE)

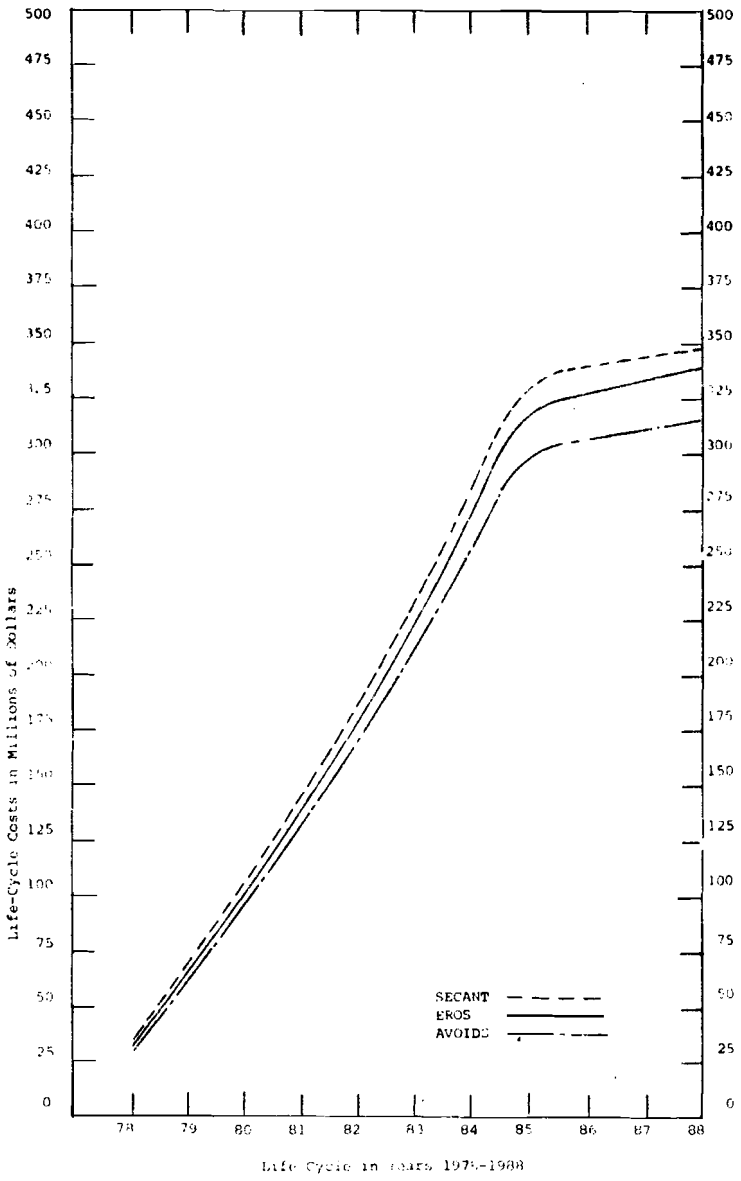


FIGURE 5-16 CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (MILITARY AVIATION, SIX-PERCENT INFLATION RATE)

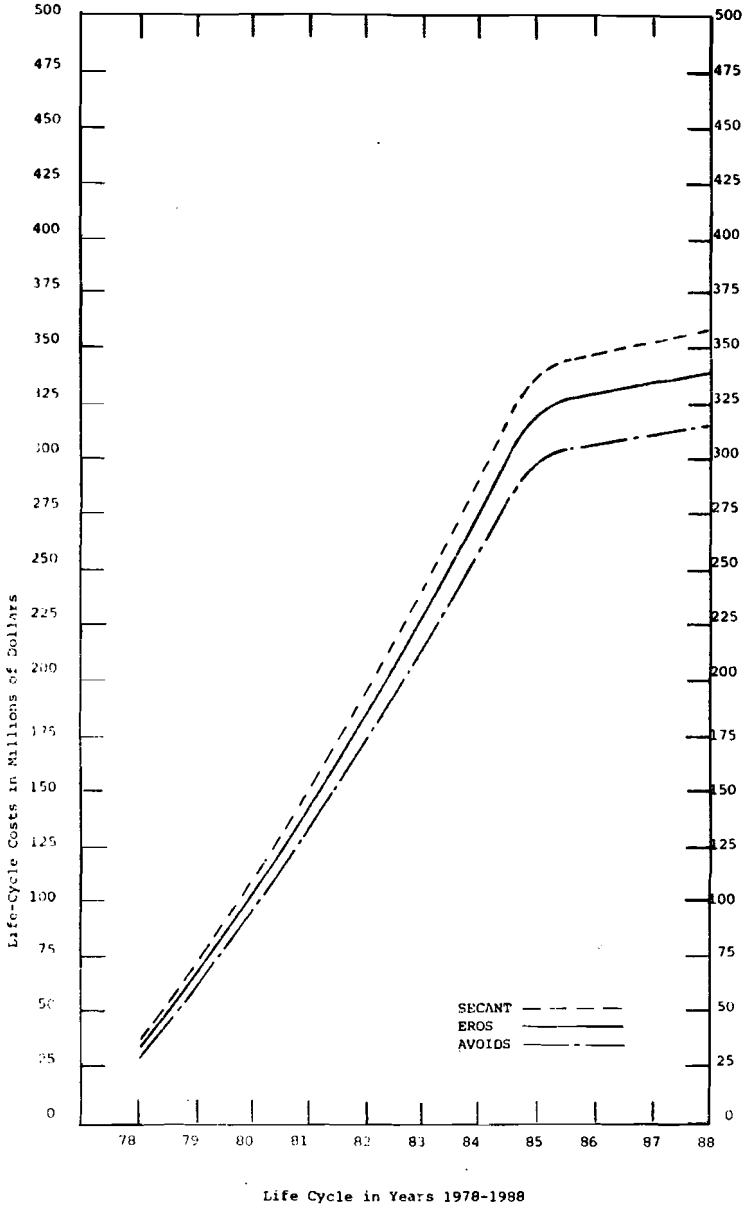


FIGURE 5-17 CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (MILITARY AVIATION, SIX-PERCENT INFLATION RATE)

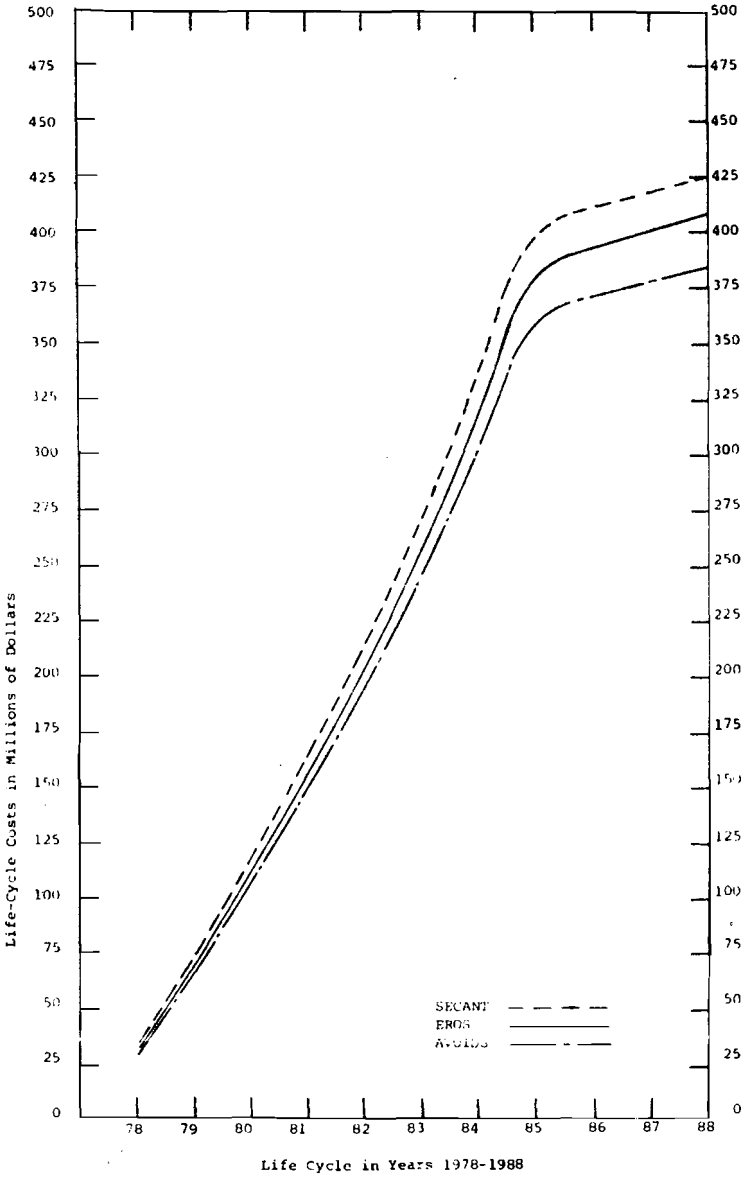


FIGURE 5-6 CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (MILITARY AVIATION, TEN-PERCENT INFLATION RATE)

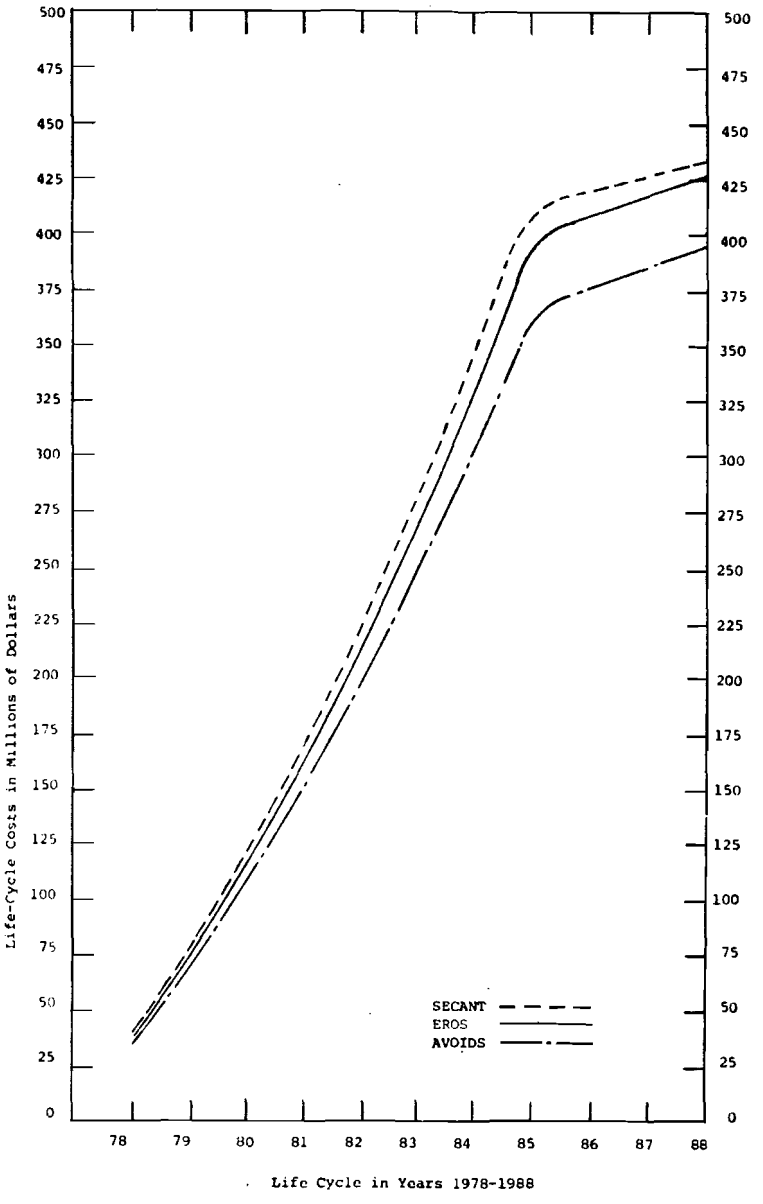


FIGURE 5-18 CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (MILITARY AVIATION, TEN-PERCENT INFLATION RATE)

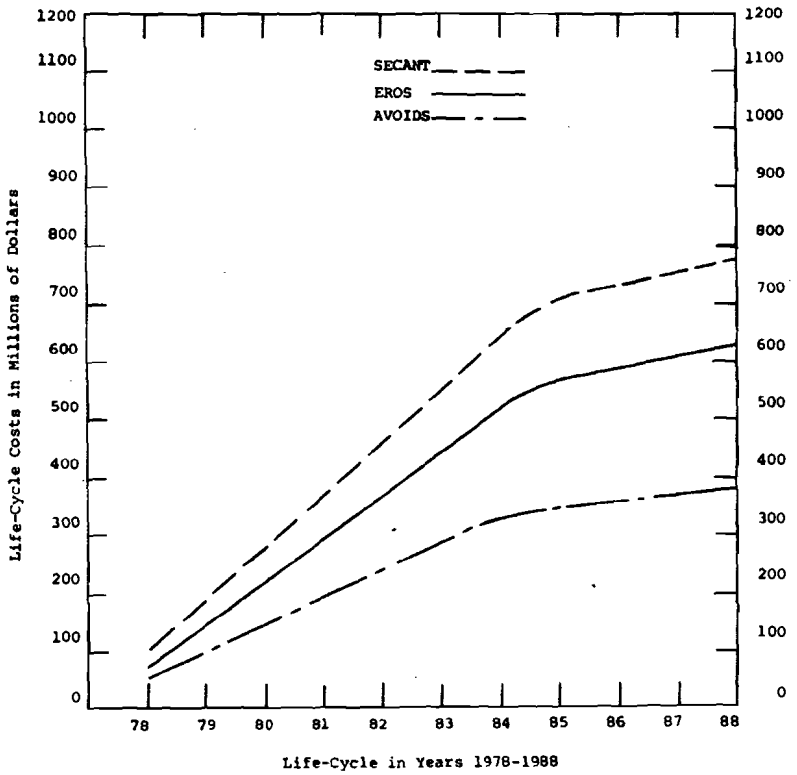


Figure 5-7. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (GENERAL AVIATION) (ZERO PERCENT INFLATION RATE)

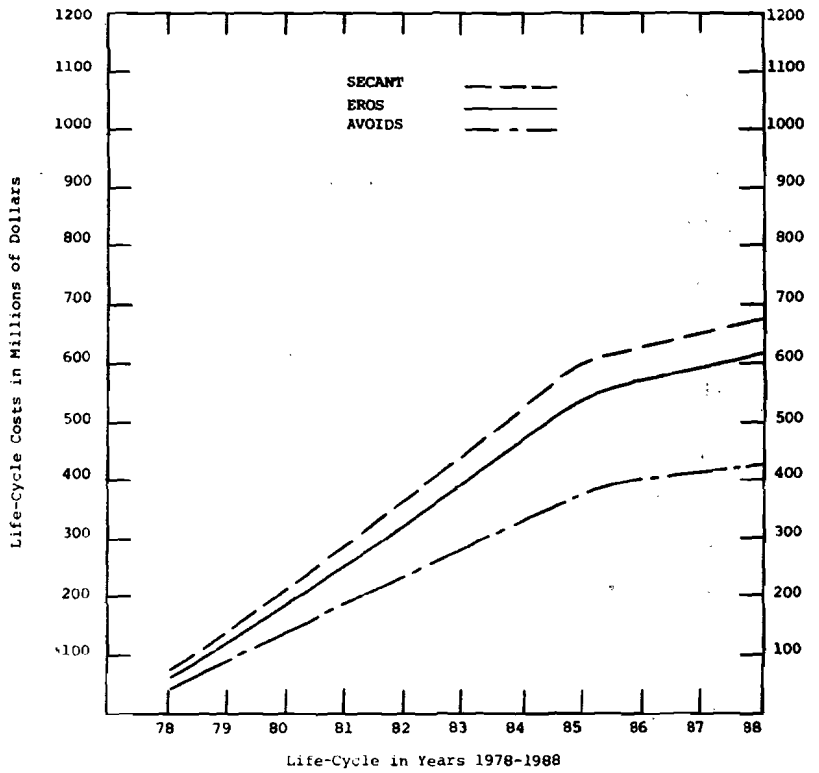


Figure 5-19. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (GENERAL AVIATION) (ZERO PERCENT INFLATION RATE)

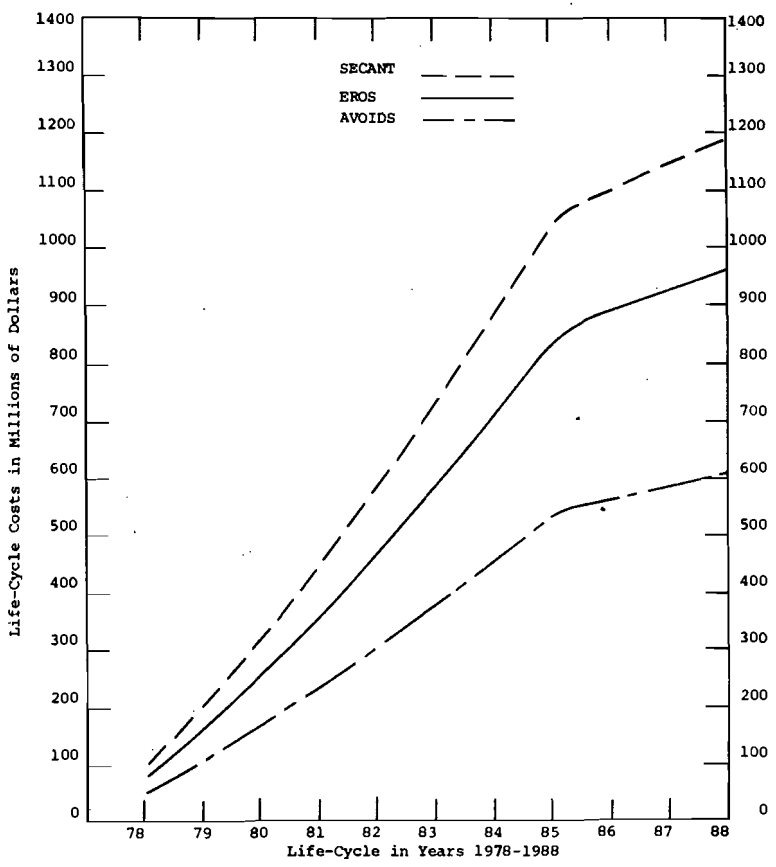


Figure 5-8. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (GENERAL AVIATION) (SIX PERCENT INFLATION RATE)

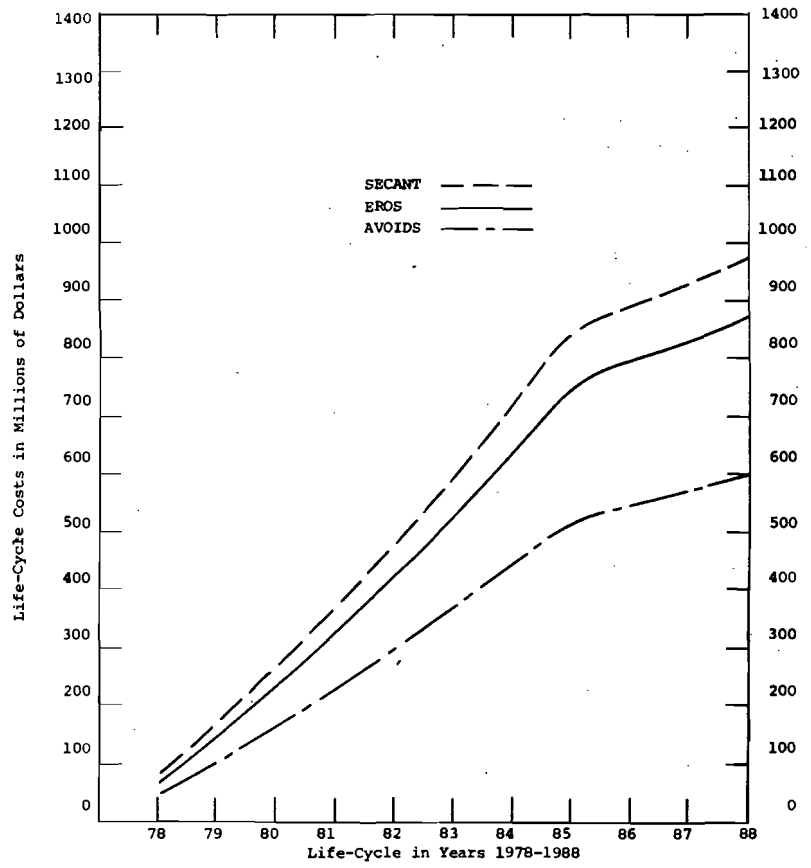


Figure 5-20. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (GENERAL AVIATION) (SIX PERCENT INFLATION RATE)

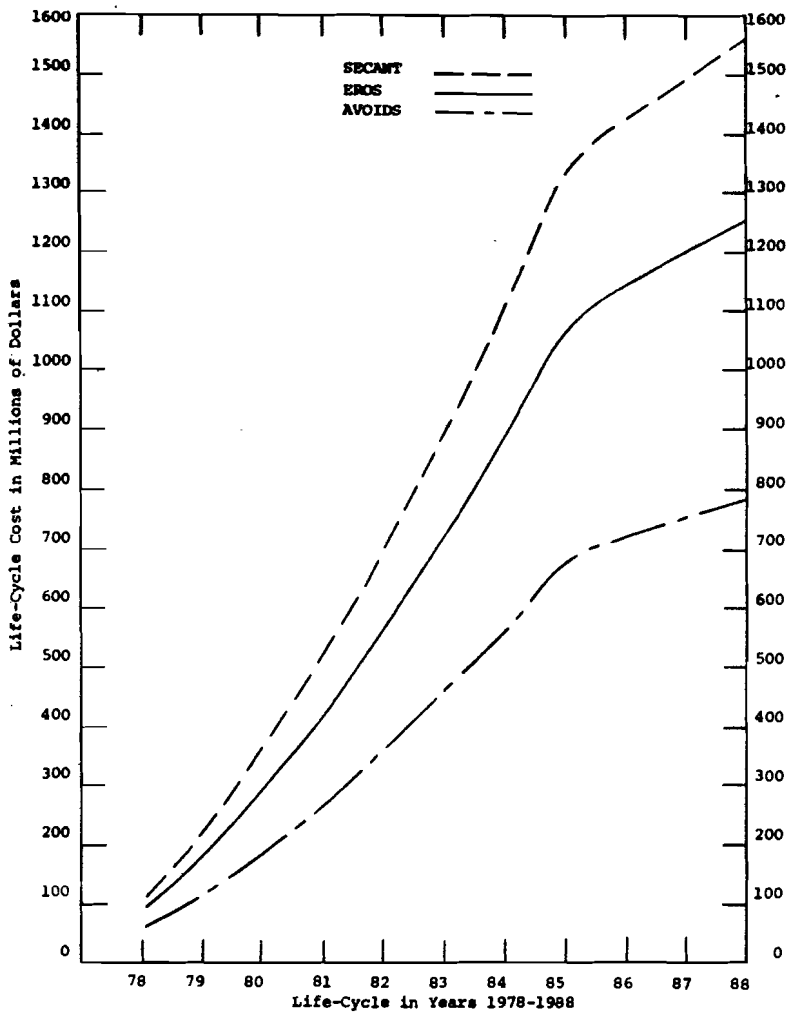


Figure 5-9. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (GENERAL AVIATION) (TEN PERCENT INFLATION RATE)

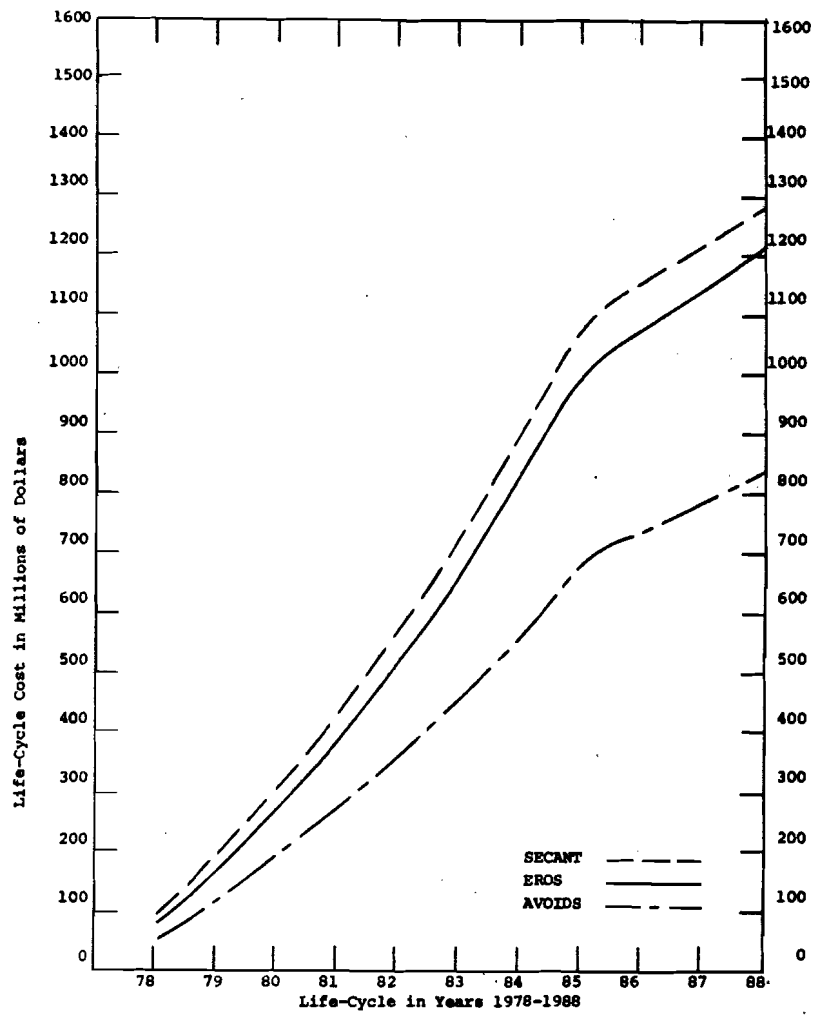


Figure 5-21. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (GENERAL AVIATION) (TEN PERCENT INFLATION RATE)

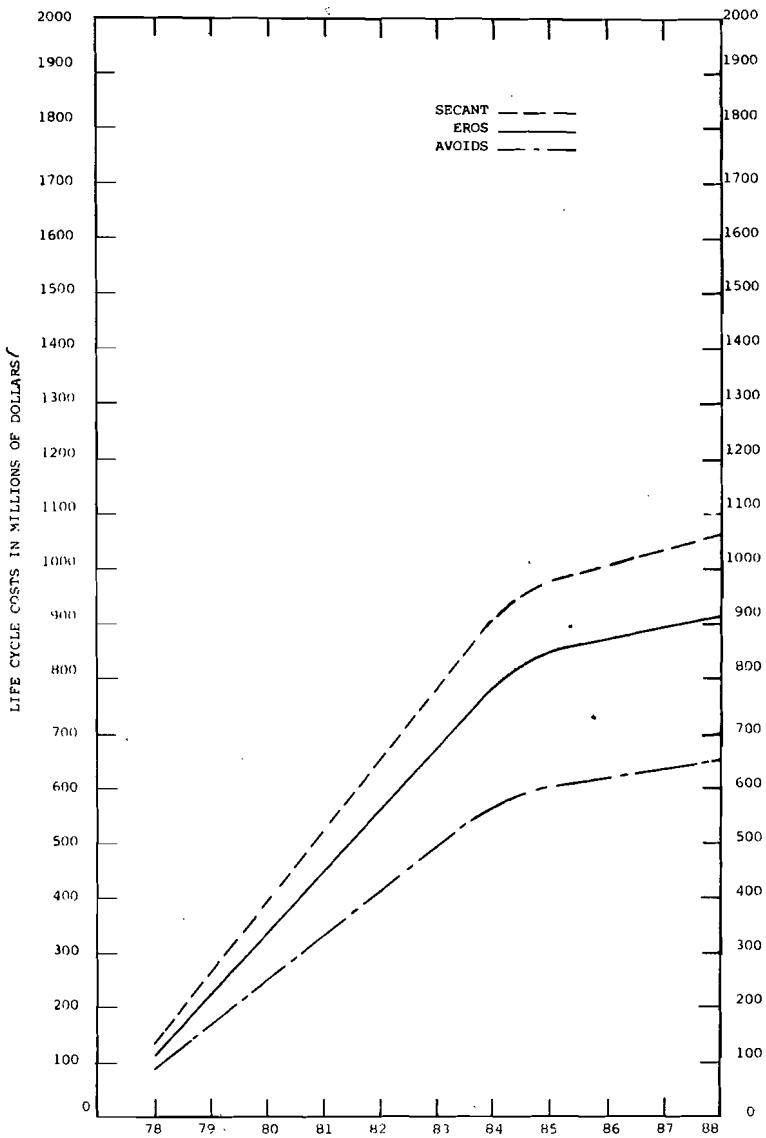


FIGURE 5-10. CUMULATIVE CAS COST FROM MANUFACTURERS'DATA (TOTAL AVIATION COMMUNITY) (ZERO PERCENT INFLATION RATE)

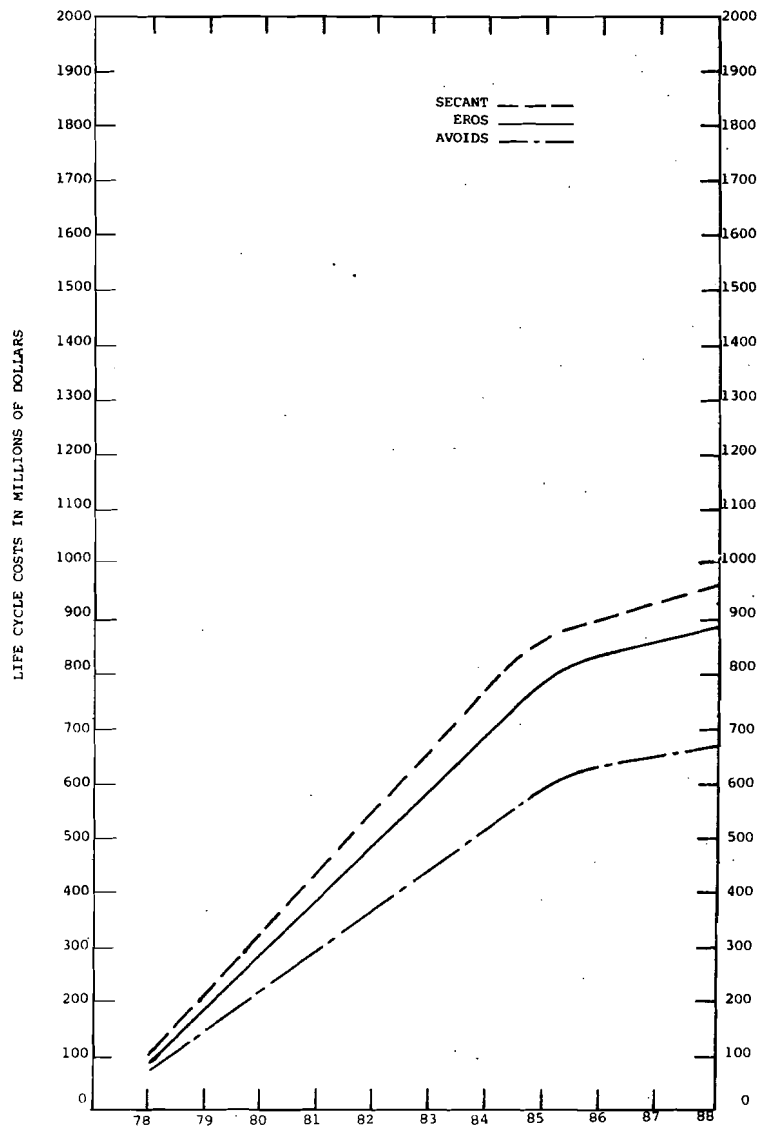


FIGURE 5-22. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (TOTAL AVIATION COMMUNITY) (ZERO PERCENT INFLATION RATE)

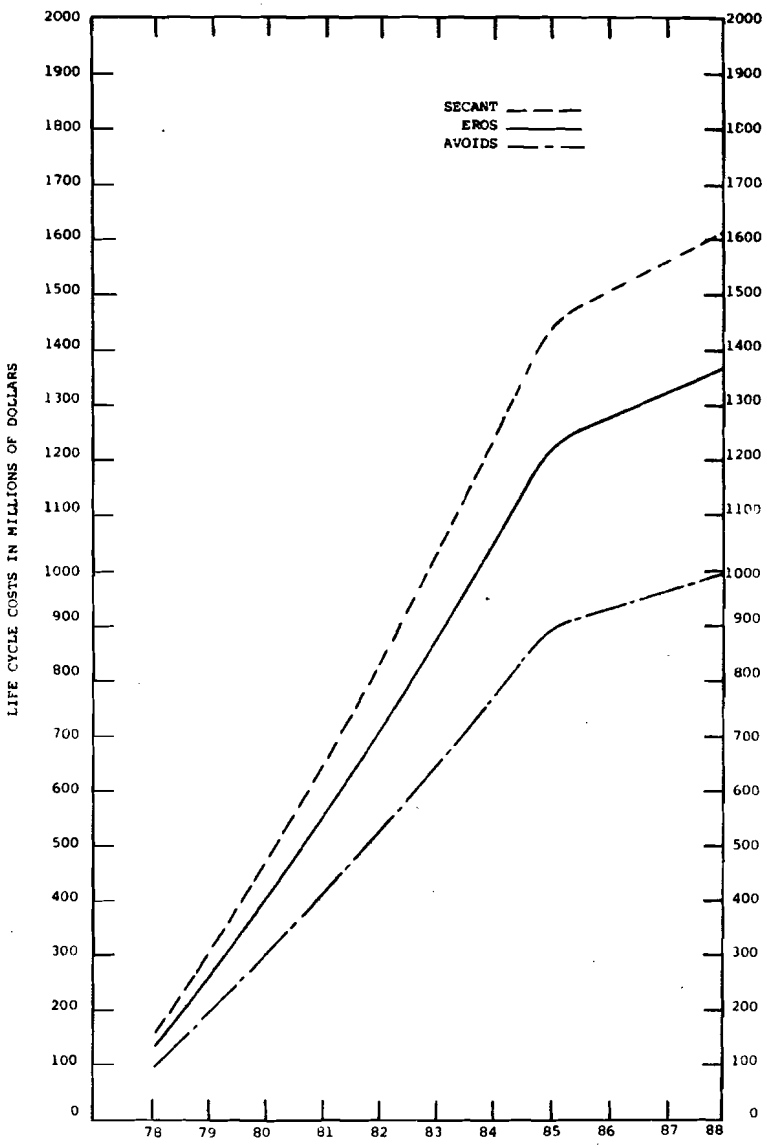


FIGURE 5-11. CUMULATIVE CAS COST FROM MANUFACTURERS'DATA (TOTAL AVIATION COMMUNITY) (SIX PERCENT INFLATION RATE)

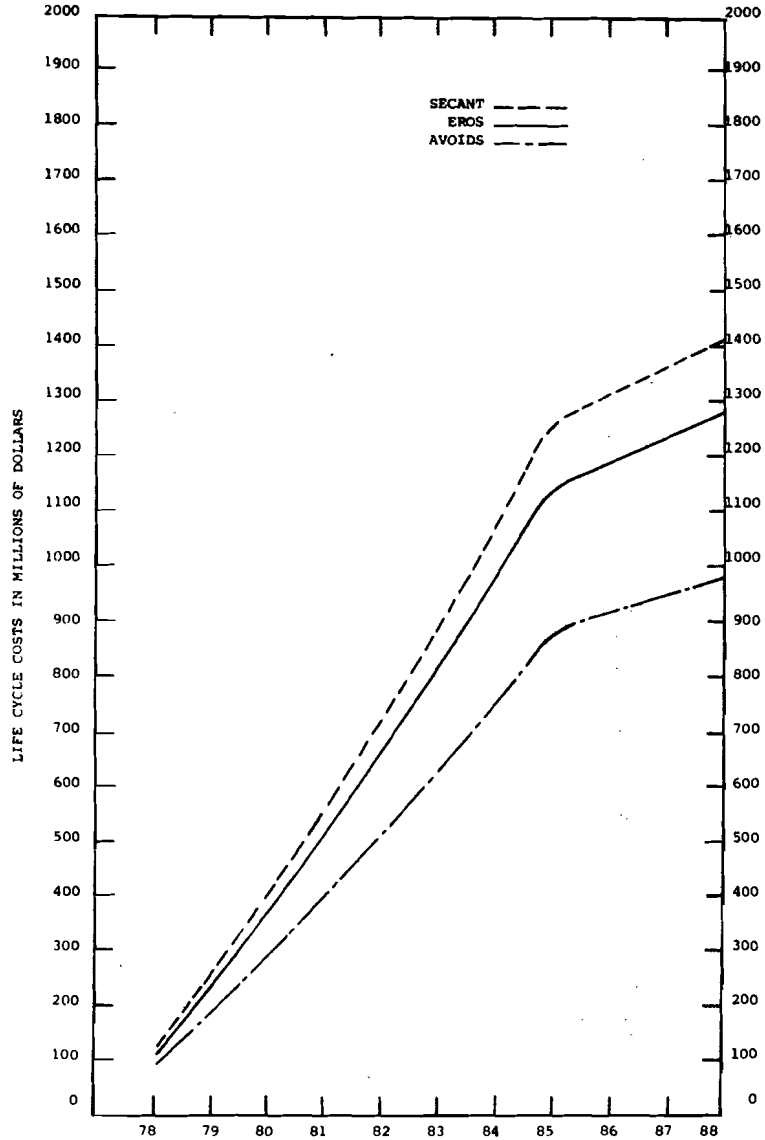


FIGURE 5-23. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA (TOTAL AVIATION COMMUNITY) (SIX PERCENT INFLATION RATE)

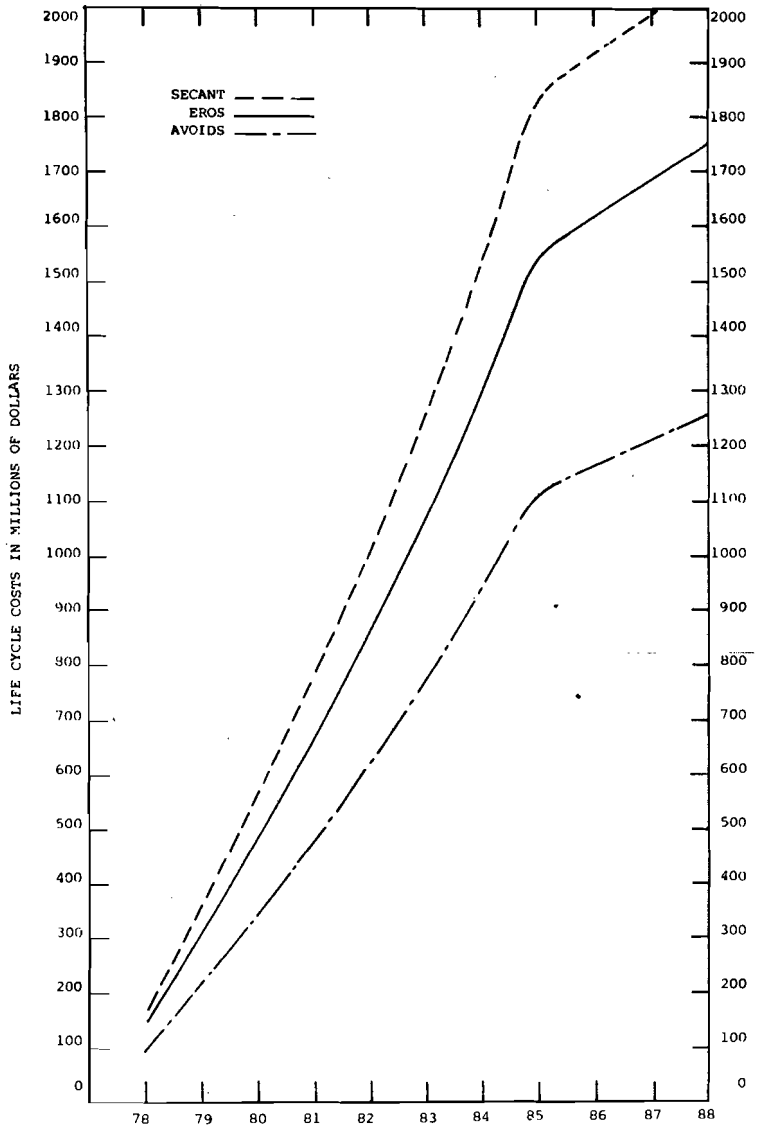


FIGURE 5-12. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA (TOTAL AVIATION COMMUNITY) (TEN PERCENT INFLATION RATE)

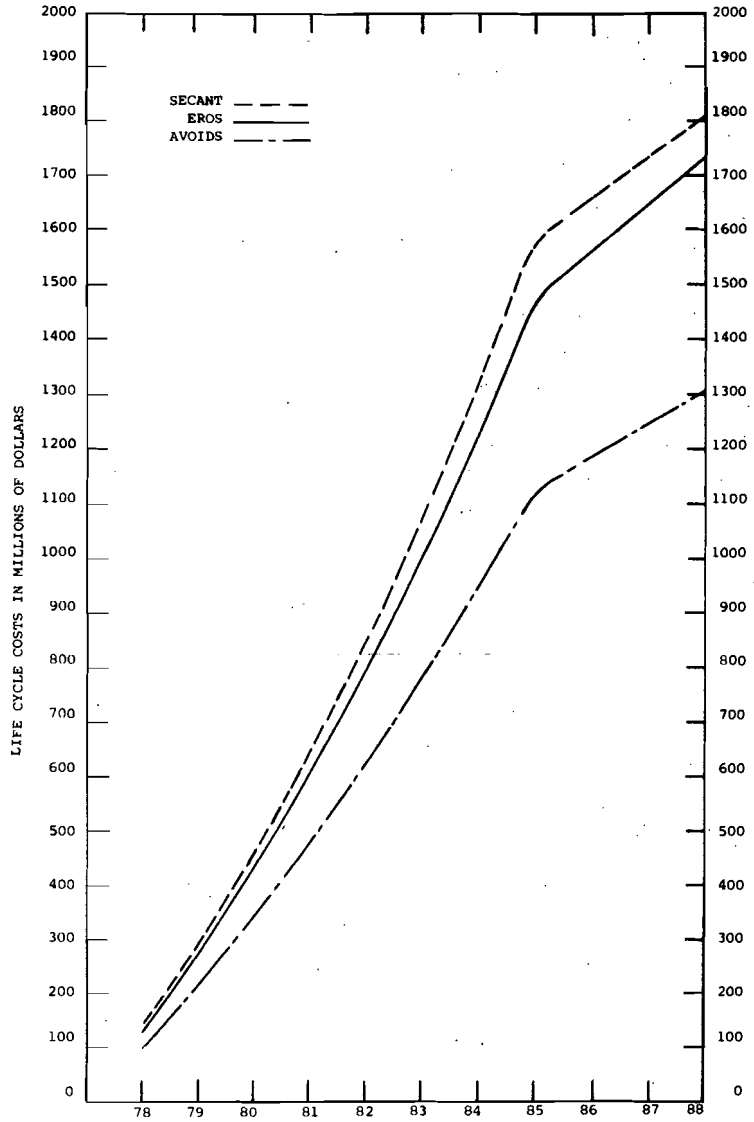


FIGURE 5-24. CUMULATIVE CAS COST FORM INDEPENDENTLY DEVELOPED DATA (TOTAL AVIATION COMMUNITY) (TEN PERCENT INFLATION RATE)

CHAPTER SIX

SENSITIVITY OF THE CAS COST ANALYSES TO PARAMETER VARIATIONS AND ALTERNATIVE ASSUMPTIONS

In developing data in Chapters Three and Four for the cost analyses of the CAS system concepts, assumptions had to be made regarding operational scenarios and system parameters. While a major effort was made to develop accurate data on the three CAS systems, it was considered advisable to review the cost analyses for any sensitivities they might exhibit to parameter variations and alternative scenarios.

The cases considered in this review were as follows:

- The sensitivity of life-cycle costs to variations in system MTBFs
- The effect of various assumptions regarding the mix of Type I and Type II CAS in the military fleet
- The effect of including amortization costs in the analyses
- The cost impact of the remitter
- The effect of providing redundant electronics in the commercial air carrier community

The reasons for conducting each of these additional analyses and the results of the analyses are presented in the following sections.

6.1 SENSITIVITY OF LIFE-CYCLE COST TO MTBF VARIATIONS

In an economic analysis of any system, the mean time between failures (MTBF) is usually difficult to predict accurately, and it has a major impact on the life-cycle cost. Therefore, the effect of MTBF variations on CAS life-cycle costs has been evaluated. Figures 6-1 through 6-3 illustrate the effect of variations in manufacturers-provided system MTBFs on the life-cycle costs predicted for the commercial, military, and general-aviation fleets, respectively. The figures indicate the system MTBFs developed in Chapter Three and present the life-cycle costs for wide variations in MTBF about these values.

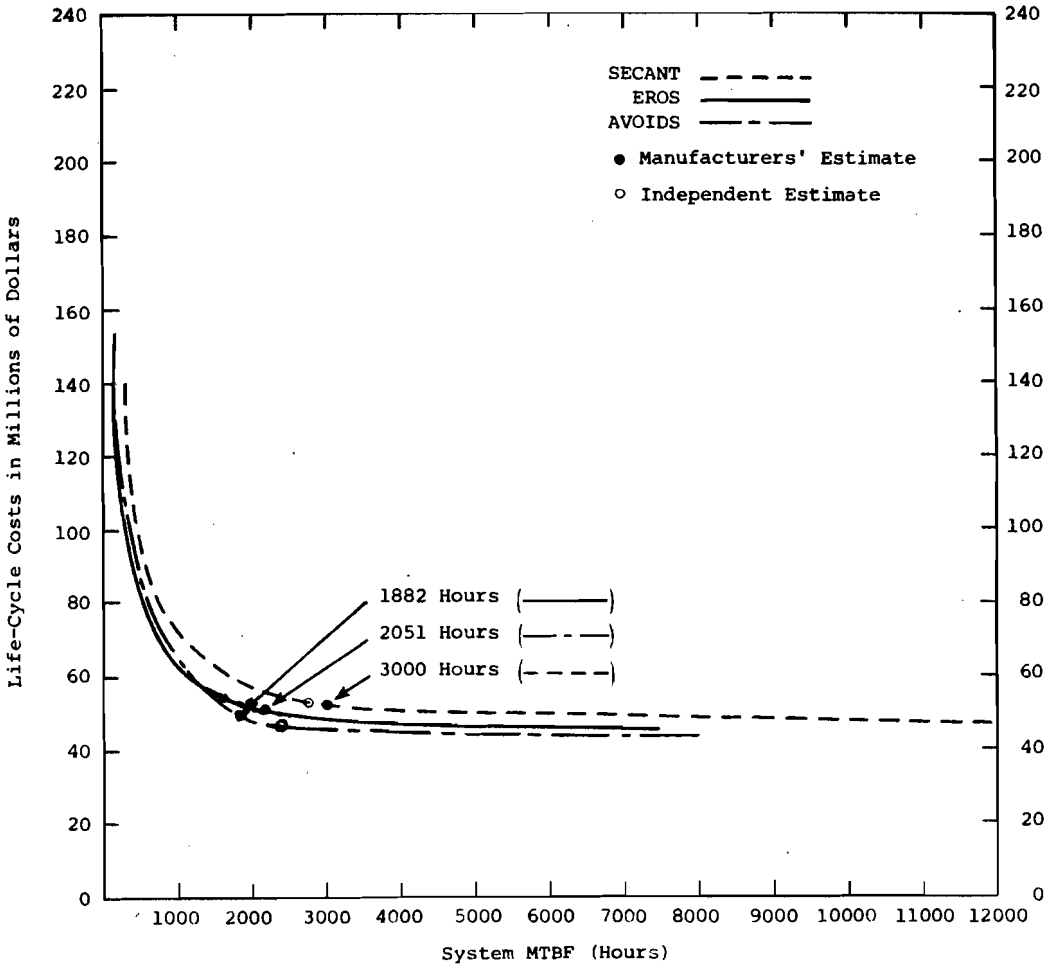


Figure 6-1. LIFE-CYCLE COSTS AS A FUNCTION OF CAS ELECTRONICS MTBF (COMMERCIAL AVIATION, ZERO-PERCENT INFLATION RATE)

For the commercial air carrier community, the life-cycle costs for the Honeywell, McDonnell Douglas, and RCA systems remain relatively close as long as the MTBFs for the three systems are approximately equal. However, it can be seen that the predicted MTBFs previously developed are near the knee of the cost curves. As a result, a significant error in the predicted MTBF of one of the systems would result in that system's becoming extremely uncompetitive with the other systems. For example, if the MTBF of only the lowest cost system has been overestimated by a small factor (e.g., less than 50 percent), then it is no longer the least costly CAS alternative for the commercial air carriers. However, the independently-developed reliability data provide equal confidence in each of the reliability estimates.

Figure 6-2 presents the effect of variations in system MTBFs on the military-aviation fleet costs. Because the military fleet was assumed to have installed Type I CAS units in the high-performance aircraft and Type II CAS in the low-performance aircraft, the MTBFs in Figure 6-2 represent a weighted average MTBF according to the mix of aircraft operating the Type I CAS (56 percent) and Type II CAS (44 percent). The appearance of the cost curves shown in Figure 6-2 is similar to that of the cost curves in Figure 6-1. As a result, the observations just developed for the commercial air carrier fleet would apply to the military.

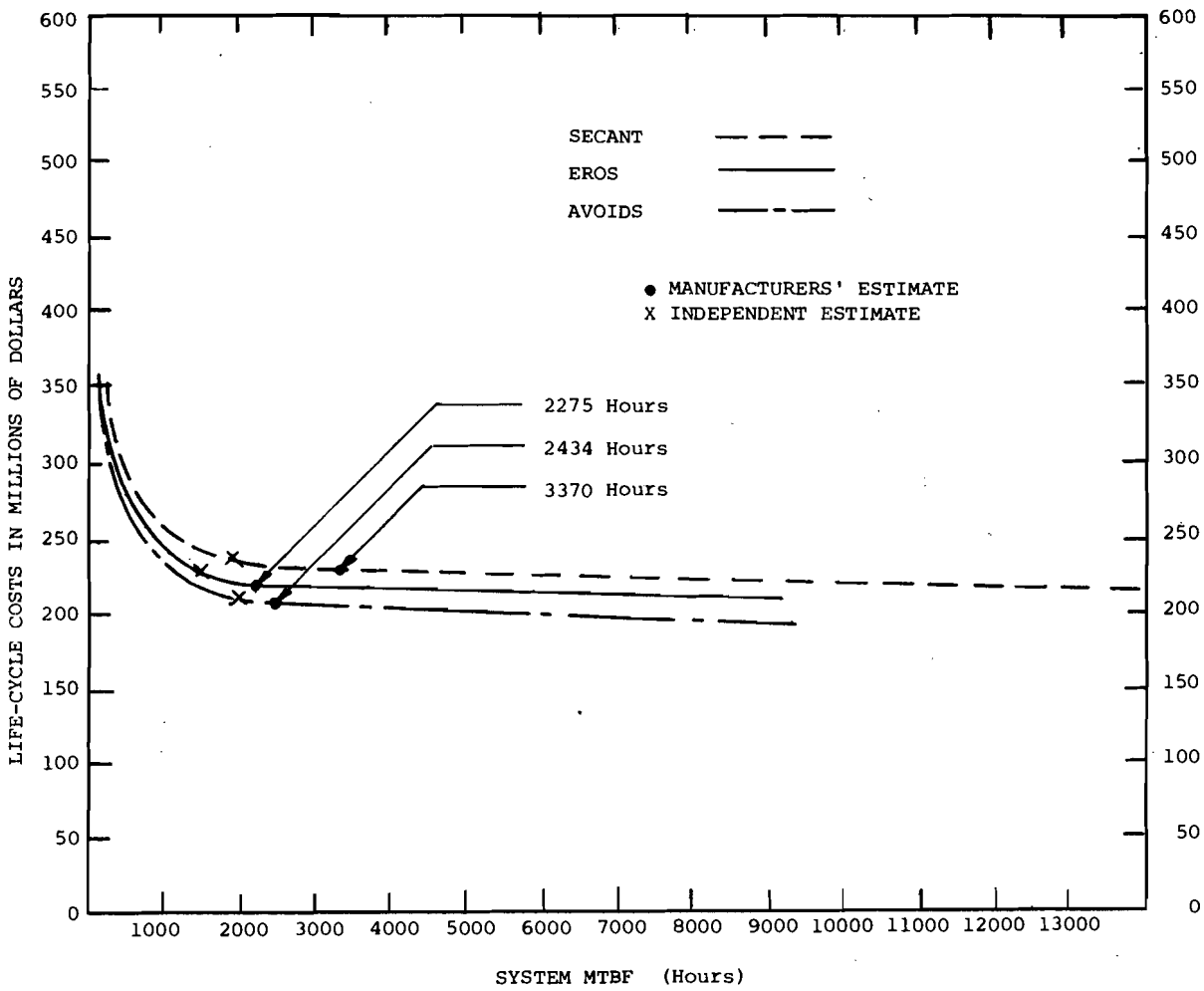


Figure 6-2. LIFE-CYCLE COST AS A FUNCTION OF CAS ELECTRONICS MTBF (MILITARY AVIATION) (ZERO PERCENT INFLATION RATE)

The variations in life-cycle costs for the general-aviation community are shown in Figure 6-3. The MTBFs represent a weighted average of 5 percent Type I CAS and 95 percent Type II CAS installations. It can be seen that the relative relationship of the life-cycle costs for the general-aviation community are virtually unaffected by MTBF variations. Therefore, for the general-aviation community, the Honeywell CAS appears to be the most attractive on a cost basis almost regardless of the MTBF values assumed for the Honeywell, McDonnell Douglas, and RCA systems.

The lower initial acquisition cost of the Honeywell Type II CAS provides a sufficient cost margin when applied over the entire general-aviation population to totally dominate the life-cycle costs of the entire aviation community even if with large variations in the system MTBF's. Therefore, it can be concluded that the Honeywell CAS concept represents the least expensive CAS alternative (based on total costs to all users) almost regardless of the variations in system MTBF's.

6.2 THE EFFECT OF VARIOUS MIXES OF CAS IN THE MILITARY FLEET

During the study is was assumed that a 250-knot performance capability would be a reasonable basis for deciding whether a military aircraft would be outfitted with a Type I CAS or Type II CAS. However, it is possible that all military aircraft will carry a sophisticated unit such as the Type I CAS or that all military aircraft will carry the minimum-capability Type II CAS. In the first case, it might be argued that the total cost of installing and operating CAS would be so large as to make it pointless to install anything other than a high-capability Type I CAS unit. On the other hand, the CAS legislation might allow military aircraft to install Type II CAS units in all of their aircraft. Therefore, the military costs associated with CAS implementation using only Type I CAS units and using only Type II CAS units have been developed. The results of these additional analyses are depicted in Figure 6-4. It can be seen that the Honeywell CAS exhibits the lowest life-cycle cost regardless of the mix of Type I and Type II CAS adopted by the military. There is no crossover in the cost curves that would affect the relative costs of the three concepts as the percentage mixture of Type I and Type II units in the military is varied.

6.3 THE EFFECT OF INCLUDING AMORTIZATION OF MANUFACTURER START-UP COSTS

Each manufacturer was asked to identify and amortize the costs of system development (e.g., the development of LSI logic circuits), production startup and tooling costs, and the engineering costs associated with equipment production. Based on the agreed-upon Uniform Ground Rules, these costs were assumed to be amortized during the first two years of production. In reviewing possible ways to evaluate the amortization costs, it was recognized that a competitive marketplace having multiple manufacturers would likely modify and reduce the amortization costs identified by the manufacturers. Therefore, amortization costs were eliminated from the cost analyses in Chapter Five. Nevertheless,

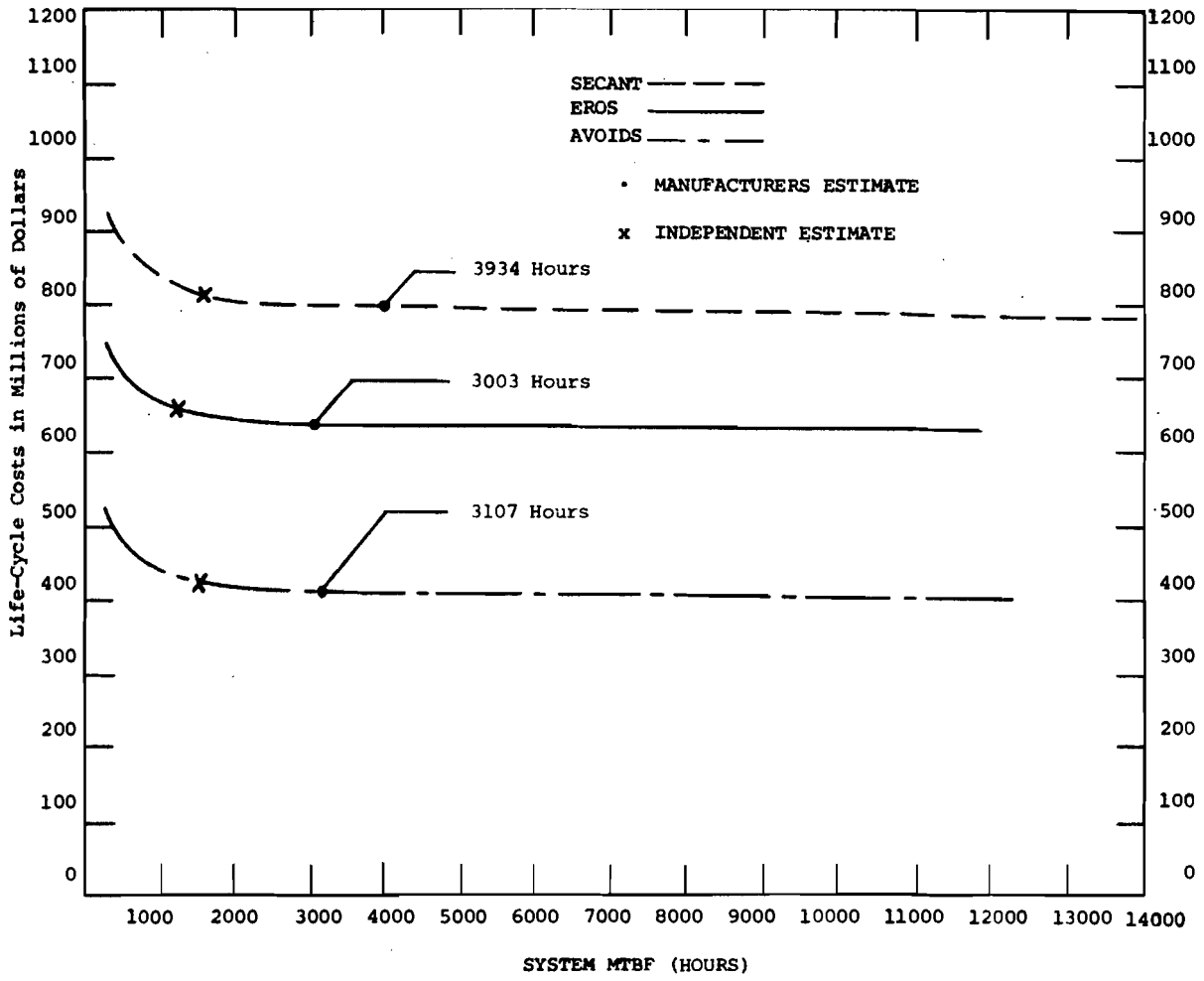


Figure 6-3. LIFE-CYCLE COSTS AS A FUNCTION OF CAS ELECTRONICS MTBF (GENERAL AVIATION) (ZERO PERCENT INFLATION RATE)

it was considered desirable to reevaluate the life-cycle costs with the effects of amortization included in order to determine if any of the cost evaluations would be altered.

The resulting costs identified by the manufacturers to be amortized by each of the three systems are identified in Table 6-1. These costs were presented for each Type of CAS to identify the variations in manufacturing costs among the full capability and general-aviation capability manufacturers. Since a linear retrofit period was assumed for all user categories, and quantities to be produced by any one manufacturer were limited to 3000 units of the Type I CAS and 1000 units of the Type II CAS, during the total implementation period, each manufacturer was allowed to amortize costs during the first two years to retrofit over the maximum number of 1500 units of the Type I CAS and 2500 units of the Type II CAS. These quantities assume a maximum demand for the Type I CAS by the commercial carriers during the four year retrofit period for this use category and a maximum production by any one manufacturer for the Type II CAS over an eight year linear retrofit period in the general-aviation community.

Table 6-1. Amortization Costs, Manufacturer's Data

	Honeywell	MDEC	RCA
Total to be Amortized	1,073,000	2,519,000	795,000
CA CAS	473,000	2,099,000	397,500
GA CAS	600,000	420,000	397,500
Per A/C, CA-CAS	315	1,399	265
Per A/C, GA-CAS	240	168	159

The amortization costs have been converted into per-aircraft costs based on limited production quantities of 1500 Type I CAS units and 2500 Type II CAS units that would be subject to amortization by any one manufacturer during the first two years of the CAS installation program. The resultant increased cost per unit was applied to all systems manufactured and installed during the first two years of system implementation under the assumptions that there would be multiple manufacturers and any manufacturer engaged in the production of a system would be subject to similar startup costs. The resulting total costs to be amortized by the multiple manufacturers during the first two years of production became $15.4 million for the AVOIDS, 21.0 million for the EROS, and 10.7 million for the SECANT system, at a zero rate of inflation.

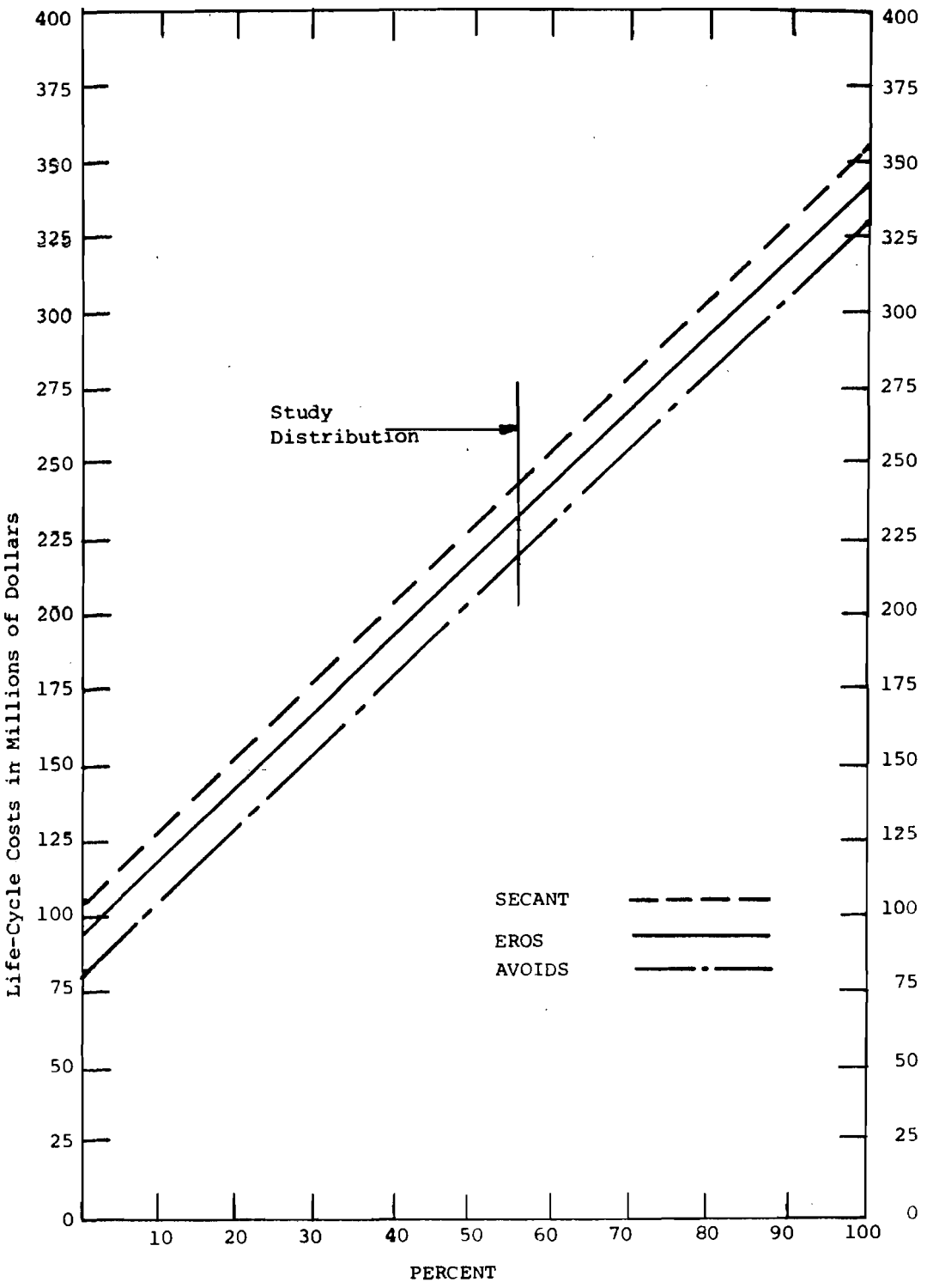


Figure 6-4. Life-Cycle Costs as a Function of Percent of Type I CAS Implemented. (Military Aviation) (Zero Percent Inflation Rate)

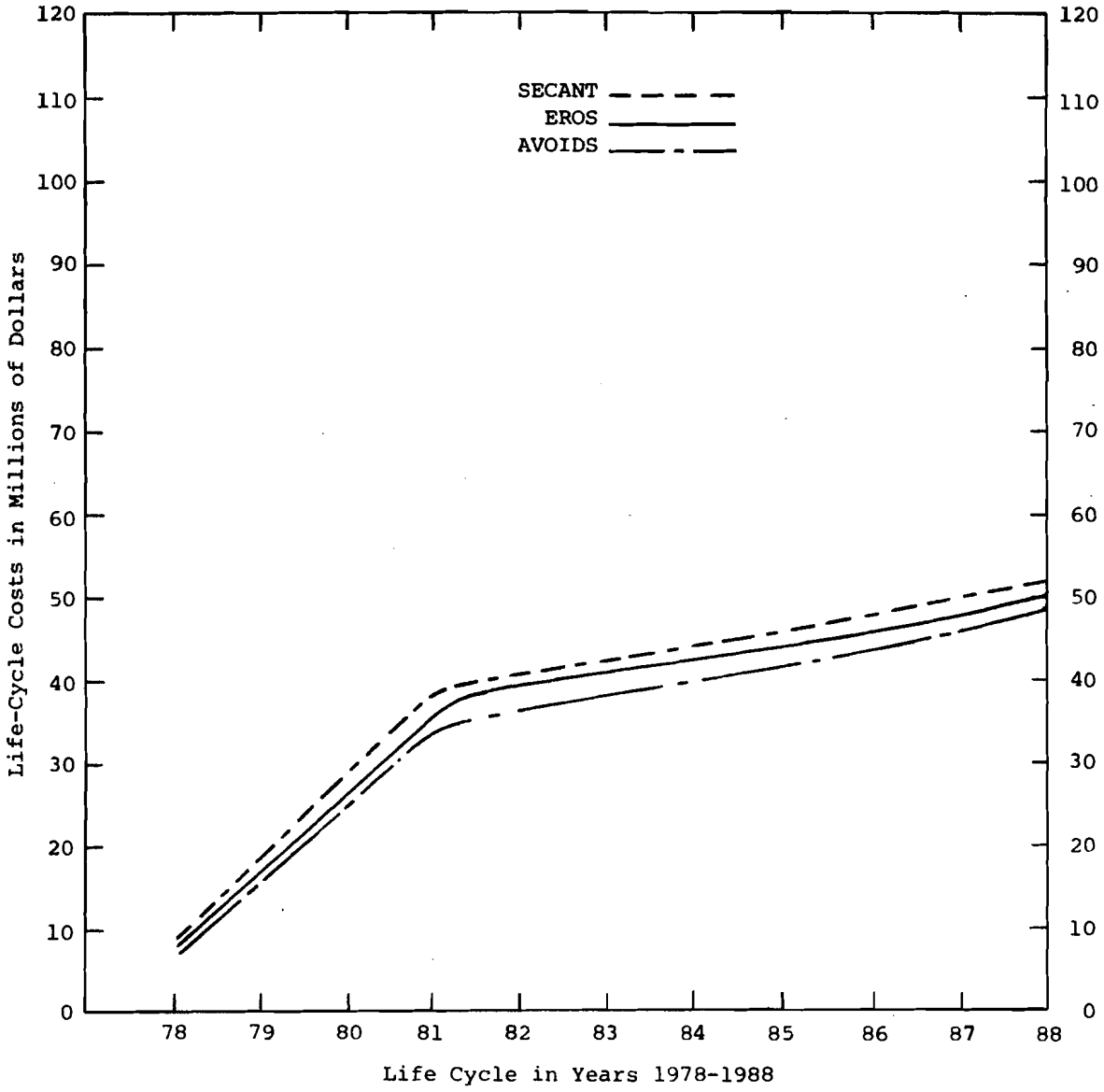


Figure 6-5. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA INCLUDING AMORTIZATION (COMMERCIAL AVIATION, ZERO-PERCENT INFLATION RATE)

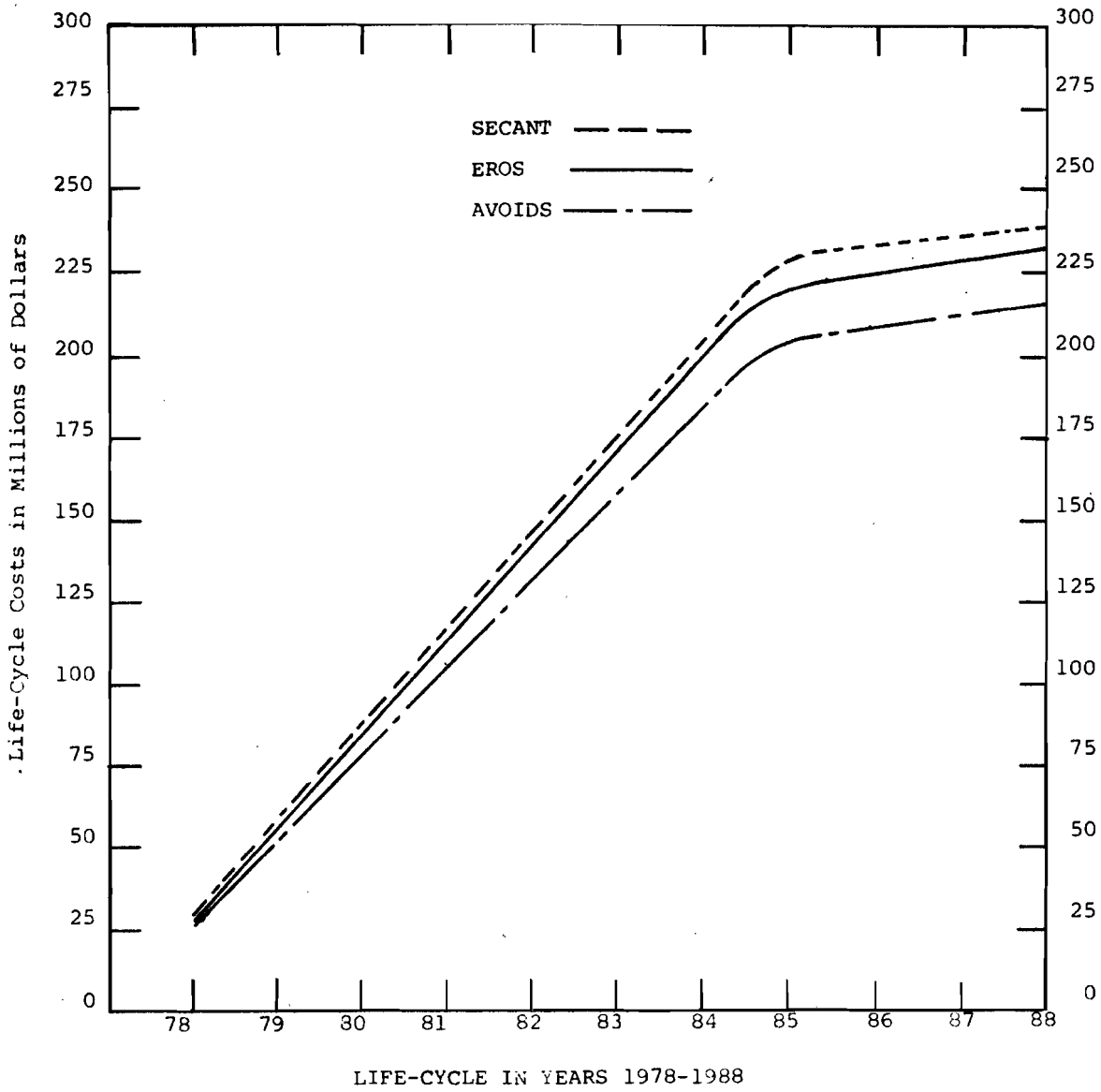


Figure 6-6. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA INCLUDING AMORTIZATION (MILITARY AVIATION) (ZERO PERCENT INFLATION RATE)

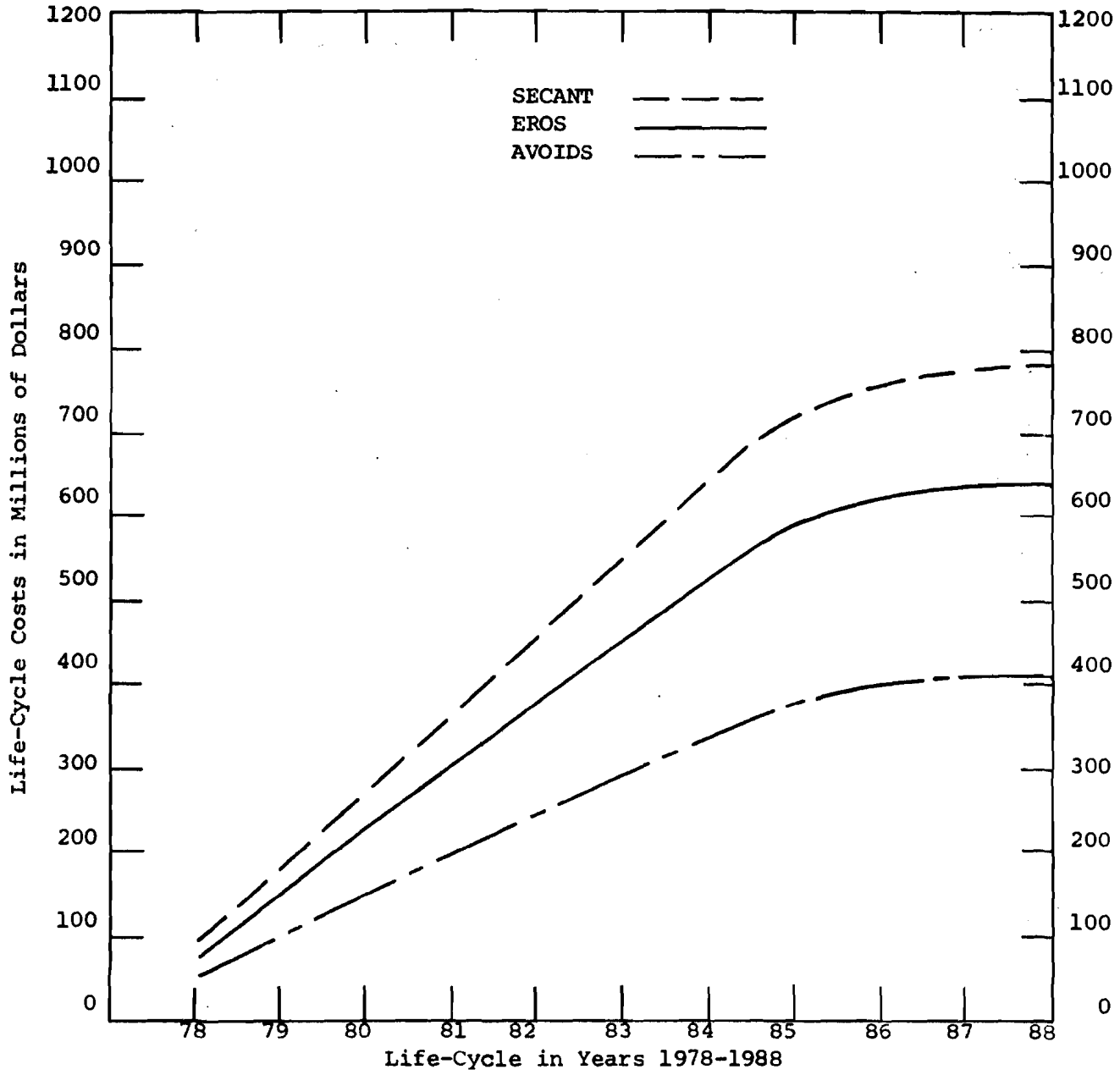


Figure 6-7. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA INCLUDING AMORTIZATION (GENERAL AVIATION) (ZERO PERCENT INFLATION RATE)

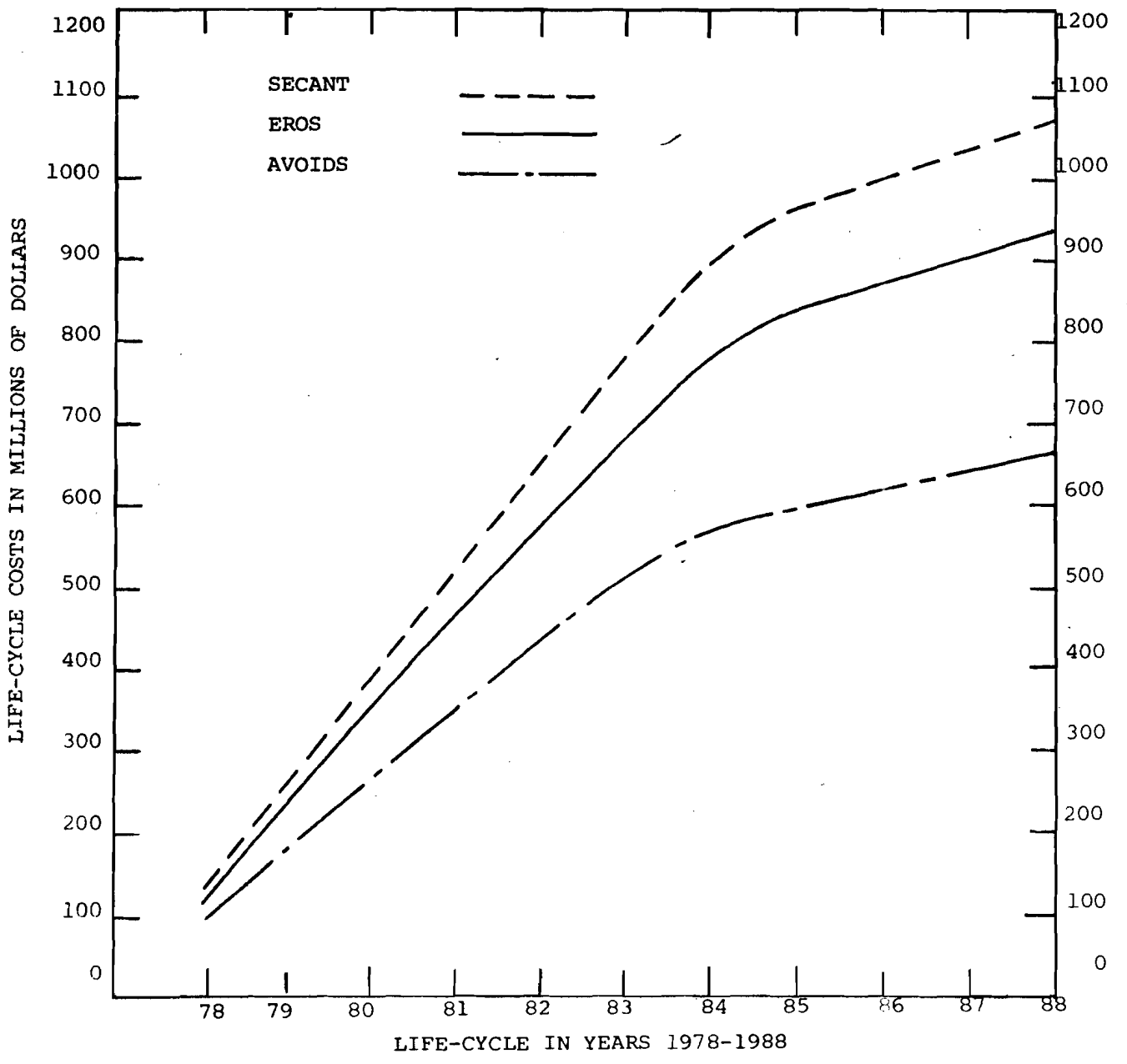


FIGURE 6-8. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA INCLUDING AMORTIZATION (TOTAL AVIATION COMMUNITY) (ZERO PERCENT INFLATION RATE)

Figures 6-5 through 6-8 present the life-cycle costs of each system with amortization costs included. Figure 6-5 shows the effect of amortization in the commercial-carrier community. The EROS system experiences the highest amortization costs and shows the greatest change in life-cycle costs. The costs of amortization in the commercial-carrier community based on the manufacturers' recommended division of the costs between the Type I and Type II CAS increase the life-cycle costs of EROS by $2.2 million, AVOIDS by $0.5 million, and SECANT by $0.4 million. The effect of amortization results in almost identical life-cycle costs for the EROS and SECANT systems and identifies the AVOIDS system as being 4.8 percent less costly than the other two concepts for the commercial-carrier community. The military-community costs with amortization included are shown in Figure 6-6 with the following cost increases: $4.4 million for EROS, $1.5 million for AVOIDS, and $1.1 million for SECANT. However, the relative cost differences between the three systems are changed very little from the results presented in Chapter Five.

The general-aviation community will be required to absorb the greatest amortization costs (based on the assumption that all Type II CAS manufacturers would amortize the amounts recommended by the three CAS competitors). The resulting system life-cycle cost increases are $13.0 million for the AVOIDS, $12.2 million for the EROS, and $8.8 million for the SECANT. Figure 6-7 presents the results of the effect of amortization on life-cycle costs. Although the cost increases in each system are appreciable, they are not evident when compared with the total expected expenditures required by this community. Amortization has little effect on the relative costs of the system because the life-cycle costs are dominated by the equipment acquisition costs.

Figure 6-8 presents the total aviation community life-cycle costs, including amortization. The actual effect of including amortization costs in the economic analyses can be seen by closely comparing Figures 5-10 and 6-8. However, Figure 6-8 indicates that the Honeywell concept remains the lowest cost alternative when amortization costs are included in the overall cost analysis.

6.4 THE COST IMPACT OF THE REMITTER

RCA has proposed the use of a collision-avoidance device (CAD) which would provide an electronic signal to be used by CAS-equipped aircraft to detect a CAD-equipped aircraft as an intruder and initiate the necessary maneuvers for collision avoidance. The system, called a remitter by RCA, is similar to the limited version of SECANT but omits the logic required to detect, track, and command escape maneuvers. The remitter provides no protection to two similarly equipped aircraft. In order to obtain a substantial reduction in CAS costs, RCA has proposed that the remitter be used by 70 percent of the general-aviation aircraft.

Figure 6-9 presents the life-cycle costs to be experienced by the total general-aviation community for a 5/95 mixture of the Honeywell and McDonnell Douglas Type I and Type II CAS and a mixture of RCA equipment consisting of 5 percent Type I CAS, 25 percent Type II CAS, and 70 percent remitter. The total life-cycle expenditures become $575.7 million for the SECANT system (which is a considerable reduction of the cost for the

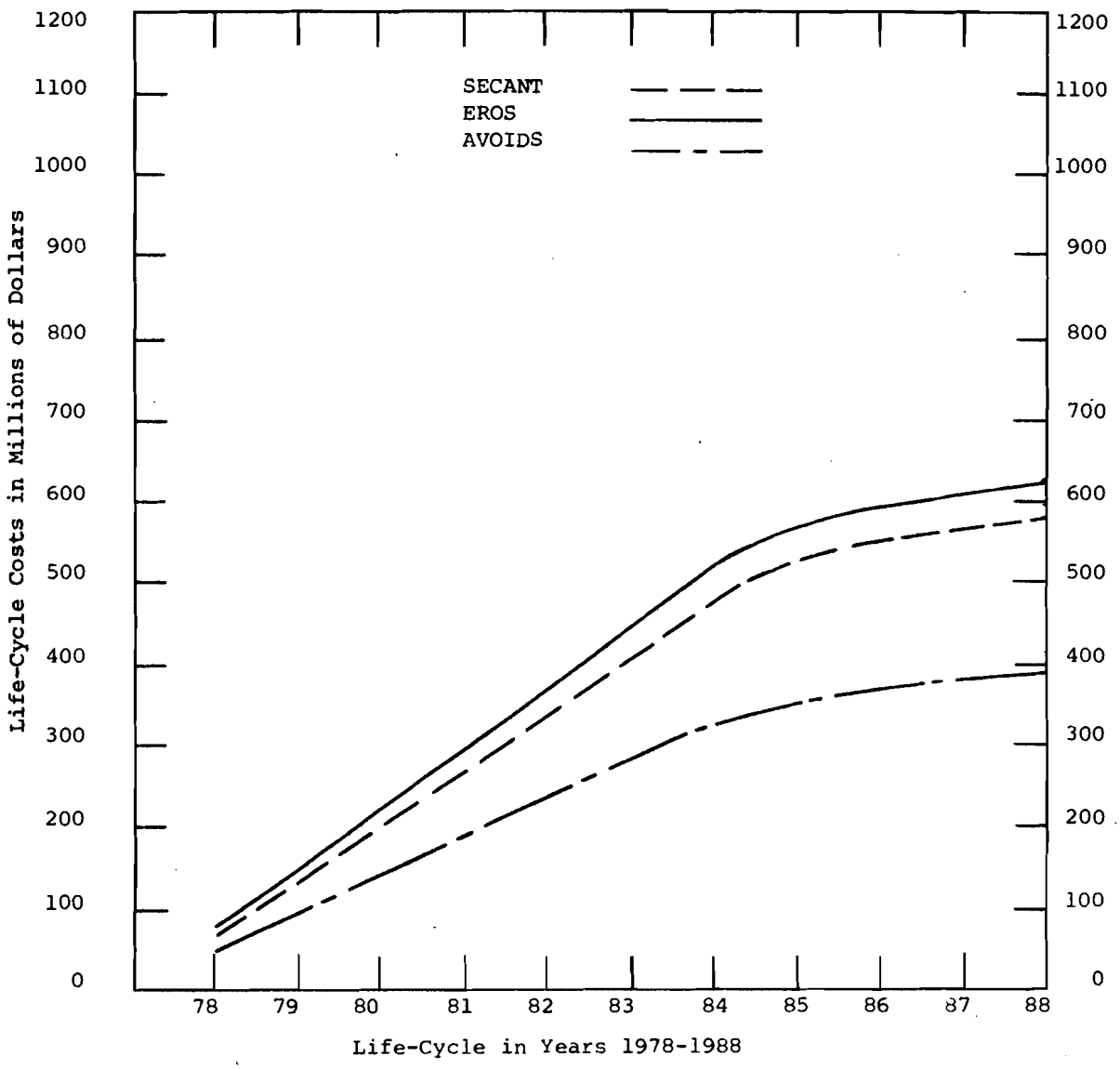


Figure 6-9. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA-REMITTER (GENERAL AVIATION) (ZERO PERCENT INFLATION RATE)

RCA concept discussed in Chapter Five), resulting in a cost advantage over the EROS system of $52.1 million, but still $180 million more than the least expensive AVOIDS-GA system. Therefore, the remitter makes the RCA concept more competitive on an economic basis, but it does not make the RCA the lowest-cost alternative considered in the present study.

6.5 THE EFFECT OF PROVIDING REDUNDANT ELECTRONICS IN THE COMMERCIAL AIR CARRIER COMMUNITY

In Chapter Five data were developed on the cost of ownership and life-cycle costs to the commercial air carrier community for implementation of a single CAS unit in each air frame. The results present the expected cost to this community based on the minimum equipment required for the successful implementation and operation of the CAS concept. However, historically the commercial carriers have followed the practice of achieving high operational availability through system redundancy. This section presents the results of an evaluation of the CAS concepts when redundant equipment is implemented in each air carrier aircraft.

The equipment required by a certified commercial air carrier to provide system redundancy consists of the following complements of collision-avoidance avionics:

- 2 sets of CAS electronics (Type I)
- 2 antennas (top and bottom)
- 2 CAS/IVS indicators (pilot and co-pilot)
- 1 set of control and switching equipment

The additional CAS electronics will be located in the normal avionics bay of the aircraft. The indicators and antennas required for a single system will be switched to operate with either of the redundant electronics.

The installation costs associated with dual system implementation will increase over those presented in section 4.4.1 by the following:

	Time Required	Cost
Shelf Fabrication and Installation	48 hours	$ 1067.
On-Aircraft Cabling	20 hours	444.
Material		541.
Total Increase	68 hours	$ 2052.

The estimated increase in time to install and the associated costs assume that the implementation of a dual system would be accomplished at one time, rather than by addition of a second system. The total cost of system implementation in an existing aircraft would be $6279.

Table 6-2 compares the costs of the dual system implementation on a per-aircraft basis for the three competing manufacturers and for the independently developed data. The results show the same relationship among the three systems as presented in section 5.3.1.1 except that the costs of each influencing parameter are higher. Based on both the manufacturers' and independently derived data, the Honeywell CAS remains the least expensive throughout the 11-year life cycle.

TABLE 6-2. COMMERCIAL AVIATION COST DATA COMPARISON-DUAL SYSTEMS (Per Aircraft-Retrofit) (Zero Percent Inflation Rate)

System / Costs	Manufacturers' Data			Independently Developed Data		
	Honeywell AVOIDS	MDEC EROS	RCA SECANT	Honeywell AVOIDS	MDEC EROS	RCA SECANT
Acquisition*	$10,342	$11,676	$12,719	$10,334	$11,698	$13,437
Installation	6,279	6,279	6,279	6,279	6,279	6,279
Non-Recurring Logistic	204	244	189	199	243	254
Recurring Logistic	571	477	463	533	462	578
1st Year Ownership	17,396	18,676	19,650	17,345	18,682	20,548
Life-Cycle Cost	$23,126	$23,465	$24,303	$22,696	$23,325	$26,342

*Electronics package (2); Antennas (2); Indicators (2); Control Unit (1)

Figures 6-10 through 6-12 identify the total annual cost and the cumulative life-cycle cost of implementing a redundant configuration of any of the three systems in the air-carrier community based on manufacturers' data. Figures 6-13 through 6-15 present the same information based on independently developed data. The graphs reflect the impact of inflation, assumed to increase at zero, six, and ten percent per year for the entire life cycle of the study.

Figures 6-10 through 6-12 identify the total annual cost and the cumulative life-cycle cost of implementing a redundant configuration of any of the three systems in the air-carrier community based on manufacturers' data. Figures 6-13 through 6-15 present the same information based on independently developed data. The graphs reflect the impact of inflation, assumed to increase at zero, six, and ten percent per year for the entire life cycle of the study. (All figures are presented at the end of this chapter for ease of comparison. The presentation is organized so that for each user category and inflation rate, CAS costs based on manufacturers' data are juxtaposed with those based on independently developed data.)

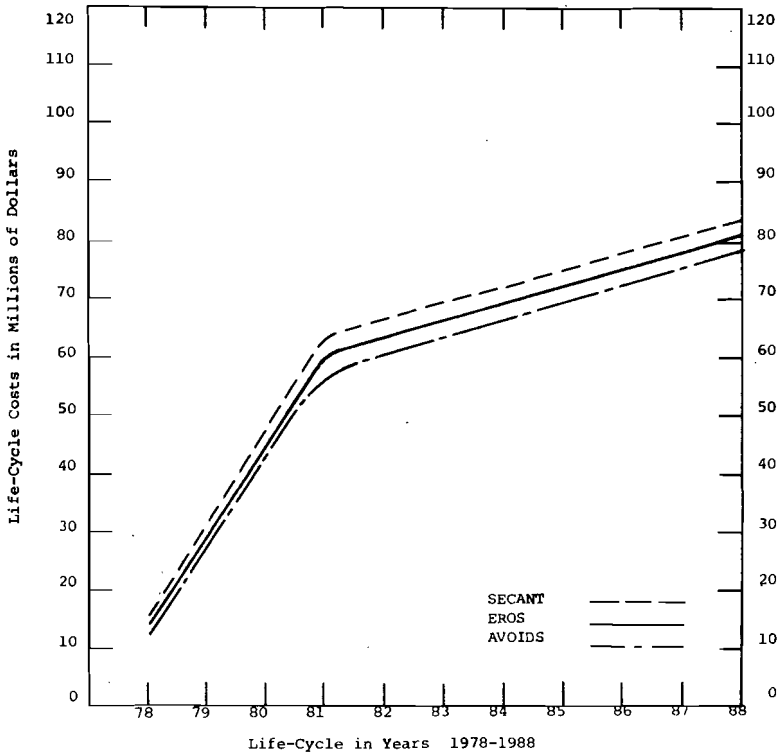


Figure 6-10. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA - DUAL SYSTEMS (COMMERCIAL AVIATION) (ZERO PERCENT INFLATION RATE)

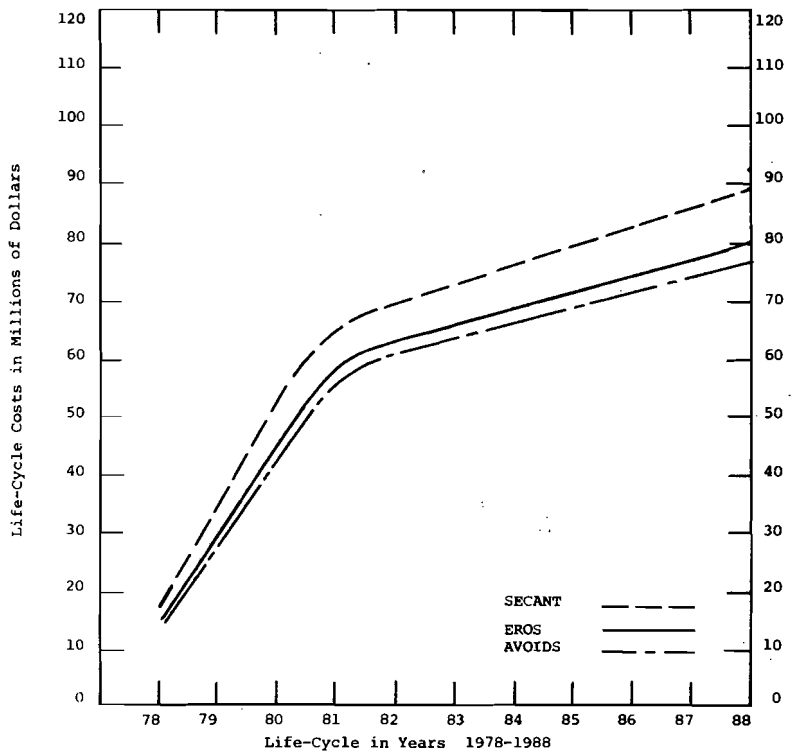


Figure 6-13. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA - DUAL SYSTEMS (COMMERCIAL AVIATION) (ZERO PERCENT INFLATION RATE)

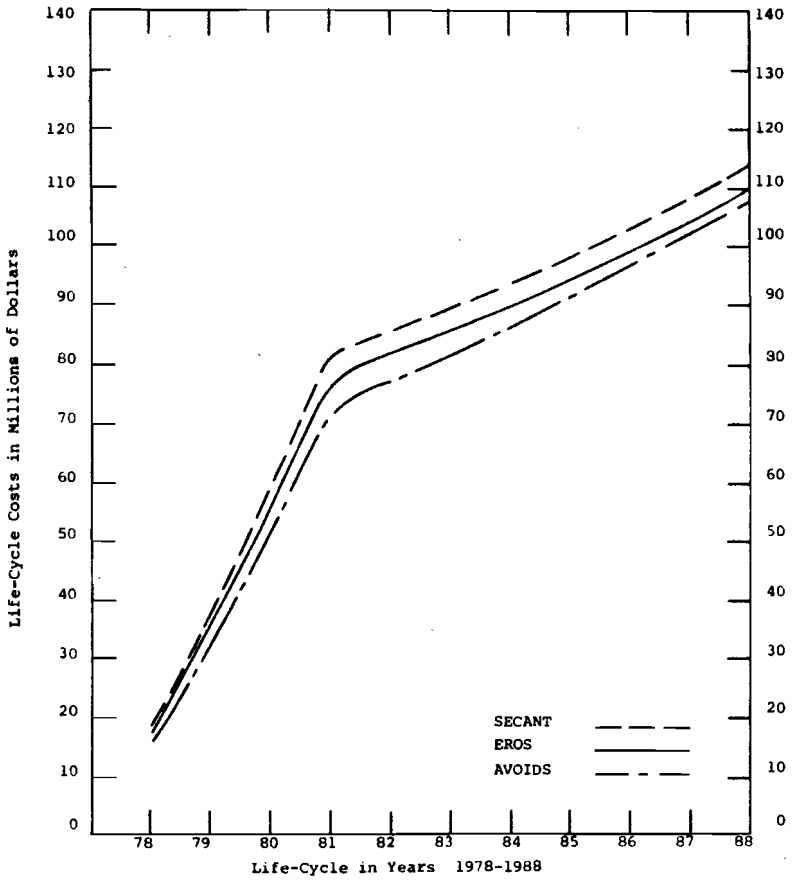


Figure 6-11. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA - DUAL SYSTEMS (COMMERCIAL AVIATION) (SIX PERCENT INFLATION RATE)

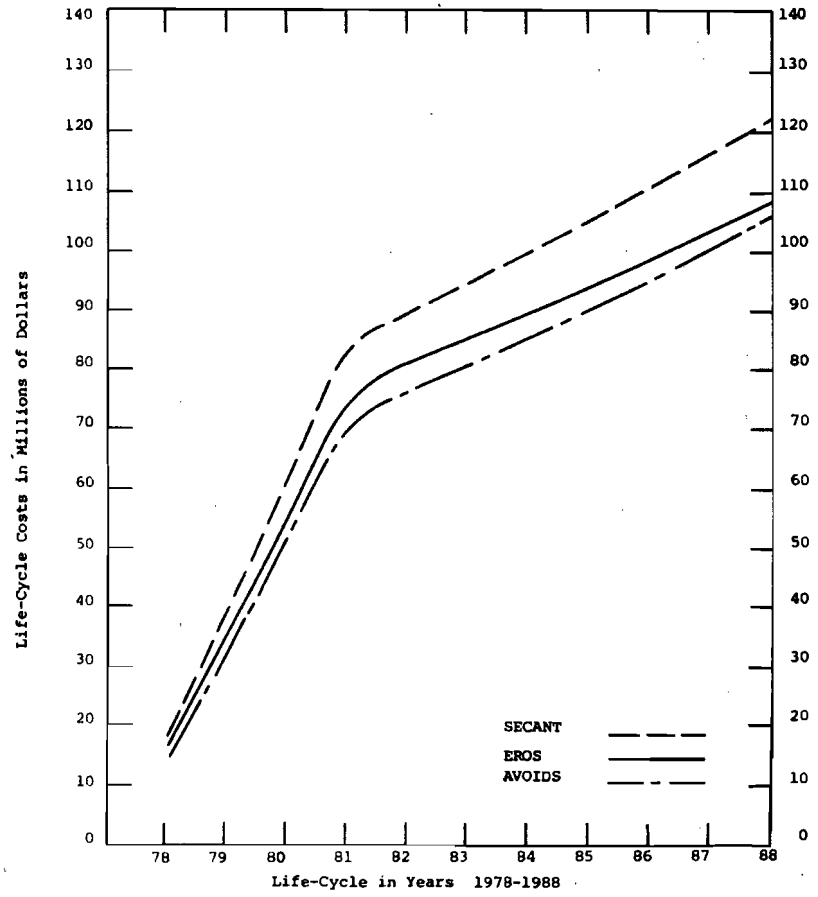


Figure 6-14. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA - DUAL SYSTEMS (COMMERCIAL AVIATION) (SIX PERCENT INFLATION RATE)

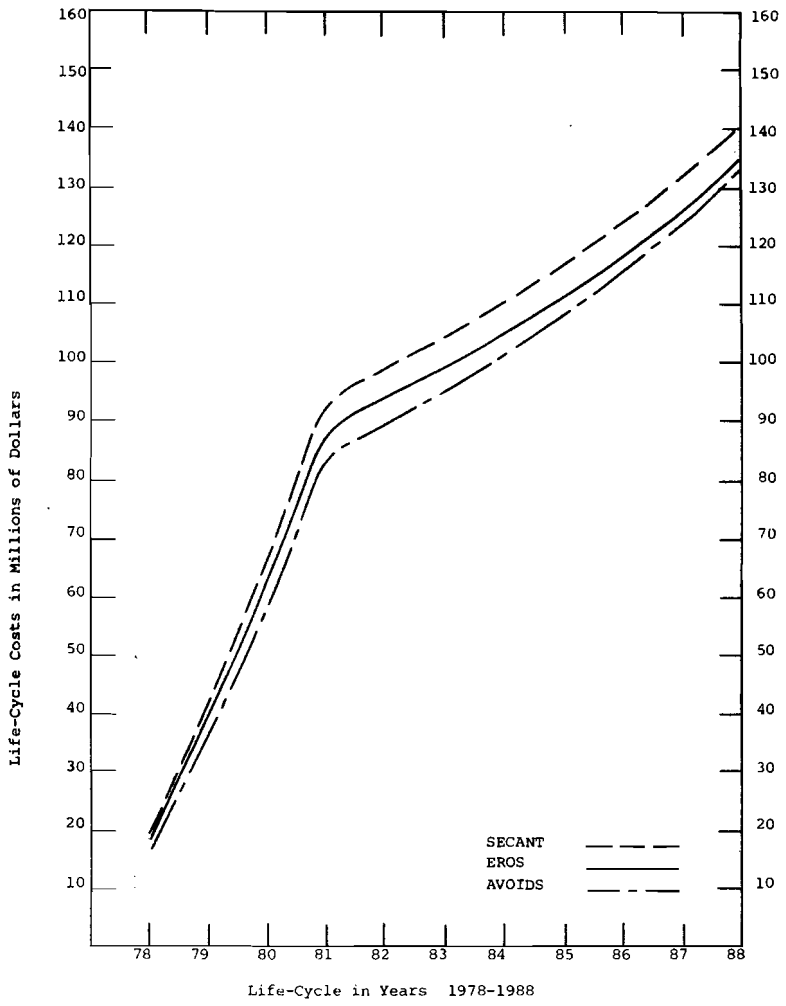


Figure 6-12. CUMULATIVE CAS COST FROM MANUFACTURERS' DATA - DUAL SYSTEMS (COMMERCIAL AVIATION) (TEN PERCENT INFLATION RATE)

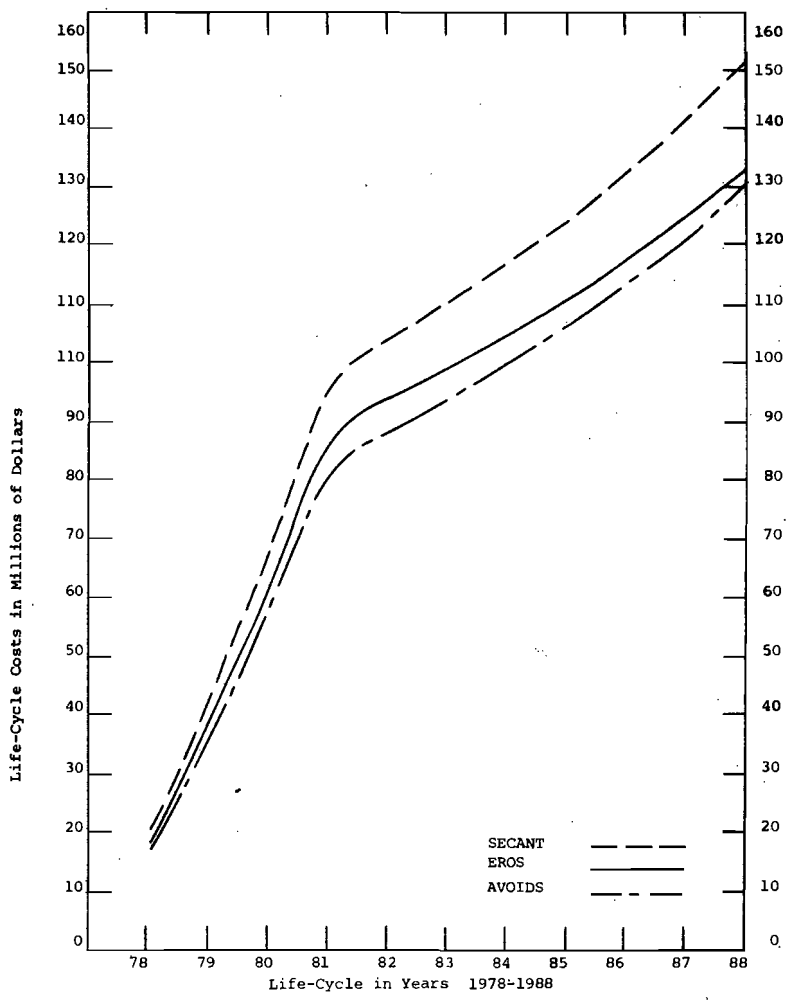


Figure 6-15. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA - DUAL SYSTEMS (COMMERCIAL AVIATION) (TEN PERCENT INFLATION RATE)

CHAPTER SEVEN

CAS OPERABILITY EVALUATION

The flight test evaluations have shown that a properly operating CAS system will provide appropriate warnings in a threat situation. However, since any system must experience failures from time to time, consideration must be given to those occasions when the system is not operating properly. For this condition, the effects of failure on the overall system performance must be evaluated.

This chapter addresses this question by defining and evaluating a characteristic termed "Operability" for each CAS candidate. As the term is used here, Operability is concerned with the consequences of failure on the overall system. The operability evaluation examines both the total incidence of failures for each of the CAS concepts and the percentage of failures that could occur without the knowledge of the pilot. Both total failures and failures that are unknown to the pilot should be kept as infrequent as possible and both failure types have been examined, based on the design data provided by the three CAS manufacturers, to provide operational inputs to be used in identifying the preferred CAS concept.

The chapter begins with a review of the relative roles of CAS and the ATC system to provide an overall perspective on CAS operability. The operability observations developed at this point can be applied equally to any CAS concept. Following this, a general discussion of failures associated with CAS operation and the methods that can be used to detect failures is presented. These failure detection methods are based on present practices associated with other avionics systems and can potentially be applied to any independent air-derived CAS concept.

The remainder of this chapter is concerned with evaluation of the operability features inherent in the manufacturer supplied CAS designs (i.e., the inherent reliabilities and failure detection methods). The severity of the total incidence of failures associated with each concept is assessed and the various classes of failures and failure detection methods included in each design are described. The total failure rates have been compared using the 1982 L. A. Basin Model to determine the total number of CAS failures to be expected from a

typical mix of aircraft. However, evaluation of the operational limitations of the CAS failure detection methods (i.e., failures that would be unknown to the pilot) was more difficult, and it was necessary to develop three special analysis tools (i.e., failure prediction equations) to permit the evaluation of the various failure detection methods suggested in each of the manufacturer-supplied CAS designs. These were applied to each of the CAS candidates to determine the percentage of systems in a given population that would have failures that would be unknown to the pilot. Of the various operational factors considered, these unknown failures proved to be the major operational difference among the three CAS candidates.

7.1 RELATIONSHIP OF CAS TO THE ATC SYSTEM

The CAS hardware and the ATC system hardware are designed to operate totally independently, but the fact that both affect the safety of aircraft movements makes an understanding of the relationship of CAS to ATC an important factor in the CAS operability evaluation.

7.1.1 The Functions of CAS and the ATC System

The CAS has the sole function of providing a totally air-derived method of detecting potential airborne collisions and providing the necessary commands to the aircraft involved to prevent actual collisions from occurring. The CAS is intended to serve as a backup for other methods of preventing mid-air collisions such as the pilot's use of "see-and-avoid" techniques and the ATC system's issuance of traffic advisories and separation commands.

The ATC system is designed to provide for the safe and orderly flow of air traffic. However, not all airspace is included within the ATC system, and not all aircraft that fly through controlled airspace are under the control of the ATC system. The ATC system can and does effectively prevent collisions within controlled areas and to a lesser extent within mixed airspace. However, it does not possess effective control over aircraft operating outside controlled airspace. While it is conceivable that all aircraft could be required to operate under the control of the ATC system, such a policy is not only overly restrictive to many aircraft operators, but it would be quite expensive to expand the ATC system to cover all of the airspace.

7.1.2 CAS and ATC Methods for Collision Protection

The CAS represents a way to provide collision protection to all aircraft with a minimal impact on the ATC system. To be generally effective CAS would have to be installed on essentially all aircraft. The CAS concepts considered in the present study are all cooperative and require that both aircraft involved in a potential encounter have operating CAS units* if either CAS is to detect the presence of

*or CAD's as discussed in Chapter 6

the other aircraft. If a threatening aircraft is detected, appropriate climb or dive commands are displayed to the pilot to eliminate the collision threat. The climb or dive will be continued until the aircraft are separated by either a safe lateral or vertical distance. An aircraft following a CAS maneuver command would do so without seeking permission from an ATC controller.

Because both CAS and the ATC system would be directing aircraft movements, there is always a concern that the two systems may conflict. However, if a CAS is operating properly, it should not generate aircraft climb or descent commands that would conflict with the ATC system unless the ATC system had either erred or failed to detect a potentially threatening aircraft.* Therefore, a properly operating CAS should appear as a silent backup to the ATC system unless a true threat existed. If a CAS unit fails, this may no longer be true. Therefore, the CAS operability evaluation must be concerned with the interaction of failed CAS units on the ATC system.

7.1.3 Impact of CAS Failures on the ATC System

The CAS units potentially could fail in such a way as to create unnecessary and unsafe aircraft climb and descent commands, although it will be shown in a later section that this is a remote possibility. The more common problem with CAS is likely to involve a single CAS unit becoming inoperative. This would not necessarily create a hazardous situation so long as the separation assurance methods used today by pilots and controllers are strictly followed. However, it is reasonable to assume that the existance of CAS as a backup to present separation assurance methods may result in a relaxation on the part of pilots and controllers so that an aircraft with an inoperative CAS may represent a larger threat to other aircraft than it would if it were operating in today's ATC environment.

As a result of the above considerations, it is apparent that failure of a CAS unit could create unsafe conditions unless the pilots and controller are aware of failures when they occur. If an aircraft is being operated with a CAS unit that is known to be inoperative, then the pilot and controller can exercise particular care to compensate for the failed system. If the aircraft is not flying under the control of the ATC system when the failure occurs, it would be reasonable to expect the aircraft to obtain special traffic advisories from ATC for the remainder of the flight. This special handling of aircraft by the ATC system can only be accomplished, however, if either the pilot or the controller or both are given an indication that the CAS unit has failed. Therefore, the CAS operability evaluations must focus on an examination of the probability of failure of the candidate CAS system and on its ability to indicate the existance of a system failure when one does occur.

*The ANTC 117 CAS threat logic will require that warnings, as opposed to commands, be generated routinely.

7.1.4 Independence of CAS to the ATC System

As mentioned above, the CAS is designed to operate wholly independently of the ATC system. This feature is a major benefit of the CAS concepts so long as the systems are working properly because it provides a completely independent backup to the ATC system. However, when the CAS units fail, this potentially creates a major problem because the ATC controller has no way of detecting a CAS failure directly.* This means that the CAS failures must either be detected by the pilot's monitoring of the equipment performance or through special FAA operated ground stations that inform the controller of a CAS failure. This independence of CAS and the ATC system means that the ATC system in its present form cannot assist in informing the pilot of the malfunctioning of the CAS.

7.2 CAS FAILURES AND FAILURE DETECTION METHODS

There are two categories of CAS failures that must be considered in the operability analysis and there are a number of ways to ensure that these failures are detected and corrected.

7.2.1 CAS Failure Categories

The most serious types of failures that could occur with a CAS are "System-Wide" failures in which the failure of a single unit causes the improper operation of one or more other CAS units. These system-wide failures could be produced by a unit transmitting signals that provide improper range or altitude information to other aircraft (i.e., phantom targets), create receiver saturation or interference, or result in some form of logical lockout in otherwise properly functioning systems. These failures are serious because they magnify the impact of CAS failures on the overall effectiveness of the system. The specific situations that could produce system-wide failures will be discussed in Section 7.3.2 for each of the candidate CAS concepts.

The more likely types of failures are "Single Unit" failures that cause a single unit to become inoperative, but have minimal impact on other CAS units. The only impact a single-unit failure would have on other CAS units would occur as a result of the aircraft with the failed unit becoming involved in a potential mid-air collision. The aircraft with the failed unit would be unprotected from other aircraft and would be invisible to the CAS units on these aircraft.

7.2.2 The Failure Detection Problem

With any system, failures are inevitable, and it is important to minimize both the relative frequency and the operational impact of these failures. The failure rates for the system affect the overall frequency

*An ATC controller can detect problems in other aircraft systems. For example, he can detect malfunctions in the aircraft's navigation equipment if the aircraft is seen to be wandering off course.

of occurrence of failures, while the inherent ability to determine inoperative systems controls the operational impact of the failures. From a safety of flight point of view, undetected failures are particularly hazardous and methods are needed whereby failures can be detected when (or soon after) they occur.

7.2.3 Failure Detection Methods

Existing practice with avionics is to use one of four methods to ensure proper equipment operation. These methods, and combinations of them, have been considered as the basis for detecting failures in the three candidate CAS concepts.

The following is a discussion of the four general methods; the actual failure detection methods proposed by the CAS manufacturers are discussed in Section 7.3.4.

Built-in-test (BIT) provides a method to monitor system performance continuously and indicate when a system failure occurs. Usually BIT monitors most but not all functions of a system so it represents an imperfect method for detecting system failures. For the present discussion BIT has been assumed to be an automatic and continous method of monitoring system performance. BIT would provide an immediate indication of a CAS failure and would thereby minimize the impact of these failures on the CAS operability.

Confidence tests or pilot initiated checks are used or required for some avionics and could be used by the various CAS concepts. The pilot initiated checks could be performed through a self test feature in the equipment or through operational checkout with another piece of equipment. An example of the latter type of checkout is the use of VOR test facilities to verify the accuracy of VOR receivers on a periodic basis. Pilot initiated checks may or may not provide a complete system checkout depending upon the thoroughness of the test. Because pilot initiated checks are performed periodically, a unit could be in a failed condition for a period of time before the failure is detected.

Periodic bench checks represent the most thorough form of system checkout. However, bench checkouts are inconvenient to the aircraft operator, and the tendency is to allow long times to occur between these checks. For example, transponders must now be bench checked on an annual basis. Bench checks are assumed to be able to detect any failure in the CAS avionics-although aircraft installation problems that would not be a part of the avionics failure rate but would affect overall operability might still go undetected.

Special ground stations to monitor CAS operation and notify the pilot when his equipment has failed could be operated by the FAA. As a part of its ATC mission the FAA presently observes the performance of certain avionics (e.g., the transponder or encoding altimeter) and advises the pilot if any discrepancies are noted. However, CAS will

not interact directly with any system being operated by an ATC controller. Consequently, special facilities designed primarily to monitor CAS operation would be required if the method is to be used.

Each of the above four potential methods for detecting CAS failures has both desirable and undesirable features. To take maximum advantage of the desirable features and to minimize the undesirable features, a combination of the above techniques should be used to ensure a high level of operability for a system such as CAS that is critical to flight safety.

7.3 EXAMINATION OF FAILURES IN THE THREE CANDIDATE CAS CONCEPTS

The failure rate data for the three candidate CAS concepts presented in Chapter Three provide a basis for the operability analysis. However, it has been necessary to review the relative frequency of occurrence of system-wide failures and single-unit failures and the relative detectability and undetectability of system failures.

7.3.1 Preliminary Evaluation of Candidate System Failures

The failure rates for the Type I and Type II units (i.e., the commercial air carrier (CA) and the general aviation (GA) units, respectively) have been developed separately. An overall assessment of the reliability impact of each of the three CAS candidates on system operability requires that a composite reliability figure be based on the anticipated relative populations of the Type I and Type II units for each of the candidate concepts. For this purpose, the 1982 Los Angeles Basin Air Traffic Model provides both a convenient tool for specifying a mix of aircraft (and thus CAS equipments) and a method to obtain a high-side estimate on the severity of the CAS operability problem. The 1982 Los Angeles Basin Air Traffic Model, as supplied by the FAA, contains a peak load of 797 aircraft broken down by types and altitudes as shown in Table 7-1.

TABLE 7-1. AIRCRAFT BY TYPE AND ALTITUDE IN THE 1982 LOS ANGELES BASIN MODEL

Type of Aircraft	Altitudes (thousands of feet)				
	0-5	5-10	10-15	15	Total
General AVN VFR	312	236	0	0	548
General AVN IFR	27	14	85	42	168
Air Carrier	21	8	2	13	44
Military	16	4	6	11	37
	376	262	93	66	797

The proportional distribution of systems based on the mix of Type I and Type II units installed in the commercial aviation, military, and general aviation aircraft is presented in Table 7-2.

TABLE 7-2. ACAS SYSTEM MIX BY CATEGORY OF AIRCRAFT

Mix Category	Type II Systems	Type I Systems	Total Aircraft
Military (44% Type II-56% Type I)	16	21	37
Commerical (100% Type I)	0	44	44
General Avn (95% Type II-5% Type I)	680	36	716

When the CAS System Mix for the Los Angeles Basin Model is computed, it is found that 87% of the population will be outfitted with the Type II version of the CAS and 13% will have the full capability or Type I version of the selected CAS.

The expected number of failures after a given interval of time for the mix of aircraft in the Los Angeles Basin Model can be computed from the following equation.

$$E(F_{LA}) = 696P_{f_{GA}}(T) + 101P_{f_{CA}}(T) \qquad (7\text{-}1)$$

Where $E(F_{LA})$ = expected number of aircraft with failed CAS units in the L.A. basin

T = time interval of interest

$P_{f_{GA}}(T) = 1 - e^{-T/MTBF_{GA}}$, probability of a single Type II unit failing

$$P_{f_{CA}}(T) = 1 - e^{-T/MTBF_{CA}}$$, probability of a single Type I unit failing

The uniformly derived Values of MTBF, the mean times between failures for the Type I and Type II units, and the expected number of failures after one hour for the three candidate CAS concepts are presented in Table 7-3.

TABLE 7-3. PRELIMINARY CAS FALURE ASSESSMENT

	MTBF		Expected Failures* during the first hr (EQ 7-1)	Probability of more than 2 failures (EQ 7-2)
	Type I	Type II		
Honeywell	2138 hrs	3101 hrs	.272	.0027
McDonnell Douglas	1813 hrs	3631 hrs	.248	.0021
RCA	2475 hrs	3227 hrs	.257	.0023

The expected number of failures are quite low and are very close to each other, indicating little difference among the three CAS candidates based on this initial analysis. However, it should be recognized that Equation 7-1 is based on the assumption that all units are operating at time zero- a situation that is unlikely in a real-world environment and will be explored more completely in a later section.

The expected number of failures in Table 7-3 represents the average number of failures that would be observed if repeated one-hour flights were conducted. However, it should be recognized that the actual number of failures must be an integer quantity (i.e., 0, 1, 2..... failures at any instant in time). By using the cumulative Poisson distribution it is possible to compute the probability that more than N failures will occur for a specified expected number of failures. The equation is given below:

*The expected failures can be considered to be an overall failure rate for a composite system consisting of CAS installations in the L.A. Basin aircraft mix.

$$P(N) = 1 - e^{-x} \sum_{i=o}^{N} \frac{x^i}{i!} \qquad (7\text{-}2)$$

where P (N) = probability that more than N failures occur

$x = E\ (F_{LA})$, the expected number of failures in the L.A. Basin

N = the number of failures

As an example, Table 7-3 presents the probability that more than 2 failures will occur in the L.A. Basin for each of the three candidate systems based on the expected number of failures computed from Equation 7-1.

7.3.2 Assessment of System-Wide Failure Mode Possibilities

System-wide failures are those failures that occur in one system that result in the inability of two or more good units to detect threats between these good units. After careful examination of the CAS concepts and designs, three types of system-wide failure possibilities have been identified. However, none appears to create a serious CAS operability problem.

For each of the candidate CAS concepts it is possible that a unit could transmit incorrect range or altitude data to other aircraft. For example, the logic that controls the pulse positioning of the altitude pulse in the Honeywell or McDonnell Douglas concepts or the pulse train encoding in the RCA system could result in a phantom target being created at an improper altitude. However, this failure would not create a serious problem with the operation of a properly functioning CAS unit unless this phantom target would conflict with the maneuvers that might be required to evade an actual threat. Because of the very low probability of encountering the complex set of conditions that would have to be met for a phantom target to create a system-wide problem and because the phantom target problem would clear up as aircraft move along their tracks, it was decided that there is no need to perform a special evaluation of this potential failure mode.

Each of the candidate CAS concepts could be affected by continuous wave (CW) interference generated by a continuously transmitting transmitter in one of the CAS units. This would seriously affect the ability of two properly operating CAS units to evaluate the threat they represent to each other. However, this CW transmission would place a heavy load on the CAS transmitter, and the transmitter would most likely burn out after a short period of time. For this reason and in view of the fact that CW generation tends not to be a problem with other avionics, such as transponders or DMEs, it has been decided that no special evaluations of this failure mode is warranted.

For the McDonnell Douglas system, there is a unique type of system-wide failure that could occur involving the time synchronization process. It is possible that a CAS unit could attempt to provide invalid synchronization to other units if it fails in a particular manner. However, an examination of the McDonnell Douglas system designs indicates that the properly operating units should be able to reject virtually all erroneous synchronization signals. Because a very special and unlikely set of circumstances would have to occur to create system-wide synchronization problems and because the system is such that synchronization problems should clear up within a short period of time (i.e., three minutes), it has been decided not to perform a special evaluation of this failure mode either.

As a result of the above observations, it has been decided that all failures of a CAS unit will be assumed to affect that unit only and will be termed single-unit failures.

7.3.3 Degraded Failure Modes

With most systems, it is possible for some performance degradation to occur before the total system fails, and the CAS concepts appear to be no exception. For example, the transmitter power output or the receiver sensitivity could vary by several decibels and the system would still provide collision protection. However, the overall capability of the unit would be affected (e.g., the fade margin would be lowered with a resulting decrease in communications reliability between units). As a result, the degraded failure modes would compromise the ability of the CAS to provide full collision protection to the aircraft. For this reason, it has been decided that any degraded failure mode occurring in a CAS will be tantamount to a complete system failure.

7.3.4 Development of Operability-Related Failure Rate Data for each of the Candidate CAS Units

The operability characteristics of the CAS concepts are a function of both the total failure rates and the ability of the user to determine that a system has failed after the occurrence of the failure. Section 7.3.1 has shown that there is little difference among the candidate systems when total failures are considered. Therefore, the failure detection characteristics of each of the candidate CAS equipments must now be examined. As noted earlier, unit failures can be detected through BIT, pilot-initiated confidence checks, and bench checking. The FAA-operated ground monitoring possibility discussed in Section 7.2.3 has not been considered because:

1. It would provide redundant system checking with the other three methods of detecting failures.

2. No equipment of this type has been proposed by either Honeywell or RCA.

3. McDonnell Douglas has proposed equipment of this type but the BIT inherent in the McDonnell Douglas designs represent a suitable method for continuously monitoring the performance of most of the systems.

The following discussion of each of the candidate CAS concepts is based on the design data provided by the manufacturers and used in the cost analyses. Each manufacturer has been given full credit for the capability claimed by the BIT or confidence testing. Although additional test capability could be designed into each of the systems, to do so at this time would result in an operability analysis based on system designs that are different from those used in the cost analysis.

The Honeywell concept employs a pilot-initiated confidence check for both the Type I and Type II CAS units. The confidence check circuitry indicates the status of the following portions of the CAS units:

Receiver

Logic

Power Supply

Additionally, the confidence check circuitry checks 70 percent of the transmitter and RF front-end modules.

The remaining portions of the Honeywell units are not monitored and can only be checked on a periodic basis using bench checkouts.

The McDonnell Douglas designs employ BIT extensively to check all portions of the Type I CAS units and the following portions of the Type II CAS units:

Receiver

Exciter

Oscillator

Logic

Power Supply

In the Type II CAS units, the transmitter and RF front end modules are not checked by the BIT, but proper pilot attention to the performance of the units will provide an indication of failures in these modules as well. Because the McDonnell Douglas concept requires time synchronization from the ground or other airborne systems, it must be able to transmit and receive properly to retain synchronization. Although synchronization may be unattainable in remote areas and the system will have to use a backup mode of operation, the system should be able to attain synchronization in most areas of the country. (Synchronization can be retained so long as a commercial air carrier aircraft or ground station is within 90 n. mi.) Therefore, the continued failure to attain synchronization can serve as an indication of a malfunctioning transmitter or RF front end. In assessing the fault detection capability, it has been assumed that at least 50% of the transmitter and RF front end failures can be detected through the synchronization status indication by proper pilot awareness of system performance.

The RCA systems as proposed and evaluated in the cost analyses of Chapter Five do not include any BIT or confidence check capabilities. However, it has been assumed that the pilot would be aware of power supply failures.

The portions of the failure rates for those portions of the CAS systems representing failures that can be detected in flight are presented in Table 7-4. Also shown is the portion of the total failure rate representing failures that can be detected only by bench checks.

7.4 FORMULATION OF THE OPERABILITY ANALYSIS EQUATIONS

As a result of the proposed BIT and confidence test features for the three candidate CAS concepts, three different operational scenarios consisting of periodic bench checking, periodic bench checking combined with continuous monitoring of portions of the CAS, and periodic bench checking combined with periodic pilot-initiated confidence tests must be considered. This Section presents the mathematical formulation of the analysis equations required to assess the operational impact of these scenarios. In Section 7.5, the equations will be applied to each of the CAS concepts.

7.4.1 Periodic Bench Checking

The most reliable method of determining system operational status is obtained through a detailed system checkout under controlled test conditions, such as a bench check, with appropriate test equipment. When bench checkout is employed, it is assumed all system failures will be detected and corrected. Bench checkouts typically are required on a calendar time basis (e.g., annually), but for the present analysis it is assumed that bench checks will be performed on an operating time basis (e.g., every 100 hours of flying time). The following analysis develops an equation that relates the probability that a system will be in a failed state at any point in time as a function of the operating hours between bench checks.

TABLE 7-4. FAILURE RATES EMPLOYED IN THE OPERABILITY EVALUATIONS

System	MTBF (hrs.)	System Failure Rates (failures/10^6 hrs.)			
		Failure Rate of Total System	Failure Rate of Components checked by Confidence Tests	Failure Rate of Components checked by BIT	Failure Rate of Components only found by Bench Checks
Honeywell Type I	2138	468	368	--	100
Honeywell Type II	3101	323	258	--	65
McDonnell Douglas Type I	1813	552	--	552	--
McDonnell Douglas Type II	3631	275	--	240*	35
RCA Type I	2475	404	--	20	384
RCA Type II	3227	310	--	20	290

* Assumes that 50% of Transmitter and RF Front End failures can be detected.

If a bench check interval of t_c hours is used, then at any instant in time the CAS unit will have between 0 and t_c hours of operation since its last bench check. The time since the last bench check is, therefore, a uniformly distributed random variable with a value between 0 and t_c hours. The resulting probability that a unit is in a failed state at any point in time can be expressed by*

$$P_f(t_c) = \frac{1}{t_c} \left[t_c + \frac{(e^{-\lambda_t t_c} - 1)}{\lambda_t} \right] \qquad (7\text{-}3)$$

Where:

P_f = Probability that a unit is in a failed state at any point in time when a bench check interval of t_c is employed

t_c = Time between bench check

λ_t = System failure rate

For a system that is monitored only through periodic bench checks, the probability of failure computed above is equal to the probability that an undetected failure exists in the unit.

7.4.2 Periodic Bench Checking Combined with Continuous Monitoring

Full-time monitoring of system operational status is an additional acceptable method of ensuring system availability. Monitoring can be accomplished by one of two techniques: either by use of built-in-test (BIT) equipment, or by external monitors. In either case, the objective of monitoring is the same, to provide an immediate indication when a failure occurs.

The ideal monitor system would be one which would provide continuous surveillance of every component in a unit, and identify failures as they occur. However, the average BIT provides failure information on only portions of a unit. Failures in the remaining portions of the system would go undetected until a bench check is performed. Therefore, the probability of failure developed in the operability analysis is a function of the undetected failures when continuous monitoring is employed.

* This formula has been derived by mathematically convolving the exponential reliability function with a rectangular probability function for the time since the system was last bench checked.

Assuming that the BIT will immediately appraise the pilot of any failure in the monitored portions of the unit, the probability that an undetected failure exists in a system is a function of the bench checking interval, t_c, and the failure rate for the unmonitored portions of the system (i.e., those portions that are only checked during a bench check). The equation required to compute the probability of an undetected failure is identical to equation 7-3 with λ_t replaced by λ_1, the failure rate for those unmonitored portions of the system. For a given operating time, the probability of an undetected failure for bench checking with continuous monitoring will be less than the probability of an undetected failure if bench checking alone is employed.

7.4.3 Periodic Bench Checking Combined with Periodic Confidence Tests

Perodic confidence testing provides another method for detecting some, but not all, failures in a system without waiting for a bench check to be performed. For a combination of bench checks and confidence tests, the probability of an undetected failure in a system will again be less than if bench checks alone are employed.

The probability of an undetected failure in a system using pre-takeoff checks can be expressed as:

$$P_f(t_c) = \text{Probability that any items checked \underline{only} by bench checkout are in a failed state} + \text{Probability of failure during flight of items checked at the start of the flight} \qquad (7\text{-}4)$$

$$P_f(t_c) = \frac{1}{t_c}\left[t_c + \frac{(e^{-\lambda_1 t_c}-1)}{\lambda_1}\right] + (1-e^{-\lambda_2 t_f}) \qquad (7\text{-}5)$$

Where:

λ_1 = failure rate of item not checked until a bench check is performed

λ_2 = failure rate of items checked on pre-takeoff check

t_c = time between bench checks (in hours)

t_f = time of a typical flight (e.g., 2 hours)

In determining the probability of failure in a population for which pre-takeoff confidence testing is performed, the average flight times of the population can be used for the value of the time into flight. The probability of failure of the untested portion of the system was determined by the use of Equation 7-3.

The probability of undetected failure of a system using a pre-takeoff confidence check should follow the form shown in Figure 7-1. The saw-tooth nature of this curve reflects the periodic performance of pre-takeoff checking.

7.5 ANALYTICAL ASSESSMENT OF CANDIDATE CAS OPERABILITY

The operational risk associated with a CAS concept can be directly related to the expected number of undetected failures that would exist at any time. While the total expected number of failures (both detected and undetected) should be as low as possible, an undetected failure represents the most serious form of failure. By multiplying the probabilities of undetected failure determined from Equations 7-3 or 7-5 by the population of equipments, the expected number of equipments with undetected failures may be determined. Using the L. A. Basin scenario, the expected numbers of failures for each of the candidate equipments can be calculated.

7.5.1 Operability Analysis of the Honeywell Concept

The Honeywell CAS concept employs periodic confidence checks that must be supplemented with periodic bench checks. Therefore, Equation 7-5 must be evaluated separately for the Type I and Type II systems and the individual results multiplied by the numbers of Type I and Type II installations in the L.A. Basin Model (see Table 7-2) to obtain the following expression for the expected number of failures for the Honeywell systems.

$$E\,(F_{LA_H}) = 696P_{f_{GA}}\,(t_c) + 101P_{f_{CA}}\,(t_c) \qquad (7\text{-}6)$$

Where: $E\,(F_{LA_H})$ = expected number of undetected failures in the L.A. Basin for the Honeywell system with a bench check interval of t_c

$P_{f_{GA}}\,(t_c)$ = Equation 7-5 with $\lambda_1 = 65/10^6$ hours, and $\lambda_2 = 258/10^6$ hours,

$P_{f_{CA}}\,(t_c)$ = Equation 7-5 with $\lambda_1 = 100/10^6$ hours, and $\lambda_2 = 368/10^6$ hours

The results of this evaluation are shown on Figure 7-2 as a function of time between bench checks.

Region I: Failures detected by confidence tests

Region II: Failures undetected until the next confidence test is performed

Region III: Failures undetected until the next bench check is performed

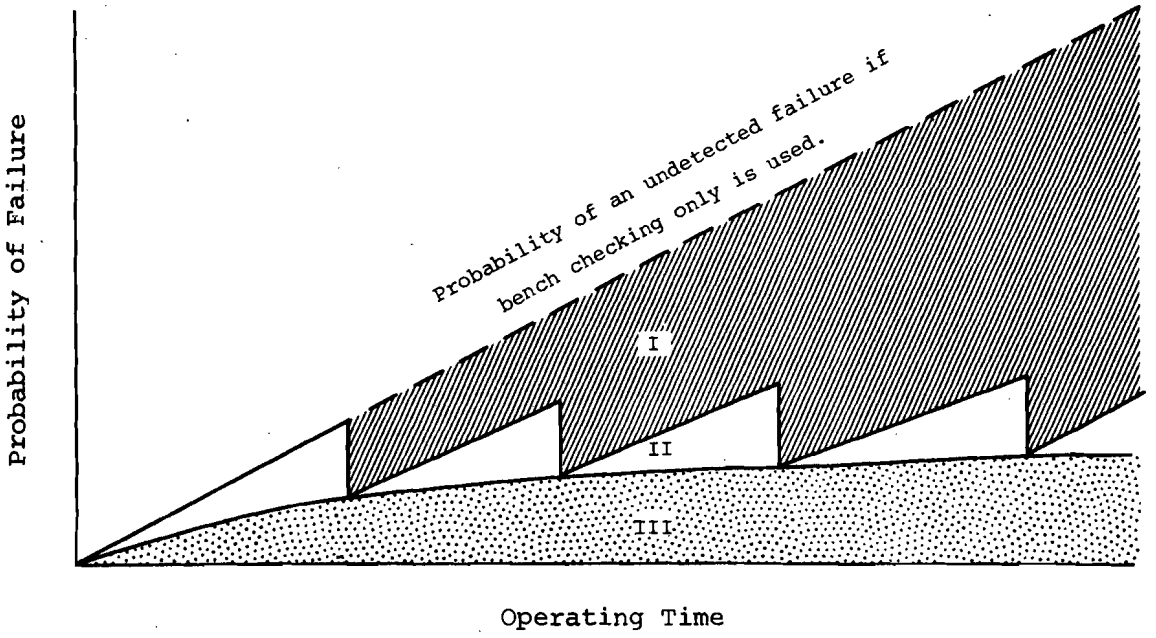


Figure 7-1. PROBABILITY OF AN UNDETECTED FAILURE USING PRE-TAKEOFF CONFIDENCE TESTING AND PERIODIC BENCH CHECK

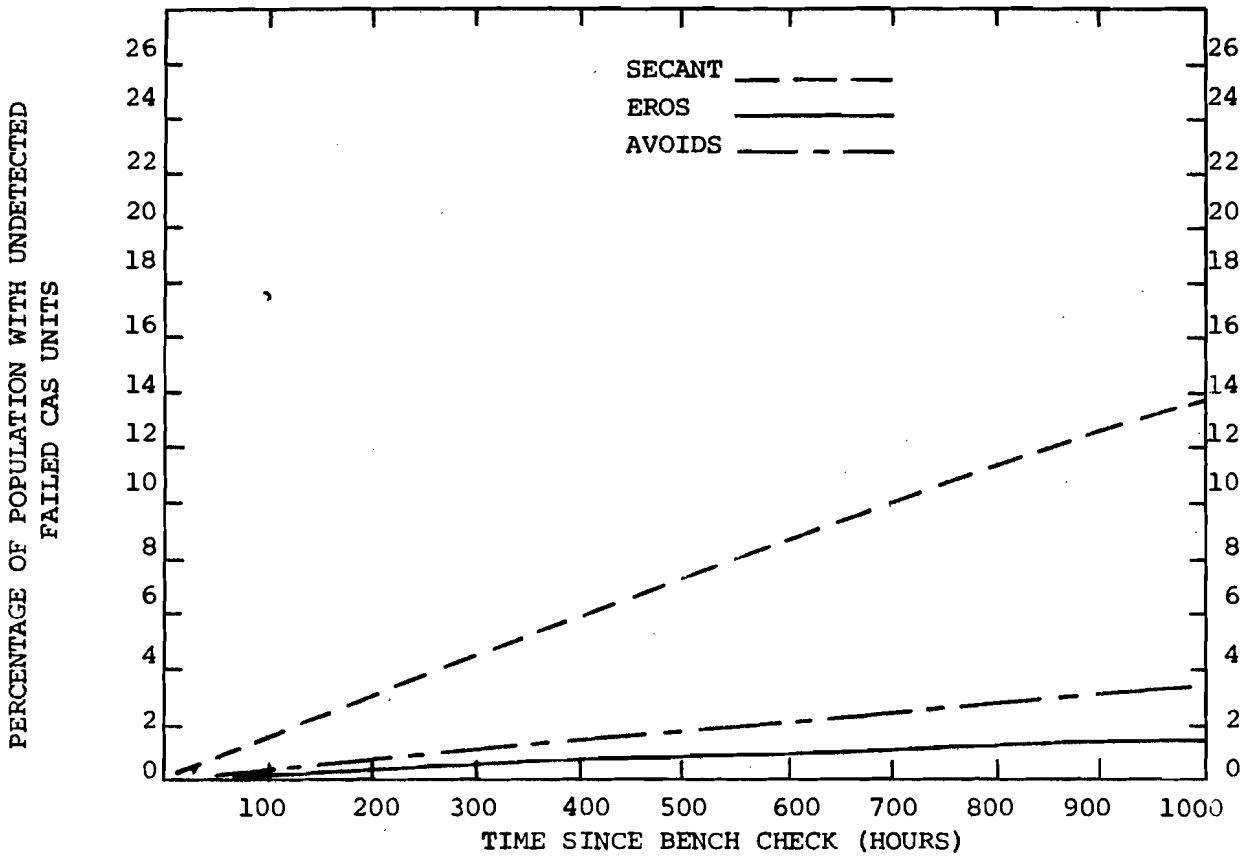


Figure 7-2. PERCENTAGE OF UNDETECTED CAS FAILURES AS A FUNCTION OF THE BENCH CHECKING INTERVAL.

7.5.2 McDonnell Douglas Operability Analysis

The McDonnell Douglas CAS concept employs continuous BIT monitoring of the majority of the system components in the Type II CAS and all of the components in the Type I CAS. Therefore, there will only be undetected failures associated with the Type II CAS units. By using Equation 7-3 and the population of Type II units, the undetected-failure rate for the McDonnell Douglas concept based on the design data supplied by McDonnell Douglas becomes:

$$E\ (F_{LA_M}) = 696 P_{f_{GA}}\ (t_c) \qquad (7\text{-}7)$$

Where: $E\ (F_{LA_M})$ = expected number of undetected failures in the L.A. Basin for the McDonnell Douglas system with a bench check interval of t_c

$P_{f_{GA}}\ (t_c)$ = Equation 7-3 with $\lambda_t = 35/10^6$ hours.

These results are also shown on Figure 7-2.

7.5.3 RCA Operability Analysis

The RCA CAS concept does not employ either BIT or confidence testing. Although either of these features could be added, their addition would result in a more costly system than the one proposed and evaluated in Chapter Five. Therefore, it has been assumed that the RCA system can only provide a continuous monitoring of the power supplies (as presently proposed by RCA). From Equation 7-3, the resulting undetected-failure rate for the RCA concept is:

$$E\ (F_{LA_R}) = 696\ P_{f_{GA}}\ (t_c) + 101 P_{f_{CA}}\ (t_c) \qquad (7\text{-}8)$$

Where: $E\ (F_{LA_R})$ = expected number of undetected failures in the L.A. Basin for the RCA system with a bench check interval of t_c

$P_{f_{GA}}\ (t_c)$ = Equation 7-3 with λ_t = $290/10^6$ hours

$P_{f_{CA}}\ (t_c)$ = Equation 7-3 with λ_t = $384/10^6$ hours

These results are also shown on Figure 7-2 as a function of the time between bench checks.

7.5.4 Comparison of CAS Operability Analyses

Examination of Figure 7-2 shows that the McDonnell Douglas CAS concept as proposed with its extensive level of built-in testing exhibits a clear advantage over the other CAS candidates. For the McDonnell Douglas concept, a requirement for bench checks once every 100 hours would result in less than one-half of one percent of the airborne population having undetected failures. On the other extreme, more than one and one-half percent of the aircraft would have undetected failed CAS units if the RCA concept is employed with a 100 hour requirement for periodic bench checks.

7.6 OVERALL CAS OPERABILITY

Evaluation of the operability of the candidate systems has produced the following observations:

- Ability to accomplish the CAS Separation Mission - Each concept has been flight tested and found capable of accomplishing the CAS Mission.

- Overall Reliability - There is little difference in the inherent reliability of the systems in the mix ratio used in the model. None of the three systems exhibit system-wide failure modes.

- ATC Workload - The ATC system can accommodate the burden of providing separation services to any one of the three candidate systems when failures are detected since all three systems exhibit only single unit failure modes.

- Combination of System Checks - The inability of BIT or confidence tests to check all portions of the systems and the general inconvenience of excessive periodic bench checks indicate that a combination of techniques to detect system failures should be used.

- Undetected Failures - There is a significant difference in the probability of an undetected failure between the systems. Based on the designs proposed for the cost analysis, the McDonnell Douglas system exhibits the lowest probability of undetected failure.

No attempt has been made to determine the preferred time interval for requiring bench checks of the CAS units. However, Figure 7-2 can be used to indicate the percentage of undetected failures that would result from various time intervals. It is recommended that a separate study be performed to determine the allowable percentage of CAS units with undetected failures that can be tolerated from an overall safety of flight point-of-view. Using this percentage and Figure 7-2, it would be possible to determine the best time interval for periodic bench checks on the basis of operational impact of CAS on flight safety.

CHAPTER EIGHT

THE COST OF ALTITUDE ENCODERS FOR THE GENERAL-AVIATION COMMUNITY

The preceding chapters of this study were concerned with the development of system acquisition costs and implementation costs of each of the three CAS concepts based on system designs provided by the CAS manufacturers. However, modified CAS units with built-in altitude encoding have been suggested as a possible refinement to the designs proposed by the three CAS manufacturers. This Chapter examines these potential modifications to the original CAS designs.

The satisfactory operation of each CAS concept requires accurate altitude information as provided by encoding altimeters, and the CAS manufactures designs assumed that there would be a separate encoding altimeter installed on all aircraft to support other avionics functions (e.g., altitude reporting from the transponders). All commercial air carriers and the majority of the military aircraft have this information available from the various encoding altimeters installed in the aircraft. The small portion of the military which does not presently have encoding altimeters has an active program for equipment implementation. The general-aviation community, however, has only a small percentage of its aircraft equipped with encoding altimeters. Therefore, a modified CAS with built-in altitude encoding has been suggested for these aircraft, and this chapter develops the costs associated with this modified equipment. Revised cost of ownership and life-cycle costs for the total general-aviation community are presented to reflect the use of the modified CAS units by a portion of the general-aviation fleet.

8.1 ALTITUDE ENCODING

All aircraft are equipped with altitude indicating devices which operate from barometric pressure or electronic pulse information. This information is displayed to the pilot by a mechanical indicator and provides the required readout for a safe flight. In 1960 the FAA started a program which was to lead to the present automatic altitude reporting using the ATCRBS system. In order to provide this automatic reporting, the altitude information in each aircraft had to be converted into digital data for transmission by the ATCRBS transponders. This was accomplished by the addition of an altitude encoder device. An altitude-reporting transponder system is now required to operate in portions of the airspace, but since the general-aviation pilot has no requirement to enter these areas he has not equipped his aircraft with an encoding altimeter.

Recently the general-aviation manufacturers have developed inexpensive blind encoders which provide the existing pressure altimeter systems with the necessary digital code for use in automatic altitude-reporting transponders (or any other avionic systems). The encoders are advertised at list prices under $600 and are available from several leading manufacturers. This report evaluates the economic benefits of two of the available designs, a Honeywell-proposed encoder and the NARCO AR-500 Altitude Reporter. Both would provide the "GREY" code required by CAS and other avionics, and could be incorporated directly into any of the CAS electronics.

8.2 THE HONEYWELL BLIND ENCODER

The Honeywell Corporation, the developer of the AVOIDS CAS concept, has proposed a blind encoder which could be incorporated into the production version of the AVOIDS-II system. The encoder system utilizes a single-crystal silicon sensing element, which measures absolute pressure relative to a vacuum, and attendant calibration circuitry, which was first developed for use on the DC-10 air data computer and more recently used for the barometric altitude rate computer for the ground proximity warning system (GPWS). The addition of the encoder to the AVOIDS-II system would provide the necessary altitude information for the proper operation of the CAS.

Figure 8-1 is a block diagram of the Honeywell altitude encoder evaluated in this chapter. The concept is adaptable to all three proposed CAS systems, taking advantage of existing timing systems, power supplies, and packaging. However, the AVOIDS-II system already uses a micro-processor and has the associated peripheral electronics as a part of the basic CAS; therefore, it does not require the duplication of that portion of the encoding system. The EROS and SECANT systems on the other hand, will require the addition of all the functions shown except the oscillator and timing subsystems.

8.3 HONEYWELL ENCODER COST DEVELOPMENT

The proposed Honeywell encoder uses standard, commercially available components with the exception of the sensor and one LSI. Table 8-1 identifies the components required to assemble the encoder and the expected costs of components based on large quantity purchasing for each of the three CAS concepts. The sensor and LSI cost estimates were obtained from Honeywell, and the remaining estimates are based on standard electronic components. The components required to modify the AVOIDS-II to provide built-in altitude encoding cost $75.42, while the components required to modify the other two CAS concepts cost a total of $135.42.

The manufacturing and assembly times required for each encoder module are shown in Appendix C for both versions of the encoder. The total time required is estimated at 1.45 hours per encoder suitable for the AVOIDS-II system and 1.55 hours for the EROS and SECANT encoder systems. An additional 1.91 hours are required for sensor testing, read-only-memory (ROM) programming, and system calibration. The additional testing is necessary to determine sixteen unique constants for each sensor element that are used by

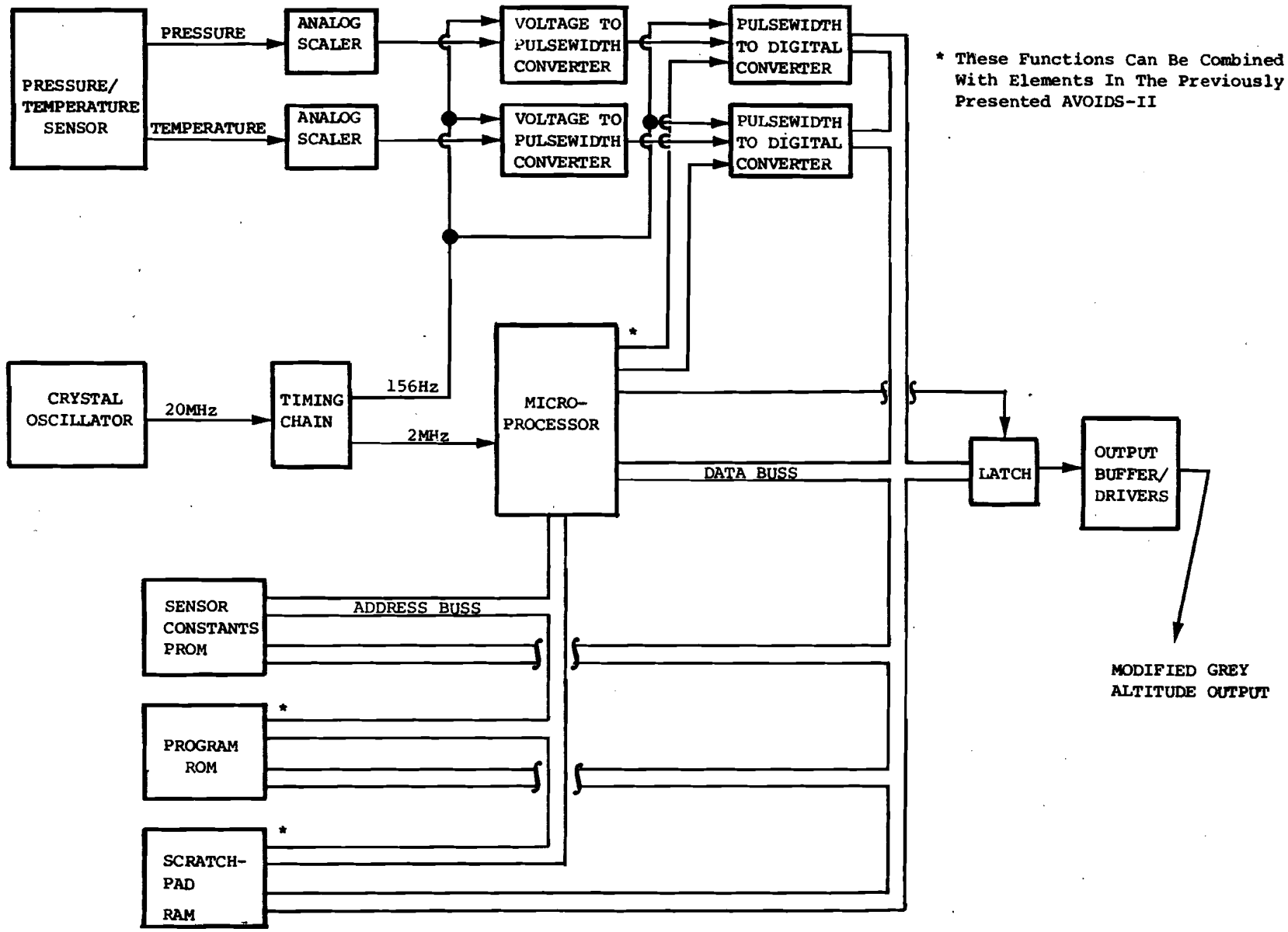


Figure 8-1. HONEYWELL ALTITUDE ENCODER BLOCK DIAGRAM

TABLE 8-1. HONEYWELL ENCODER PARTS BREAKDOWN

PARTS	ENCODER MODULE	
	QTY	COST
SENSOR	1	5.00
LSI	1	13.00
IC	9	35.75
TRANSISTORS	8	6.40
DIODES	8	1.04
RESISTORS	39	1.61
CAPACITORS	6	1.02
POTENTIOMETER	1	3.65
PRINTED CIRCUITS	1	5.00
MISC. ELECTRICAL	1	1.00
MISC. HARDWARE	Lot	1.95
SUB-TOTALS	75.42	
ADDITIONAL COMPONENTS REQUIRED FOR EROS AND SECANT		
MICROPROCESSOR	1	10.00
ROM	2	20.00
RAM	2	20.00
PERIPHERAL	1	10.00
TOTALS	135.42	

the micro-processor to produce the desired calibration. These constants must be determined for each sensor and stored in a programmable ROM. The testing and programming equipment which would be required by each manufacturer has been estimated at $60,000 and amortized over production quantities during the first two years resulting in an increase in module costs of $7.50 per encoder. The expected cost of the Honeywell encoder module for the AVOIDS-II system should be:

Material Cost	$75.42
Less Altitude Decoder LSI (Removed from Basic AVOIDS-II)	(6.50)
Total Material Cost	$68.92
Labor: 3.36 hours @ $2.75/hour	9.24
Direct Cost	$78.16
Manufacturers Burden Overhead and Profit at 67%	$ 52.36
Special Equipment Amortization	7.50
Factory Selling Price	$138.02
List Price	276.04

The expected cost of the Honeywell encoder module when incorporated in the EROS and SECANT CAS equipments should be:

Material Cost	$135.42
Labor: 3.46 hours 2 $2.75/hour	9.50
Direct Cost	$144.92
Manufacturers Burden, Overhead and Profit @ 67%	97.10
Special Equipment Amortization	7.50
Factory Selling Price	$249.52
List Price	499.04

8.4 NARCO BLIND ENCODER

NARCO Avionics has developed an "Altitude Reporter", the NARCO AR-500, which converts the barometric pressure used by the aircraft altimeter to the "GREY" code required by transponders through the use of a sealed aneroid capsule which operates a transducer. The transducer information is converted into the correct altitude code electronically.

ARINC Research has reviewed the published data on the AR-500 and has evaluated the use of the pressure sensor and electronics in the three CAS designs under the assumption that the general-aviation manufacturers would attempt to develop a single-package CAS containing the necessary avionics. Price-competitive blind encoders of other manufacturers would be similarly applicable to the CAS concepts.

8.5 NARCO ENCODER COST DEVELOPMENT

The NARCO encoder uses standard, commercially available components. Table 8-2 identifies the components required to assemble the encoder module and the expected costs of components based on large quantity purchasing common to most avionics manufacturers. Again, it is assumed that the encoder module could be incorporated into each of the three proposed CAS concepts, thereby utilizing the available power supplies and timing systems inherent in each CAS concept.

The manufacturing and assembly times required for each encoder module are shown in Appendix C. The total time required is estimated at 4.45 hours per encoder module, with an additional 1.0 hours for calibration and testing. The expected cost of the encoder module for any of the CAS concepts should be:

Material Cost	73.39
Labor: 5.45 hours @ $2.75/hour	14.99
Direct Cost	88.38
Manufacturer's Burden, Overhead and Profit @ 67%	59.21
Factory Selling Price	147.59
List Price	295.18

TABLE 8-2. NARCO ENCODER PARTS BREAKDOWN

PARTS	ENCODER MODULE	
	QTY	COST
SENSOR	1	35.00
IC	15	9.03
TRANSISTORS	13	4.09
DIODES	1	.37
RESISTORS	48	5.69
CAPACITORS	11	1.45
POTENTIOMETERS	5	4.75
PRINTED CIRCUITS	1	5.00
MISC. ELECTRICAL	3	1.56
MISC. HARDWARE	Lot	6.45
TOTALS		73.39

This list price reflects the cost of a module without a power supply, timing systems, and aircraft packaging(all of which are already available in the CAS electronics),and the cost also reflects large production quantities expected for CAS. Therefore the list price is considerably lower than the presently advertised AR-500 "Altitude Reporter".

8.6 APPLICATION OF ENCODERS TO THE CAS CONCEPTS

The expected costs of encoder modules developed in this chapter show that the most economical approach to providing altitude information to the CAS systems is by incorporating the encoders into the CAS electronics. The encoder based on the NARCO design is the least expensive alternative for two of the three concepts and is recommended for the EROS and SECANT systems. The AVOIDS system, however, should incorporate the Honeywell-developed encoder because of the availability of the micro-processor in the AVOIDS and the ability to achieve a more compact design at a slightly lower cost. The addition of the encoder to any of the CAS concepts should be possible without an increase in case size and only a nominal increase in weight. Table 8-3 presents the expected selling price of each of the CAS concepts with built-in altitude encoders, based on the independently developed CAS costs. The prices shown include the expected distribution costs as developed in Chapter Four.

TABLE 8-3. PER AIRCRAFT COST OF EQUIPMENT INCLUDING ALTITUDE ENCODERS FROM INDEPENDENTLY DEVELOPED DATA (GENERAL AVIATION-LOW PERFORMANCE)

EQUIPMENT	TYPE II CAS WITH ALTITUDE ENCODERS		
	AVOIDS	EROS	SECANT
ELECTRONIC*	1124.	1820	2073
ANTENNA**	26	13	13
TOTAL	1150.	1833	2086

*Costs Shown Include Mark-Up For Distribution

**One Antenna For EROS and SECANT, Two Antennas For AVOIDS

8.7 ENCODER RELIABILITY AND MAINTAINABILITY

The reliability of the encoder modules was evaluated using similar techniques to those presented in Chapter Three. Failure rate data of common components were dervied from FARADA and the curves and data tables of MIL-217A. The predicted reliability of the sensors was based on information provided by Honeywell on their reliability prediction for the Barometric Altitude Rate Computer System. The Honeywell data show that a commercial-grade solid-state pressure sensor has an expected failure rate of 16 failures per million hours of operation. The reliability of the aneroid capsule and transducer, "the sensor" used in the NARCO encoder, was assumed to be the same as for the Honeywell solid state sensor. These data were used with the FARADA data to establish the encoder reliability and are documented in Appendix C to this study. The predicted reliability for the encoder module to be used with AVOID-II is estimated at 12000 hours and the encoder reliability for the EROS and SECANT systems is estimated at 19461 hours.

Maintainability of either the Honeywell-designed or the NARCO-designed encoder module has been estimated at two hours per repair action. The estimate was based on the probability of failure of the sensor, the highest failure rate item in the module, and the test and calibration time required when the sensor is replaced.

8.8 COST OF OWNERSHIP AND LIFE-CYCLE COSTS

The cost, reliability, and maintainability data developed in this chapter were combined with the independently developed CAS cost and reliability data of Chapter Three and applied to the Economic Analysis Model to determine cost of ownership and life-cycle costs in the general-aviation community. The introduction of the encoder does not affect the life-cycle costs of the commercial aviation, the military, or the high performance general-aviation aircraft, since all are assurred to have encoding altimeters. The CAS installation data developed in Chapter Four should also apply to the CAS units with altitude encoding. The CAS with built-in altitude encoding will require a static pressure line connection in lieu of an electrical connection to a separate encoding altimeter. It is assumed that the costs of these two types of installation are identical.

Table 8-4 presents the cost of ownership and the anticipated life-cycle costs for the general aviation limited performance aircraft for each CAS concept with the required altitude encoding, based on independently developed data. The costs are shown in 1975 dollars, for equipment installed in 1978. The acquisition costs are the average costs developed by NARCO and GENAVE with the addition of the altitude encoding as developed in this chapter. Consistent with Chapter Four, the distribution costs represent a 60 percent mark-up. The first year of ownership shows the expected cost for implementation and maintenance for the private aircraft owner, and the life-cycle cost identifies the expected cost of the system installed and operated for eleven years.

GENERAL AVIATION (LIMITED PERFORAMNCE) COST DATA COMPARISON INCLUDING ALTITUDE ENCODING -(PER AIRCRAFT) (ZERO PERCENT INFLATION RATE)

TABLE 8-4.

SYSTEM / COSTS	INDEPENDENTLY DEVELOPED SYSTEM COST DATA		
	HONEYWELL AVOIDS	MDEC EROS	RCA SECANT
ACQUISITION	729.	1151.	1309.
INSTALLATION	226.	226.	226.
DISTRIBUTION	422.	683.	777
RECURRING LOGISTICS	23.	39.	32.
1st YEAR OF OWNERSHIP	1400.	2099.	2344.
LIFE-CYCLE COST	1632.	2489.	2665.

Figures 8-2 through 8-4 present the life-cycle costs to the entire general-aviation community for implementing each of the CAS concepts when altitude encoding is provided. Of the total general-aviation fleet, all of the high performance aircraft (5% percent) are assumed to have encoding altimeters and ten percent of the low performance aircraft are assumed to have either altitude encoders or encoding altimeters. The remaining 85 percent of the population will require the CAS equipment with built-in altitude encoders. The cumulative CAS cost figures reflect this division of capability and present the life-cycle costs at the three annual inflation rates used in the study. The results based on independently developed data, show that the addition of altitude encoding capability to the CAS concept will result in an increase of 46 million dollars in life-cycle costs to the AVOIDS concept and 48 million dollars to the EROS and SECANT concepts, at a zero percent inflation rate. The variation in cost increase between the AVOIDS and the other CAS concepts is caused by the slightly lower acquisition cost of the altitude encoder used in the AVOIDS concept.

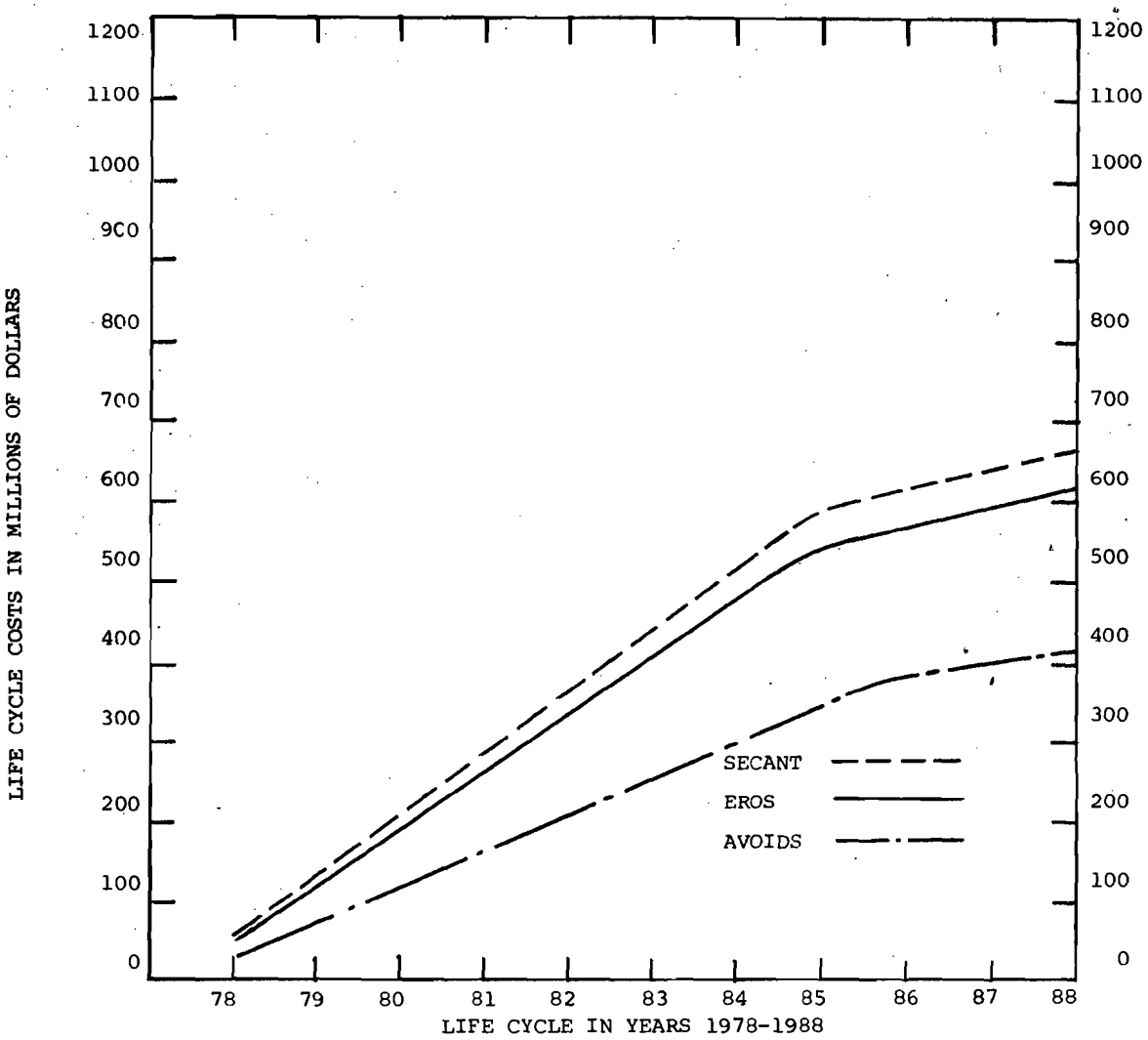


Figure 8-2. CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA, INCLUDING ALTITUDE ENCODERS (GENERAL AVIATION) (ZERO PERCENT INFLATION RATE)

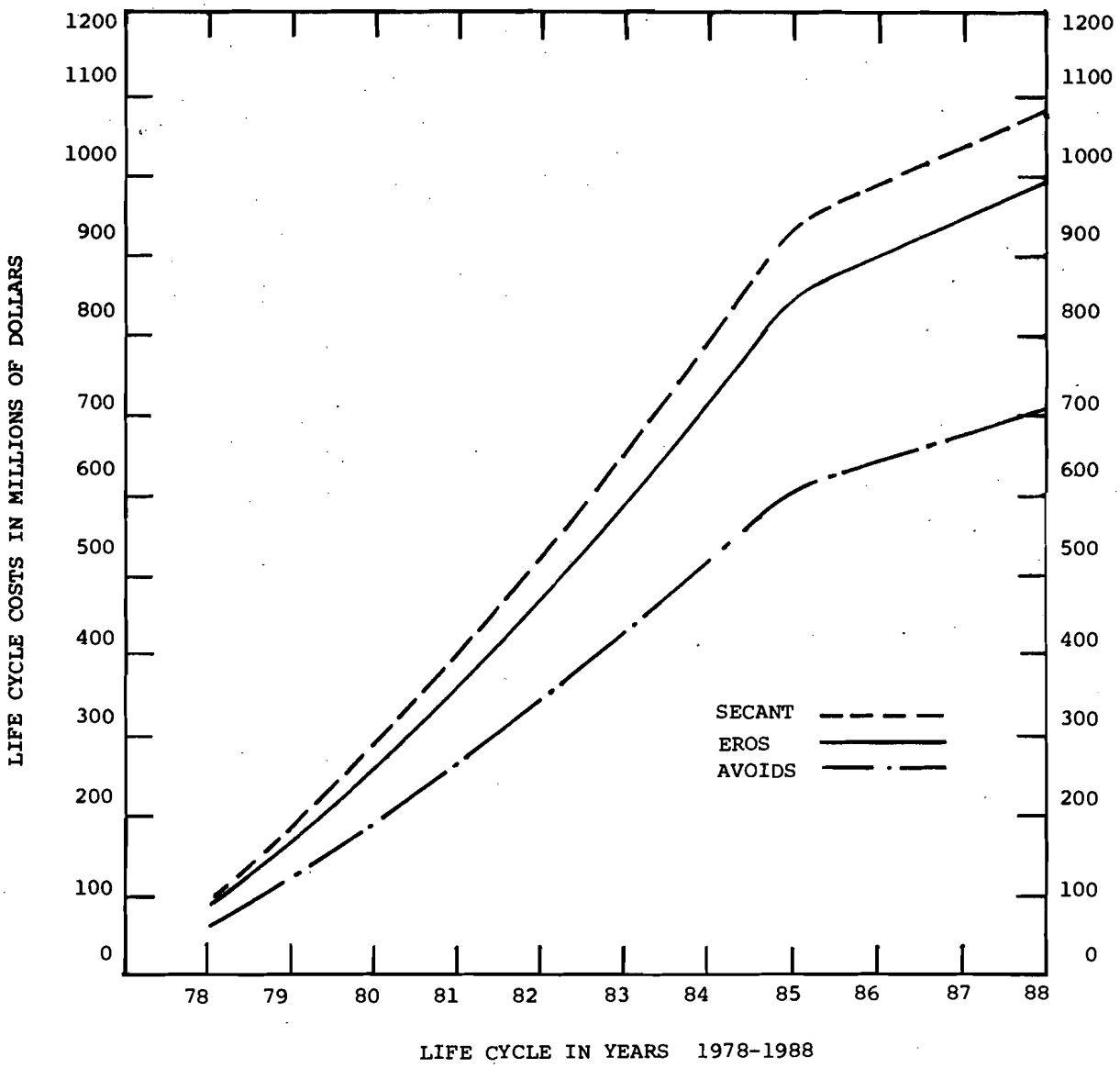


Figure 8-3 CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA, INCLUDING ALTITUDE ENCODERS (GENERAL AVIATION) (SIX PERCENT INFLATION RATE)

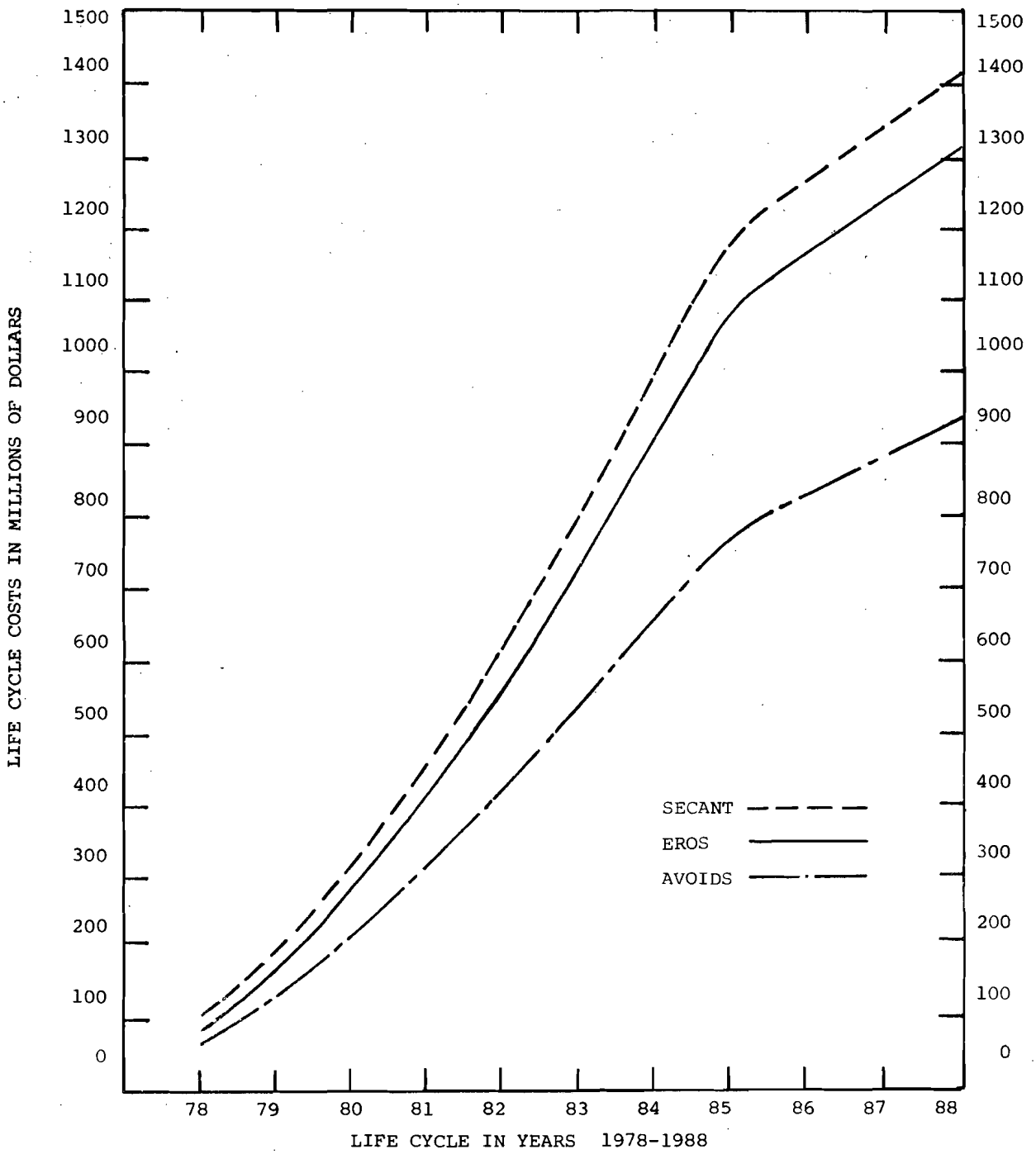


Figure 8-4 CUMULATIVE CAS COST FROM INDEPENDENTLY DEVELOPED DATA, INCLUDING ALTITUDE ENDODERS (GENERAL AVIATION) (TEN PERCENT INFLATION RATE)

CHAPTER NINE

RESULTS AND CONCLUSIONS OF CAS COST AND OPERABILITY ANALYSES

The cost analyses of the Honeywell, McDonnell Douglas, and RCA CAS concepts have shown that the Honeywell CAS concept exhibits the lowest overall costs. The cost advantage enjoyed by the Honeywell CAS equipments is the direct result of the lower acquisition costs for the Honeywell equipments.

The operability analysis of the Honeywell, McDonnell Douglas, and RCA proposed designs has shown that the McDonnell Douglas CAS exhibits an operational advantage due to the extensive use of built-in testing in the proposed McDonnell Douglas designs.

9.1 REVIEW OF THE CAS COST ANALYSES

The primary results of the CAS cost analyses are summarized in Table 9-1. The results are presented both on an individual aircraft basis and for the entire user communities. The individual aircraft costs are likely to be the most important costs to general aviation, while the total user community life-cycle costs will be most important to the commercial and military aviation interests concerned with the overall costs of implementing CAS. Life-cycle costs developed for each user category are also presented at an annual inflation rate of six and ten percent to identify the probable and maximum anticipated expenditures in the introduction of CAS. Based on either the manufacturer-supplied data or the independently developed data, the Honeywell system exhibits the lowest overall costs.

A key element in the CAS cost analyses reported herein has been the cost and reliability data developed by the three competing CAS manufacturers. The manufacturers were asked to develop cost and reliability data based on production versions of their CAS concepts under the assumption that production is to begin in 1978. The manufacturers responded to this request and provided data on both the commercial-aviation and the general-aviation versions of their proposed production systems. The thoroughness of the data provided by the manufacturers is sufficient to place a high degree of confidence in the relative economic evaluations of the three concepts based on these data.

Table 9-1. SUMMARY OF CAS COST ANALYSIS (INDEPENDENTLY DEVELOPED DATA)

COST CATEGORY	COMMERCIAL AVIATION			MILITARY AVIATION			GENERAL AVIATION			
	AVOIDS	EROS	SECANT	AVOIDS	EROS	SECANT	AVOIDS	EROS	SECANT	SECANT WITH REMITTER
Cost of Acquiring and Installing CAS in a Single Aircraft. (ZERO Percent Inflation)	$ 10553 (10549)	$ 11220 (11231)	$ 11805 (12165)	$ 14578 (14574)	$ 15245 (15256)	$ 15830 (16189)	$ 1198 (1156) 1377	$ 2183 (1823) 2060	$ 2799 (2076) 2312	$ 1527
Anticipated 11-Year Life Cycle Cost for a Single Aircraft. (ZERO Percent Inflation)	14633 (14382)	14797 (14730)	15278 (16286)	18776 (18374)	19017 (19007)	19433 (20064)	1267 (1407) 1632	2246 (2253) 2489	2879 (2425) 2665	1582
Total Life Cycle Cost for the Entire User Community (ZERO Percent Inflation Rate)	48.6M (46.9M)	49.6M (48.3M)	51.4M (53.5M)	215.3M (219.8M)	227.9M (237.2M)	236.9M (247.8M)	395.7M (411.9M) 464.1M	627.8M (602.2M) 650.6M	779.1M (658.8M) 708.1M	575.7M
Total Life Cycle Cost for the Entire User Community (Six Percent Inflation Rate	68.5M (67.5M)	69.2M (68.8M)	71.6M (76.3M)	316.9M (316.1M)	334.7 (338.5M)	347.8M (357.4M)	609.7M (598.2M) 709.7M	962.4M (873.9M) 993.1M	1192.2M (975.9M) 1081.9M	Not Evaluated
Total Life Cycle Cost for the Entire User Community (Ten Percent Inflation Rate)	84.1M (82.6M)	84.2M (83.8M)	87.5M (93.4M)	385.7M (395.4M)	407.9M (429.0M)	425.3M (438.5M)	792.4M (829.4M) 934.2M	1257.9M (1218.4M) 1316.0M	1563.6M (1280.9M) 1420.5M	Not Evaluated

Notes
1. The values in parenthesis represent the costs based on independent evaluations of the CAS designs
2. The individual aircraft data for the military apply to high performance aircraft which is the major category of military aircraft. The user community life cycle costs include the combination of high and low performance aircraft.
3. The individual aircraft data for general-aviation apply to the low performance aircraft which is the major category of general aviation. The user community life-cycle costs include the combination of high and low performance aircraft.
4. Life cycle costs for the users of EROS systems do not include the cost of the five mandatory ground stations, required for system synchronization.
5. Underlined values represent the costs of CAS including altitude encoders based on independently developed data.

In addition to the cost and reliability data provided by the manufacturers, independent cost and reliability analyses were conducted to provide an additional basis for identifying the most economical CAS concept. The independent analysis of the commercial-aviation CAS equipments consisted of an independent verification of the CAS equipment cost and reliability data based on the equipment designs provided by the manufacturers. The independent analysis of the general-aviation equipments, however, included the consideration of potential redesigns of the systems to obtain the lowest possible system costs. The general agreement between the manufacturers' data and the independently developed data provides strong substantiation of the costs provided in Table 9-1.

Numerous additional data inputs (e.g., installation costs, distribution costs, aircraft scenarios, etc.) were developed to permit a realistic total cost of CAS implementation to be determined. Although these factors are not critical to the comparative cost analysis of the three CAS concepts, accurate total cost projections will be needed to determine if implementation of any of the three CAS concepts can be cost-justified.

9.2 DISCUSSION OF THE SENSITIVITY ANALYSES

Major variations in the reliability data and alternative assumptions for the implementation of CAS were considered to determine if there were any conditions that would cause a change in the relative economic ranking of the three CAS concepts. The areas investigated were system reliabilities, military mix of Type I and Type II CAS, amortization costs, impact of the remitter, and redundant electronics in commercial-carrier aircraft. The results of each sensitivity analysis are discussed below and their effect on the relative evaluation identified.

- Variations in system MTBFs - A significant error (e.g., 50 percent) in the predicted MTBF of any of the systems would result in a change in the relative economic ranking of the system in the commercial carrier category. However, because of the reduced average flight hours for the other two communities, a comparable error in the predicted MTBF would have no effect on the relative economic ranking when the entire aviation community is considered.

- Military mix of Type I and Type II CAS - Although a choice by the military to use only the Type II CAS would result in a very competitive life-cycle cost of any of the systems, the results still show that the Honeywell CAS exhibits the lowest life-cycle investment. If the military were to choose the Type I CAS for all aircraft, the life-cycle cost advantage to Honeywell would be greater for this community than it is for the assumed mix used in the study.

- Amortization of start-up costs - The effect of including amortization costs is evident in the commercial-carrier community by narrowing the total cost difference between the EROS and SECANT systems. However, when the entire aviation community is considered, the effect in relative ranking of the systems is negligible, increasing each system's total costs by the amounts amortized.

- Impact of the remitter - When the remitter (a device that protects CAS-equipped aircraft from remitter-equipped aircraft but provides no protection to remitter-equipped aircraft) was considered, there was a change in the relative ranking of the three CAS concepts. The remitter concept has been proposed by RCA alone and, as a result, the remitter evaluation produced substantially lower costs for the RCA concept when compared with the cost originally developed for the RCA systems. The net effect of the remitter-cost evaluation was that the RCA concept exhibited lower costs than the McDonnell Douglas CAS concept, but the RCA costs were still higher than those projected for the Honeywell CAS concept.

- Redundant electronics in commercial-carrier aircraft - The addition of a second set of electronics at time of CAS implementation in the commercial-carrier community will increase the cumulative life-cycle costs in proportion to the acquisition cost of the second system and provide the air carriers the desired operational availability common in this community, but the effect on the competitive evaluation of the CAS concepts will remain unchanged, with the Honeywell concept exhibiting the lowest life-cycle costs.

The results of the sensitivity analysis show that for any reasonable variation in the assumptions made in this study, there is no change in the relative ranking of the three CAS concepts.

9.3 DISCUSSION OF THE OPERABILITY ANALYSES

The operational consequences of CAS can be directly related to the interaction of CAS failures with the ATC system. The basic reliability data for the three CAS concepts indicate only small differences in the number of failures that could be expected with each CAS candidate. However, there are major differences among the three candidate systems in their ability to indicate system failures to the pilot so precautions (e.g., providing notification to ATC and having the CAS repaired prior to the next flight) can be taken to minimize the hazards associated with the operation of failed systems. The built-in test features incorporated in the McDonnell Douglas design give it a clear advantage in the ability to detect system failures as soon as they occur. The Honeywell design employs pre-takeoff confidence tests that would generally prevent a flight from being initiated with a CAS unit that is inoperative but would not help to detect failures that occur during a flight. The RCA design, as proposed by RCA, does not include any special system test features.

Although these system test features could be added to the RCA design, they would most likely result in the RCA systems becoming slightly more expensive.

9.4 DISCUSSION OF THE ALTITUDE ENCODERS FOR GENERAL-AVIATION

The availability of altitude encoding equipment has been investigated and cost-effective alternatives developed. Although blind encoders are presently available at prices acceptable to the general-aviation community, a more cost effective solution would be to design the altitude encoding capability into the Type II CAS concept. Of the two types of encoder concepts evaluated, the adaptation of the NARCO developed system offers the lowest cost alternative for EROS and SECANT CAS, although the Honeywell concept is the most economical for the AVOIDS CAS. The slight variation in costs of the two concepts allows adaptation of either concept for the AVOIDS CAS. However, the Honeywell concept provides the benefits of a properly integrated system which would result from the merging of the AVOIDS CAS with the Honeywell altitude encoder.

9.5 RELATION OF THE CAS COST AND OPERABILITY ANALYSES TO THE DEVELOPMENT OF A NATIONAL CAS STANDARD

The present study has been concerned with the comparative economic and operational evaluations of the Honeywell, McDonnell Douglas, and RCA CAS concepts. It has not addressed other key issues that will most likely affect the development of a national CAS standard. For example, critical performance parameters such as false-alarm rates and missed-alarm rates for each of the systems have not been considered. It is felt that in any overall CAS decision, these performance factors must be given the same careful consideration as the economic data reported herein.

In addition, the analyses and conclusions reported herein have been based on the assumption that all aircraft will be required to install and operate CAS equipments. However, if there is a significant change from this policy whereby only a portion of the total aviation community will have to be CAS equipped, then the cost advantage attributed to the Honeywell CAS concept virtually disappears. For example, if only commercial air carrier aircraft are required to install CAS equipments, then the life cycle costs predicted for the AVOIDS, EROS, and SECANT systems are sufficiently close so as to make the projected cost differences relatively unimportant.

While there are many factors such as the above that must be considered by the FAA, it is felt that the cost and operability analyses of the three CAS concepts will nevertheless remain key elements in the ultimate selection of a national CAS standard.

APPENDIX A

UNIFORM GROUND RULES

REVISION 1

RECOMMENDED UNIFORM GROUND RULES FOR THE EVALUATION OF LIFE CYCLE COSTS, SYSTEMS OPERABILITY AND RELIABILITY OF ALTERNATIVE COLLISION AVOIDANCE SYSTEMS

Prepared for

Federal Aviation Administration

Office of Systems Engineering Management

AEM-200

under Contract DOT-FA74WA-3506

24 JULY 1974
Revised 9 August 1974

Prepared by

The Telecommunications Program

of

ARINC Research Corporation

A Subsidiary of Aeronautical Radio Incorporated

2551 Riva Road

Annapolis, Maryland 21401

The contents of this report reflect the views of ARINC Research Corporation and do not necessarily reflect the official views or policy of the Federal Aviation Administration.

STUDY OF LIFE CYCLE COSTS OF AIRBORNE CAS

A critical factor in the selection of an airborne Collision Avoidance System (CAS) is the costs of the systems, which must be borne by the government and the aviation community. The purpose of this study is to make that factor available by determining the potential costs of each of the competing CAS concepts.

The study will be conducted in three phases, each of approximately three months duration. In the first phase, a set of ground rules acceptable to the concerned parties will be drawn up, the primary effort of data collection from the developers of each of the competing concepts will be accomplished and the life cycle cost model will be exercised to obtain a preliminary analysis of life cycle costs. In the second phase data voids will be identified and filled, supplementary data will be obtained from additional sources and life cycle costs will be analyzed in detail. Since failure rates and failure modes data will be obtained in conducting the cost analysis, the third phase will be an operability analysis of each of the concepts to identify and evaluate equipment failures that can extend beyond the failed unit by causing improper operation or degraded protection in other units, and to identify the requirements for periodic recertification and for pre-flight checks to assure system integrity.

In order to accomplish the study fairly, without favoring or penalizing any of the competitors, it will be necessary to have a set of ground rules for the conduct of the study. The ground rules are predicated on there being multiple manufacturers, producing compatible but not necessarily identical designs, using a common level of technology, and experiencing a level of reliability that is a function of the technology used and the design complexity imposed by the system concept. Certain other assumptions are made as shown by the attached list of ground rules.

1. GROUND RULES FOR THE CAS LIFE CYCLE COST STUDY

1.1 Classes of Equipments

The classes of equipments to be studied will be limited to a CAS, i.e., one that follows ANTC 117 vertical threat logic, intended for commercial air carriers and other high performance aircraft and a limited capability CAS intended for general aviation aircraft. This is in keeping with the conclusions that in certain encounters involving high performance aircraft, the beacon and PWI versions of a CAS will fail to perform their intended function satisfactorily. However, where a manufacturer feels that a remitter concept is technically feasible, he may submit costing data on the system and it will be evaluated as an addendum to the study.

1.2 Technology Levels of the Production Designs

Due to the size of the market, should CAS be made a national standard, the production quantities will be large enough to make the use of LSI designs the most economical. Therefore it is assumed that the production designs will make maximum use of LSI circuitry, with MSI circuits, ICs and discrete components used where they are most appropriate.

1.3 Quality Level of Components

Present commercial practice in selection of avionics components will be used for both classes of CAS equipments. For military aircraft it is assumed that commercial equipments will be used. For those military aircraft which provide a hostile environment for the equipment, i.e., an unpressurized avionics compartment, an appropriate cost differential will be applied to account for pressurized packaging.

1.4 Quantities Produced Per Manufacturer

It is assumed that there will be multiple manufacturers of each class of equipment and that each manufacturer will produce sufficient quantities to complete the production learning curve (assumed to be 85%) and to amortize start up costs. It is assumed that each manufacturer of full systems will produce at least 3,000 units and each manufacturer of limited systems will produce at least 10,000 units.

1.5 Time Span Under Consideration

The time span considered under the study will be from 1978 as the start of deployment to 1988 as the end of the period for determination of life cycle costs. Full deployment for commercial air carriers is assumed to be approximately four years (1982) and for military aircraft and general aviation aircraft, is assumed to be approximately eight years (1986). These time spans for full deployment were selected as a basis for the study and are not intended as a representation of FAA intent or policy.

1.6 Computation of Equipment Costs to the Users

In addition to the developers of the competing concepts, other potential manufacturers of each class of equipment will be consulted in order to develop estimates of the equipment costs to the users. The estimated costs will include the effects of inflation and learning. The annual rate of inflation will be 6%. Learning curve factors and quantities will be averaged from the values used by the consulted manufacturers. Start up costs will be amortized over the first two years production. The assumed production rates, quantities and number of manufacturers will be consistent with other assumptions stated elsewhere in the ground rules on target dates, rates of deployment and numbers of installations.

1.7 Installation Costs

Aircraft will be categorized as air carrier, military and general aviation and installation costs will be developed for each category for the appropriate type CAS for that category of aircraft. Separate installation costs will be developed for production line installation in new aircraft and for retrofit installation in existing aircraft. Installation cost estimates will be validated by comparing them against installation costs of comparable equipments such as DME and transponders.

1.8 Maintenance

It is assumed that air carriers and the military will apply present maintenance practices to the CAS equipment. The designs of the general aviation equipments will be examined for maintenance requirements to determine the distribution of service facilities that will be likely to add CAS equipment maintenance to their present capabilities. The expansion of the availability of general aviation service facilities will be commensurate with the cumulative installations of the CAS equipments.

1.9 Pre-Flight and In-Flight Performance Checks

In conjunction with the FAA and the developers of the concepts, the need for and a method(s) of accomplishing, pre-flight and in-flight performance checks will be identified. In view of the potential interaction with the ATC system, the FAA can be expected to require an effective method of identifying when an airborne equipment is not operating or is operating improperly.

1.10 Ground or Auxiliary Equipment

The distribution and costs will be estimated for the ground or unique auxiliary equipments required for each system concept for proper operation of the system or for pre-flight and in-flight performance checks.

1.11 Ground Equipment Performance Checks

A method of certifying and/or monitoring proper operation of the ground equipment identified above will be selected and the operating costs will be estimated.

1.12 Operating Scenarios

Descriptions will be developed of typical operations of the various classes of aircraft to obtain estimates of peak and average monthly operating hours and of other factors required for life cycle cost estimating.

1.13 Equipment Description

The airborne equipment that will be the subject of this study consists of the following main components; (1) the principal electronics, i.e., transmitter, receiver, BIT and logic circuitry, (2) pilot's maneuver indicator, (3) control panel and (4) antenna(s), antenna cabling and antenna switch. Any other displays such as for range and altitude of an intruder are considered to be optional. They will be costed separately unless the manufacturer considers them to be an essential part of the system. The purpose here is to maintain comparability between the concepts.

1.14 Numbers of Aircraft

The numbers of aircraft installations involved will be based on FAA information on the number of existing aircraft and projections of increases. A straight line installation rate is assumed for retrofit of aircraft existing in the start year of 1978. Subsequent to the start date all new aircraft are assumed to have CAS equipment installed during manufacture.

2. CAS LIFE CYCLE COST MODEL

2.1 CAS Cost Model Description

A common cost model which is applicable to all three categories of aircraft being considered within the study, i.e., military, commercial and general aviation, is planned for the study. Individual cost elements which may differ among the categories will be handled through specification of the input parameter values. For example, the times required to fill out forms for the maintenance management systems of the military represent a cost producing element which one would not expect to incur in the GA category. Hence, in the GA evaluation, these and other similar input parameters would be zeroed out.

The cost model will compute for each CAS concept in each aircraft category on an annual and cumulative basis beginning with the year 1978 and extending through at least 1988 the following major cost elements: acquisition cost, installation cost, logistic support cost and FAA support cost. These costs will be displayed on a total category fleet basis and on a per aircraft basis. In addition, the logistic support costs will be broken down into eight constituent elements and displayed in terms of their non-recurring, annual recurring and total values. These cost elements are:

- Initial and replacement spares.
- On-aircraft maintenance.
- Off-aircraft maintenance.
- Inventory and supply management.
- Test equipment.
- Training.
- Data management and technical documentation.
- Facilities.

2.2 CAS Cost Model Inputs

Evaluation of the cost model will require specification of numerous data items. Where such data elements are unknown or estimated with uncertainty, the model will be evaluated over the range of possible values of the element in order to ascertain the sensitivity of the projected cost to its value and to identify the expected range of results. For example, in computing the cost of spares, a key element is the expected pipeline

delay. If this quantity is unknown for a given category but is expected to be somewhere between two weeks to two months, then the model would be evaluated over this range. The following discusses some of the principal inputs and assumptions considered within the model.

2.2.1 It is assumed that the number of aircraft in each category is known for each year in the interval 1978 - 1988. The retrofit schedule will be approximated with a straight line between the retrofit initiation and completion dates.

2.2.2 The unit acquisition costs will include on a parameterized basis, the effects of learning and inflation. Similarly, the installation and logistic support costs (where applicable) will include the effects of inflation.

2.2.3 Weighted cost estimates will be used for the initial and retrofit installation costs in each category of aircraft and for each type of CAS.

2.2.4 On-aircraft maintenance is assumed to be limited to remove and replace actions.

2.2.5 Off-aircraft maintenance costs will include labor, material and shipping costs, with the latter corresponding to the expected percentage of the removals where repair cannot be completed at a base location.

2.2.6 For costing purposes, all maintenance actions are treated as failures with the MTBF's being adjusted to MTBR's as discussed in the definitions (paragraph 3.2) and the material costs similarly adjusted to allow for the expected percentage of repair actions having "no trouble found" results.

2.2.7 Test equipment and training costs will be attributed only to those factors directly attributable to the CAS system, i.e. general support equipment costs will not be factored into the cost element.

2.2.8 The number of repair sites for the military and commercial CAS systems is assumed constant over the time interval. However, the number of GA repair sites is assumed to increase with time according to a model input specified distribution to be developed.

2.3 Data Sources

As noted earlier, there are a large number of cost and performance data element inputs to the cost model. Many of these, as also previously discussed, can only be bounded at this time, and their sensitivity determined accordingly. As many as possible of the elements will be initially established through discussions with the three producers and through contact with a limited number of users in each category. These data elements will be refined as applicable as

the study progresses. For example, initial estimates of the MTBF and MTTR of the systems will be obtained from the producers. Then, as better and more complete design information becomes available so that R and M predictions can be made, these estimates will be updated. Similarly, cost estimates will be updated as additional potential producers and users are contacted and initial sensitivity exercises are completed.

3. DEFINITION OF TERMS

3.1 Mean Time Between Failure (MTBF) is the expected operating time between verified failures of the equipment.

3.2 Mean Time Between Removals (MTBR) is the expected operating time between suspected failures of the equipment. It is assumed that MTBR = k MTBF, where k is a factor less than one which is to be established for each category of users during the study.

3.3 Mean Time To Repair (MTTR) is the expected time required to verify a failure, isolate its cause and perform the necessary repair actions.

3.4 Mean Maintenance Man Hours (MMMH) is the expected man hours required to complete a maintenance action. For purposes of the cost model, it is assumed that MMMH = MTTR i.e. a single maintenance man will be performing the repair action. It is also assumed for the purposes of the cost model that the MMMH will be the same for a verified failure as for a "no trouble found" situation. This latter assumption may require reducing the predicted MTTR in accordance with the expected percentage of "no trouble found" occurances.

3.5 Reliability is the probability that an item will perform its intended function for a specified interval under stated conditions.*

3.6 Mean Down Time (MDT) is the expected time during which the item is not in condition to perform its intended function. This time includes expected administrative and logistic delays as well as active repair times.

3.7 Maintainability is a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.*

3.8 Availability is a measure of the degree to which an item is in the operable and commitable state at the start of the mission, when the mission is called for at an unknown (random) point in time.*

---

* MIL-STD-721B

3.9 Intrinsic Availability is defined as the ratio of the MTBF to the sum of the MTBF and MTTR.

3.10 Operability is defined to be the capability of the participating systems to continue proper operation in the event of failure or improper operation of any of the airborne or ground units.

3.11 Critical Failures are defined to be failures that adversely affect the operability of the overall system. A failure that merely removes the failed system from participation is a non-critical failure. A failure in one airborne or ground unit that causes improper operation of one or more other units in the overall system is a critical failure.

3.12 Learning Curve is defined, for purposes of this study, by the following expression:

$$LC = A(R + P/2)^b$$

A = Price of first production unit

R = Cumulative number of units produced in past

P = Production lot size under consideration

b = Ln q/Ln 2, slope of the learning curve

q = Constant percentage of decrease = .85

4. Summary Table of CAS Study Groundrule Assumptions

Item	Paragraph	Assumptions
1	1.1	There will be two classes of CAS (commercial air carrier and general aviation)
2	1.2	Maximum use of LSI technology will be made in the designs
3	1.3	Commercial quality components will be used
4	1.4	Learning and inflation factors will be applied to the costs. Learning curve at 85% and inflation at an annual rate of 6%.
5	1.4	Manufacturers of full systems will produce at least 3000 units
6	1.4	Manufacturers of limited systems will produce at least 10,000 units
7	1.5	The deployment of units will begin in 1978 with full deployment of commercial users reached in four years and military and general aviation users in eight years Retrofit for all users will be linear..
8	1.6	Start up costs will be amortized over the first two years production
9	1.8	Existing military and commercial maintenance philosophy and procedures will be followed
10	1.9	There will be a method for pre-flight and in-flight performance checks
11	1.11	There will be a method for certifying and/or monitoring operation of ground equipment
12	1.13	Equipment consists of the principal electronics, pilot's indication control panel, antenna, antenna cabling and antenna switch
13	1.14	Aircraft numbers in each user category will be based on FAA estimates for the time period of interest
14	2.1	A common cost model will be used for all three user categories

Item	Paragraph	Assumptions
15	2.1	The cost model will compute annual and cumulative values in each major cost element for each user category
16	2.1	Elements of the logistic support costs will also be divided into non-recurring and recurring costs
17	2.2.1	A linear retrofit schedule is assumed
18	2.2.4	On-aircraft maintenance is limited to remove and replace actions
19	2.2.6	All maintenance actions are treated, for costing purposes, as failures with the MTBF's being adjusted to MTBR's (MTBR) = k(MTBF), $k<1$
20	2.2.7	Only training and test equipment peculiar to CAS will be costed
21	2.2.8	The number of repair sites for the military and commercial users is assumed constant with time, whereas the number of general aviation sites is assumed to be time dependent
22	3.4	A single maintenance man will be used per repair action (MMHR = MTTR)

APPENDIX B

MANUFACTURERS' DATA

The data presented in this appendix are the cost and reliability quotations and performance characteristics provided by each competing manufacturer in response to data requisition forms provided by ARINC Research. Certain parameters have been updated throughout the study and either the updates or the latest data packages are included. Where necessary, data parameters have been changed prior to programming into the Cost Model data files based on the extensive supplemental data furnished by each manufacturer. Information contained in the supplemental data is considered proprietary by each manufacturer and not presented in the appendix.

CONTENTS

1. Honeywell Cost and Reliability Data

2. McDonnell Douglas Cost and Reliability Data

3. RCA Cost and Reliability Data

APPENDIX B-1

HONEYWELL

COLLISION AVOIDANCE SYSTEM

DATA SHEET

	Commercial Carrier	General Aviation
1. Transmitter		
1.1 Power Output	800	200 wtts
Duty Cycle	.001	.0005
1.2 Amplifier: No. of stages	1	Cavity Osc.
1.3 Amplifier: Gain	approx. 9db	N/A
1.4 Amplifier: Solid State or Tube Type	Tube Type	Tube Type Osc.
1.5 Modulator: Type	Transistor Switch	
IF Frequency	N/A	
1.6 UP Converter: No. of mixers & frequency		
1.7 Packaging Modular or Hard Wired	Modulator	
1.8 Number of Modules	1	
1.9 Tech. Level: LSI, MSI, T-L, etc.	Vacuum Tube Triode	
1.10 Freq. Stability	±5mhz	
How Derived	Microwave Oscillator	
2. Receiver		
2.1 Sensitivity	-80 dbm	-73.5 dbm
RF Bandwidth	30mhz	
Dynamic Range	50 db	
2.2 Type of Preamp	Transistor	
2.3 Gain of Preamp	12db	9db
2.4 Noise Temperature of Preamp	290°K	
2.5 Down converter: No. of mixers	1	
Frequency	75mhz	
2.6 Demodulator: Type	Logarithmic Detector	
Frequency	Video base band 10mhz	
2.7 Packaging:	Modular	
2.8 Number of Modules	3	1
2.9 Tech Level	Stripline	PCB
2.10 Frequency Stability	+.15 mhz	
How derived	Crystal Osc.	
2.11 IF: Bandwidth	30mhz	

		Commercial Carrier	General Aviation
3.	Signal Processor/Logic Circuitry		
3.1	Type of construction	Modular	
3.2	Number of modules	1	1
3.3	Required Bandwidth	N/A	
3.4	Required $\frac{s+n}{n}$	14 db	
3.5	No. of type of filters	N/A	
3.6	Tech. Level	LSI	
3.7	Pulse Generator: Type & No.	N/A	
3.8	Clock Source and Stability	N/A	
4.	Assembly (Items 1, 2 & 3)		
4.1	Weight in Kgms	3.62	1.13
4.2	Volume in cu. cm.	5933	2565
4.3	Size in ATR Terminology	3/8	N/A
5.	Indicator		
5.1	Weight Kgms	91	N/A
5.2	Volume in cu. cm.	787	N/A
5.3	Size in cu.	8.28X8.28X11.43	N/A
5.4	Type	1DC-550 Part #18417-502	N/A
6.	Control Panel		
6.1	Weight	N/A	N/A
6.2	Volume	"	"
6.3	Size	"	"
6.4	Idnetify electronics, if any	"	"
7.	Antennas		
7.1	Type	Blade	1/4 w STUB
7.2	Polorization	Vertical	
7.3	Number Required	2	
7.4	Gain Forward & Omn.	3db	
7.5	Preamp (if required)	no remote preamp	
7.6	Recommended Location (s)	N/A	
7.8	Max Distance from Tx/Rx	N/A	

SUMMARY OF PARAMETER INPUTS DESIRED FROM PRODUCERS

LEVEL	PARAMETER	CA	GA
System	Initial sell price of initial sell price due to Amortization		
	Cost of special support equipment		
	New inventory coded items	None	None
	Total inventory coded items		
	Est. Pages of base level T.O's		
	Est. Pages of depot level T.O's		
Subsystem Principal Electronics	Initial sell price	$4015	584
	No. of modules	5	2
	Time to isolate failure* to module level	1.0 hr (.68)	-
	MTBF	4,213 hr (2,051 hr)	8,843 hr (3,194 hr)
	Weight	3.62 kg	1.13 kg
Pilot's Maneuver Indicator	Initial sell price		N/A
	MTBF		N/A
	Weight	.91 kg	N/A
Control	Initial sell price	N/A	N/A
	MTBF	N/A	N/A
	Weight	N/A	N/A

* Values in parenthesis include cavity wearout

LEVEL	PARAMETER	CA	GA
Antenna System	Initial sell price (1)	41.30	
	MTBF (1)		
	No. of Antennas	2	2
Principal Electronics Modules			
Module 1 Receiver Assy	Allocated of principal electronics sell price	25%	
	Allocated MTBF	17,677 hr	13,400 hr (2,451 hr)
	MTTR	1.2 hr	
	Av. Material cost per repair action	$12.28	
Module 2 Power Supply	Allocated of principal electronics sell price	6%	
	Allocated MTBF	50,787 hr	
	MTTR	1.2 hr	
	Av. Material cost per repair action	1.50	
Module 3 Transmitter Assy	Allocated of prinicpal electronics sell price	8%	
	Allocated MTBF	16,779 hr (1,746 hr)	
	MTTR	1.2 hr	
	Av. Material cost per repair action	85.90	
Module 4 Chassis	Allocated of principal electronics sell price	24%	
	Allocated MTBF	33,036 hr	
	MTTR	2.0 hr	
	Av. Material cost per repair action	15.58	

LEVEL	PARAMETER	CA	GA
Module 5 Digital Module	Allocated of principal electronics sell price	37%	
	Allocated MTBF	14,029 hr	26,001 hr
	MTTR	1.7 hr	1.7 hr
	Av. Material cost per repair action	$11.10	

* Values in Parenthesis include cavity wearout

MATERIAL REPAIR COSTS & MTBFs

		AVOID-I		AVOID-II	
		MTBF (hrs)	Avg.Mat'l. Repair Cost	MTBF (hrs)	Avg.Mat'l. Repair Cost
BY DEVICE	Without Cavity Wearout	4213	$24.94	8843	$ 4.78
	With Cavity Wearout	2051	65.84	3194	12.59
BY MODULE	Receiver	17677	12.28		
	Power Supply	50787	1.50		
	*Transmitter	3230	97.28		
	Digital Mod.	14029	11.10		
	Chassis	33036	15.58		

*Figures include effects of cavity wearout.

AVOID-I NON-RECURRING COSTS
DATA PROCESSOR ASSEMBLY

(MICRO-PROCESSOR-CUSTOM LSI CONFIGURATION)

			Non-Recurring	Used On
1 ea	40 pin	CMOS Custom LSI Interface/Latch Chip	$10,000	I & II
1 ea	40 pin	DCTTL Custom LSI Interrogation and Response Timing Chip	42,000	I & II
1 ea	40 pin	DCTTL Custom LSI Interrogation and Response Control Chip	41,000	I & II
1 ea	40 pin	DCTTL Custom LSI Input/Output Control Chip	41,000	I & II
1 ea	40 pin	DCTTL Custom LSI Adder/Latch Chip	41,500	I only
1 ea	40 pin	DCTTL Custom LSI High Speed Data Accumulator Chip	41,000	I & II
1 ea	16 pin	DCTTL Custom LSI Pulse Pair Decoder Chip	38,500	I & II
1 ea	16 pin	DCTTL Custom LSI Antenna Switch Control Chip	37,000	I only
1 ea	40 pin	CMOS Custom LSI Data Processor Control Chip	10,000	I & II

APPENDIX B-2

McDONNELL DOUGLAS

MCDONNELL DOUGLAS ELECTRONICS COMPANY

Box 426, St. Charles, Missouri 63301 (314) 232-0232

1161-35466
27 January 1975

To: Arinc Research Corporation
2551 Riva Road
Annapolis, Maryland 21401

Subject: Arinc Life Cycle Cost Study

References: (a) L. J. Robertson's Letter 0050-LJR-342, dated 27 September 1974
(b) L. J. Robertson's Letter 0050-LJR-359, dated 3 January 1975

Attachment: (1) Revised Life Cycle Cost Parameters

Gentlemen:

The attachment to this letter supersedes the estimated cost information provided in the referenced letters. Please call if you have any questions regarding the enclosed material.

Very truly yours,

Walter N. Weiss

Walter N. Weiss
Specialist
Contract Pricing

WNW:crl

A SUBSIDIARY OF
MCDONNELL DOUGLAS CORPORATION

REVISED LIFE CYCLE COST PARAMETERS

McDONNELL DOUGLAS ELECTRONICS COMPANY

	COMMERCIAL AVIATION	GENERAL AVIATION
NUMBER OF UNITS	3,000	10,000
AVERAGE SYSTEM PRICE	$ 8,900	$ 1,456
INDICATOR (AVERAGE PRICE)	$ 1,500	N/A
ANTENNA(s) [AVERAGE PRICE]	$ 150	$ 8
PRINCIPAL ELECTRONICS	$ 7,250	$ 1,448

PRINCIPAL ELECTRONICS MODULES:

	% ELECTRONICS	
	COMMERCIAL AVIATION	GENERAL AVIATION
LOGIC	20	30
RF FRONT END	35	22
RECEIVER	5	3
OSCILLATOR	3	8
POWER SUPPLY	4	10
EXCITER	8	8
TRANSMITTER	25	19

ALL PRICES ARE IN 1978 DOLLARS.

PRICES EXCLUDE DISTRIBUTION COSTS AND AMORTIZATION OF NON-RECURRING.

1/27/75

REVISED LIFE CYCLE COST PARAMTERS
MCDONNELL DOUGLAS ELECTRONICS COMPANY

MODULE NAME	% ELECTRONICS SELL PRICE	ALLOCATED MTBF
C.A.:		
Transmitter	34	5,265
Receiver	7	14,768
Exciter	3	15,083
Logic	14	7,086
Oscillator	2	100,000
R.F. Front End	29	47,736
Power Supply	11	28,377
Misc.	-	49,799
TOTAL	100	1814

(Distribution costs are 10% of price for C.A.)

G.A.:		
Transmitter	19	19,991
Receiver	5	25,713
Exciter	8	16,436
Logic	33	10,918
Oscillator	7	100,000
R.F. Front End	20	47,736
Power Supply	8	34,276
Misc.	-	47,356
TOTAL	100	3007

(Distribution costs are 14% of price for G.A.)

8 January 1975

		COMMERCIAL CARRIER	GENERAL AVIATION
1.	Transmitter:		
1.1	Power Output & Duty Cycle	1000 Watts ± 3dB 0.002 Duty Cycle	100 Watts ± 3 dB 0.00008 Duty Cycle
1.2	Amplifier: No. of Stages	3 Tube P.A.	2 Tube P.A.
1.3	Amplifier: Gain	30 dB	20dB
1.4	Amplifier: Solid State or Tube & Type	Solid State to 1 Watt, Tube Above 1 Watt	Solid State to 1 Watt, Tube Above 1 Watt
1.5	Modulator: Type	Transistor	Transistor
1.6	UP Converter: No. of mixers & Freq.	(See Item 8)	(See Item 8)
1.7	Packaging: Modular or Hard Wired	Modular	Modular
1.8	Number of Modules	4 Modules in 1 Module	2 Modules
1.9	Tech. Level: LSI, MSI, TTL, etc.	Tubes & Discretes	Tubes
1.10	Freq. Stability & How Derived	.002% Using Crystals	.002% Using Crystals
2.	Receiver:		
2.1	Sensitivity, RF Bandwidth, & Dynamic Range	3dB BW = 30 MHZ 1dB BW = 20 MHz -15 to -88 dBm	3 dB BW = 30 MHz 1 dB BW = 20 MHz -15 to -78dBm
2.2	Type of Preamp	Solid State	None
2.3	Gain of Preamp	10dB	NA
2.4	Noise Figure of Preamp	6dB	NA
2.5	Down Converter: No. of Mixers & Freq.	One Mixer - Freq 1540/1545/ 1550/1555	One Mixer - Freq. 1540/1545 1550/1555

2.	Receiver: Continued		
2.6	Demodulator: Type and Freq.	Amplitude & B1Ø, 60 MHz	Amplitude, 60 MHz
2.7	Packaging: Modular or Hardwired	Modular	Modular
2.8	Number of Modules	3 Modules	2 Modules
2.9	Tech. Level: LSI, MSI, TTL, etc.	IC & Discretes	IC & Discretes
2.10	Freq. Stability & How Derived	.002% Using Crystals	.002% Using Crystals
2.11	IF: Bandwidth	2 MHz	2 MHz
3.	Signal Processor/Logic Circuitry:		
3.1	Type of Construction: Modular or Fixed	Modular	Modular
3.2	Number of Modules	2	1
3.3	Required Bandwidth	NA	NA
3.4	Required S+N/N	15dB	15dB
3.5	No. and Type of Filters	NA	NA
3.6	Technical Level: LSI, MSI, TTL, etc.	LSI, MSI & Discretes	LSI, MSI & Discretes
3.7	Pulse Generator: Type and No.	NA	NA
3.8	Clock Source and Stability	5MHz, $5x10^{-8}$ ($3x10^{-9}$ with VCO)	5MHz, $5x10^{-8}$ ($3x10^{-9}$ with VCO)
4.	Assembly: (Items 1, 2 & 3)*		
4.1	Weight in lbs.	25 lbs.	10 lbs.
4.2	Volume in cu. in.	1120	275
4.3	Size in ATR Terminology	3/4 ATR	<Short 3/8 ATR

SUMMARY OF LIFE CYCLE COST PARAMETERS

McDONNELL DOUGLAS ELECTRONICS COMPANY

MODULE NAME	% ELECTRONICS SELL PRICE	ALLOCATED MTBF	MTTR	AVERAGE MATERIAL COST/REPAIR ACTION
C.A.:				
TRANSMITTER	12	3,400 Hrs	1.0 Mhrs	$ 1.50
RECEIVER	9	10,000 "	1.0 "	$ 1.75
EXCITER	10	6,700 "	1.0 "	$ 2.50
LOGIC	60	5,000 "	1.0 "	$ 2.00
OSCILLATOR	2	100,000 "	0.5 "	$60.00
R.F. FRONT END	4	10,000 "	1.5 "	$15.00
POWER SUPPLY	3	6,700 "	1.0 "	$ 2.50
C.A.:				
TRANSMITTER	17	10,000 Hrs	1.0 Mhrs	$ 1.50
RECEIVER	6	14,000 "	1.0 "	$ 1.75
EXCITER	21	6,700 "	1.0 "	$ 2.50
LOGIC	31	7,100 "	1.0 "	$ 2.50
OSCILLATOR	6	100,000 "	0.5 "	$60.00
R.F. FRONT END	10	25,000 "	1.0 "	$15.00
POWER SUPPLY	9	6,300 "	1.0 "	$ 2.50

APPENDIX B-3

RCA

RCA | Government and Commercial Systems | Electromagnetic and Aviation Systems Division
8500 Balboa Boulevard | Van Nuys, California 91409 | Telephone (213) 894-8111

RCA

ARINC Research Corporation
2551 Riva Road
Annapolis, Maryland 21401

Attention: S. H. Kowalski

16 September 1974

Dear Stan:

Attached herewith we are submitting the technical Data Summary Sheets and Summary of Parameter Sheets covering the RCA SECANT equipments.

Concerning the cost data submitted, we wish to reiterate that the costs are our current projections based on a future product design fully utilizing LSI and advanced manufacturing techniques. The cost projections are given in 1974 dollars, at O.E.M. (original equipment manufacturer's) price.

Should you have any questions concerning our equipment, please call me.

Very truly yours,

P. B. Korda
SECANT Program Manager

Attachments

RCA-SECANT
SUMMARY OF PARAMETER INPUTS

LEVEL	PARAMETER	CA	GA	REMITTER
System	Initial sell price (O.E.M.) Less amortization	$10,900 (fully redundant)	$1550	$800
	Amortization per system	$500	$150	$150
	Cost of special support equip.			
	New inventory coded items	90	70	40
	Total inventory coded items	110	90	50
	Est. pages of base level T.O.'s			
	Est. pages of depot level T.O.'s			
Subsystem Principle Electronics	Initial sell price less Amortization (O.E.M.)	$4850	$1460	$740
	No. of modules	8	7	5
	Time to isolate failure to module level (min)	6	5	3
	MTBF	3000 hrs	4000 hrs	4500 hrs
	redundant system	700k hrs		
	Weight			
Pilot's Indicator	Initial Sell Price (O.E.M.)	$500-(X2)	$50	N/A
	MTBF			
	Weight	1 KG	.4 KG	N/A
Control Panel	Initial Sell Price (O.E.M.)	$120	N/A	$20
	MTBF			
	Weight	1 KG	N/A	.4 KG
Antenna System	Initial Sell Price (O.E.M.)	$40-(X2)	$40	$40
	MTBF			
	No. of Antennas	2	1	1
Principle Electronics Modules				
Microwave Mod.	% of Sell Price	57.7	41.0	53.7
	Allocated MTBF			
	MTTR	3.0	2.5	2.2
	AV. Mat'l. Cost per Repair Action	$25	$20	$15

RCA-SECANT
SUMMARY OF PARAMETER INPUTS (Continued)

LEVEL	PARAMETER	CA	GA	REMITTER
IF Detector Mod.	% of Sell Price	9.3	10.3	10.8
	Allocated MTBF			
	MTTR			
	Av. Mat'l Cost per Repair Action	$20	$20	$20
Control Logic	% of Sell Price	4.1	8.4	16.4
	Allocated MTBF			
	MTTR	1.3	1.3	1.3
	Av. Mat'l Cost per Repair Action	$12	$12	$12
Threat Logic	% of Sell Price	4.1	8.4	N/A
	Allocated MTBF			N/A
	MTTR	1.3	1.3	N/A
	Av. Mat'l Cost Per Repair Action	$12	$12	N/A
Tracker/Data	% of Sell Price	4.7	11.0	N/A
	Allocated MTBF			N/A
	MTTR	1.3	1.3	N/A
	Av. Mat'l Cost Per Repair Action	$12	$12	N/A
Tracker Expansion	% of Sell Price	4.7	N/A	N/A
	Allocated MTBF		N/A	N/A
	MTTR	1.3	N/A	N/A
	Av. Mat'l Cost Per Repair Action	$12	N/A	N/A
Power Supply	% of Sell Price	6.2	10.3	8.1
	Allocated MTBF			
	MTTR	1.5	1.3	1.2
	Av. Mat'l Cost Per Repair Action	$50	$30	$20

RCA-SECANT
SUMMARY OF PARAMETER INPUTS (Continued)

LEVEL	PARAMETER	CA	GA	REMITTER
Housing Assem.	% of Sell Price	8.2	10.3	10.8
	Allocated MTBF			
	MTTR	1.0	.9	.9
	Av. Mat'l Cost Per Repair Action	$5	$5	$5

TECHNICAL DATA COMPARISON - COMMERCIAL CARRIER CAS

EQUIPMENT	RCA SECANT
1. TRANSMITTER	
1.1 Power Output	+ 44 dBM
1.2 Duty Cycle	0.01
1.3 Amplifier: Gain	44 dB
: Type	Solid State
1.4 Modulator Type	Pulse
1.5 Up Converter/Exciter	
No. of Mixers	2
1.6 Packaging	MIC**
1.7 Number of Modules	1
1.8 Technology Level	MIC
1.9 Frequency Stability & How Derived	.005% XTAL
2. RECEIVER	
2.05 Noise Figure	5dB
2.1 Sensitivity	-95 dBm*
2.2 RF Bandwidth (3dB)	50 MHz
2.3 Preamp: Type	Solid State
: Gain	10 dB
2.4 Down Converter, Number of Mixers	2
2.5 Demodulator: Type	Amplitude Coherent
: Frequency	60 MHz
2.6 Packaging	MIC
2.7 Number of Modules	1
2.8 Technology Level	MIC/MSI
2.9 Frequency Stability	.005%
How Derived	XTAL
2.10 IF Bandwidth	1 MHz

* 50% Crossing Threshold

EQUIPMENT	RCA SECANT
3. SIGNAL PROCESSOR/LOGIC CIRCUITRY	
3.1 Type of Construction	Modular
3.2 Number of Modules	4
3.3 Bandwidth	Digital
3.4 Required S+N/N	8 dB
3.5 Number & Type of Filters	8 SAW***
3.6 Technical Level	MSI & LSI
3.7 Clock Source	10 MHz XTAL
3.8 Stability	10ppm
4. ASSEMBLY (Items 1, 2, & 3)	
4.1 Weight in Kgms	10.5
4.2 Volume in cu.cm	16000.
4.3 Size in ATR	1 ATR Short
5. ANTENNAS	
5.1 Type	Blade ($\lambda/4$)
5.2 Polarization	Vertical
5.3 Number Required	2
5.4 Gain: (Forward)	2 dB
5.5 Preamp	none
5.6 Location	Top and Bottom
5.7 Cable Loss (dB)	4 dB

*** Surface Acoustical Wave

TECHNICAL DATA COMPARISON
GENERAL AVIATION CAS

EQUIPMENT	RCA SECANT GA & REMITTER
1. TRANSMITTER	
1.1 Power Output	+42
1.2 Duty Cycle	.01
1.3 Amplifier Gain	42 dB
Type	Solid State
1.4 Modulator Type	Pulse
1.5 Up Conv./Exciter No. of Mixers	2
1.6 Packaging	MIC**
1.7 Number of Modules	1
1.8 Tech-Level	MIC
1.9 Frequency Stability	.005% XTAL
and How Derived	.005% XTAL
2. RECEIVER	
2.05 Noise Figure	5dB
2.1 Sensitivity	-90 dBm *
2.2 RF Bandwidth (3dB)	100 MHz
2.3 D/C Number of Mixers	2
2.4 Demodulator: Type	Amplitude Coherent
: Frequency	60 MHz
2.5 Packaging	MIC
2.6 Number of Modules	1
2.7 Technology Level	MIC/MSI
2.8 Frequency Stability	.005%
2.9 IF Bandwidth	1 MHz

* 50% Crossing Threshold
** Microwave Integrated Circuits

EQUIPMENT	RCA REMITTER	SECANT GA
3. SIGNAL PROCESSOR		
3.1 Type of Construction	Modular	Modular
3.2 Number of Modules	1	1
3.3 Bandwidth	Digital	Digital
3.4 Required S+N/N	8 dB	8 dB
3.5 Number & Type of Filter	4 SAW	8 SAW
3.6 Technology Level	LSI	LSI
3.7 Clock Source	1 MHz XTAL	10 MHz XTAL
3.8 Stability	10 ppm	10 ppm
4. ASSEMBLY		
4.1 Weight in kgms	6,000	8,000
4.2 Volume in cu.cm	3/8 SHT	1/2 SHT
4.3 Size in ATR		
5. ANTENNAS		
5.1 Type	$\lambda/4$ Stub	$\lambda/4$ Stub
5.2 Polarization	Vertical	Vertical
5.3 Number Required	1	1
5.4 Gain (Forward)	2 dB	2 dB
5.5 Location	Top	Top
5.6 Cable Loss (dB)	2 dB	2 dB

PERFORMANCE COMPARISON
FULL CAPABILITY CAS

		RCA
1.	Frequency of Operation	1595 - 1620 MHz
2.	No. of Frequencies (Discrete)	24
3.	Maximum Range	15.1 nm
4.	Altitude Limit	126,000 ft.
5.	Maximum Closure Rate	1200 Knots - TAU 2
6.	Signal Formal	Query 1 us pulses, 1 pulse-pair Reply 1 us pulse
7.	Epoch Duration or Round Time	5.1 Seconds
8.	Minimum number of transmissions per Epoch or Round Time (no intruder)	450 Q
9.	Maximum number of transmissions per Epoch or Round Time (1 intruder)	754 Q
10.	Maximum number of Transmissions per Epoch or Round Time (>1 intruder)	2274 Q
11.	Number of Intruders Capability	288 nearest per round

PERFORMANCE CHARACTERISTICS
GA CAS

		RCA
1.	Frequency of Operation	1595 - 1620 MHz
2.	Number of Frequencies	24
3.	Maximum Range	11.5 nm
4.	Altitude Limit	126,000 ft.
5.	Maximum Closure Rate	TAU 2 - 875 knots TAU 1 - 1600 knots
6.	Signal Format	1 us pulses, 1 pulse-pair Reply 1 us Pulse
7.	Epoch Duration or Round Time	5.1 Seconds
8.	Minimum number of transmissions per Epoch or Round Time (no intruder)	350 Q
9.	Maximum number of transmissions per Spoch or Round Time (no intruder)	654 Q
10.	Maximum number of transmissions per Epoch or Round Time (>1 intruder)	1414 Q
11.	Number of Intruders Capability	144 nearest per round

APPENDIX C

INDEPENDENTLY DEVELOPED COST AND RELIABILITY

1. GENAVE CAS Cost and Reliability Study - Final Report
2. NARCO CAS Cost and Reliability Study
3. ARINC Research Cost and Reliability Data

APPENDIX C-1

GENAVE

GENERAL
AVIATION
ELECTRONICS
INC.

Genave

4141 KINGMAN DRIVE
INDIANAPOLIS, IND. 46226
AREA 317 • 546-1111

March 3, 1975

Mr. Stanley H. Kowalski
ARINC Research Corporation
2551 Riva Road
Annapolis, MD 21401

Dear Mr. Kowalski:

Enclosed is the final report on our study of the three CAS Systems. It is slightly different than the preliminary data which I gave to you by telephone, but not enough to change the results in any significant manner. Primarily, I neglected to include the labor figures in the retail estimates when I gave you the preliminary figures. Also, slight revisions in a few prices and an addition error have caused the RCA and McDonnell Douglas systems to change places in terms of the cost of building them today. The differential is so slight, however, that little significance can be assigned to it.

Stan, I have shown below the man-days expended on the project. You can see that we exceeded our 11 day estimate by a considerable amount. We agreed not to exceed the quoted price, however, and we will live by that agreement, but any further work or time we put in beyond this report will have to be billed at the published rates.

Person	Time (man-days)
Rice, E. W.	0.2
Henderson, C. L.	0.3
Boelter, D. A.	2.0
Atkinson, N. D.	5.75
Bovard, L. R.	6.5
Clerical	.7
Total	15.45 man-days

I hope that you are pleased with the results of our study and that they will help you in your effort. It has been a pleasure working with you, and we look forward to further associations.

Sincerely,

GENERAL AVIATION ELECTRONICS

Donald A. Boelter
Chief Engineer

DAB/th
Enc.

CAS COST & RELIABILITY STUDY

FINAL REPORT

ARINC CONTRACT NO: DOT-FA74WA-3506

GENAVE JOB NO: 7093900

At the request of ARINC Research Corporation, supported by their Purchase Order No. Y-8947, Genave has performed a study of the cost of producing three varieties of Collision Avoidance Systems and their estimated reliabilities. Our study was limited to units which would be used in the General Aviation type aircraft which our company would service. Since detailed information, such as schematics, was not made available, the estimates were based, in some areas, on our "best guess" of what would be required to provide the desired function. Most areas of this type were in the RF or microwave sections of the units and as such were well within our realm of experience and we feel as a result that the estimates are quite accurate. Some sections of the units were well defined by parts lists and with these we computed prices and labor figures based upon our current production parts costs and labor rates making them also very accurate. In several spots, we found items such as cables and shield assemblies which were not called out, but which we felt would be required and these items were added to the parts costs where appropriate.

Table 1 shows a breakdown of each system and the parts and labor costs for each subassembly or subsystem. Please note that all costs are in "1975 Dollars" without regard to future inflation.

TABLE 1

1975 PARTS & LABOR COSTS

HONEYWELL

Item	Parts	Labor
Transmitter	$ 29.00	$ .55
Receiver	41.02	1.51
Data Processor	520.46	1.32
Power Supply	19.16	.90
Packaging Misc.	51.45	2.93
Final Assembly		15.00
Test & Inspection		25.00
Total Costs	661.09	47.21

RCA

Item	Parts	Labor
Transmitter Synthesizer	$ 64.08	$ 5.17
Receiver	233.11	11.23
Microwave Circuits	236.50	8.07
Data Processing	347.10	1.35
Power Supply	20.80	.64
Packaging & Misc.	27.00	2.00
Final Assembly		15.00
Test & Inspection		30.00
Total Costs	928.59	73.46

McDONNELL DOUGLAS

Item	Parts	Labor
RF Front End	$200.00	$ 8.25
Exciter	93.32	3.13
Transmitter	141.00	.25
Oscillator, Crystal	150.00	.15
Receiver	28.90	1.78
Data Processing	188.37	1.95
Power Supply	25.30	.93
Packaging & Misc.	71.30	5.05
Final Assembly		15.00
Test & Inspection		30.00
Total Costs	$898.19	66.49

The costs listed in Table 1 above were combined in Table 2 below and a retail price computed for each system assuming that it were built today. The "out-of-house" or factory price would be twice the parts and labor cost which, of course, represents a 50% gross margin.

Table 2

1975 SYSTEM COSTS

System	Total Cost	Retail Price
Honeywell	$ 708.30	$2351.55
RCA	1002.05	3326.80
McDonnell Douglas	964.68	3202.73

In our evaluation of the probable system costs for production in 1978, we felt that, not including inflation, the costs of the parts and labor would remain stable with one major exception. This exception is the LSI complement of each system. We therefore broke out the LSI costs independently of the other costs and estimated the 1978 prices in terms of the expected reduction in LSI costs for the next three years. Table 3 shows the current costs of the LSI in relation to the other costs. Table 4 indicates the expected reduction in LSI costs by 1978 and the resulting cost and retail prices of the units based on 1975 dollars.

Table 3

LSI BREAKOUT

System	LSI Costs	Other Costs
Honeywell	$493.98	$214.32
RCA	324.00	678.05
McDonnell Douglas	159.95	804.73

Table 4

1978 SYSTEM COSTS (In 1975 Dollars)

System	LSI Costs	Other Costs	Total Cost	Retail Price
Honeywell	$164.66	$214.32	$378.98	$1258.21
RCA	97.20	678.05	775.25	2573.83
McDonnell Douglas	47.99	804.73	852.72	2831.03

None of the systems, in our opinion, could be called unfeasible even with today's technology. Some of the borderline approaches, such as the surface acoustic wave filters, are not the most suitable for low-cost units today, but will more than likely be quite suitable by 1978. What IS significant in comparing the three systems is the overall costs involved and the projected reliability of each. Reliability is closely tied to component type and count and also to the number and type of interconnections required. Component counts were made, insofar as possible, for each of the systems. Reliability estimates were then made based on the frequency and type of repair records which we have accumulated over the years on equipment of similar type and/or complexity. Table 5 lists the results of that analysis in terms of frequency of repair and probable cost per repair cycle. These figures assume that the "Infant Mortality" problems are eliminated for the most part by factory burn-in procedures prior to shipment.

Table 5

RELIABILITY ESTIMATES

System	Total Electronic Components	Frequency * of Repair	Cost/Repair Cycle
Honeywell	181	3860 hours	$100
RCA	325	2150 hours	$150
McDonnell Douglas	340	2050 hours	$150

A cursory glance at the data shows that the obvious system preferred for the General Aviation fleet would be similar to the Honeywell approach. Cost and reliability both heavily favor that design. There seems to be insufficient difference between the other two systems to justify a second and third choice and we therefore will not indicate a preference.

* This is NOT an MTBF figure. It is a figure based on our proprietary warranty repair information. Several problems may be fixed in one repair cycle.

We believe that the above data supplies all of the essential information desired and requested under this contract.

GENERAL AVIATION ELECTRONICS

Donald A. Boelter
Chief Engineer

DAB/th

Date: March 3, 1975

APPENDIX C-2

NARCO

NARCO AVIONICS

A DIVISION OF NARCO SCIENTIFIC INDUSTRIES

NARCO

21 March 1975

ARINC Research Corporation
2551 Riva Road
Annapolis, MA 21401

Attn: Mr. Stanley H. Kowalski

Dear Mr. Kowalski:

We have evaluated per your request the following Collision Avoidance Systems:

1. Aviods II
2. Eros II GA
3. Secant GA

The evaluation was made using the data supplied by ARINC Research with particular attention to areas of difference in the different systems. Areas of similarity are assumed to be identical in cost; I.E. packaging, readout, logic. This evaluation results in the following differences:

	Aviods	Secant	Eros
1. RF Generator (Synthesis)	1 xtal	13 xtals	7 (170)
2. RF Power	1 tube no mulit-pliers	xistorized (120) power amp-lifier	2 tubes (60) multipliers
3. IF Designs	1 IF	2 IF (20) 8 Saw Filters (80)	1 IF
Sell Differences	0	510	230
List Prices	1000	2220	1460

The list price of the Avoids System is based on Narco list prices in 1975 dollars and is approximately $350 price increase over selling price of Narco AT-50A Transponder which utilizes similar techniques with less integrated logic and RF Receiver inputs and less stability in the Oscillator as well as wider bandwidth techniques. Some cost increase is a result of the more complex display in Collision Avoidance Systems. All other costs and list prices are derived by adding to this Avoids II System cost.

COMMERCE DRIVE, FORT WASHINGTON, PENNSYLVANIA 19034
TELEPHONE: (215) 643-2900 TELEX: 845137

Failure Analysis:

The MTBF is presented as a classical (Mil) analysis as well as expected based on experience of similar systems such as AT-50A, DME-190 systems.

	Calculated	Expected
AT-50A	4900	1500
DME-190	2914	1500
Avoids II	4900	1500
Secant GA	3800	1500
Eros II GA	3400	1200

I hope the above data is what you need in your study. If you need additional data please let us know. I am looking forward to completing a similar study for the DABS IPC study.

Very Truly Yours,

Howard Kaufmann
Chief Engineer

HLK/csk

APPENDIX C-3

ARINC RESEARCH CORPORATION

SYSTEM AVOIDS I

SUB-ASSEMBLY TRANSMITTER

SHEET 1 OF 5

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N4949	1	2.00	2.00		6	2.498	2.498	4.996
2N2222	2	.16	.32		12	1.266	2.532	.405
2N4300	1	6.80	6.80		6	3.749	3.749	25.493
2N5682	1	1.30	1.30		6	4.688	4.688	6.094
1N4531	4	.03	.12		20	.155	.62	.019
1N753A	1	.10	.10		5	.4	.4	.04
52-F	2	1.00	2.00		10	.155	.31	.31
NE-555	1	.68	.68		8	.715	.715	.486
54221	1	2.10	2.10		8	.715	.715	1.502
54304	1	.75	.75		8	.715	.715	.536
Transformer	1	.50	.50		315	2.309	2.309	1.155
Inductor	3	.44	1.32		45	2.309	6.927	4.295
Potentiometer	3	6.50	19.50		15	.664	1.992	12.948
Capacitor	10	.47	4.68		50	.55	5.5	2.574
Resistor	17	.13	2.26		85	.013	.221	.029
Cavity Osc.	1	100.00	100.00		25	250.00	250.00	25,000.00
Insulator	5	.13	.65		25	-	-	
Heat Sink	1	.16	.16		20	-	-	
PC Board	1	10.00	10.00	818	10	-	-	
TOTALS			155.24	818 x 2	679 x 2		283.891	$\frac{25060.7}{283.891} = 88.29$

SYSTEM AVOIDS I

SUB-ASSEMBLY RECEIVER

SHEET 2 OF 5

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MC1590	2	1.05	2.09		16	.715	1.43	1.502
MC1733	6	.81	4.83		48	.715	4.29	3.475
NE521	2	.57	1.14		16	.715	1.43	.815
54S02	2	1.42	2.84		16	.715	1.43	2.031
2N4134	2	1.75	3.50		12	.316	.632	1.106
2N2707	6	.60	3.60		36	1.192	7.152	4.291
1N4454	16	.05	.80		80	.155	2.48	.125
Capacitors	64	.23	14.72		320	.55	35.2	8.096
Resistors	84	.09	7.15		420	.013	1.092	.104
PC Board	1	11.99	11.99	818	10	-	-	
RF Head	1	424.64	424.64		25	-	-	
IF Cover			6.69	781	37			
TOTALS			483.99	1599 x 2	1036 x 2		55.136	$\frac{21.545}{55.136} = .39$

SYSTEM AVOIDS I

SUB-ASSEMBLY LOGIC

SHEET 3 OF 5

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL. RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
LSI-Custom	9	11.22	100.99		180	.4	3.6	40.396
Multiplexer	3	2.50	7.50		24	.715	2.145	5.363
IM5508	2	10.00	20.00		16	.715	1.43	14.3
MM6255	1	30.00	30.00		8	.715	.715	21.45
DM7488	1	4.00	4.00		8	.715	.715	2.86
DM74187	1	5.00	5.00		8	.715	.715	3.575
74393	1	2.00	2.00		8	.715	.715	1.43
NE553	1	1.50	1.50		8	.715	.715	1.073
NE556	2	1.00	2.00		16	.715	1.43	1.43
NE555	1	.50	.50		8	.715	.715	.358
MA747	2	3.00	6.00		16	.627	1.254	3.762
Crystal	1	5.00	5.00		15	.226	.226	1.13
2N4949	2	1.00	2.00		12	2.498	4.996	4.996
1N4531	20	.03	.60		100	.155	3.1	.093
Capacitors	14	.36	5.10		70	.55	7.7	2.805
Resistors	25	.56	13.90		75	.013	.325	.181
8101	10	11.00	110.00		12	.4	4.	44.00
8308	1	11.00	11.00		120	.4	.4	4.4
8080	1	11.00	11.00		20	.4	.4	4.4
PC Boards	2	25.00	50.00	1294	25			
Connector	4	3.00	12.00		80			
Testing					1000			
TOTALS			400.09	1294	1829		35.296	$\frac{158.002}{35.296} = 4.48$

SYSTEM AVOIDS I

SHEET 4 OF 5

SUB-ASSEMBLY POWER SUPPLY

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL. RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
52710	1	.92	.92		8	.715	.715	.658
2N3716	3	1.33	3.99		18	3.749	11.247	14.959
2N2905	1	.33	.33		6	.316	.316	.104
2N3700	2	.49	.98		12	.316	.632	.310
IN5615	7	.11	.77		35	.358	2.506	.276.
IN5550	1	1.13	1.13		5	.358	.358	.405
IN5326	2	1.50	3.00		10	.358	.716	1.074
IN938B	1	.75	.75		5	.4	.4	.3
IN753A	1	.10	.10		5	.4	.4	.04
Transformer	2	.55	1.10		1240.	1.5	3.0	1.65
MC7805	1	1.50	1.50		8	.715	.715	1.073
MC7812	1	1.50	1.50		8	.715	.715	1.073
MC7905	1	1.50	1.50		8	.715	.715	1.073
MC7915	1	1.50	1.50		8	.715	.715	1.073
MC7912	1	1.50	1.50		8	.715	.715	1.073
Potentiometer	1	3.65	3.65		15.	.664	.664	2.424
Inductor	2	.50	1.00		830	2.304	4.608	2.304
Relay	1	4.35	4.35		15.	8.002	8.002	34.809
Capacitor	12	.91	10.92		60	.55	6.6	6.006
Resistor	8	.44	3.48		40	.013	.104	.003
PC Board	1	10.-	10.-	818	10			
Misc. Hard.& Test		7.64	5.27		556			
TOTALS			59.24	818.	2910.		43.843	$\frac{70.687}{43.843} = 1.62$

SYSTEM AVOIDS I

SUB-ASSEMBLY HOUSING w/RF

SHEET 5 OF 5

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL. RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
RF Preamp	2	8.24	16.48			8.447	16.894	8.385
BP Filter	2	5.00	10.00			.692	1.384	6.92
RF Switch	2	15.00	30.00	P/O RF HEAD		3.490	6.98	104.7
Bal. Mixer	2	15.00	30.00			1.000	2.00	30.0
L.O.	1	12.43	12.43			12.303	12.303	7.916
PWR Divider	2	5.00	10.00			5.00	10.00	50.0
Hardware		176.32	176.32	3791	8175			
TOTALS			176.32	3791	8175		49.561	$\frac{207.921}{49.561} = 4.20$

SYSTEM EROS II

SUB-ASSEMBLY TRANSMITTER

SHEET 1 OF 9

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL. RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
8847A	3	44.50	133.50	1,000	75	30.	90.	4005.
EMI-Filter	4	.55	2.20		15	5.127	20.508	11.28
Transformer	3	9.24	27.72		945	2.309	6.927	64.01
Choke	1	5.04	5.04		15	2.12	2.12	10.68
2N3227	2	.92	1.84		12	1.266	2.532	2.33
2N3507	3	5.25	15.75		18	3.749	11.247	59.05
2N5337	1	3.90	3.90		6	3.749	3.749	14.62
2N2222A	4	.34	1.36		24	1.266	5.064	1.72
1N4148	6	.11	.66		30	.155	.93	.10
1N746A	1	.41	.41		5	.4	.4	.16
1N751A	1	.41	.41		5	.4	.4	.16
5M3.32	1	1.07	1.07		5	.358	.358	.38
M5B774132	1	.92	.92		8	.715	.715	.66
M6A994531	1	.92	.92		8	.715	.715	.66
M6A994631	2	1.06	2.12		16	.715	1.43	1.52
Capacitor	35	.97	33.95		175	.55	19.25	18.67
Resistor	74	.15	11.10		370	.013	.962	.14
2N 2905A	4	.51	2.04		24	2.124	8.496	4.33
2N3879	2	1.26	2.52		12	3.749	7.498	9.45
2N2819A	1	.63	.63		6	3.749	3.749	2.36
2N2907	1	.29	.29		6	2.124	2.124	.62
2N2957	1	1.26	1.26		6	18.518	18.518	23.33
TOTALS								

SYSTEM EROS II

SHEET 2 OF 9

SUB-ASSEMBLY TRANSMITTER (Cont'd)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N2222A	3	.29	.87		18	1.266	3.798	1.10
2N1778	2	3.57	7.14		12	2.412	4.824	17.22
1N5415	2	1.13	2.26		10	.358	.716	.81
1N5550	2	.71	1.42		10	.358	.716	.51
1N4002	6	.10	.60		30	.358	2.148	.21
1N914	3	.10	.30		15	.155	.465	.05
1N4740A	1	.17	.17		5	.4	.4	.07
1N965B	1	.34	.34		5	.4	.4	.14
1N5251A	1	.34	.34		5	.4	.4	.14
1N5254	2	.34	.68		10	.4	.8	.27
VB50X	2	.84	1.68		10	.155	.31	.26
LM105	2	8.40	16.80		16	.715	1.43	12.01
U5R7723312	2	2.18	4.36		16	.715	1.43	3.12
Potentiometer	3	4.55	13.65		45	.664	1.992	9.06
1N4625	4	.50	2.00		20	.4	1.6	.80
Filter Cables	3	1.67	5.00		45	2.859	8.578	14.33
Connector	6	1.31	7.86		150			
Hardware	set	50.00	50.00			4.00	4.00	200.00
Housing for Hi-Volt	-			1,000				
TOTALS			365.08	2,000 x 2	2208 x 2		237.699	$\frac{4490}{238.7} = 18.85$

SYSTEM EROS II

SUB-ASSEMBLY RECEIVER

SHEET 3 OF 9

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MC1550	4	.50	2.00		32	.4	1.60	.80
MC1702	1	.50	.50		8	.4	.40	.20
MC1710	1	.42	.42		8	.4	.40	.168
5400	1	1.68	1.68		8	.03	.03	.050
56142	1	1.26	1.26		8	.715	.715	.901
U527710393	1	.63	.63		8	.715	.715	.450
2N5245	1	.21	.21		6	1.266	1.266	.266
2N918	2	1.26	2.52		12	1.266	2.532	3.190
2N2857	2	1.43	2.86		12	1.266	2.532	3.621
MP5082-2800	8	.42	3.36		40	.155	1.240	.521
1N914	2	.10	.20		10	.155	.310	.031
1N5242	1	.29	.29		5	.4	.40	.116
1N5233B	1	.42	.42		5	.4	.40	.168
1N753A	1	.38	.38		5	.4	.40	.152
Potentiometer	4	.96	3.82		60	.664	2.656	2.550
Inductor	8	.59	4.72		64	2.309	18.472	10.898
Ind. Core	5	.04	.20		40	2.309	11.545	.462
Cap. Adj.	4	.92	3.68		60	1.58	6.32	5.814
Capacitor	59	.03	1.95		295	.55	32.45	9.74
Delay line	1	20.99	20.99		10	.226	.226	4.744
T30-65F	2	.04	.08		16	2.309	4.618	.185
Resistors	53	.03	1.59		265	.013	.689	.021
TOTALS								

SYSTEM EROS II

SHEET 4 OF 9

SUB-ASSEMBLY RECEIVER (Cont'd)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
PC Board	1	6.72	6.72	600	10	-	-	
Hardware	set	5.12	5.12		25	-	-	
Misc. Elect.	lot	.17	.17			-	-	
TOTALS			64.54	600	1012 x 2		89.916	$\frac{44.848}{89.916} = .49$

SYSTEM EROS II

SUB-ASSEMBLY EXCITER

SHEET 5 OF 9

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MC835	2	.61	1.22		16	.715	1.43	.872
MC1812	1	.71	.71		8	.715	.715	.508
CA3028F	4	1.05	4.20		32	.715	2.860	3.003
2N918	7	.34	2.38		42	1.266	8.862	3.013
2N3646	1	.29	.29		6	1.266	1.266	.367
2N3866	1	.84	.84		6	3.749	3.749	3.149
2N5641	1	1.09	1.09		6	3.749	3.749	4.086
HP5082-0182	2	.50	1.00		10	.155	.31	.155
MA43000	1	10.08	10.08		5	.155	.155	1.562
IN914	9	.10	.90		45	.155	1.395	.140
Potentiometer	3	.29	.87		45	.664	1.992	.578
Inductor	7	.59	4.13		35	.069	.483	.285
Ind. Core	11	.04	.44		55	.069	.759	.030
Cap. Aj.	7	.50	3.50		105	1.59	11.130	5.565
Cap.	40	0.09	3.72		200	.55	22.00	1.980
Crystal	8	1.68	13.44		160	.226	1.808	3.037
UM7902E	1	15.95	15.95		5	.155	.155	2.472
Sub-Strate	1	16.79	16.79		32	-	-	
Resistor	58	.04	2.32		290	.013	.767	.030
PC Board	1	4.20	4.20	818		-	-	
Misc. Hard.	lot	20.99	20.99	500	50	-	-	
TOTALS			109.10	1318	1153		63.585	$\frac{30.833}{63.585} = .48$

SYSTEM EROS II

SHEET 6 OF 9

SUB-ASSEMBLY RF AND HOUSING

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL. RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
RF Front End	1	504	504		500			
*Reliability and maintainability of RF Front End								
-MC1550	4				N/A	.627	2.508	
-MC1702	1				N/A	.627	.627	
-MC1710	1				N/A	.627	.627	
-MPS3646	1				N/A	1.266	1.266	
-2N5245	1				N/A	.290	.290	
-MP2800	8				N/A	.155	1.240	
-IN914	2				N/A	.155	.31	
-IN5242B	1				N/A	.4	.4	
-IN5233B	1				N/A	.4	.4	
-Pots	3				N/A	.664	1.992	
-Ind.	2				N/A	.069	.138	
- Cores	5				N/A	.069	.345	
-Bends	12				N/A	.069	.828	
-Caps	34				N/A	.55	18.7	
-Adj. Cap.	4				N/A	1.58	6.32	
-Resistor	26				N/A	.013	.338	
Misc. Hardware								
and Conn.	195	401	401	425	737			
TOTALS			905	425 x 2	1237 x 2		36.329	

SYSTEM EROS II

SUB-ASSEMBLY LOGIC

SHEET 7 OF 9

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
LSI	8	16.79	134.32		160	.4	3.2	53.728
2502	8	8.40	67.20		160	.715	5.72	48.048
1302	1	8.40	8.40		60	.715	.715	6.006
TMS2300	1	8.40	8.40		6	.715	.715	6.006
MN3004	1	16.79	16.79		6	.715	.715	12.005
54L505	3	.50	1.50		24	.035	.105	.053
MS935	2	.58	1.16		16	.715	1.430	.829
54107	1	.63	.63		8	.035	.035	.022
5417	3	.50	1.50		24	.715	2.145	1.073
MH0026	1	1.05	1.05		6	.715	.715	.751
CD4049	1	.59	.59		6	.035	.035	.021
CD4050	2	.59	1.18		12	.715	1.43	.844
CD4029	3	3.78	11.34		18	.715	2.145	8.108
2N2222A	4	.29	1.12		24	1.266	5.064	1.469
2N2369A	1	.32	.32		6	1.266	1.266	.405
2N2907A	2	.29	.58		12	2.124	4.248	1.232
2N5783	14	.50	7.00		84	2.498	34.972	17.486
1N749A	1	.40	.40		5	.4	.4	.160
1N750A	1	.40	.40		5	.4	.4	.160
1N914	18	.10	1.80		90	.155	2.79	.279
Resistors	38	.03	1.74		290	.013	.754	.022
Capacitors	17	.03	.70		85	.39	9.35	.281
TOTALS								

SYSTEM EROS II

SUB-ASSEMBLY LOGIC (Cont'd)

SHEET 8 OF 9

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Connector	2	2.94	5.88		125	-	-	
PC Board	2	5.88	11.75	1303	20	-	-	
TOTALS			285.75	1303	1252 x 2		78.07	$\frac{158.99}{78.08} = 2.05$

SYSTEM EROS II

SUB-ASSEMBLY POWER SUPPLY

SHEET 9 OF 9

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
2N3055	3	.84	2.52		18	3.749	11.247	9.45
IN4002	14	.10	1.40		70	.358	5.012	.501
IN4738A	1	.25	.25		5	.4	.4	.100
IN5401	8	.25	2.00		40	.358	2.864	.716
Capacitors	17	.73	12.47		85	.55	9.35	6.826
Resistors	11	.25	2.75		55	.013	.143	.036
Transformer	3	12.03	36.10		945	2.309	6.927	83.332
PC Board	1	2.52	2.52	150	20			
Chassis	1	4.20	4.20	100	15			
Connector	1	2.18	2.18		25			
Fuse & Holder	1	1.26	1.26		25			
TOTALS			67.65	250	1303.		35.943	$\frac{100.958}{35.943} = 2.82$

SYSTEM SECANT

SHEET 1 OF 5

SUB-ASSEMBLY MICROWAVE MODULE

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MC1350	25	.67	16.75		150	.715	17.875	11.980
MPSH81	45	.21	9.45		270	1.266	56.97	11.964
MMT8015	6	3.07	18.42		36	1.266	7.596	23.320
7403	6	.35	2.10		36	.030	.18	.063
7442	1	1.45	1.45		6	.030	.03	.044
9582	3	1.45	4.35		18	.715	2.145	3.110
HP Diode	6	.35	2.10		30	.155	.93	.326
Limit er Pin-Diode	2	.35	.70		10	.155	.31	.109
2N6389	5	2.67	13.35		30	3.749	18.745	50.049
RCA41038	1	2.39	2.39		6	1.266	1.266	3.026
CA3083	1	.42	.42		6	.715	.715	.300
2N6266	1	62.54	62.54		6	9.76	9.76	610.39
2N6267	2	69.96	139.92		12	8.48	16.96	1186.522
Cap. Var.	12	.11	1.32		60	1.58	18.96	2.086
Coils	111	.06	6.66		555	.069	7.659	.460
H3302	10	3.02	30.20		250	.93	9.3	28.086
Mixer	8	3.02	24.16		200	.379	3.032	9.157
Crystal	12	1.06	12.72		240	.226	2.712	2.875
Potentiometer	3	.37	1.11		45	.664	1.992	.737
Circulator	2	56.92	113.84		50	5.00	10.00	569.200
Filter	2	3.18	6.36		40	4.43	8.86	28.175
Diode Switch	1	3.02	3.02		10	.155	.155	.468
TOTALS								

SYSTEM SECANT

SHEET 2 OF 5

SUB-ASSEMBLY MICROWAVE MODULE

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL. RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
BP Filter	1	3.18	3.18		20	4.43	4.43	14.087
Sub-Strate	5	3.18	15.90		30	1.0	5.00	15.900
Capacitors-T	19	.27	5.13		95	.55	10.450	2.822
Capacitors-M	450	.05	22.50		2250	.11	49.50	2.475
Resistors	210	.02	4.20		1050	.013	2.73	.055
PC Board	2	5.29	10.58	1636	20			
Misc. Hardware	Lot	340.04	340.04		500			
Connectors	Lot	31.80	31.80	3000	50			
Chassis	-	-	-	500	200			
Testing					1500			
TOTALS			906.66	5136	7781 x 2		268,262	$\frac{2577.786}{268.262} = 9.61$

SYSTEM SECANT

SUB-ASSEMBLY DETECTOR

SHEET 3 OF 5

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
MSI	8	2.12	16.96		48	.4	3.2	6.784
Potentiometer	8	.37	2.96		120	.664	5.312	1.965
Inductor	24	.85	20.40		120	.475	11.400	9.690
Cap. Adj.	8	.11	.88		120	1.58	12.64	1.390
Capacitor D	16	.05	.80		80	.55	8.8	.440
Capacitor T	16	.27	4.32		80	.55	8.8	2.376
Saw Filter	8	4.24	33.92		200	1.18	9.44	40.026
By-Pass Cap.	4	.16	.64		20	.55	2.2	.352
1C Amp.	1	2.12	2.12		8	.715	.715	1.516
P.C. Boards	10	.53	5.30	2000	100	-	-	-
Housing	1	9.00	9.00	400	125	-	-	-
TOTALS			97.30	2400	1021 x 3		61.792	$\frac{64.539}{61.792} = 1.04$

SYSTEM SECANT

SUB-ASSEMBLY LOGIC

SHEET 4 OF 5

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
LSI-Custom	42	12.70	533.20		252	.4	16.8	213.36
Crystal	1	1.06	1.06		15	.226	.226	.240
Diode	1	.35	.35		5	.155	.155	.054
Transistor	1	2.39	2.39		6	1.266	1.266	3.026
Resistor	4	.02	.08		20	.013	.052	.001
Capacitor	4	.05	.20		20	.55	2.2	.110
Tuned Coil	1	.06	.06		15	.475	.475	.029
I.C.	1	.35	.35		6	.715	.715	.250
P.C. Board	4	5.29	21.16	700	40			
P.C. Connector	4	3.71	14.84		60			
TOTALS			573.65	700	439 x 2		21.889	$\frac{217.27}{21.889} = 9.93$

SYSTEM ECANT

SUB-ASSEMBLY HOUSING

SHEET 5 OF 5

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL. RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
Front Panel	1	26.50	26.50	150	75	-	-	-
P. C. Cardholder	1	64.00	64.00		250	-	-	-
Assembly						-	-	-
HW 40D2	4	3.50	14.00		200	-	-	-
Fan	1	7.50	7.50		120	-	-	-
Dust Cover Slide		10.60	10.60	130	25	-	-	-
MS3102	1	15.90	15.90		25	-	-	-
PC02A 14-195W	1	14.84	14.84		25	-	-	-
PC02A 14-195	1	14.84	14.84		25	-	-	-
N-Conn.	2		1.44		50	-	-	-
Wiring	Lot	.72	-		400	-	-	-
TOTALS			169.62	280	1195 x 2			

SYSTEM HONEYWELL

SHEET 1 OF 3

SUB-ASSEMBLY ENCODER MODULE

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
PRESSURE SENSOR	1.	5.00	5.00		125.	16.	16	80.
LM 124	2	3.15	6.30		16.	.715	1.43	4.505
SN 7400	1	.30	.30		8.	.12	.12	.036
2N 2907	4	.35	1.40		24.	2.124	8.496	2.974
2N 4857	4	1.25	5.00		24.	11.904	47.616	59.520
IN 4148	8	.13	1.04		40.	.155	1.24	.161
LSI-CUSTOM	1	13.00	13.00		20.	.4	.4	5.200
POTENTIOMETER	1	3.65	3.65		15.	.664	.664	2.424
RESISTORS	37	.03	1.11		185.	.013	.481	.014
RESISTORS-WW	2	.25	.50		10.	.013	.026	.007
CAPS - DISC	2	.05	.10		10.	.291	.582	.029
CAPS - TANT	4	.23	.92		20.	.55	2.20	.056
PROM 93434	1	10.00	10.00		12.	.4	.4	4.00
LM 3612	4	4.00	16.00		40.	.715	2.86	11.440
SN 74273	1	3.15	3.15		8.	.715	.715	2.252
PC BOARD	1	35.00	5.00	818	25.			
PRESSURE FITTING	1	.45	.45		5.			
CONNECTOR	1	1.00	1.00		15.			
MISC. HARDWARE	LOT	1.50	1.50		25.			
TOTALS			75.42	818	627		83.23	$\frac{173.067}{83.23} = 2.08$

SYSTEM HONEYWELL

SUB-ASSEMBLY ENCODER MODULE

SHEET 2 OF 3

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL. RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
BASIC (PAGE)	1	75.42	75.42	818	627	83.23	83.23	173.067
INTEL 8080	1	10.00	10.00		20	.4	.4	4.000
8216	2	10.00	20.00		32	.715	1.43	14.300
8111-2	2	10.00	20.00		32	.715	1.43	14.300
8212	1	10.00	10.00		16	.715	.715	7.150
SENSOR TEST					200			
CALIBRATION					1710			
TOTALS			135.42	818	2637		87.205	$\frac{212.817}{87.205} = 2.44$

SYSTEM NARCO

SHEET 3 OF 3

SUB-ASSEMBLY ENCODER MODULE

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT FAILURE RATE	TOTAL FAILURE RATE	QTY x FAIL.RATE x UNIT COST
				MANUFACTURING	ASSEMBLY			
RESISTOR - PREC.	11	.25	2.75		55	.013	.143	.036
RESISTOR - POT	5	.95	4.75		75	.664	3.32	3.154
RESISTOR -TEMP. SENS	1	1.50	1.50		5	1.35	1.35	2.025
THERMISTOR	1	.56	.56		5	1.35	1.35	.756
OPTICAL COUPLER	1	.75	.75		8	1.35	1.35	1.013
THERMAL CUT-OFF	1	.25	.25		15			
PC BOARD	1	5.00	5.00	818	25			
CONNECTOR	1	1.00	1.00		15			
PNEUMATIC CONN.	1	.45	.45		5			
MISC. HARDWARE	LOT	1.50	1.50		25			
25 COND. CABLE	1	2.50	2.50		1042.			
ALIGNMENT & TEST					1000.			
6 CONDUCTOR CABLE w/PLUG	1	1.00	1.00		250.			
TOTALS			73.39	818	3088x1.5		51.385	$\frac{597.575}{51.385} = 11.24$

APPENDIX D

LIFE CYCLE COST MODEL

CONTENTS

1. Mathematical Formulation of the Cost Model

2. CAS Life Cycle Cost Model Parameter Summary

3. Typical Data File for "Test" CAS

4. Typical User File for "Use" Category

5. Life Cycle Cost Model Program

REVISION No. 1

LIFE CYCLE COST MODEL FOR THE EVALUATION OF LIFE CYCLE COSTS, SYSTEM OPERABILITY AND RELIABILITY OF ALTERNATIVE COLLISION AVOIDANCE SYSTEMS

Prepared For

FEDERAL AVIATION ADMINISTRATION
OFFICE OF SYSTEMS ENGINEERING MANAGEMENT

AEM-200
UNDER CONTRACT DOT-FA 74WA-3506

3 September 1974
Revised 16 October 1974

Prepared By

The Telecommunications Program
of
ARINC Research Corporation
a Subsidiary of Aeronautical Radio, Inc.
2551 Riva Road
Annapolis, Maryland 21401

CONTENTS

		Page
1.	GENERAL DESCRIPTION	1
2.	PROGRAM FEATURES	1
3.	MODEL FORMULATION	2
4.	SAMPLE RESULTS	15

1. GENERAL DESCRIPTION

ARINC Research Corporation's life cycle cost model (LCCM) has been adapted to evaluate the economic impact of proposed collision avoidance systems (CAS) and to provide a basis for cost comparisons among the several competing CAS concepts currently under development. The specific concepts being evaluated within the current ARINC Research study are:

(1) AVOIDS (Minneapolis-Honeywell)
(2) EROS (McDonnell-Douglas)
(3) SECANT (RCA)

The model evaluates each of these concepts in three different user environments: Commercial Aviation, General Aviation, and Military Aviation. Further, within each user category and concept combination evaluation, the model considers (as appropriate) three levels of CAS: a full or commercial aviation capability, a limited or general aviation capability, and a remitter capability. The distribution of these three levels within a specific user category is specified by the input data to the model.

The model itself is an expected value model which has been programmed in FORTRAN for evaluation using the Control Data KRONOS 2.1 Time Sharing System. The model computes the expected acquisition, installation and logistic support costs by year and cumulative for each concept/user combination desired. The program is designed for flexibility so that data changes can be readily implemented, sensitivity evaluations can be performed, or additional data outputs can be obtained.

2. PROGRAM FEATURES

The CAS LCCM implementation consists of a common main program, called CASCOST, and six input data files called AVOIDS, EROS, SECANT, COM, GEN, and MIL. (Differences due to the specific user categories are handled through appropriate modification of the data files.) At the beginning of the program's exercise, the system and user file names are specified from the teletype terminal keyboard. The program then calls the designated files and reads them to obtain the specific data parameters used in the evaluation.

In addition to calling the user and system files, the inflation rate and the type of evaluation to be performed (i.e., whether for full only, limited only, remitter only, or the composite of all three) are also specified as inputs from the teletype terminal keyboard.

The specific outputs of the model are as follows:

(1) The total acquisition cost for the designated user category and system by year and cumulative.

(2) The total installation cost for the designated user category and system by year and cumulative.

(3) The total non-recurring logistic support cost for the designated user category and system by year.

(4) The total recurring logistic support cost for the designated user category and system by year.

(5) The total logistic support cost for the designated user category and system by year and cumulative.

(6) The total cost for the designated user category and system by year and cumulative.

(7) The cost per aircraft for the designated user category and system by year (e.g., the cumulative total cost in year I divided by the number of CAS equipped user aircraft in year I.)

(8) The ratio of average cumulative total logistic support cost to cumulative acquisition cost in percent for the designated user category and system by year (e.g., 100 times the cumulative total logistic support cost in year I divided by I times the cumulative acquisition cost in year I.)

(9) The detailed cost element breakdowns of the non-recurring, recurring and total logistic support costs for the designated user and system by year.

(10) The cost per aircraft per year to the aircraft owner and the corresponding average annual logistic support to acquisition cost ratio (General Aviation case only).

3. MODEL FORMULATION

The following describes the mathematical formulation of the CAS LCCM which has been implemented into the program CASCOST. The parameter definitions used in the model are presented in Attachment A and correspond to those previously submitted to the FAA.* As noted earlier, the model computes on a yearly and cumulative basis the acquisition, installation, logistic support costs, and their totals for a given CAS system concept and user category combination in the time period 1978-1988. Inflation factors are applied to all of the cost categories over the time period of interest.

---

* Submitted in conjunction with the revision of the "Recommended Uniform Ground Rules for the Evaluation of Life-Cycle Costs, Systems Operability and Reliability of Alternative Collision Avoidance Systems"prepared for the FAA by ARINC Research on 9 August 1974.

3.1 Acquisition Costs

The acquisition costs are determined by the number of CAS systems purchased for a given user category each year, the average unit cost of the systems during the year (reflecting learning and amortization factors), and the effects of inflation. The acquisition costs for the i'th year are given by:

$$
\begin{aligned}
ACOS_i &= \Big[F(FUCOS + AFCOS) + L(LUCOS + ALCOS) \\
&\quad + E(EUCOS + AECOS)\Big] \; (1 + XINF)^{i-1}; \; i \leq 2 \\
&= \Big[F(FUCOS + L(LUCOS) + E(EUCOS)\Big] \; (1 + XINF)^{i-1}; \; i > 2 \qquad (1)
\end{aligned}
$$

where:

$$F = Q(Q1) \; (IRAC_i + NNAC_i) \qquad (2)$$

$$L = Q(1-Q1) \; (1-FREM) \; (IRAC_i + NNAC_i) \qquad (3)$$

$$E = Q(1-Q1) \; (FREM) \; (IRAC_i + NNAC_i) \qquad (4)$$

$IRAC_i$ = the number of aircraft retrofitted in year i

$NNAC_i$ = the number of new aircraft in year i

All other variables are as identified in Attachment A.

The cumulative acquisition cost is simply:

$$TCOSA_i = \sum_{j=1}^{i} ACOS_j \qquad (5)$$

3.2 Installation Costs

The installation cost in the i'th year is determined simply by the number of CAS units installed in new aircraft or retrofited into existing aircraft that year times the appropriate per unit installation rate and modified by the inflation factor. The resultant installation cost is given by:

$$ICOS_i = Q \Big[Q1\ (IRAC_i \cdot RICOS + NNAC_i \cdot FICOS) + (1-Q1)\ (1-FREM)\ (IRAC_i \cdot LRCOS + NNAC_i \cdot LICOS) + (1-Q1)\ (FREM)\ (IRAC_i \cdot ERCOS + NNAC_i \cdot EICOS) \Big]\ (1 + XINF)^{i-1} \qquad (6)$$

The cumulative installation cost is simply:

$$TOCI_i = \sum_{j=1}^{i} ICOS_j \qquad (7)$$

3.2 Logistic Support Cost

The logistic support cost is considered to be composed of the sum of eight cost elements, each having a non-recurring and recurring cost component. Hence, the logistic support cost in the i'th year and the cumulative logistic support cost to that year are given by:

$$LCOS_i = \sum_{j=1}^{8} \left[NRCOS_{i,j} + RLCOS_{i,j} \right] \qquad (8)$$

$$TCOSL_i = \sum_{j=1}^{i} LCOS_j \qquad (9)$$

The following paragraphs present the methodology for determining the individual cost elements and their components.

3.3.1 Initial and Replacement Spares

This cost element consists of the expenses associated with the procurement of the spares inventory. The nonrecurring component is the expenditure in the i'th year to purchase the additional spares required to satisfy the demand with a given level of spares sufficiency. In determining the nonrecurring costs, there are several assumptions and constraints which should be noted:

(1) A minimum of one spare at each base is assumed for the principal electronics, pilot's maneuver indicator, and control panel for each level of CAS capability.

(2) A minimum of one spare of each type of principal electronics module is assumed for each depot.

(3) No spares are assumed for the complete antenna systems.

The recurring spares cost represents the cost of purchasing additional spares to replace those which are lost to the logistic system through condemnation actions. Inflation factors are applied to both components. The resultant components are given by:

$$
\begin{aligned}
NRCOS_{i,1} = \Bigg\{ \sum_{j=1}^{NFMOD} \Bigg[& \frac{(PFOH)(Q)(Q1)}{FMTBF_j} \left[DRCT(1-RTS_j) + BRCT(RTS_j) \right] \\
& + SUF \sqrt{\frac{(PFOH)(Q)(Q1)}{FMTBF_j} \left[DRCT(1-RTS_j) + BRCT(RTS_j) \right]} - TSPRF_j \Bigg] FUC_j \\
& + \sum_{j=1}^{NFMOD} \Bigg[\frac{(PFOH)(Q)(1-Q1)(1-FREM)}{LMTBF_j} \left[DRCT(1-RTS_j) + BRCT(RTS_j) \right] \\
& + SUF \sqrt{\frac{(PFOH)(Q)(1-Q1)(1-FREM)}{LMTBF_j} \left[DRCT(1-RTS_j) + BRCT(RTS_j) \right]} \\
& - TSPRL_j \Bigg] LUC_j + \sum_{j=1}^{NEMOD} \Bigg[\frac{(PFOH)(Q)(1-Q1)(FREM)}{EMTBF_j} \left[DRCT(1-RTS_j) \right. \\
& \left. + BRCT(RTS_j) \right] + SUF \sqrt{\frac{(PHOH)(Q)(1-Q1)(FREM)}{EMTBF_j}} \\
& \sqrt{\left[DRCT(1-RTS_j) + BRCT(RTS_j) \right]} - TSPRE_j \Bigg] EUC_j \Bigg\} (1+XINF)^{i-1} \qquad (10)
\end{aligned}
$$

$$RLCOS_{i,1} = (TFOH)(Q)\left\{ Q1 \sum_{j=1}^{NFMOD} \frac{(FUC_j)(COND_j)}{(FMTBF_j)} \right.$$

$$+ (1-Q1)(1-FREM) \sum_{j=1}^{NLMOD} \frac{(LUC_j)(COND_j)}{(LMTBF_j)}$$

$$\left. + (1-Q1)(FREM) \sum_{j=1}^{NEMOD} \frac{(EUC_j)(COND_j)}{(EMTBF_j)} \right\} (1+XINF)^{i-1} \qquad (11)$$

where:

$$PFOH = (PHR)(NAC_i - (IT-i)/IT) \; ; \; i \leq IT$$

$$= (PHR)(NAC_i) \; ; \; i > IT \qquad (12)$$

$$TFOH = 12(AHR)(NAC_i - (IT-i)/IT) \; ; \; i \leq IT$$

$$= 12(AHR)(NAC_i) \; ; \; i > IT \qquad (13)$$

$$NFMOD = NMODF + 4$$

$$NLMOD = NMODL + 4$$

$$NEMOD = NMODE + 4$$

$TSPRF_j$, $TSPRL_j$ and $TSPRE_j$ represent the total number of the j'th type of spares purchased prior to the year i.

3.3.2 On-Aircraft Maintenance

This cost element represents the expected expenditure in performing on-aircraft corrective maintenance. This element contains only a recurring cost component, i.e., $NRCOS_{i,2} = 0$, and represents the labor cost associated with remove and replace actions. It is assumed that no individual principal electronics modules will be removed and replaced on an on-aircraft basis. The cost element is given by:

$$RLCOS_{i,2} = (TFOH)(Q)(BLR)\left[\sum_{j=1}^{4} \frac{(Q1)(FRMH_j)}{(FMTBF_j)} + \frac{(1-Q1)(1-FREM)(LRMH_j)}{(LMTBF_j)} + \frac{(1-Q1)(FREM)(ERMH_j)}{(EMTBF_j)}\right](1+XINF)^{i-1} \tag{14}$$

3.3.3 Off-Aircraft Maintenance

The expected labor, materiel, and shipping costs associated with performing corrective maintenance at base and depot locations are represented by this cost element. Like the preceeding element, this element is a recurring cost only, i.e. $NRCOS_{i,3} = 0$. The element is given by: (the factor 1.125 shown in the equation represents the additional weight due to packaging for shipment.)

$$
\begin{aligned}
RLCOS_{i,3} = (TFOH)(Q)\Bigg\{ & Q1 \sum_{j=1}^{NFMOD} \Big[(FDMH_j)\big[(RTS_j)(BLR)+(1-RTS_j)(DLR)\big] \\
& + FDMC_j + 1.125\ (SHC)(FWT_j)\big[2(1-RTS_j)(1-FCOND_j)+ FCOND_j\big]\Big]/(FMTBF_j) \\
& + (1-Q1)(1-FREM) \sum_{j=1}^{NLMOD} \Big[(LDMH_j)\big[(RTS_j)(BLR) + (1-RTS_j)(DLR)\big] \\
& + LDMC_j + 1.125\ (SHC)(LWT_j)\big[2(1-RTS_j)(1-LCOND_j) + LCOND_j\big]\Big]/ LMTBF_j) \\
& + (1-Q1)(FREM) \sum_{j=1}^{NEMOD} \Big[(EDMH_j)\big[(RTS_j)(BLR) + (1-RTS_j)(DLR)\big] \\
& + EDMC_j + 1.125\ (SHC)(EWT_j)\big[2(1-RTS_j)(1-ECOND_j) \\
& + ECOND_j\big]\Big]/(EMTBF_j)\Bigg\}(1 + XINF)^{i-1} \qquad (15)
\end{aligned}
$$

3.3.4 Inventory Entry and Supply Management

This cost element represents the management cost associated with introducing and maintaining new coded supply items into the user inventory and the management cost of maintaining a supply inventory for all of the coded items for the system that are stocked at the repair sites. The first year's inventory entry cost is treated as a nonrecurring cost and is then treated as part of the recurring cost in subsequent years. The supply management cost is treated as a recurring cost throughout. The resultant components are given by:

$$NRCOS_{i,4} = (IAC)\left[(PPF)(PPFB) + (PPL)(PPLB) + (PPE)(PPEB)\right] \; ; \quad i = 1$$

$$= 0 \; ; \quad i > 1 \tag{16}$$

$$RLCOS_{i,4} = SA\left[4\,(PPFB+PPLB+PPEB)(NBAS_i) + \left[(TPF)(PPFB) + (TPL)(PPLB) + (TPE)(PPEB)\right](NDEP_i)\right] \; ; \quad i = 1$$

$$= \left\{(IAC)\left[(PPF)(PPFB) + (PPL)(PPLB) + (PPE)(PPEB)\right] + SA\left[4\,(PPFB+PPLB+PPEB)(NBAS_i) + \left[(TPF)(PPFB) + (TPL)(PPLB) + (TPE)(PPEB)\right](NDEP_i)\right]\right\}(1+XINF)^{i-1} \; ; \quad i > 1 \tag{17}$$

where:

$PPFB = 0; \quad Q1 = 0$

$\quad\;\; = 1; \quad Q1 \neq 0$

$PPLB = 0; \quad Q1 = 1 \text{ or } FREM = 1$

$\quad\;\; = 1; \quad Q1 \neq 1 \text{ and } FREM \neq 1$

$$PPEB = 0; \quad Q1 = 1 \text{ or } FREM = 0$$

$$= 1; \quad Q1 \neq 1 \text{ and } FREM \neq 0$$

3.3.5 Special Support Equipment

This cost element includes the nonrecurring cost of purchasing special test equipment ($NRCOS_{i,5}$) and the recurring cost of operating the test equipment ($RLCOS_{i,5}$). It is assumed in the model that the test equipment will be unique to the principal electronics and will only be operated at depot level facilities. It is further assumed that there will be a minimum of one such unit at each depot facility. The nonrecurring and recurring costs of special support equipment in the i'th year, assuming NSUPF, NSUPL, and NSUPE units of support equipment have been purchased prior to year i, are given by:

$$NRCOS_{i,5} = \left\{ \left[\frac{(PFOH)(Q)(Q1)(FDMH_1)(DUR)}{(FMTBF_1)(ATE)(DAA)} - NSUPF \right] (CADF) \right.$$

$$+ \left[\frac{(PFOH)(Q)(1-Q1)(1-FREM)(LDMH_1)(DUR)}{(LMTBF_1)(ATE)(DAA)} - NSUPL \right] (CADL)$$

$$+ \left[\frac{(PFOH)(Q)(1-Q1)(FREM)(EDMH_1)(DUR)}{(EMTBF_1)(ATE)(DAA)} - NSUPE \right] (CADE)$$

$$(1+XINF)^{i-1} \tag{18}$$

$$RLCOS_{i,5} = \frac{(PFOH)(Q)(DUR)}{(ATE)(DAA)} \left[\frac{(Q1)(FDMH_1)(CODF)}{(FMTBF_1)} + \frac{(1-Q1)(1-FREM)(LDMH_1)(CODL)}{(LMTBF_1)} + \frac{(1-Q1)(FREM)(EDMH_1)(CODE)}{(EMTBF_1)} \right] (1+XINF)^{i-1} \quad (19)$$

3.3.6 Training

The training cost consists of the specialized maintenance training to meet the expected corrective maintenance demands ($NRCOS_{i,6}$) and the recurrent cost of additional specialized training resulting from turnover of personnel ($RLCOS_{i,6}$). It is assumed that training requirements are associated with only the principal electronics and are common to all three levels of systems. It is further assumed that this training cost is only incurred for depot level personnel and that a minimum of one person per depot will receive training. The training costs in the i'th year are then, assuming NPERS have been trained prior to year i:

$$NRCOS_{i,6} = \left[\frac{(TFOH)(Q)}{(PMD)} \left[(Q1) \sum_{\substack{j=1 \\ j\neq 2,3,4}}^{NFMOD} \frac{(FDMH_j)}{(FMTBF_j)} + (1-Q1)(1-FREM) \sum_{\substack{j=1 \\ j\neq 2,3,4}}^{NLMOD} \frac{(LDMH_j)}{(LMTBF_j)} + (1-Q1)(FREM) \sum_{\substack{j=1 \\ j\neq 2,3,4}}^{NEMOD} \frac{(EDMH_j)}{(EMTBF_j)} \right] - NPERS \right] (TCD)(1+XINF)^{i-1} \quad (20)$$

$$RLCOS_{i,6} = \frac{(TFOH)(Q)(TRD)(TCD)}{(PMD)} \left[(Q1) \sum_{\substack{j=1 \\ j \neq 2,3,4}}^{NFMOD} \frac{(FDMH_j)}{(FMTBF_j)} \right.$$

$$+ (1-Q1)(1-FREM) \sum_{\substack{j=1 \\ j \neq 2,3,4}}^{NLMOD} \frac{(LDMH_j)}{(LMTBF_j)}$$

$$+ (1-Q1)(FREM) \sum_{\substack{j=1 \\ j \neq 2,3,4}}^{NEMOD} \frac{(EDMH_j)}{(EMTBF_j)} (1+XINF)^{i-1} \; ; \quad i > 1$$

$$= 0; \quad i = 1 \tag{21}$$

3.3.7 Data Management and Technical Documentation

This cost element consists of the recurring costs arising from the labor time involved in filling out the necessary forms associated with each maintenance action ($RLCOS_{i,7}$) and the nonrecurring cost ($NRCOS_{i,7}$) associated with the preparation of base and depot level documentation. These are given by:

$$NRCOS_{i,7} = TD \left[(NBDF+NDDF)(PPFB) + (NBDL+NDDL)(PPLB) + (NBDE+NDDE) \right.$$

$$(PPEB) \; ; \quad i = 1$$

$$= 0; \quad i > 1 \tag{22}$$

$$RLCOS_{i,7} = (TFOH)(Q)(BLR)\left\{\sum_{j=1}^{4}\left[\frac{(Q1)(OR+FR+SR+(1-RTS_j)TR)}{(FMTBF_j)}\right.\right.$$

$$+\frac{(1-Q1)(1-FREM)(OR+FR+SR+(1-RTS_j)TR)}{(LMTBF_j)}$$

$$\left.\left.+\frac{(1-Q1)(FREM)(OR+FR+SR+(1-RTS_j)TR)}{(EMTBF_j)}\right]\right\}(1+XINF)^{i-1} \qquad (23)$$

3.3.8 Facilities

The facilities costs are considered to consist of the recurring operating costs of the repair facilities (e.g., space rent, electricity, general tools, telephone, etc.) It is assumed that no new support facilities will be needed for the system and hence no nonrecurring costs will be required, i.e., $NRCOS_{i,8} = 0$. The recurring cost is then given by:

$$RLCOS_{i,8} = \left[(FIB)(NBAS_i) + (FID)(NDEP_i)\right](1+XINF)^{i-1} \qquad (24)$$

4. SAMPLE RESULTS

In order to demonstrate the application of the model and its resultant outputs, the program was exercised for a sample system (File Name TEST) and a sample user (File Name USE). Attachments B through D present the data files used for this exercise as well as the listing of CASCOST. The resultant output obtained from the program exercise is presented below.

TYPICAL LIFE CYCLE COST PROFILE PRINTOUT

"TEST" CAS IN A "USE" CATEGORY

RUN,MA=77777

74/08/26. 16.19.33.
PROGRAM CASCOST

-------CAS LIFE CYCLE COST EVALUATION-------
SYSTEM ? TEST
USER ? USE

YEAR	ACQ COST	CUM COST	INST COST	CUM COST
1978	1733774	1733774	4176458	4176458
1979	1299975	3033749	4427045	8603503
1980	1175809	4209558	4692668	13296170
1981	1150699	5360257	4974228	18270400
1982	1149493	6509750	5272682	23543082
1983	1162231	7671981	5589043	29132125
1984	1184509	8856490	5924385	35056510
1985	1214064	10070554	6279849	41336359
1986	181342	10251896	551392	41887751
1987	191430	10443326	584475	42472226
1988	202095	10645421	619544	43091770

YEAR	NREC LCOST	REC LCOST	TOT LCOST	CUM LCOST
1978	242500	437312	679812	679812
1979	151580	645993	797573	1477386
1980	161202	871105	1032313	2509699
1981	180230	1120913	1301143	3810842
1982	185048	1397856	1582903	5393745
1983	196318	1703364	1899682	7293427
1984	217530	2041171	2258701	9552128
1985	230882	2433387	2664270	12216398
1986	30682	2616385	2647067	14863464
1987	35775	2812582	2848357	17711821
1988	35459	3022904	3058362	20770183

YEAR	CAS COST	CUM COST	PER A/C	ANNUAL LCOS/ACOS
1978	6590044	6590044	9243	32.21
1979	6524594	13114638	9203	24.35
1980	6900791	20015428	9362	19.37
1981	7426071	27441499	9629	17.77
1982	8005078	35446577	9949	16.57
1983	8650955	44097533	10315	15.84
1984	9367595	53465128	10719	15.41
1985	10158183	63623310	11162	15.16
1986	3379800	67003111	11552	16.11
1987	3624262	70627373	11971	16.96
1988	3880001	74507374	12418	17.74

DØ YØU WANT LØGISTIC SUPPØRT CØSTS BREAKDØWN BY YEAR?
TYPE YES ØR NØ ? YES

YEAR	ELEMENT	NREC LCØST	REC LCØST	TØT LCØST
1978				
	SPARES	173475	17963	191438
	ØNMAINT	0	9103	9103
	ØFFMAINT	0	125673	125673
	INVMGT	5775	11700	17475
	SUPPØRT	15250	241	15491
	TRAINING	3200	0	3200
	TECHDATA	44800	12633	57433
	FACILITIES	0	260000	260000
1979				
	SPARES	148188	38056	186244
	ØNMAINT	0	19284	19284
	ØFFMAINT	0	266239	266239
	INVMGT	0	18523	18523
	SUPPØRT	0	511	511
	TRAINING	3392	1018	4410
	TECHDATA	0	26763	26763
	FACILITIES	0	275600	275600
1980				
	SPARES	159411	60523	219233
	ØNMAINT	0	30668	30668
	ØFFMAINT	0	423419	423419
	INVMGT	0	19635	19635
	SUPPØRT	0	812	812
	TRAINING	1798	1348	3146
	TECHDATA	0	42563	42563
	FACILITIES	0	292136	292136
1981				
	SPARES	170464	85519	255983
	ØNMAINT	0	43335	43335
	ØFFMAINT	0	598293	598293
	INVMGT	0	20813	20813
	SUPPØRT	5955	1148	7103
	TRAINING	3811	2001	5812
	TECHDATA	0	60141	60141
	FACILITIES	0	309664	309664
1982				
	SPARES	181008	113328	294336
	ØNMAINT	0	57426	57426
	ØFFMAINT	0	792849	792849
	INVMGT	0	22062	22062
	SUPPØRT	0	1521	1521
	TRAINING	4040	2727	6767
	TECHDATA	0	79698	79698
	FACILITIES	0	328244	328244
1983				
	SPARES	194177	144133	338310
	ØNMAINT	0	73036	73036
	ØFFMAINT	0	1008363	1008363
	INVMGT	0	23385	23385
	SUPPØRT	0	1934	1934
	TRAINING	2141	3212	5353
	TECHDATA	0	101362	101362
	FACILITIES	0	347939	347939

```
1984
    SPARES          205898      178262      384160
    ØNMAINT              0       90330       90330
    ØFFMAINT             0     1247134     1247134
    INVMGT               0       24789       24789
    SUPPØRT           7093        2392        9485
    TRAINING          4539        4085        8625
    TECHDATA             0      125363      125363
    FACILITIES           0      368815      368815
1985
    SPARES          218177      215930      434107
    ØNMAINT              0      109418      109418
    ØFFMAINT             0     1510662     1510662
    INVMGT               0       33042       33042
    SUPPØRT           7894        1449        9343
    TRAINING          4812        5052        9864
    TECHDATA             0      151854      151854
    FACILITIES           0      405980      405980
1986
    SPARES           30682      232902      263583
    ØNMAINT              0      118018      118018
    ØFFMAINT             0     1629395     1629395
    INVMGT               0       35025       35025
    SUPPØRT              0        1563        1563
    TRAINING             0        5355        5355
    TECHDATA             0      163789      163789
    FACILITIES           0      430339      430339
1987
    SPARES           35775      251132      286907
    ØNMAINT              0      127256      127256
    ØFFMAINT             0     1756937     1756937
    INVMGT               0       37126       37126
    SUPPØRT              0        1685        1685
    TRAINING             0        5677        5677
    TECHDATA             0      176610      176610
    FACILITIES           0      456159      456159
1988
    SPARES           35459      270712      306171
    ØNMAINT              0      137177      137177
    ØFFMAINT             0     1893919     1893919
    INVMGT               0       39354       39354
    SUPPØRT              0        1816        1816
    TRAINING             0        6017        6017
    TECHDATA             0      190379      190379
    FACILITIES           0      483529      483529
DØ YØU WANT TØ RUN ANØTHER CASE (TYPE YES ØR NØ) ? NØ
   STØP
```

ATTACHMENT B

TYPICAL DATA FILE FOR "TEST"CAS

```
 74/03/26. 16.12.27.
PROGRAM    TEST

10 TEST DATA FILE
20 FUCOS 10000. LUCOS 5000. EUCOS 3000.
30 AFCOS 50000. ALCOS 25000. AECOS 10000.
40 NMODF 4 NANTF 2
50 LECTRONICS FUC 300. FMTBF 1000. FWT 25.
60 FRMH .25 FDMH .5 FDMC 0. FCOND .001
70 INDICATOR FUC 250. FMTBF 3000. FWT 3.
80 FRMH .5 FDMH 2. FDMC 25. FCOND .01
90 CONTROL FUC 50. FMTBF 10000. FWT 1.
100 FRMH .25 FDMH .75 FDMC 5. FCOND .01
110 ANTENNA FUC 0. FMTBF 50000. FWT 0.
120 FRMH 2. FDMH 0. FDMC 50. FCOND 0.
130 XMTTR FUC 200. FMTBF 4000. FWT 0.
140 FRMH 0. FDMH 2. FDMC 50. FCOND .1
150 RCVR FUC 200 FMTBF 4000. FWT 0.
160 FRMH 0. FDMH 2. FDMC 25. FCOND .1
170 LOGIC FUC 200. FMTBF 4000. FWT 0.
180 FRMH 0. FDMH 3. FDMC 75. FCOND .1
190 BIT FUC 200 FMTBF 4000. FWT 0.
200 FRMH 0. FDMH 1. FDMC 20. FCOND .1
300 NMODL 4 NANTL 2
310 LECTRONICS FUC 500. LMTBF 500. LWT 15.
320 LRMH .25 LDMH .5 LDMC 0. LCOND .001
330 INDICATOR LUC 50. LMTBF 1000. LWT 2.
340 LRMH 1. LDMH 2. LDMC 10. LCOND .01
350 CONTROL LUC 50. LMTBF 10000. LWT .5
360 LRMH .5 LDMH .75 LDMC 5. LCOND .01
370 ANTENNA LUC 0. LMTBF 50000. LWT 0.
380 LRMH 2. LDMH 0. LDMC 50. LCOND 0.
390 XMTTR LUC 125. LMTBF 2000. LWT 0.
400 LRMH 0. LDMH 2. LDMC 50. LCOND .1
410 RCVR LUC 125. LMTBF 2000. LWT 0.
420 LRMH 0. LDMH 1.5 LDMC 30. LCOND .1
430 LOGIC LUC 125. LMTBF 2000. LWT 0.
440 LRMH 0. LDMH 3. LDMC 50. LCOND .1
450 BIT LUC 125. LMTBF 2000. LWT 0.
460 LRMH 0. LDMH 1. LDMC 20. LCOND .1
```

```
600 NMØDE 2 NANTE 1
610 LECTRØNICS EUC 175. EMTBF 1000. EWT 5.
620 ERMH .25 EDMH .5 EDMC 0. ECØND .001
630 INDICATØR EUC 0. EMTBF 10.E10 EWT 0.
640 ERMH 0. EDMH 0. EDMC 0. ECØND 0.
650 CØNTRØL EUC 25. EMTBF 10000. EWT .5
660 ERMH .75 EDMH 1. EDMC 2. ECØND .01
670 ANTENNA EUC 0. EMTBF 50000. EWT 0.
680 ERMH 2. EDMH 0. EDMC 25. ECØND 0.
690 XMITTER EUC 100. EMTBF 2000. EWT 3.
700 ERMH 0. EDMH 2. EDMC 30. ECØND .1
710 RCVR EUC 75. EMTBF 2000. EWT 2.
720 ERMH 0. EDMH 2. EDMC 20. ECØND .1
800 CADE 10000. CADL 5000. CADE 250.
810 CØDE 1000. CØDL 500. CØDE 25.
820 PPE 25. PPL 25. PPE 5.
830 TPE 150. TPL 125. TPE 100.
840 NBDE 50. NBDL 25. NBDE 5.
850 NDDE 100. NDDL 75. NDDE 25.
```

ATTACHMENT C

TYPICAL USER FILE FOR "USE" CATEGORY

```
 74/08/26. 16.17.21.
PRØGRAM,  USE

10 USE DATA FILE
20 FICØS 5000. LICØS 2500. EICØS 1000.
30 RICØS 8000. LRCØS 5000. ERCØS 2000.
40 1978 NAC 5000 NBAS 50 NDEP 1
50 1979 NAC 5100 NBAS 50 NDEP 1
60 1980 NAC 5200 NBAS 50 NDEP 1
70 1981 NAC 5300 NBAS 50 NDEP 1
80 1982 NAC 5400 NBAS 50 NDEP 1
90 1983 NAC 5500 NBAS 50 NDEP 1
100 1984 NAC 5600 NBAS 50 NDEP 1
110 1985 NAC 5700 NBAS 50 NDEP 2
120 1986 NAC 5800 NBAS 50 NDEP 2
130 1987 NAC 5900 NBAS 50 NDEP 2
140 1988 NAC 6000 NBAS 50 NDEP 2
150 NRAC 4900 IT 8 Q 1.1 Q1 .3 PQTY 5000.
160 ATE .9
170 DRCT 2.
180 BRCT .33
190 AHR 80.
200 PHR 100.
210 SUF 0.
220 BLR 10.
230 SHC .33
240 DLR 15.
250 RTSE 0.
260 RTSI 1.
270 RTSC 1.
280 RTSA 1.
290 IAC 105.
300 DUR .95
310 SA 12.
320 DAA 160.
330 TCB 1600.
340 TCD 1600.
350 PMB 1680.
360 PMD 1788.
370 3R .08
380 FR .24
390 SR .25
400 TR .16
410 TRB .33
420 TRD .15
425 TD 160.
430 FIB 5000.
440 FID 10000.
```

ATTACHMENT D

LIFE CYCLE COST MODEL PROGRAM

CAS COST

```
LNH
10 PRØGRAM CASCØST (INPUT,ØUTPUT,TAPE2,TAPE3)
20 DIMENSIØN NYR(12),NAC(12),NBAS(12),NDEP(12),ACØS(12),ICØS(12)
30 DIMENSIØN FUC(25),FMTBF(25),FWT(25),FRMH(25),FDMH(25),FDMC(25),
31+FCØND(25),LUC(25),EUC(25),TSPRF(25),TSPRL(25),TSPRF(25)
40 DIMENSIØN LMTBF(25),EMTBF(25),LWT(25),EWT(25),LRMH(25),ERMH(25),
41+LDMH(25),EDMH(25),LDMC(25),EDMC(25),LCØND(25),ECØND(25),AF(10),
42+AL(10),AE(10),AR(35),NRCØS(11,8),RLCØS(11,8),LCØS(12),RTS(4)
50 REAL LUCØS,LICØS,LRCØS,LA,ICØS,LUC,LMTBF,LWT,LRMH,LDMH,LDMC
60 REAL LCØND,IAC,NRCØS,LCØS,L1,L2
61 REAL NBDF,NBDL,NBDE,NDDF,NDDL,NDDE
62 DIMENSIØN TNRCØS(12),TRLCØS(12),TLLCØS(12)
63 DIMENSIØN CRFT(12)
70 53 PRINT,*-------CAS LIFE CYCLE CØST EVALUATIØN-------*
80 PRINT,* SYSTEM*,
90 READ, SFILE
100 PRINT,* USER*,
110 READ, UFILE
120 CALL GET (5HTAPE2,SFILE,0,0)
130 CALL GET (5HTAPE3,UFILE,0,0)
140 READ (2,) L,L,L,L
150 READ (2,) L,L,FUCØS,L,LUCØS,L,EUCØS
160 READ (2,) L,L,AFCØS,L,ALCØS,L,AECØS
170 READ (3,) L,L,L,L
180 READ (3,) L,L,FICØS,L,LICØS,L,EICØS
190 READ (3,) L,L,RICØS,L,LRCØS,L,ERCØS
200 READ (3,) (L,NYR(I),L,NAC(I),L,NBAS(I),L,NDEP(I),I=1,11)
210 DATA FREM /.1/,XLRN/.85/,XINF/.06/
220 READ (3,) L,L,NRAC,L,IT,L,Q,L,Q1,L,RØTY
230 IRAC=NRAC/IT
240 PRINT,* YEAR     ACQ CØST     CUM CØST    INST CØST     CUM CØST*
250 TCØSA=TCØSI=TCØSL=NNACT=TCØSR=TCØSN=0
260 B=ALØG(XLRN)/ALØG(2.0)
270 F1=L1=E1=0
280 EQUIVALENCE (FUCØS,FA),(LUCØS,LA),(EUCØS,EA)
290 AMØRF=AFCØS/2.$AMØRL=ALCØS/2.
300 AMØRE=AECØS/2.
310 DØ 1 I=1,11
320 ACØS(I)=ICØS(I)=0
330 NNAC=NAC(I)-NNACT-NRAC
335 CRFT(I)=NAC(I)-NRAC*(IT-I)/IT
336 IF(I.GT.IT)CRFT(I)=NAC(I)
337 IF(I.GT.IT)IRAC=0
340 F=INT(Q*Q1*(IRAC+NNAC))+1
350 L=INT(Q*(1-Q1)*(1-FREM)*(IRAC+NNAC))+1
360 E=INT(Q*(1-Q1)*FREM*(IRAC+NNAC))+1
```

```
370 F2=F1+F
380 L2=L1+L
390 E2=E1+E
400 IF(F1.GT.PQTY) GØTØ 2
410 IF(F2.GT.PQTY) GØTØ 3
420 XDUM=FA*(F2**(B+1)-F1**(B+1))/(F*(B+1))
430 GØTØ 4
440 3 XDUM=FA*((PQTY**(B+1)-F1**(B+1))/(B+1)+(F2-PQTY)*(PQTY**B))/F
450 GØTØ 4
460 2 XDUM=FA*(PQTY**B)
470 4 IF(I.GT.2) GØTØ 5
480 XDUM=XDUM+AMØRF/F
490 5 ACØS(I)=ACØS(I)+F*XDUM
500 IF(L1.GT.PQTY) GØTØ 6
510 IF(L2.GT.PQTY) GØTØ 7
520 XDUM=LA*(L2**(B+1)-L1**(B+1))/(L*(B+1))
530 GØTØ 8
540 7 XDUM=LA*((PQTY**(B+1)-L1**(B+1))/(B+1)+(L2-PQTY)*(PQTY**B))/L
550 GØTØ 8
560 6 XDUM=LA*(PQTY**B)
570 8 IF(I.GT.2) GØTØ 9
580 XDUM=XDUM+AMØRL/L
590 9 ACØS(I)=ACØS(I)+L*XDUM
600 IF(E1.GT.PQTY) GØTØ 10
610 IF(E2.GT.PQTY) GØTØ 11
620 XDUM=EA*(E2**(B+1)-E1**(B+1))/(E*(B+1))
630 GØTØ 12
640 11 XDUM=EA*((PQTY**(B+1)-E1**(B+1))/(B+1)+(E2-PQTY)*(PQTY**B))/E
650 GØTØ 12
660 10 XDUM=EA*(PQTY**B)
670 12 IF(I.GT.2) GØTØ 13
680 XDUM=XDUM+AMØRE/E
690 13 ACØS(I)=(ACØS(I)+E*XDUM)*((1+XINF)**(I-1))
700 TCØSA=TCØSA+ACØS(I)
710 IF(I.LE.IT)GØTØ 14
720 IRAC=0
730 14 ICØS(I)=Q*(Q1*(IRAC*RICØS+NNAC*FICØS)+(1-Q1)*(1-FREM)*(IRAC*
731+LRCØS+NNAC*LICØS)+(1-Q1)*FREM*(IRAC*ERCØS+NNAC*EICØS))*((
732+1+XINF)**(I-1))
740 TCØSI=TCØSI+ICØS(I)
750 PRINT 901, NYR(I),ACØS(I),TCØSA,ICØS(I),TCØSI
760 901 FØRMAT (I5,4F12.0)
770 F1=F2
780 L1=L2
790 E1=E2
800 1 NNACT=NNACT+NNAC
810 READ (2,) L,L,NMØDF,L,NANTF
820 NFMØD=NMØDF+4
830 DØ 15 I=1,NFMØD
840 READ (2,) L,L,L,FUC(I),L,FMTBF(I),L,FWT(I)
850 READ (2,) L,L,FRMH(I),L,FDMH(I),L,FDMC(I),L,FCØND(I)
851 15 CØNTINUE
860 READ (2,) L,L,NMØDL,L,NANTL
870 NLMØD=NMØDL+4
880 DØ 16 I=1,NLMØD
890 READ (2,) L,L,L,LUC(I),L,LMTBF(I),L,LWT(I)
```

```
900 16 READ (2,) L,L,LRMH(I),L,LDMH(I),L,LDMC(I),L,LCOND(I)
910 READ (2,) L,L,NMODE,L,NANTE
920 NEMOD=NMODE+4
930 DO 17 I=1,NEMOD
940 READ (2,) L,L,L,EUC(I),L,EMTBF(I),L,EWT(I)
950 17 READ (2,) L,L,ERMH(I),L,EDMH(I),L,EDMC(I),L,ECOND(I)
960 READ (2,)(L,L,AF(I),L,AL(I),L,AE(I),I=1,6)
980 EQUIVALENCE (AF(1),CADF),(AL(1),CADL),(AE(1),CADE),(AF(2),CODF),(
981+AL(2),CODL),(AE(2),CODE),(AF(3),PPF),(AL(3),PPL),(AE(3),PPE),(AF(4),
982+TPF),(AL(4),TPL),(AE(4),TPE),(AF(5),NBDF),(AL(5),NBDL),(AE(5),
983+NBDE),(AF(6),NDDF),(AL(6),NDDL),(AE(6),NDDE)
990 READ (3,)(L,L,AR(I),I=1,30)
1000 EQUIVALENCE (AR(1),ATE),(AR(2),DRCT),(AR(3),BRCT),(AR(4),AHR),(
1001+AR(5),PHR),(AR(6),SUF),(AR(7),BLR),(AR(8),SHC),(AR(9),DLR),(AR(
1002+10),RTS(1)),(AR(11),RTS(2)),(AR(12),RTS(3)),(AR(13),RTS(4)),(AR
1003+(14),IAC),(AR(15),DUR),(AR(16),SA),(AR(17),DAA),(AR(18),TCB),(
1004+AR(19),TCD),(AR(20),PMB),(AR(21),PMD),(AR(22),OB),(AR(23),FB),
1005+(AR(24),SR),(AR(25),TR),(AR(26),TRB),(AR(27),TRD),(AR(28),TD),
1006+(AR(29),FIB),(AR(30),FID)
1009 PRINT,*  *
1010 PRINT,* YEAR  NREC LCOST    REC LCOST    TOT LCOST    CUM LCOST*
1015 NSUPF=NSUPL=NSUPE=NPERS=0
1020 EMTBF(4)=EMTBF(4)/NANTE
1021 FAILF=FAILL=FAILE=0.
1022 DO 46 K=2,4
1023 FAILF=FAILF+1/EMTBF(K)
1024 FAILL=FAILL+1/LMTBF(K)
1025 46 FAILE=FAILE+1/EMTBF(K)
1030 LMTBF(4)=LMTBF(4)/NANTL
1040 EMTBF(4)=EMTBF(4)/NANTE
1042 DO 21 K=1,25
1044 21 TSPRF(K)=TSPRL(K)=TSPRE(K)=0
1050 DO 18 I=1,11
1060 MINSPB=NBAS(I)
1070 MINSPD=NDEP(I)
1072 TNRCOS(I)=TRLCOS(I)=0
1080 IF(UFILE.EQ.3HGEN)RTS(I)=FLOAT(NDEP(I))/FLOAT(NBAS(I))
1090 PFOH=PHR*CRFT(I)
1100 TFOH=12*AHR*CRFT(I)
1110 DO 19 J=1,8
1120 19 NRCOS(I,J)=RLCOS(I,J)=0
1130 DO 20 K=1,4
1140 NDUM=PFOH*Q*Q1*(DRCT*(1-RTS(K))+BRCT*RTS(K))/EMTBF(K)+SUF*
1141+SQRT(PFOH*Q*Q1*(DRCT*(1-RTS(K))+BRCT*RTS(K))/EMTBF(K))
1150 IF(NDUM.LT.MINSPB) NDUM=MINSPB
1155 IF(Q1.EQ.0.)NDUM=0
1160 NSPRF=NDUM-TSPRF(K)
1170 TSPRF(K)=NDUM
1180 NDUM=PFOH*Q*(1-Q1)*(1-FREM)*(DRCT*(1-RTS(K))+BRCT*RTS(K))/LMTBF(K)
1181++SUF*SQRT(PFOH*Q*(1-Q1)*(1-FREM)*(DRCT*(1-RTS(K))+BRCT*RTS(K))
1182+/LMTBF(K))
1190 IF(NDUM.LT.MINSPB) NDUM=MINSPB
1195 IF((Q1.EQ.1.).OR.(FREM.EQ.1.))NDUM=0
```

```
1200 NSPRL=NDUM-TSPRL(K)
1210 TSPRL(K)=NDUM
1220 NDUM=PFØH*Q*(1-Q1)*FREM*(DRCT*(1-RTS(K))+BRCT*RTS(K))/EMTBF(K)+
1221+SUF*SQRT(PFØH*Q*(1-Q1)*FREM*(DRCT*(1-RTS(K))+BRCT*RTS(K))/EMTBF(K))
1230 IF(NDUM.LT.MINSPB) NDUM=MINSPB
1235 IF((Q1.EQ.1.).ØR.(FREM.EQ.0.))NDUM=0
1240 NSPRE=NDUM-TSPRE(K)
1250 TSPRE(K)=NDUM
1260 NRCØS(I,1)=NRCØS(I,1)+NSPRF*FUC(K)+NSPRL*LUC(K)+NSPRE*EUC(K)
1270 XDUM=TFØH*Q*(Q1*FUC(K)*FCØND(K)/EMTBF(K)+(1-Q1)*LUC(K)*LCØND(K)
1271+*(1-FREM)/LMTBF(K)+(1-Q1)*FREM*EUC(K)*ECØND(K)/EMTBF(K))
1280 20 RLCØS(I,1)=RLCØS(I,1)+XDUM
1290 DØ 22 K=5,NFMØD
1300 NDUM=PFØH*Q*Q1*BRCT/EMTBF(K)+SUF*SQRT(PFØH*Q*Q1*BRCT/EMTBF(K))
1310 IF(NDUM.LT.MINSPD)NDUM=MINSPD
1315 IF(Q1.EQ.0.)NDUM=0
1320 NSPRF=NDUM-TSPRF(K)
1330 TSPRF(K)=NDUM
1340 XDUM=TFØH*Q*Q1*FUC(K)*FCØND(K)/EMTBF(K)
1350 NRCØS(I,1)=NRCØS(I,1)+NSPRF*FUC(K)
1360 22 RLCØS(I,1)=RLCØS(I,1)+XDUM
1370 DØ 23 K=5,NLMØD
1380 NDUM=PFØH*Q*(1-Q1)*(1-FREM)*BRCT/LMTBF(K)+SUF*SQRT(PFØH*Q*(1-
1381+Q1)*(1-FREM)*BRCT/LMTBF(K))
1390 IF(NDUM.LT.MINSPD)NDUM=MINSPD
1395 IF((Q1.EQ.1.).ØR.(FREM.EQ.1.))NDUM=0
1400 NSPRL=NDUM-TSPRL(K)
1410 TSPRL(K)=NDUM
1420 XDUM=TFØH*Q*(1-Q1)*(1-FREM)*LUC(K)*LCØND(K)/LMTBF(K)
1430 NRCØS(I,1)=NRCØS(I,1)+NSPRL*LUC(K)
1440 23 RLCØS(I,1)=RLCØS(I,1)+XDUM
1450 DØ 24 K=5,NEMØD
1460 NDUM=PFØH*Q*(1-Q1)*FREM*BRCT/EMTBF(K)+SUF*SQRT(PFØH*Q*(1-Q1)*
1461+FREM*BRCT/EMTBF(K))
1470 IF(NDUM.LT.MINSPD)NDUM=MINSPD
1475 IF((Q1.EQ.1.).ØR.(FREM.EQ.0.))NDUM=0
1480 NSPRE=NDUM-TSPRE(K)
1490 TSPRE(K)=NDUM
1500 XDUM=TFØH*Q*(1-Q1)*FREM*EUC(K)*ECØND(K)/EMTBF(K)
1510 NRCØS(I,1)=NRCØS(I,1)+NSPRE*EUC(K)
1520 24 RLCØS(I,1)=RLCØS(I,1)+XDUM
1530 NRCØS(I,1)=NRCØS(I,1)*((1+XINF)**(I-1))
1540 RLCØS(I,1)=RLCØS(I,1)*((1+XINF)**(I-1))
1550 DIMENSIØN LNAME(8)
1560 DATA (LNAME(I),I=1,8)/6HSPARES,7HØNMAINT,8HØFFMAINT,6HINVMGT,
1561+7HSUPPØRT,8HTRAINING,8HTECHDATA,10HFACILITIES/
1570 DØ 25 K=1,4
1580 XDUM=TFØH*Q*(Q1*FRMH(K)/EMTBF(K)+(1-Q1)*(1-FREM)*LRMH(K)/
1581+LMTBF(K)+(1-Q1)*FREM*ERMH(K)/EMTBF(K))*RLR
1590 25 RLCØS(I,2)=RLCØS(I,2)+XDUM
```

```
1600 RLCØS(I,2)=RLCØS(I,2)*((1+XINF)**(I-1))
1610 DØ 26 K=1,NEMØD
1620 IF(K.GT.4)GØTØ 27
1630 XDUM=TFØH*Q*Q1*(EDMH(K)*(RTS(K)*RLR+(1-RTS(K))*DLR)+EDMC(K)+
1631+1.125*SHC*EWT(K)*(2*(1-RTS(K))*(1-ECØND(K))+ECØND(K)))/
1632+EMTBF(K)
1640 GØTØ 26
1650 27 XDUM=TFØH*Q*Q1*(EDMH(K)*DLR+EDMC(K))/EMTBF(K)
1660 26 RLCØS(I,3)=RLCØS(I,3)+XDUM
1670 DØ 28 K=1,NLMØD
1680 IF(K.GT.4)GØTØ 29
1690 XDUM=TFØH*Q*(1-Q1)*(1-FREM)*(LDMH(K)*(RTS(K)*RLR+(1-RTS(K))*
1691+DLR)+LDMC(K)+1.125*SHC*LWT(K)*(2*(1-RTS(K))*(1-LCØND(K))+
1692+LCØND(K)))/LMTBF(K)
1700 GØTØ 28
1710 29 XDUM=TFØH*Q*(1-Q1)*(1-FREM)*(LDMH(K)*DLR+LDMC(K))/LMTBF(K)
1720 28 RLCØS(I,3)=RLCØS(I,3)+XDUM
1730 DØ 30 K=1,NEMØD
1740 IF(K.GT.4)GØTØ 31
1750 XDUM=TFØH*Q*(1-Q1)*FREM*(EDMH(K)*(RTS(K)*RLR+(1-RTS(K))*
1751+DLR)+EDMC(K)+1.125*SHC*EWT(K)*(2*(1-RTS(K))*(1-ECØND(K))+
1752+ECØND(K)))/EMTBF(K)
1760 GØTØ 30
1770 31 XDUM=TFØH*Q*(1-Q1)*FREM*(EDMH(K)*DLR+EDMC(K))/EMTBF(K)
1780 30 RLCØS(I,3)=RLCØS(I,3)+XDUM
1790 RLCØS(I,3)=RLCØS(I,3)*((1+XINF)**(I-1))
1800 PPFB=PPLB=PPEB=1.
1810 IF(FREM.EQ.0.)32,33
1820 32 PPE=TPE=PPEB=0.
1830 33 IF(FREM.EQ.1.)34,35
1840 34 PPL=TPL=PPLB=0.
1850 35 IF(Q1.EQ.0.)36,37
1860 36 PPF=TPF=PPFB=0.
1870 37 IF(Q1.EQ.1.)38,39
1880 38 PPL=TPL=PPLB=PPE=TPE=PPEB=0.
1890 39 IF(I.GT.1)40,41
1900 40 NRCØS(I,4)=0.
1910 RLCØS(I,4)=IAC*(PPF*PPFB+PPL*PPLB+PPE*PPEB)+SA*(4*(PPFB+PPLB+
1911+PPEB)*NBAS(I)+(TPF*PPFB+TPL*PPLB+TPE*PPEB)*NDEP(I))
1920 GØTØ 42
1930 41 NRCØS(I,4)=IAC*(PPF*PPFB+PPL*PPLB+PPE*PPEB)
1940 RLCØS(I,4)=SA*(4*(PPFB+PPLB+PPEB)*NBAS(I)+(TPF*PPFB+TPL*PPLB+
1941+TPE*PPEB)*NDEP(I))
1950 42 RLCØS(I,4)=RLCØS(I,4)*((1+XINF)**(I-1))
1960 XDUM=PFØH*Q*Q1*DUR*EDMH(1)/(EMTBF(1)*ATF*DAA*NDEP(I))
1970 NDUM=INT(XDUM)+1
1980 IF(NDUM.LT.NDEP(I))NDUM=NDEP(I)
1985 IF(Q1.EQ.0.)NDUM=0
1990 NNDUM=NDUM-NSUPF
```

```
2000 NSUPF=NDUM
2010 NRCØS(I,5)=NNDUM*CADF
2020 RLCØS(I,5)=XDUM*CØDF
2030 XDUM=PFØH*Q*(1-Q1)*(1-FREM)*DUR*LDMH(1)/(LMTBF(1)*ATF*DAA*NDEP(I))
2040 NDUM=INT(XDUM)+1
2050 IF(NDUM.LT.NDEP(I)) NDUM=NDEP(I)
2055 IF((Q1.EQ.1.).ØR.(FREM.EQ.1.))NDUM=0
2060 NNDUM=NDUM-NSUPL
2070 NSUPL=NDUM
2080 NRCØS(I,5)=NRCØS(I,5)+NNDUM*CADL
2090 RLCØS(I,5)=RLCØS(I,5)+XDUM*CØDL
2100 XDUM=PFØH*Q*(1-Q1)*FREM*DUR*EDMH(1)/(EMTBF(1)*ATF*DAA*NDEP(I))
2110 NDUM=INT(XDUM)+1
2120 IF(NDUM.LT.NDEP(I))NDUM=NDEP(I)
2125 IF((Q1.EQ.1.).ØR.(FREM.EQ.0.))NDUM=0
2130 NNDUM=NDUM-NSUPE
2140 NSUPE=NDUM
2150 NRCØS(I,5)=(NRCØS(I,5)+NNDUM*CADE)*((1+XINF)**(I-1))
2160 RLCØS(I,5)=(RLCØS(I,5)+XDUM*CØDE)*((1+XINF)**(I-1))
2170 XDUM=0
2180 DØ 43 K=1,NEMØD
2190 IF((K.GT.1).AND.(K.LT.5))GØTØ 43
2200 XDUM=XDUM+TFØH*Q*Q1*EDMH(K)/(EMTBF(K)*PMD)
2210 43 CØNTINUE
2220 DØ 44 K=1,NLMØD
2230 IF((K.GT.1).AND.(K.LT.5))GØTØ 44
2240 XDUM=XDUM+TFØH*Q*(1-Q1)*(1-FREM)*LDMH(K)/(LMTBF(K)*PMD)
2250 44 CØNTINUE
2260 DØ 45 K=1,NEMØD
2270 IF((K.GT.1).AND.(K.LT.5))GØTØ 45
2280 XDUM=XDUM+TFØH*Q*(1-Q1)*FREM*EDMH(K)/(EMTBF(K)*PMD)
2290 45 CØNTINUE
2300 NDUM=INT(XDUM)+1
2305 IF(NDUM.LT.NDEP(I))NDUM=NDEP(I)
2310 NNDUM=NDUM-NPERS
2315 RLCØS(I,6)=NDUM*TRD*TCD*((1+XINF)**(I-1))
2320 NPERS=NDUM
2325 IF(I.EQ.1)RLCØS(I,6)=0.
2330 NRCØS(I,6)=NNDUM*TCD*((1+XINF)**(I-1))
2340 XDUM=(ØR+FR+SR)*(Q1*FAILF+(1-Q1)*(1-FREM)*FAILL+(1-Q1)*
2341+FREM*FAILE)
2350 XDUM=(XDUM+(ØR+FR+SR+(1-RTS(1))*TR)*(Q1/EMTBF(1)+(1-Q1)*(1-
2351+FREM)/LMTBF(1)+(1-Q1)*FREM/EMTBF(1)))*TFØH*Q*BLR
2360 RLCØS(I,7)=XDUM*((1+XINF)**(I-1))
2370 NRCØS(I,7)=TD*(NBDF*PPFB+NBDL*PPLB+NBDE*PPEB+NDDF*PPFB+NDDL*PPLB
2371++NDDE*PPEB)
2380 IF(I.GT.1)NRCØS(I,7)=0.
2390 RLCØS(I,8)=(FIB*NBAS(I)+FID*NDEP(I))*((1+XINF)**(I-1))
```

```
2400 DØ 47 J=1,8
2410 TNRCØS(I)=TNRCØS(I)+NRCØS(I,J)
2420 47 TRLCØS(I)=TRLCØS(I)+RLCØS(I,J)
2430 TLLCØS(I)=TNRCØS(I)+TRLCØS(I)
2440 TCØSL=TCØSL+TLLCØS(I)
2450 18 PRINT 901, NYR(I),TNRCØS(I),TRLCØS(I),TLLCØS(I),TCØSL
2470 CLCC=TCØSA=TCØSL=0
2475 PRINT,*  *
2480 PRINT,* YEAR   CAS CØST   CUM CØST     PER A/C   ANNUAL LCØS/ACØS*
2490 DØ 48 I=1,11
2500 TLCC=TLLCØS(I)+ACØS(I)+ICØS(I)
2503 TCØSA=TCØSA+ACØS(I)
2504 TCØSL=TCØSL+TLLCØS(I)
2505 XXX=100*TCØSL/(I*TCØSA)
2510 CLCC=CLCC+TLCC
2515 XX=CLCC/CRFT(I)
2520 48 PRINT 902,NYR(I),TLCC,CLCC,XX,XXX
2525 PRINT,*  *
2530 902 FØRMAT (I5,3F12.0,F16.2)
2540 PRINT,* DØ YØU WANT LØGISTIC SUPPØRT CØSTS BREAKDØWN BY YEAR?*
2545 PRINT,* TYPE YES ØR NØ*,
2550 READ,AA
2560 IF(AA.NE.3HYES)GØTØ 50
2570 PRINT,* YEAR   ELEMENT  NREC LCØST   REC LCØST   TØT LCØST*
2580 DØ 51 I=1,11
2590 PRINT 903,NYR(I)
2600 903 FØRMAT (I5)
2610 DØ 52 J=1,8
2620 XX=NRCØS(I,J)+RLCØS(I,J)
2630 52 PRINT 904,LNAME(J),NRCØS(I,J),RLCØS(I,J),XX
2640 904 FØRMAT (A15,3F12.0)
2650 51 CØNTINUE
2660 50 PRINT,* DØ YØU WANT TØ RUN ANØTHER CASE (TYPE YES ØR NØ)*,
2670 READ,AA
2680 IF(AA.NE.3HYES)GØTØ 9999
2690 REWIND 2
2700 REWIND 3
2710 GØTØ 53
2720 9999 STØP
2730 END

BYE
```

ATTACHMENT A

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
1	SFILE	System File Name Input	N/A	AVOIDS, EROS, SECANT	
2	UFILE	User File Name Input	N/A	MIL, COM, GEN	
3	FUCOS	Sell price less amortization of first unit off line of CA CAS (i.e. value to which learning factors may be applied	MH, MD, RCA		Det. by sources
4	LUCOS	Sell price less amortization of first unit off line of GA CAS	MH, MD, RCA		" " "
5	EUCOS	Sell price less amortization of first unit off line of remitter	MH, MD, RCA		" " "
6	AFCOS	Total amount to be amortized on CA CAS production	MH, MD, RCA		" " "
7	ALCOS	Total amount to be amortized on GA CAS production	MH, MD, RCA		" " "
8	AECOS	Total amount to be amortized on remitter production	MH, MD, RCA		" " "
9	FICOS	Installation cost in new A/C of CA capability CAS	Mil, CA, Users & A/C Mfgrs.		Det. by ARC
10	RICOS	Retrofit cost of CA capability CAS	Mil, CA users & support orgs.		" " "
11	LICOS	Installation cost in new A/C of GA capability CAS	GA users & A/C Mfgrs.		" " "
12	LRCOS	Retrofit cost of GA capability CAS	GA users & support orgs.		" " "
13	EICOS	Installation cost in new A/C of remitter	GA users & A/C Mfgrs.		" " "

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
14	ERCOS	Retrofit cost of remitter	GA users & support orgs.		Det. by ARC
15	NYR(I)	Year I	N/A	1978 - 1988	" " "
16	NAC(I)	No. of A/C in each user category in year I	FAA		" " "
17	NBAS(I)	No. of bases in each user category in year I	FAA		" " "
18	NDEP(I)	No. of depots in each user category in year I	FAA		" " "
19	FREM	Fraction of GA A/C with remitters	FAA	0 and .5	
20	NRAC	No. of A/C in each user category to be retrofitted	FAA		N/A
21	XLRN	Learning curve parameter	ARC	.85	
22	XINF	Inflation parameter	ARC	.06	
23	IT	Retrofit completion period	ARC	4 yrs. CA and 8 yrs. Mil & GA	
24	Q	Av. No. of CAS units per A/C in each user category	FAA		Det. by ARC
25	Q1	Fraction of A/C in each user category with CA capability CAS	FAA		" " "
26	NMODF	No. of modules in CA capability CAS principal electronics	MH, MD, RCA		Det. by sources

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
27	NMODL	No. of modules in GA capability CAS principal electronics	MH, MD, RCA		Det. by sources
28	NMODE	No. of modules in remitter principal electronics	MH, MD, RCA		" " "
29	NANTF	No. of antennas in CA capability CAS configuration	MH, MD, RCA		" " "
30	NANTL	No. of antennas in GA capability CAS configuration	MH, MD, RCA		" " "
31	NANTE	No. of antennas in remitter configuration	MH, MD, RCA		" " "
32	FUC(1)	Initial selling price of CA capability CAS principal electronics	MH, MD, RCA		" " "
33	LUC(1)	Initial selling price of GA capability CAS principal electronics	MH, MD, RCA		" " "
34	EUC(1)	Initial selling price of remitter principal electronics	MH, MD, RCA		" " "
35	FUC(2)	Initial selling price of CA capability pilot's maneuver indicator	MH, MD, RCA		" " "
36	LUC(2)	Initial selling price of GA capability pilot's maneuver indicator	MH, MD, RCA		" " "
37	EUC(2)	Initial selling price of remitter pilot's maneuver indicator	ARC	0.00	N/A
38	FUC(3)	Initial selling price of CA capability control panel	MH, MD, RCA		Det. by sources
39	LUC(3)	Initial selling price of GA capability control panel	MH, MD, RCA		" " "

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
40	EUC(3)	Initial selling price of remitter control panel	MH, MD, RCA		Det. by sources
41	FUC(4)	Initial selling price of CA capability antenna system (1)	MH, MD, RCA		" " "
42	LUC(4)	Initial selling price of GA capability antenna system (1)	MH, MD, RCA		" " "
43	EUC(4)	Initial selling price of remitter antenna system (1)	MH, MD, RCA		" " "
44	FUC(J)	Allocated % of initial selling price of J'th module of CA capability principal electronics	MH, MD, RCA		" " "
45	LUC(J)	Allocated % of initial selling price of J'th module of GA capability principal electronics	MH, MD, RCA		" " "
46	EUC(J)	Allocated % of initial selling price of J'th module of remitter principal electronics	MH, MD, RCA		" " "
47	FMTBF(1)	MTBF of CA capability principal electronics	MH, MD, RCA		" " "
48	LMTBF(1)	MTBF of GA capability principal electronics	MH, MD, RCA		" " "
49	EMTBF(1)	MTBF of remitter principal electronics	MH, MD, RCA		" " "
50	FMTBF(2)	MTBF of CA capability pilot's maneuver indicator	MH, MD, RCA		" " "
51	LMTBF(2)	MTBF of GA capability pilot's maneuver indicator	MH, MD, RCA		" " "
52	EMTBF(2)	MTBF of remitter pilot's maneuver indicator	ARC	∞	N/A

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
53	FMTBF(3)	MTBF of CA capability control panel	MH, MD, RCA		Det. by sources
54	LMTBF(3)	MTBF of GA capability control panel	MH, MD, RCA		" " "
55	EMTBF(3)	MTBF of remitter control panel	MH, MD, RCA		" " "
56	FMTBF(4)	MTBF of CA capability antenna system (1)	MH, MD, RCA		" " "
57	LMTBF(4)	MTBF of GA capability antenna system (1)	MH, MD, RCA		" " "
58	EMTBF(4)	MTBF of remitter antenna system (1)	MH, MD, RCA		" " "
59	FMTBF(J)	Allocated MTBF of J'th module of CA capability principal electronics	MH, MD, RCA		" " "
60	LMTBF(J)	Allocated MTBF of J'th module of GA capability principal electronics	MH, MD, RCA		" " "
61	EMTBF(J)	Allocated MTBF of J'th module of remitter principal electronics	MH, MD, RCA		" " "
62	FWT(1)	Weight of CA capability principal electronics	MH, MD, RCA		" " "
63	LWT(1)	Weight of GA capability principal electronics	MH, MD, RCA		" " "
64	EWT(1)	Weight of remitter principal electronics	MH, MD, RCA		" " "
65	FWT(2)	Weight of CA capability pilot's maneuver indicator	MH, MD, RCA		" " "

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
66	LWT(2)	Weight of GA capability pilot's maneuver indicator	MH, MD, RCA		Det. by sources
67	EWT(2)	Weight of remitter pilot's maneuver indicator	ARC	0	
68	FWT(3)	Weight of CA capability control panel	MH, MD, RCA		Det. by sources
69	LWT(3)	Weight of GA capability control panel	MH, MD, RCA		" " "
70	EWT(3)	Weight of remitter control panel	MH, MD, RCA		" " "
71	FWT(4)	Weight of CA capability antenna system (1)	ARC	0	N/A
72	LWT(4)	Weight of GA capability antenna system (1)	ARC	0	N/A
73	EWT(4)	Weight of remitter antenna system (1)	ARC	0	N/A
74	FWT(J)	Weight of J'th module of CA capability principal electronics	ARC	0	N/A
75	LWT(J)	Weight of J'th module of GA capability principal electronics	ARC	0	N/A
76	EWT(J)	Weight of J'th module of remitter principal electronics	ARC	0	N/A
77	FRMH(1)	Av. time to remove and replace CA capability principal electronics	Users		Det. by ARC
78	LRMH(1)	Av. time to remove and replace GA capability principal electronics	Users		" " "

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
79	ERMH(1)	Av. time to remove and replace remitter principal electronics	Users		Det. by ARC
80	FRMH(2)	Av. time to remove and replace CA capability pilot's maneuver indicator	Users		" " "
81	LRMH(2)	Av. time to remove and replace GA capability pilot's maneuver indicator	Users		" " "
82	ERMH(2)	Av. time to remove and replace remitter pilot's maneuver indicator	ARC	0	N/A
83	FRMH(3)	Av. time to remove and replace CA capability control panel	Users'		Det. by ARC
84	LRMH(3)	Av. time to remove and replace GA capability control panel	Users		" " "
85	ERMH(3)	Av. time to remove and replace remitter control panel	Users		" " "
86	FRMH(4)	Av. time for on A/C repair of CA capability antenna system	Users		" " "
87	LRMH(4)	Av. time for on A/C repair of GA capability antenna system	Users		" " "
88	ERMH(4)	Av. time for on A/C repair of remitter antenna system	Users		" " "
89	FRMH(J)	Av. time to remove and replace J'th module of CA capability principal electronics	ARC	0	N/A
90	LRMH(J)	Av. time to remove and replace J'th module of GA capability principal electronics	ARC	0	N/A
91	ERMH(J)	Av. time to remove and replace J'th module of remitter principal electronics	ARC	0	N/A

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
92	FDMH(1)	Av. time to isolate to module level in the CA capability principal electronics	MH, MD, RCA		Det. by sources
93	LDMH(1)	Av. time to isolate to module level in the GA capability principal electronics	MH, MD, RCA		" " "
94	EDMH(1)	Av. time to isolate to module level in the remitter principal electronics	MH, MD, RCA		" " "
95	FDMH(2)	Av. time to repair CA capability pilot's maneuver indicator	Users		Det. by ARC
96	LDMH(2)	Av. time to repair GA capability pilot's maneuver indicator	Users		" " "
97	EDMH(2)	Av. time to repair remitter pilot's maneuver indicator	ARC	0	N/A
98	FDMH(3)	Av. time to repair CA capability control panel	Users		Det. by ARC
99	LDMH(3)	Av. time to repair GA capability control panel	Users		" " "
100	EDMH(3)	Av. time to repair remitter control panel	Users		" " "
101	FDMH(4)	Av. time to repair CA capability antenna system	ARC	0	N/A
102	LDMH(4)	Av. time to repair GA capability antenna system	ARC	0	N/A
103	EDMH(4)	Av. time to repair remitter antenna system	ARC	0	N/A
104	FDMH(J)	Av. time to repair J'th module of CA capability principal electronics	MH, MD, RCA		Det. by sources

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
105	LDMH(J)	Av. time to repair J'th module of GA capability principal electronics	MH, MD, RCA		Det. by sources
106	EDMH(J)	Av. time to repair J'th module of remitter principal electronics	MH. MD, RCA		" " "
107	FDMC(1)	Av. material cost per repair action of CA capability principal electronics	ARC	0	N/A
108	LDMC(1)	Av. material cost per repair action on GA capability principal electronics	ARC	0	N/A
109	EDMC(1)	Av. material cost per repair action on remitter principal electronics	ARC	0	N/A
110	FDMC(2)	Av. material cost per repair action on CA capability pilot's maneuver indicator	Users		Det. by ARC
111	LDMC(2)	Av. material cost per repair action on GA pilot's maneuver indicator	Users		" " "
112	EDMC(2)	Av. material cost per repair action on remitter maneuver indicator	ARC	0	N/A
113	FDMC(3)	Av. material cost per repair action on CA capability control panel	Users		Det. by ARC
114	LDMC(3)	Av. material cost per repair action on GA capability control panel	Users		" " "
115	EDMC(3)	Av. material cost per repair action on remitter control panel	Users		" " "
116	FDMC(4)	Av. material cost per repair action on CA capability antenna system	Users		" " "
117	LDMC(4)	Av. material cost per repair action on GA capability antenna system	Users		" " "

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
118	EDMC(4)	Av. material cost per repair action on remitter antenna system	Users		Det. by ARC
119	FDMC(J)	Av. material cost per repair action on J'th module CA capability principal electronics	MH, MD, RCA		Det. by sources
120	LDMC(J)	Av. material cost par repair action on J'th module of GA capability principal electronics	MH, MD, RCA		Det. by sources
121	EDMC(J)	Av. material cost per repair action on J'th module of remitter principal electronics	MH, MD, RCA		" " "
122	FCOND(1)	Fraction of CA capability principal electronics failures resulting in condemnations	ARC	.001	
123	LCOND(1)	Fraction of GA capability principal electronics failures resulting in condemnations	ARC	.001	
124	ECOND(1)	Fraction of remitter capability principal electronics failures resulting in condemnations	ARC	.001	
125	FCOND(2)	Fraction of CA capability pilot's maneuver indicator failures resulting in condemnations	ARC	.01	
126	LCOND(2)	Fraction of GA capability pilot's maneuver indicator failures resulting in condemnations	ARC	.01	
127	ECOND(2)	Fraction of remitter capability pilot's maneuver indicator failures resulting in condemnations	ARC	0	N/A
128	FCOND(3)	Fraction of CA capability control panel failures resulting in condemnations	ARC	.01	
129	LCOND(3)	Fraction of GA capability control panel failures resulting in condemnations	ARC	.01	
130	ECOND(3)	Fraction of remitter capability control panel failures resulting in condemnations	ARC	.01	

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
131	FCOND(4)	Fraction of CA capability antenna system failures resulting in condemnations	ARC	0	
132	LCOND(4)	Fraction of GA capability antenna system failures resulting in condemnations	ARC	0	
133	ECOND(4)	Fraction of remitter capability antenna system failures resulting in condemnations	ARC	0	
134	FCOND(J)	Fraction of J'th module failures in CA capability principal electronics resulting in condemnations	ARC	.10	
135	LCOND(J)	Fraction of J'th module failures in GA capability principal electronics resulting in condemnations	ARC	.10	
136	ECOND(J)	Fraction of J'th module failures in remitter capability principal electronics resulting in condemnations	ARC	.10	
137	CADF	Unit acquisition cost of special support equipment for CA capability	MH, MD, RCA		Det. by sources
138	CADL	Unit acquisition cost of special support equipment for GA capability	MH, MD, RCA		" " "
139	CADE	Unit acquisition cost of special support equipment for remitter capability	MH, MD, RCA		" " "
140	CODF	Annual operating cost rate of special support equipment for CA capability	Users		Det. by ARC
141	CODL	Annual operating cost rate of special support equipment for GA capability	Users		" " "
142	CODE	Annual operating cost rate of special support equipment for remitter capability	Users		" " "
143	PPF	New inventory coded items in CA CAS	MH, MD, RCA		Det. by sources

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
144	PPL	New inventory coded items in GA CAS	MH, MD, RCA		Det. by sources
145	PPE	New inventory coded items in remitter	MH, MD, RCA		" " "
146	TPF	Total inventory coded items in CA CAS	MH, MD, RCA		" " "
147	TPL	Total inventory coded items in GA CAS	MH, MD, RCA		" " "
148	TPE	Total inventory coded items in remitter	MH, MD, RCA		" " "
149	NBDF	No. of pages of base level Tech. documentation for CA CAS	MH, MD, RCA		" " "
150	NBDL	No. of pages of base level Tech. documentation for GA CAS	MH, MD, RCA		" " "
151	NBDE	No. of pages of base level Tech. documentation for remitter	MH, MD, RCA		" " "
152	NDDF	No. of pages of depot level Tech. documentation for CA CAS	MH, MD, RCA		" " "
153	NDDL	No. of pages of depot level Tech. documentation for GA CAS	MH, MD, RCA		" " "
154	NDDE	No. of pages of depot level Tech. documentation for remitter	MH, MD, RCA		" " "
155	FIBF	Base facilities costs for CA CAS	Users		Det. by ARC
156	FIBL	Base facilities costs for GA CAS	Users		" " "

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
157	FIBE	Base facilities costs for remitter	Users		Det. by ARC
158	FIDF	Depot facilities costs for CA CAS	Users		" " "
159	FIDL	Depot facilities costs for GA CAS	Users		" " "
160	FIDE	Depot facilities costs for remitter	Users		" " "
161	ATE	Support equipment availability figure for each user category	Users		" " "
162	DRCT	Av. Depot level response time (pipeline) for each user category	Users	2 mo. (Mil)	" " "
163	BRCT	Av. Base level response time (pipeline) for each user category	Users	.33 mo. (Mil)	" " "
164	AHR	Av. flight hours per mo. for each user category	Users		" " "
165	PHR	Peak flight hours per mo. for each user category	Users		" " "
166	SUF	Spares sufficiency factor (standard deviations from mean)	ARC	0	
167	BLR	Base labor rate for each user category	Users	$10.00/hr.(Mil)	Det. by ARC
168	SHC	Shipping costs per lb. for each user category	Users	$.33/lb(Mil)	" " "
169	DLR	Depot labor rate for each user category	Users	$15.00/hr.(Mil)	" " "

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
170	RTS	Fraction of maintenance actions repaired at base level for each user category	Users		Det. by ARC
171	IAC	Cost of introducing and maintaining each new inventory coded item for user category	Users	$105/yr. (Mil)	" " "
172	DUR	Support equipment utilization factor for each user category	Users		" " "
173	SA	Annual supply mgt. cost for each inventory coded item for each user category	Users	$12/item/yr. (Mil)	" " "
174	DAA	Support equipment time available per month for each user category	Users		" " "
175	TCB	Cost per man of base level training for each user category	Users	$1600 (Mil)	" " "
176	TCD	Cost per man of depot level training for each user category	Users	$1600 (Mil)	" " "
177	PMB	Direct base productive man hours per man year for each user category	Users	1680 hrs. (Mil)	" " "
178	PMD	Direct depot productive man hours per man year for each user category	Users	1788 hrs. (Mil)	" " "
179	ØR	Av. time to complete on A/C maintenance records for each user category	Users	.08 hrs. (Mil)	" " "
180	FR	Av. time to complete off A/C maintenance records for each user category	Users	.24 hrs. (Mil)	" " "
181	SR	Av. time to complete supply transaction records for each user category	Users	.25 hrs. (Mil)	" " "
182	TR	Av. time to complete transportation forms for each user category	Users	.16 hrs. (Mil)	" " "

CAS Life Cycle Cost Model Parameter Summary

ITEM	VARIABLE	DESCRIPTION	SOURCES	VALUES	COMMENTS
183	TRB	Av. annual turnover rate at base for each user category	Users	.33 per year(Mil)	Det. by ARC
184	TRD	Av. annual turnover rate at depot for each user category	Users	.15 per year(Mil)	" " "
185	TD	Cost per page of original technical documentation for each user category	Users	$160(Mil)	" " "

APPENDIX E

COMMON PARAMETERS AFFECTING LIFE CYCLE COSTS

ITEM	VARIABLE	DESCRIPTION	COMMERCIAL CARRIER	MILITARY	GENERAL AVIATION
1.	SFILE	System File Name Input	AVOIDS EROS SECANT	AVOIDS EROS SECANT	AVOIDS EROS SECANT
2.	UFILE	User File Name Input	COM	COM	COM
3.	FICOS	Installation cost in new A/C of Type I capability CAS	$2536	11141.	$1155
4.	RICOS	Retrofit cost of Type I capability CAS	4227	8252.	1925
5.	LICOS	Installation cost in new A/C of Type II capability CAS	N/A	2715	135
6.	LRCOS	Retrofit cost of Type II capability CAS	N/A	2479	226
7.	EICOS	Installation cost in new A/C of remitter	N/A	N/A	135
8.	ERCOS	Retrofit cost of remitter	N/A	N/A	226
9.	NYR (I)	Year I	1978	1978	1978
10.	NAC (I)	Number of A/C in each user category in in Year I	2693	19,501	173,500
11.	NBAS (I)	Number of bases in each user category in Year I	15	166	146
12.	NDEP (I)	Number of depots in each user category in Year I	3	8	5
13.	FREM	Fraction of GA A/C with remitters	N/A	N/A	.7*
14	NRAC	Number of A/C in each user category to be retrofitted	2560	19,345	167,800
15.	XLRN	Learning curve parameter			
16.	XINF	Inflation parameter	0, .06, .1	0, .06, .1	0, .06, .1

ITEM	VARIABLE	DESCRIPTION	COMMERCIAL CARRIER	MILITARY	GENERAL AVIATION
17	IT	Retrofit completion period	4	8	8
18	Q	Average number of CAS units per A/C in each user category	1	1	1
19	Q1	Fraction of A/C in each user category with Type I capability CAS	1	0.56	0.05
20	NMODF	Number of modules in Type I capability CAS principal electronics	AVOIDS 5 EROS 7 SECANT 8	AVOIDS 5 EROS 7 SECANT 8	AVOIDS 5 EROS 7 SECANT 8
21	NMODL	Number of modules in Type II capability CAS principal electronics	N/A	AVOIDS 4 EROS 7 SECANT 7	AVOIDS 4 EROS 7 SECANT 7
22	NMODE	Number of modules in remitter principal electronics	N/A	N/A	SECANT 5
23	NANTF	Number of antennas in Type I capability CAS Configuration	2	2	2
24	NANTL	Number of antennas in Type II capability CAS configuration	N/A	AVOIDS 2 EROS/SECANT 1	AVOIDS 2 EROS/SECANT 1
25	NANTE	Number of antennas in remitter configuration	N/A	N/A	1
26	FUC(2)	Initial selling price of Type I capability pilot's maneuver indicator	$1092	$1092	$1092
27	LUC(2)	Initial selling price of Type II capability pilot's maneuver indicator	N/A	SECANT $53	SECANT $53
28	FUC(3)	Initial selling price of Type I capability control panel	SECANT $127	SECANT $127	SECANT $127
29	FUC(4)	Initial selling price of Type I capability antenna system (1)	$63	$63	$63

ITEM	VARIABLE	DESCRIPTION	COMMERCIAL CARRIER	MILITARY	GENERAL AVIATION
30	LUC(4)	Initial selling price of Type II capability antenna system (1)	N/A	$13	$13
31	EUC (4)	Initial selling price of remitter antenna system (1)	N/A	N/A	$13
32	FMTBF (2)	MTBF of Type I capability pilot's maneuver indicator	7500 hours	7500 hours	7500 hours
33	LMTBF (2)	MTBF of Type II capability pilot's maneuver indicator	N/A	10,000 hours	10,000 hours
34	FMTBF (4)	MTBF of Type I capability antenna system (1)	50,000 hours	50,000 hours	50,000 hours
35	LMTBF (4)	MTBF of Type II capability antenna system (1)	N/A	50,000 hours	50,000 hours
36	EMTBF (4)	MTBF of remitter antenna system (1)			50,000 hours
37	FWT(2)	Weight of Type I capability pilot's maneuver indicator	2.2 lbs.	2.2 lbs.	2.2 lbs.
38	FRMH(1)	Average time to remove and replace Type I capability principal electronics	.25 hours	.25 hours	.25 hours
39	LRMH(1)	Average time to remove and replace Type II capability principal electronics	.5 hours	.5 hours	.5 hours
40	FRMH(2)	Average time to remove and replace Type I capability pilot's maneuver indicator	.5 hours	.5 hours	.5 hours

CAS LIFE CYCLE COST MODEL PARAMETER SUMMARY - COMMON DATA

ITEM	VARIABLE	DESCRIPTION	COMMERCIAL CARRIER	MILITARY	GENERAL AVIATION
41	FRMH(4)	Average time for on A/C repair of Type I capability antenna system	2 hours	2 hours	2 hours
42	LRMH(4)	Average time for on A/C repair of Type II capability antenna system	.25 hours	.25 hours	.25 hours
43	FDMH(2)	Average time to repair Type I capability pilot's maneuver indicator	1 hour	1 hour	1 hour
44	FDMC(2)	Average material cost per repair action on Type I capability pilot's maneuver indicator	$109	$109	$109
45	FCOND (1)	Fraction of Type I capability principal electronics failures resulting in condemnations	.001	.001	.001
46	LCOND (1)	Fraction of Type II capability principal electronics failures resulting in condemnations	N/A	.001	.001
47	ECOND (1)	Fraction of remitter capability principal electronics failures resulting in condemnations	N/A	N/A	.001
48	FCOND (2)	Fraction of Type I capability pilot's maneuver indicator failures resulting in condemnations	.01	.01	.01
49	FCOND (4)	Fraction of Type I capability antenna system failures resulting in condemnations	1	1	1
50	LCOND (4)	Fraction of Type II capability antenna system failures resulting in condemnations	N/A	1	1
51	ECOND (4)	Fraction of remitter capability antenna system failures resulting in condemnations	N/A	N/A	1

CAS LIFE CYCLE COSTS MODEL PARAMETER SUMMARY-COMMON DATA

ITEM	VARIABLE	DESCRIPTION	COMMERCIAL CARRIER	MILITARY	GENERAL AVIATION
52	CODF	Annual operating cost rate of special	$1058	$1058	$1058
53	CODL	Annual operating cost rate of special support equipment for Type II capability	N/A	$ 529	$ 529
54	CODE	Annual operating cost rate of special support equipment for remitter capability	N/A	N/A	$ 529
55	FIBF	Base facilities costs for Type I CAS	N/A	$ 529	N/A
56	FIBL	Base facilities costs for Type II CAS	N/A	$ 529	N/A
57	FIDF	Depot facilities costs for Type I CAS	$529	$ 100,000	N/A
58	FIEL	Depot facilities costs for Type II CAS	N/A	$ 100,000	N/A
59	ATE	Support equipment availability figure for each user category	1	0.9	1
60	DRCT	Average depot level response time (pipeline) for each user category	0.1 months	2.0 months	.25 months
61	BRCT	Average base level response time (pipeline) for each user category	0.1 months	0.33 months	0.1 months
62	AHR	Average flight hours per month for each user category	238 hours	80 hours	17.3 hours
63	PHR	Peak flight hours per month for each user category	298 hours	100 hours	20 hours
64	SUF	Spares sufficiency factor (standard deviations from mean)	0	1.65	0
65	BLR	Base labor rate for each user category	22.29	13.00	16.28
66	SHC	Shipping costs per lb. for each user category	.35	.35	.35
67	DLR	Depot labor rate for each user category	22.29	15.80	17.90

CAS LIFE CYCLE COST MODEL PARAMETER SUMMARY-COMMON DATA

ITEM	VARIABLE	DESCRIPTION	COMMERCIAL CARRIER	MILITARY	GENERAL AVIATION
68	RTS	Fraction of maintenance actions repaired at base level for each user category	Electronics = 0 Indicator = 1 Antenna = 1	Electronics = 0 Indicator = 1 Antenna = 1	Electronics = 0.2 Indicator = 1 Antenna = 1
69	IAC	Cost of introducing and maintaining each new inventory coded item for user category	$16	$990.	N/A
70	DUR	Support equipment utilization factor for each user category	3	3	3
71	SA	Annual supply management cost for each inventory coded item for each user category	$6.35	$12.72	N/A
72	DAA	Support equipment time available per month for each user category	160 hours	160 hours	160 hours
73	TCB	Cost per man of base level training for each user category	N/A	N/A	N/A
74	TCD	Cost per man of depot level training for each user category	$1695	$8000.	N/A
75	PMB	Direct base productive manhours per man year for each user category	N/A	1456 hours	N/A
76	PMD	Direct depot productive manhours per man year for each user category	1788 hours	1456 hours	1788 hours
77	ØR	Average time to complete on A/C maintenance records for each user category	0.08 hours	0.25 hours	0.08 hours
78	FR	Average time to complete off A/C maintenance records for each user category	0.24 hours	0.5 hours	0.24 hours
79	SR	Average time to complete supply transaction records for each user category	0.24 hours	0.5 hours	0.25 hours

CAS LIFE CYCLE COST MODEL PARAMETER SUMMARY-COMMON DATA

ITEM	VARIABLE	DESCRIPTION	COMMERCIAL CARRIER	MILITARY	GENERAL AVIATION
80	TR	Average time to complete transportation forms for each user category	0.16 hours	0.5 hours	0.16 hours
81	TRB	Average annual turnover rate at base for each user category	N/A	.2	N/A
82	TRB	Average annual turnover rate at depot for each user category	0.05	.06	N/A
83	TD	Cost per page of original technical documentation for each user category	N/A	$170	N/A

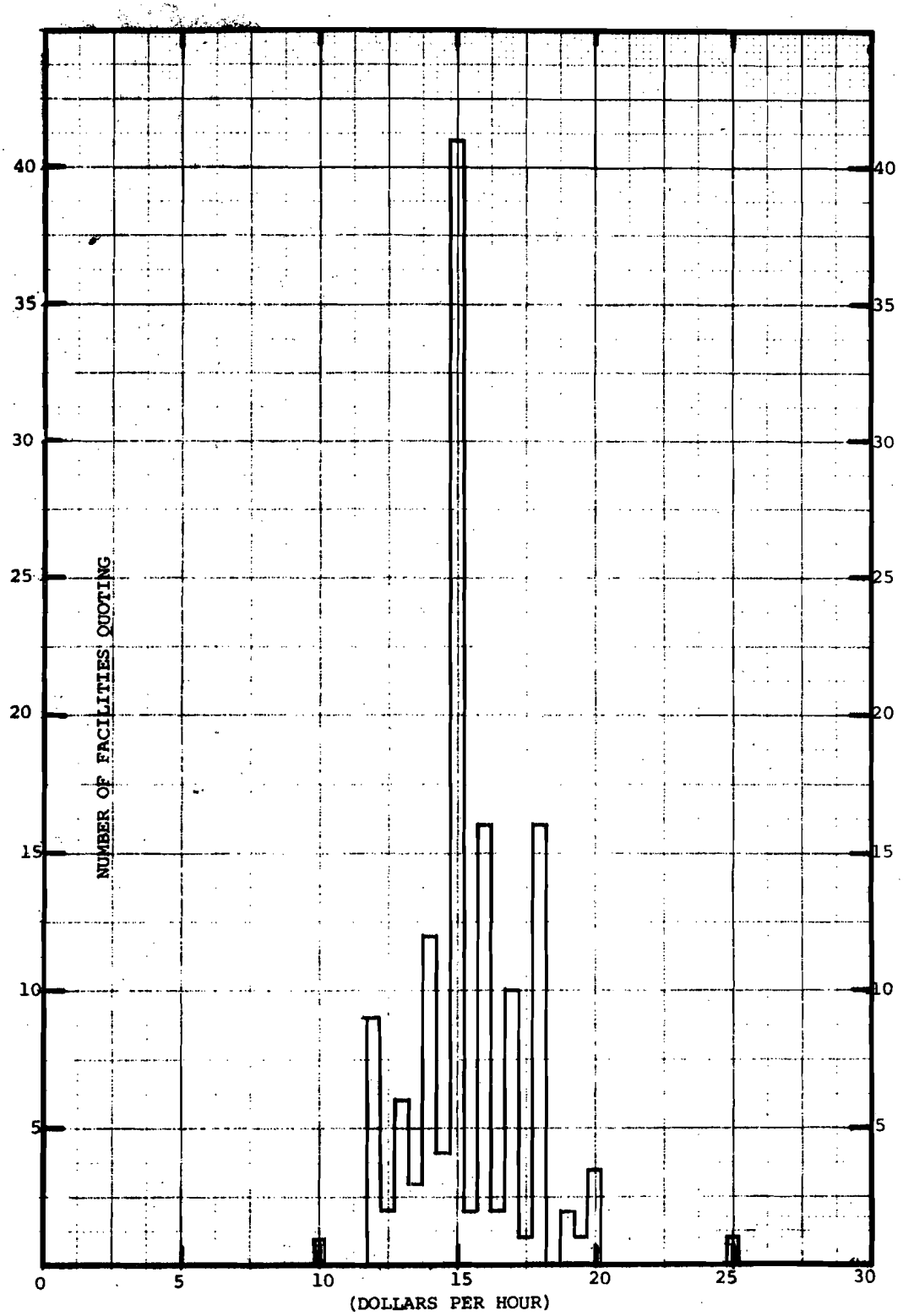
APPENDIX F

RESULTS OF GENERAL AVIATION INSTALLATION FACILITIES RESPONSE TO QUESTIONNAIRE

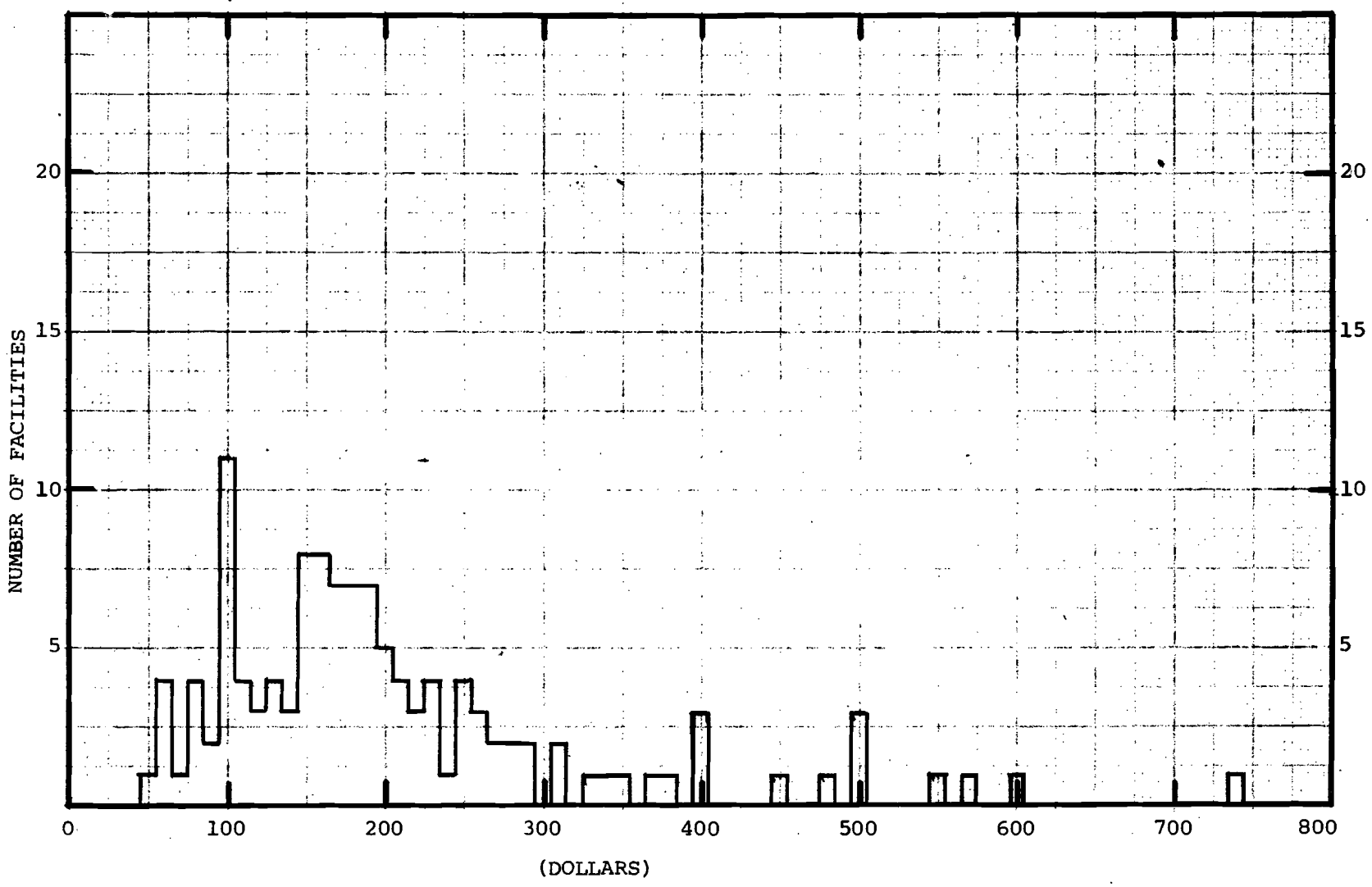
DEVELOPMENT OF GENERAL AVIATION INSTALLATION COSTS

The large population of the general aviation community dictated that detailed installation costs of CAS be developed accurately if the study results were to be valid. Several methods were considered and tried but the results showed that there exists a large variation in installation costs between the many installing shops because of labor rates, geographical locations, and competition. Finally a decision was made to query all the installation facilities in the continental US and average the influencing data such as hours, labor rates, material costs and total installation costs. The DOT/FAA Consolidated Listing of FAA Certified Repair Stations advisory circular was used to identify all the repair facilities involved in radio repair and a questionnaire asking for detailed installation data was sent to each facility. The advisory lists in excess of 500 repair facilities and replies were received from more than 25% of these facilities providing a good average from all over the country.

The questionnaire requested the cost of installation, in hours and dollars, of a piece of avionics considered similar to CAS for installation complexity but one with which all the repair facilities were familiar with-the NARCO DME-190. The DME-190 was chosen because it is approximately the same size as the proposed CAS systems, is mounted in the flight console of a small aircraft as will be CAS, requires similar aircraft power and wiring, and uses an L-band stub antenna similar to that required by CAS. The results of the questionnaire have been averaged and are shown in this section. In addition, charts showing the distribution of labor rates and total installation cost quoted have been prepared and are included.


NUMBER OF FACILITIES QUOTING
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
(DOLLARS PER HOUR)

LABOR RATES



INSTALLATION COST PER AIRCRAFT (SINGLE ENGINE)

ARINC
A Subsidiary of Aeronautical Radio, Inc.
2551 Riva Road • Annapolis Maryland 21401

October 31, 1974
NDCG/TSP-74-76
W. O. 1306

ARINC Research Corporation is currently under contract to the Federal Aviation Administration to develop estimates of the life cycle cost of implementing a Collision Avoidance System in the total aviation community. General aviation, with which you are concerned, represents a very large portion of the total costs. In order that we may provide the most realistic estimate of costs, we are requesting your cooperation in completion of the attached questionnaire pertaining to the costs of retrofitting existing general aviation aircraft.

Although some variations exist among the equipment proposed by the three competing manufacturers for the CAS, for purposes of this estimate we request that you consider the installation to be comparable to that of a DME similar to the NARCO DME-190. The CAS will consist of a package (including the transmitter, receiver, logic circuitry and display) designed to fit in the aircraft console, sized approximately the same as the DME-190, an antenna ($\lambda/4$ stub) mounted on centerline of fuselage on top of the aircraft, and cabling to provide a connection to the aircraft power supply and encoding altimeter. Hardware and cabling would be provided by the installing agency.

You are requested to consider only single and twin engine aircraft, unpressurized, and limited by existing regulations to normal flights below 10,000 feet.

Your cooperation in this study is appreciated. Information provided will be held in strict confidence, with only community averages becoming a part of the published study.

Very truly yours,

Stanley H. Kowalski
Project Engineer

Enclosure

F-5

Phones: Annapolis 301-268-4000 Washington, D.C. 261-1600 Santa Ana, Calif. 714-547 7594
TWX Annapolis 710-867-8553
Santa Ana, Calif. 910-595-1110

RESULTS OF REPLIES RECEIVED FROM 125 REPAIR AND INSTALLATION FACILITIES

DATA SHEET

DATE _____

COMPANY _____

ADDRESS _____

_____

CERTIFICATION: COMM _____ NAV _____ RADAR _____

PRESENT LABOR RATE $ 15.40 /hr. (INSTALLATION)

ESTIMATE OF INSTALLATION:	SINGLE ENGINE A/C	TWIN ENGINE A/C
CAS UNIT (APPROX. 2-1/2" x 6-1/4" x 12")	4.51 hours	6.43 hours
ANTENNA (λ/4 STUB)	2.32 hours	3.21 hours
CABLING (AVERAGE MANHOURS)	3.92 hours	5.31 hours
MATERIAL (AVERAGE)	$ 26.39	$ 35.48
TOTAL INSTALLATION COST	$213.54	$261.69 *

1. If CAS is made a mandatory, national standard, would you stock complete spare units? (YES 40.5% -), spare parts? (YES 82.5% -)

2. Would you purchase test equipment to maintain the CAS-GA at a unit price of $5,000? (YES 58% -)

3. What percent of aircraft that you service have encoding altimeters? 20.2%

*NOTE: TOTAL INSTALLATION COSTS ARE THE MEAN OF COSTS QUOTED BY 125 FACILITIES. HOURLY ESTIMATES ARE THE MEAN FOR 90% OF FACILITIES RESPONDING.