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IMPACT OF TECHNOLOGY ON AVIONICS COST TRENDS

AD A108494

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W. Lovelace

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November 1981

PREPARED FOR

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

Office of System Engineering Management

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16. Abstract

This study provides an overview of nonmilitary general aviation and commercial avionics price and cost structures as influenced by technology. It quantifies, computes, and evaluates the unique characteristics and behavior patterns of the industry, especially those that affect the frequency of innovation, the rate of technology diffusion from manufacturer to manufacturer or from product to product, and the anticipated major cost drivers of the future. The report reviews the impact of technology on the cost of avionics during the past 20 years and projects this impact for the next 20 years.

This report concentrates on avionics in the low-performance general aviation aircraft category because they are the major components of the avionics industry. Typical units of detailed study are transponders, transceivers, navigation receivers, and course deviation indicators (CDIs).

An examination of the price histories of more than twenty equipment families indicates that unit prices have been and are likely to continue increasing at the Producer Price Index (PPI) rate. This rate of price growth results from a balance between costs rising at the Consumer Price Index (CPI) rate and manufacturing cost reductions made possible through the introduction of new technologies.

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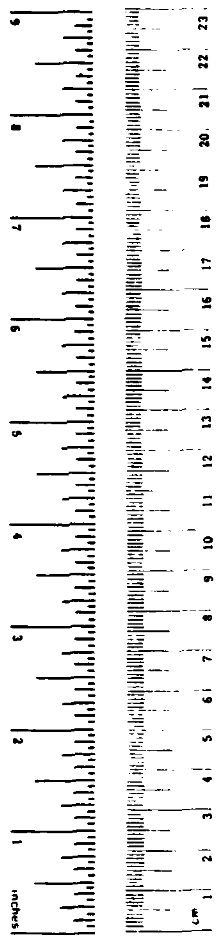
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

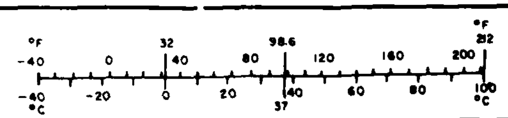
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH*		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2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

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



Approximate Conversions from Metric Measures

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



ACKNOWLEDGMENT

This study could not have been completed without the active participation and support of avionics manufacturers. The study team is indebted to the design engineers at Bendix, Narco, and Collins for their candid evaluation of technical and market trends. We thank the costing personnel of these firms for providing detailed financial information on specific products and product lines. In particular, the study team wishes to express its gratitude to Mr. Bergmann of Bendix for refining our initial findings, Mr. Dan Anderson of Narco for providing insight into general aviation avionics technology, and Mr. Howard Rooks of Collins for permitting a detailed comparative look at a large variety of manufacturing techniques.

SUMMARY

The FAA contracted with ARINC Research Corporation to examine the impact of technology on the cost of nonmilitary avionics. This study, conducted under Contract DTFA01-80-C-10030 with the FAA's Office of Systems Engineering Management, reviewed the impact of the past 20 years of technological advances on the cost of avionics and forecast these impacts for the next 20 years on the basis of historical trends.

Unit-level avionics prices have been increasing at the Producer Price Index (PPI) Rate. (See Figure S-1.) This relationship was determined by examining the cost histories of more than 20 representative avionics equipment families. An avionics family includes the initial avionics unit and its technologically improved deriatives (e.g., the Collins 621A-2, -2A, -3, -6, and -6A transponders). The underlying reason that costs follow the PPI appears to be the result of a balance between rising cost trends that follow the CPI (the Consumer Price Index, a rate that is more than the PPI) and cost reductions that result from the introduction of new technology. The market place appears to create a balance between these trends that closely follow the PPI. However, the PPI has been increasing at a slower pace than average earnings: only 64 percent as many wage-earned hours were required in 1979 to purchase a piece of avionics as were required in 1967. In addition, the functional capability of the comparable unit has increased over the performance of its predecessors of 10 to 15 years ago.

The list price of avionics is composed of the direct cost of materials and labor and the indirect costs of manufacturing overhead, administrative and sales expenses, and distribution costs.

Materials have dominated direct costs during the past 20 years. The materials used in avionics have changed from the heavy use of expensive mechanical and electromechanical components to less costly semiconductors. This shift reflects the revolution experienced by the entire electronics industry since the invention of the transistor and the associated introduction of solid-state technologies. Future cost reductions will continue for many years but at an ever decreasing rate as semiconductors approach physical performance limits. The greatest potential for cost reduction in future avionics designs lies in the elimination of inflation-sensitive components such as L-band transmitter tubes and electromechanical displays, minimizing the few other mechanical items. When RF semiconductor power devices become cost competitive with tubes, transmitters will experience

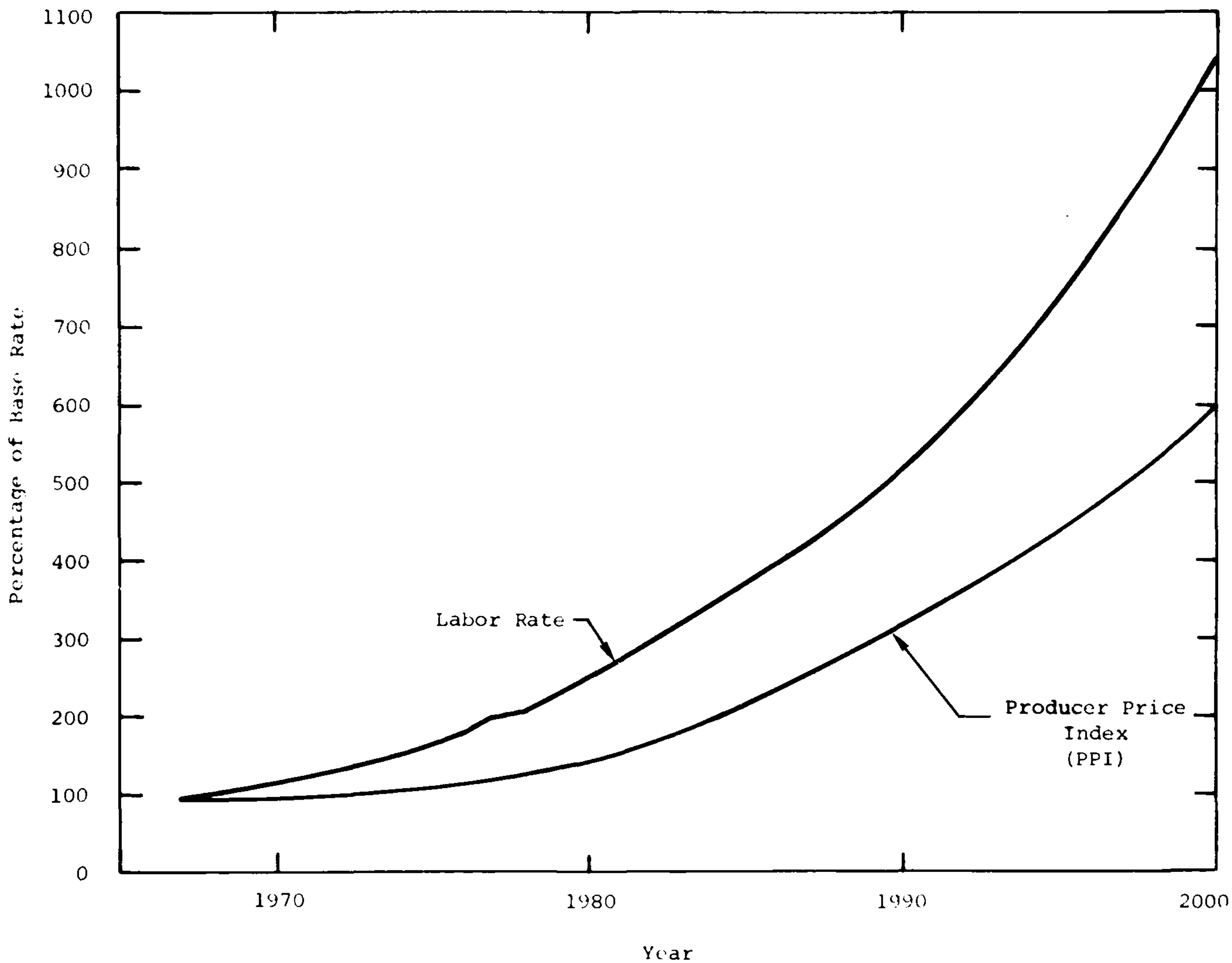


Figure S-1. LABOR RATE TREND IN ELECTRONICS MANUFACTURING (BASE YEAR 1967) the price reductions of discrete solid-state devices. Such servo-driven displays as course deviation indicators (CDIs), although popular with pilots, will eventually be replaced by electronic displays that are available at about half the cost. Some additional savings may be achieved through creative new packaging concepts and size reductions. Changes in system architecture may also produce cost savings if existing barriers to implementation of new architectures can be overcome.

The availability of compact, low-cost, powerful semiconductor devices has affected avionics manufacturing. These components, developed for use with automatic assembly equipment, have reduced labor hours and offset increasing labor rates. Consequently, the percentage of direct cost attributed to labor remains constant, about 15 percent of the total direct cost. These changes are affecting indirect costs as well. Manufacturing overhead burden is increasing as a result of the increased capital costs of automated equipment, the additional development engineering required for new units, and the fewer labor hours against which fixed or rising overhead is prorated. As a result, the average manufacturing overhead burden, which was under 300 percent in the middle of the 1960s, will increase to about 430 percent by the year 2000. Administrative and sales expenses and distribution costs are unaffected by technological advances, and they will continue to consume a constant percentage of the total list price of avionics.

Avionics circuit architecture has experienced several significant changes. Nevertheless, the adoption of innovations by commercial avionics manufacturers has been and will continue to be a slow process. The industry's market is limited: its growth is less than 5 percent per year. This market does not now and will not in the future provide a sufficient production base for large research and development efforts. Consequently, avionics manufacturers depend upon other segments of the electronics industry for innovation and concentrate their research and development efforts on product development. Major innovation, such as the introduction of transistor technology, requires 15 to 20 years to progress from invention to avionics application. Other key advances, such as the transitions from transistors to integrated circuits (ICs) and from ICs to large-scale integration, required eight years to mature and be adopted. As a result, the current semiconductor technology will continue to dominate avionics design until the year 2000. Manufacturers will use some key innovations to provide expanded avionics capabilities. At the same time, these innovations will moderate the effects of inflation so that prices will correspond to the PPI rate.

CONTENTS

CONTENTS (continued)

CHAPTER ONE

INTRODUCTION

The FAA contracted with ARINC Research Corporation to examine the impact of technology on avionics costs and to forecast probable avionics costs for the next 20 years. This evaluation requires an accurate assessment of past trends and a prediction of possible future technological revolutions that would permit continuing quantum jumps in capability. This report, prepared under Contract DTFA01-80-C-10030 with the FAA's Office of Systems Engineering Management, describes the findings of that examination.

1.1 PURPOSE

The objective of this report is to document the impact of technology on avionics costs and to project future trends by anticipating new technological advances. This report is intended to serve as a long-term forecasting tool in the establishment of accurate input parameters to use in cost modeling future avionics prices through the year 2000.

1.2 SCOPE

This report presents the results of a study of the nonmilitary avionics industry of the past 20 years and the next 20 years. The study is limited to the interaction between technology and the production cost of avionics -- the relationship between market forces and retail cost has not been analyzed. The avionics systems investigated included very high frequency (VHF) communication sets, navigation receivers, course deviation indicators (CDIs), and transponders. Nonelectronic instruments, such as temperature gauges, have been excluded from the investigation.

This report intentionally presents only industrywide average data to preserve the confidentiality of some sensitive figures and more importantly to remove the biases inherent in specific approaches of particular products, manufacturers, or users. Detailed cost figures and technical parameters have been aggregated and smoothed sufficiently to clarify long-term trends because the comparison and evaluation of competing products and design philosophies were not within the scope of this study. However, the product design philosophy and cost of goods sold throughout the industry are remarkably similar.

Great care has been taken to ensure that the report represents most major avionics system functions, equipment manufacturers' experiences, and the general aviation and air carrier markets.

1.3 METHODOLOGY

The study was conducted in six steps as illustrated in Figure 1-1. The first three steps are concerned with data collection, and the second three are concerned with data analysis and documentation of the results.

Two independent data collection efforts were initiated concurrently to ensure the compilation of accurate, comprehensive information about industry behavior. The first of these two efforts consisted of a thorough literature search to obtain past productivity and technology indicators and forecasts. Data bases containing government-sponsored studies, such as the Defense Technical Information Center and the NASA Information Retrieval Service, were queried. Articles appearing in periodic publications, such as "Electronics" and "Aviation Week and Space Technology," also were reviewed. Statistics maintained by government agencies, such as the Department of Labor and the Federal Aviation Administration, and industry trade associations, such as the Aircraft Electronics Association, were compiled. The second of these two parallel efforts consisted of a detailed study of the design and manufacture of a representative sample of avionics. Units selected for this detailed study included those items that have exhibited a long production history with minimal functional changes over the years. In particular, the units included transponders, VOR receivers, VHF communication or communication/navigation units, CDIs, and distance measuring equipment (DME) manufactured by Bendix, Collins, King, and Narco. The list prices of units with similar functions, adjusted for inflation, were used to develop an average trend in avionics prices. Each unit was then subdivided into discrete functions (e.g., VHF receiver, L-band transmitter, VOR baseband logic) and a cost analysis was performed. These units were analyzed with respect to cost, component count, and technology trends. The results of the analysis were later refined in lengthy personal interviews during visits to these manufacturers' plants.

The results of these two independent data searches were combined and correlated. An example of this process is the combination of U.S. Department of Labor published inflation figures with manufacturers' list prices to "deflate" equipment retail prices to a constant dollar value. The results provided an accurate assessment of the real constant dollar prices of avionics compared with the progression of technology. Combined data subsequently were separated into individual cost elements (such as materials/labor and direct/indirect cost) that represent the different factors affecting avionics costs. Least-squares curve fitting techniques were used, where applicable, to project future trends from the historical data. Engineering judgment and form fitting were used to smooth discontinuities and to highlight long-term trends.

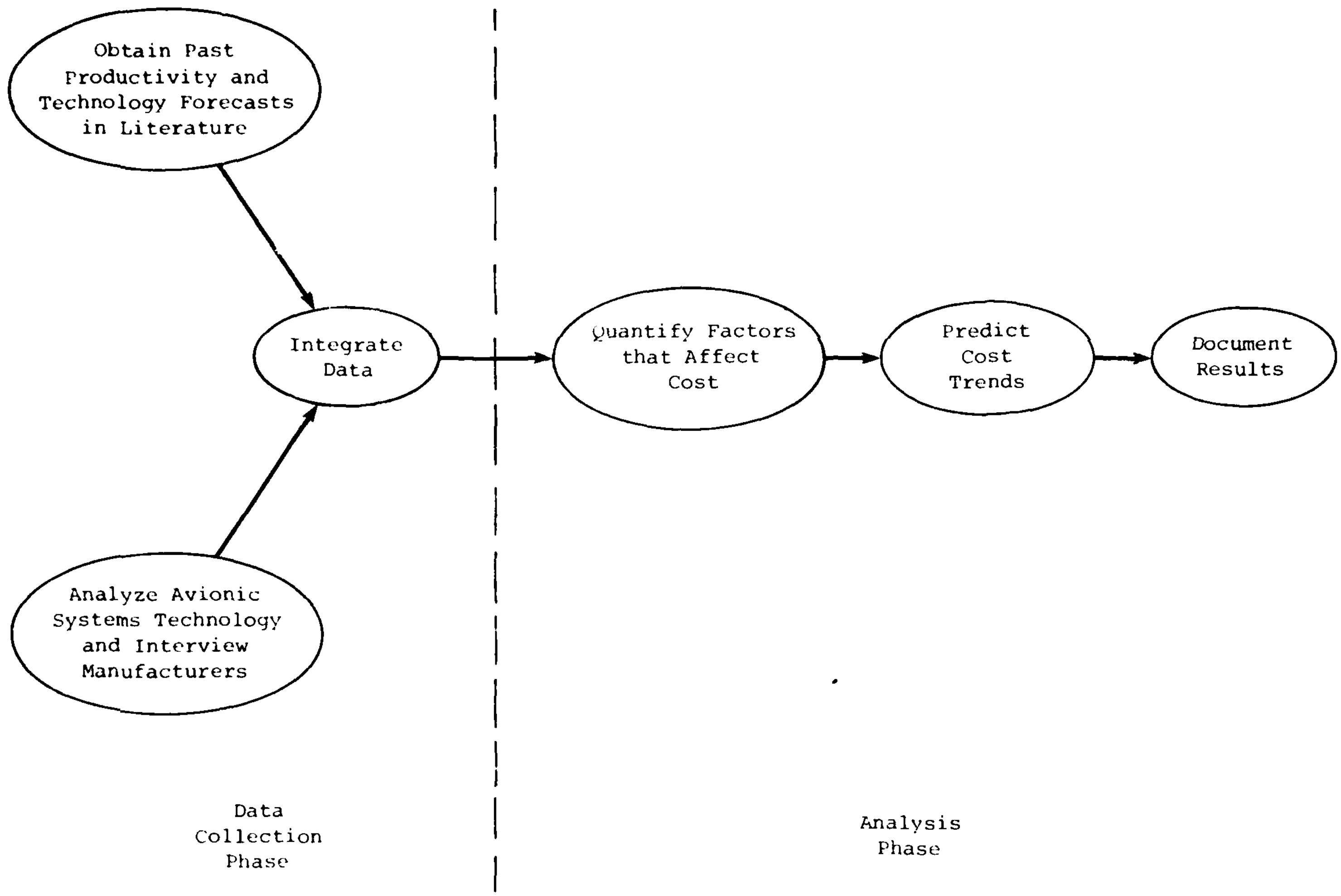


Figure 1-1. TECHNICAL APPROACH

1.4 ORGANIZATION OF REPORT

The five chapters of the report describe factors that comprise retail prices, technology and cost trade-offs, functional module costs, and conclusions.

Chapter Two describes the different factors that make up the final retail prices of avionics equipment. Trends of different nontechnical cost factors, the impact of inflation on prices, and a projected inflation trend are described. Constant 1967 dollars are used throughout the remainder of this report because most government statistics and many economic analytical services use 1967 as the base year in their indexing and reports. Figures also include 1980 dollars for comparison purposes.

Chapter Three develops a hypothetical model of how technology and cost trade-offs are made by manufacturers. Factors that affect these trade-offs, such as packaging and manufacturing techniques, materials, and technology diffusion, are described in detail.

Chapter Four forecasts manufacturing costs and design considerations related to standard avionics functional modules. These modules represent functional building blocks of avionics units for future cost predictions.

Chapter Five summarizes the results of the investigation and presents the major conclusions.

CHAPTER TWO

THE PRICE OF AVIONICS

This chapter describes the nonmilitary avionics market, summarizes the trends in avionics prices, and explains the major components of these prices. It also examines the relationship between avionics prices and inflation.

2.1 THE NONMILITARY AVIONICS MARKET

The nonmilitary avionics market is made up of the owners of three categories of aircraft. This market spans the range of quality and quantity of today's avionics. The three categories of aircraft are: low-performance, general aviation aircraft; high-performance, general aviation and commuter aircraft; and commercial and supplemental carriers, cargo, and large corporate fleets.

Low-performance, general aviation aircraft avionics dominate the market volume. Two- and four-passenger aircraft, six-passenger single-engine-aircraft, and light, twin-engine aircraft make up more than 80 percent of the 200,000 registered aircraft in the United States. The equipment installed tends to be compact and of minimum cost and functional capability. This part of the avionics market forms the lowest cost market.

The second market is made up of owners of high-performance general aviation aircraft, heavy twins, business jets, and commuter airlines. These owners have slightly different requirements than the typical general aviation pilot: they are less cost conscious and more performance oriented and they tend to equip aircraft more comprehensively. Manufacturers offer a mid-priced line for this market. This line typically incorporates general aviation manufacturing and design techniques, but it has features comparable to those of the commercial air carrier equipment.

The commercial and supplemental carriers, cargo, and large corporate fleets are a unique market. Although less than 3,000 of these aircraft are registered in the U.S., avionics for this market is manufactured to exacting FAA certification requirements. In addition, many airlines have adopted ARINC characteristic requirements for standardization purposes. Typically, these specifications demand high reliability, ease of aircraft maintainability, and more control over the manufacturing process than is applied to most general aviation equipment. As a result, avionics in this market tends to be lower in volume but higher in price than in the other markets.

Theoretically, the avionics market is a competitive oligopoly. More than 50 manufacturers offer products for sale, but more than 90 percent of the market is dominated by three or four manufacturers of any product type. Because the customers are price conscious, a small price swing on a unit among the major suppliers can mean the difference between a major market share and lack of sales.* As a result, manufacturers share a strong incentive to maintain prices over the years.

2.2 TRENDS IN AVIONICS PRICES

Figure 2-1 shows some sample price trends of VHF transceivers produced during the 1970s. An increasing price trend is clearly discernible. This trend closely parallels purely inflationary price increases, in spite of increasing capabilities of the transceivers offered for sale. In Figure 2-1, inflation is depicted as a band representing the different effects of inflation on items with high and low list prices. The close similarity between inflation and price increases suggests a relative inelasticity of prices and provides a convenient mechanism for projecting future prices. The lowest cost transceivers available typically range between $300 and $400. When the price of a unit such as the Mentor TR-12 increases, less expensive units such as the Terra TPX-10 are introduced to fill the void. Of course, these units have less capability than the other units.

2.3 EFFECT OF INFLATION

Inflation represents the decreasing value of money. Three commonly used measures of inflation will be examined: the Consumer Price Index (CPI); the Producer Price Index (PPI), formerly the Wholesale Price Index; and an index of average earnings. Statistical data on all three indices are maintained by and available in great detail from the Department of Labor.

The CPI represents the average cost of a standard market basket of goods that an average family purchases during the year. This index compares current dollars with constant 1967 dollars. Many different specific expenditure categories of items are weighted and compiled into one composite CPI index. Table 2-1 lists the major CPI index categories. These different indices vary significantly, and it is important to select the one most closely related to the subject under investigation. In the case of avionics, "Other Goods and Services" is the most appropriate CPI index for inflation.

The PPI is a completely unrelated set of indices prepared by the Department of Labor on the basis of different commodity groupings, Standard Industrial Classifications (SICs), and census codes. Table 2-2 lists the major PPI categories. Like the CPI, PPI indices can vary significantly and proper index selection is critical. The specific PPI index most closely related to avionics is Index Code 1178, "Electronic Components and Accessories."

The index of average earnings also is derived from Department of Labor statistics. Employment figures and earnings are maintained by industry and

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*Other factors such as convenience, service, and marketing organization also affect market share but are outside the scope of this effort.

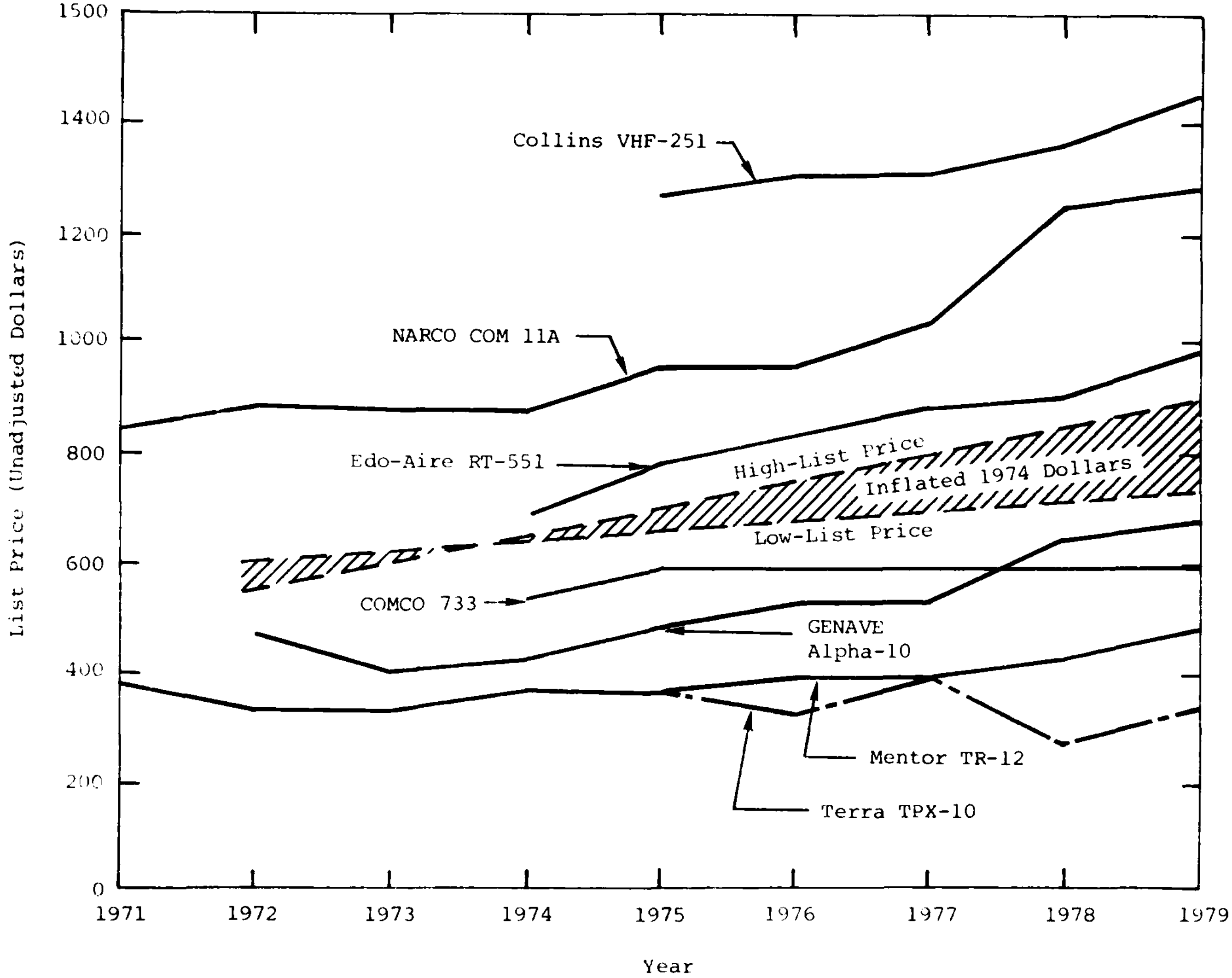

Figure 2-1. SAMPLE PRICE TRENDS OF VHF TRANSCEIVERS

[illegible] INDEX FROM 1967 TO 197[illegible] BY EXPENDITURE CATEGORY								
Year	[illegible]	[illegible]	[illegible] Index	Apparel and Upkeep Index	Transportation Index	Medical Care Index	Entertainment Index	Other Goods and Services Index
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0	100.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	112.[illegible]	1[illegible].6	116.7	116.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16[illegible].6	1[illegible]2.2	153.9
[illegible]	[illegible]	[illegible]	[illegible]	1[illegible]6.4	[illegible]	24[illegible].1	187.6	196.3

Table 2-2. MAJOR CATEGORIES AND COMPONENTS OF PPI	
Category	Components
Crude materials for further processing	Crude foodstuffs and feedstuffs Crude nonfood materials except fuel Crude fuel
Intermediate materials, supplies, components	Manufacturing Materials and components for construction Processed fuels and lubricants Containers, nonreturnable Supplies
Finished Goods	Finished consumer goods Capital equipment

labor categories. These data are traceable before 1950. They cover several hundred different industries and several different labor categories for each industry. The detail to which this data is available is illustrated by SIC Code 36, "Electric and Electronic Equipment," shown in Table 2-3.

Figure 2-2 shows past and projected inflation curves for CPI, PPI, and earnings. Projections for CPI through 1993 were obtained from the Wharton Econometric Forecasting Associates. We then extrapolated the CPI through the year 2000 via an exponential least square fit exhibiting a correlation coefficient of .9 or better. The PPI was assumed to track the rate of growth of the CPI during this extrapolation interval.

Earnings have slightly led the CPI in the 1970s and indications are that this trend will continue. This relationship between earnings and the CPI provided the basis for projection of earnings. The PPI has traditionally lagged the CPI by a significant margin. This difference between the

Table 2-3. TYPICAL CATEGORIES AND SUBCATEGORIES IN SIC CODE 36 -- ELECTRIC AND ELECTRONIC EQUIPMENT -- FOR WHICH EARNINGS DATA ARE COMPILED

Category	Subcategory
Electric distributing equipment	Transformers Switchgear and switchboard apparatus
Electrical industrial apparatus	Motors and generators Industrial controls
Household appliances	Household refrigerators and freezers Household laundry equipment Electric housewares and fans
Electric lighting and wiring equipment	Electric lamps Current-carrying wiring devices Residential lighting fixtures
Radio and TV receiving equipment	Radio and TV receiving sets
Communication equipment	Telephone and telegraph apparatus Radio and TV communication equipment
Electronic components and accessories	Electronic tubes Semiconductors and related devices Electronic components
Miscellaneous electrical equipment and supplies	Storage batteries Engine electrical equipment

CPI and PPI has existed for the past 20 years, appears to be the result primarily of the selection of market basket items, and (combined with least squares fit) provides the basis for projection. In particular, the CPI will continue to be heavily influenced by strong inflationary factors such as food, housing, and transportation, whereas these effects are not as predominant in the PPI.

Figure 2-3 examines the effects of inflation on prices of Collins 621 series transponders. This series of transponders appears to exhibit about average price growth rates. The list prices adjusted for inflation by the PPI in Figure 2-3 appear constant, while the list prices adjusted for inflation by the CPI decrease, indicating that the price increases experienced by this series of units during the past 15 years has tracked the PPI. The PPI, in fact, is an excellent measurer (and consequently predictor) of the effects of inflation on avionics costs for a wide variety of equipments, as illustrated in Figures 2-4 through 2-7 by the relatively constant prices after adjustment for inflation.

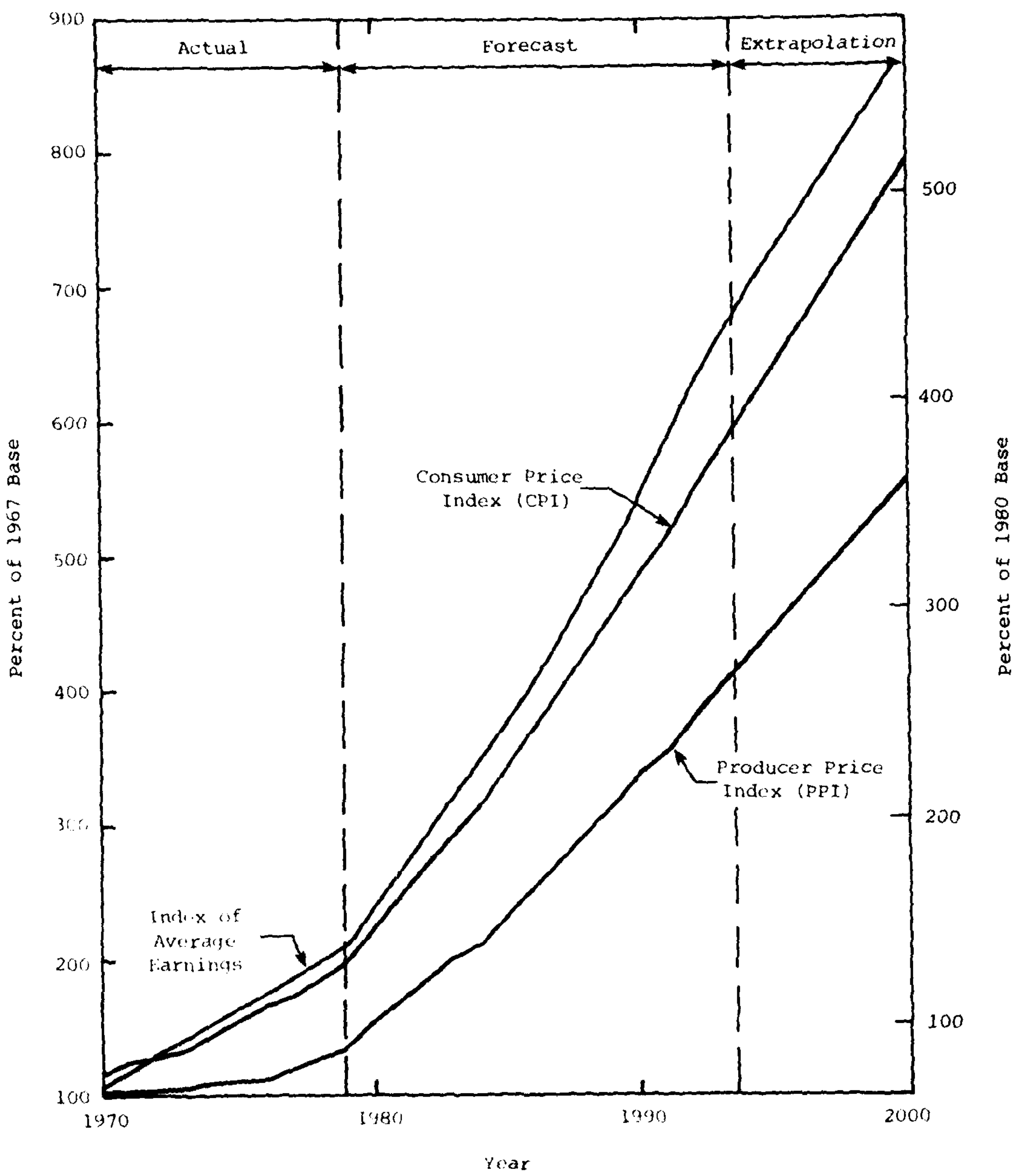

Figure 2-2. INFLATION INDEXES

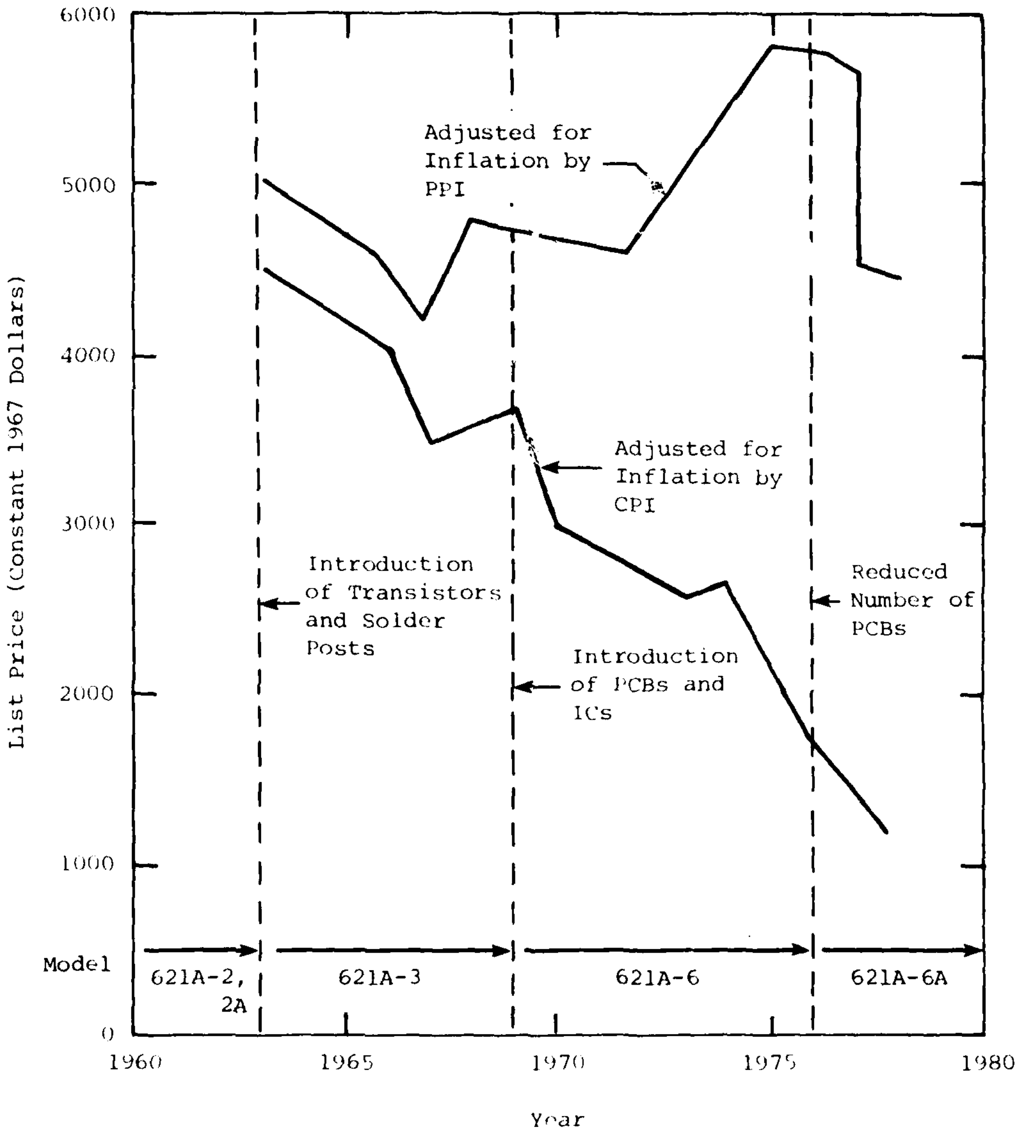

Figure 2-3. LIST PRICES OF COLLINS 621A TRANSPONDERS

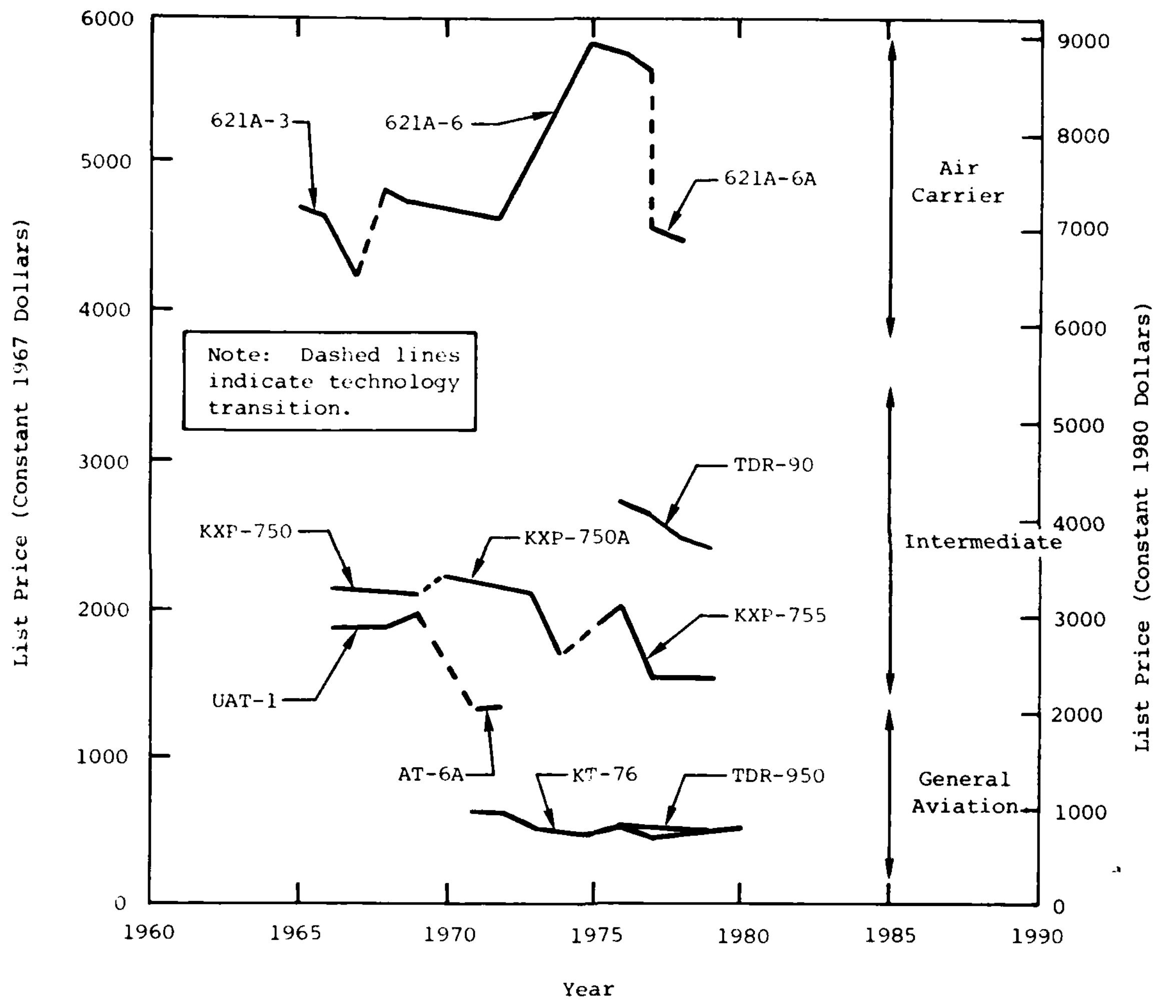

Figure 2-4. LIST PRICES OF TRANSPONDERS (ADJUSTED FOR INFLATION BY PPI)

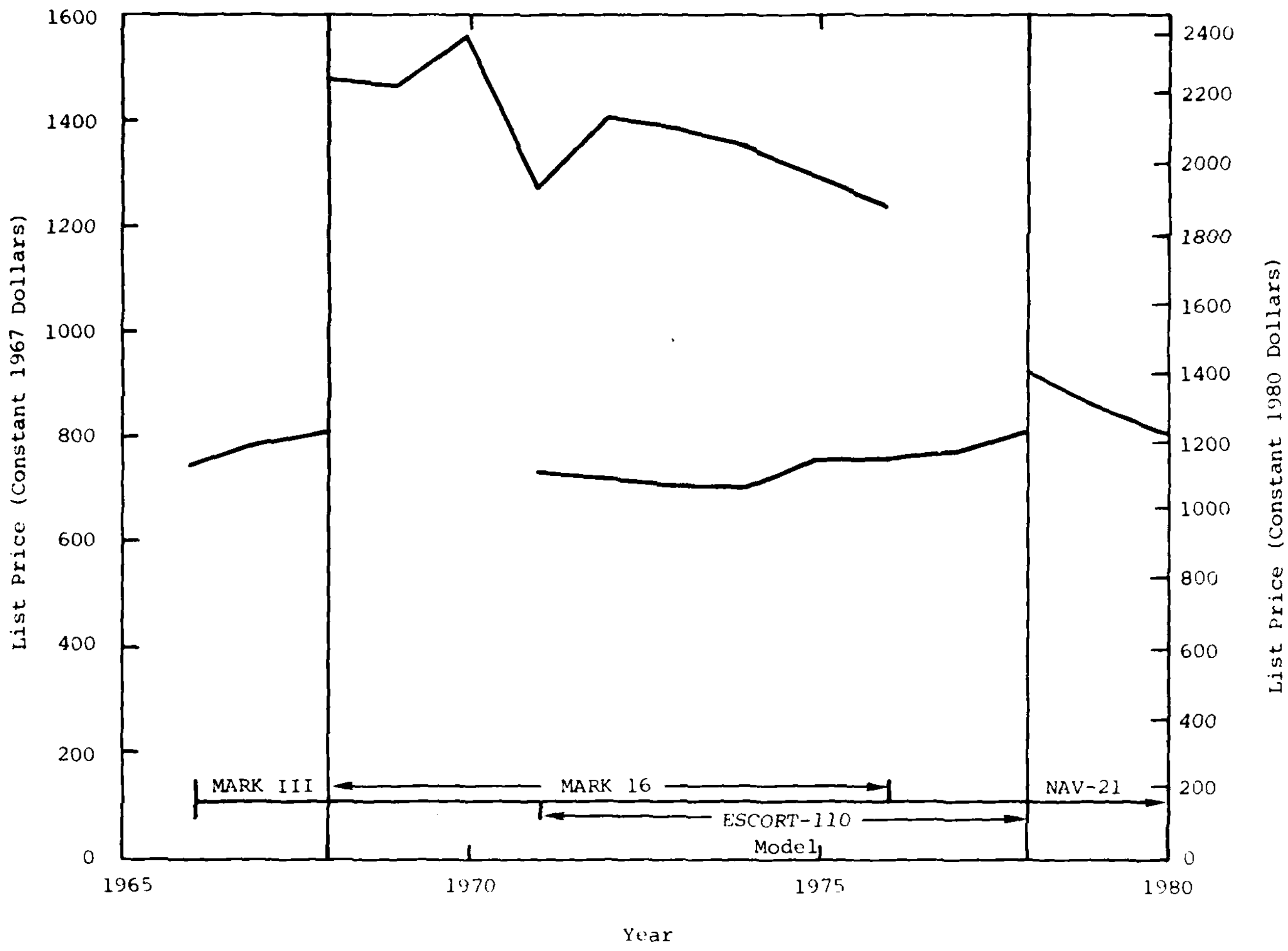

Figure 2-5. LIST PRICES OF NARCO VHF COMMUNICATIONS/NAVIGATION TRANSCEIVERS (ADJUSTED FOR INFLATION BY PPI)

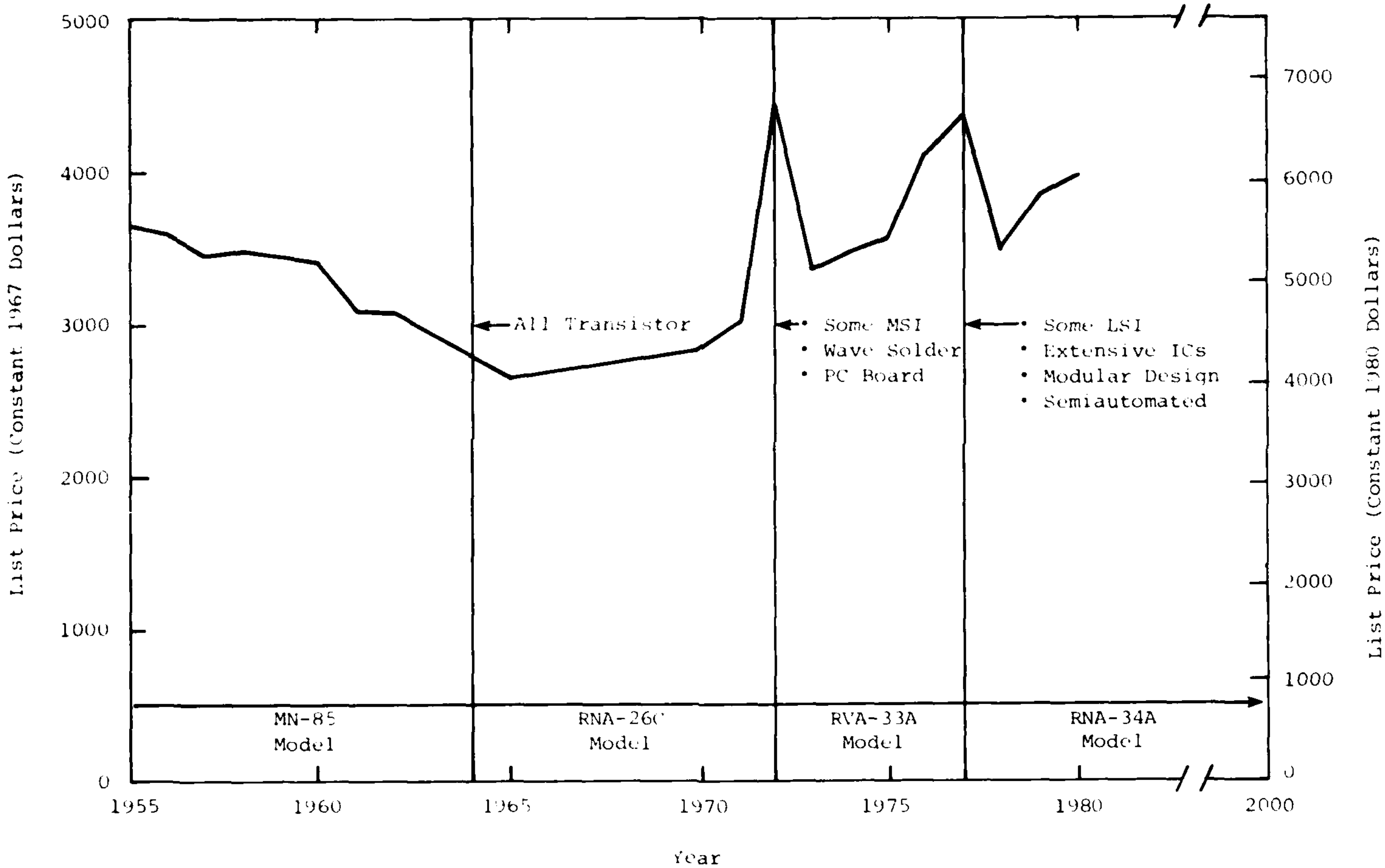

Figure 2-6. LIST PRICES OF BENDIX VOR NAVIGATION RECEIVERS (ADJUSTED FOR INFLATION BY PPI)

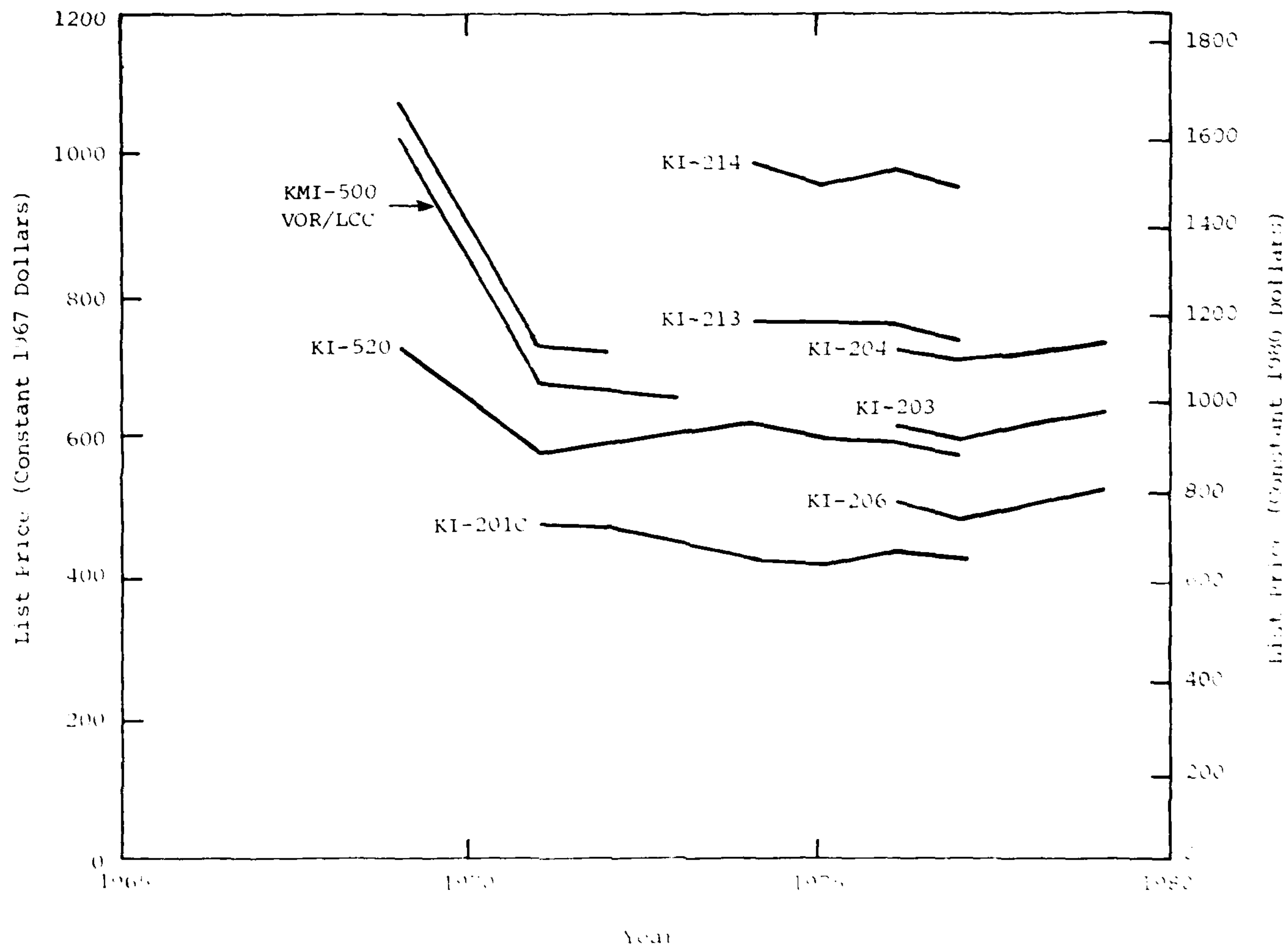

Figure 2-7. LIST PRICES OF KING COURSE DEVIATION INDICATORS (ADJUSTED FOR INFLATION BY PPI)

Although Figures 2-4 through 2-7 indicate that prices adjusted for inflation by the PPI remain constant (in constant 1967 dollars), the units provide more functional capabilities than their predecessors of 10 to 15 years ago. Furthermore, avionics is more affordable because earnings have been increasing faster than the cost of avionics, i.e. the time required to earn the value of a unit in 1979 is 64 percent of the time required to earn the value of an equivalent unit in 1967.

Unless otherwise noted, constant 1967 dollars (adjusted for inflation by PPI) are used throughout the remainder of this report because most government statistics and many economic analytical services use 1967 as the base year in their indexing and reports. Figures also include 1980 dollars for comparison purposes ($1.00 in 1967 inflated by the PPI equals $1.43 in 1980).

2.4 FACTORS IN AVIONICS PRICING

Avionics prices respond to technology, market forces, and other factors. Technology mainly affects the cost of goods sold, whereas market considerations tend to drive both the original manufacturer's and the retail sales prices. Other factors such as regulation may affect the cost of avionics, the market, or both.

The cost of goods sold consists of the direct cost of materials and labor and indirect factory costs assessed against a product as a combination of factory labor-burden rate, factory material-burden rate, and factory-overhead burden rate. These three burdens make up the total manufacturing overhead associated with producing a piece of avionic equipment.

The final sales price includes the manufacturer's cost of goods sold, administrative and sales expenses, profit, and distribution costs. Some of these items are market sensitive. The marketing expenses and profits of the manufacturer may be adjusted to achieve the desired price, while distribution costs may be changed by changing distribution channels or the provision of discounts, rebates, and other purchase incentives at either the wholesale or retail level. Each manufacturer has devised a unique pricing structure that suits its marketing, organizational, and financial strategy best. Typical avionics pricing is shown in Figure 2-8.

The total avionics manufacturing burden has been increasing steadily over the years. As shown in Figure 2-9, the rate of increase for a labor-intensive manufacturer will be significantly greater than for a capital-intensive manufacturer, due in part to the conscious trade-off by manufacturers between the direct manual labor costs and indirect costs of fixed capital assets, such as automated assembly, inventory, and information management. Variations in these trade-off strategies account for the variation in burdens. However, to stay competitive and to support the expanding business volume, smaller companies (which initially had low fixed costs and overhead) began to acquire new automated capabilities. These capabilities have driven up the manufacturing overhead of small companies more rapidly than that of firms which had accumulated a large stock of fixed assets earlier. Consequently, burden rates will become more uniform throughout

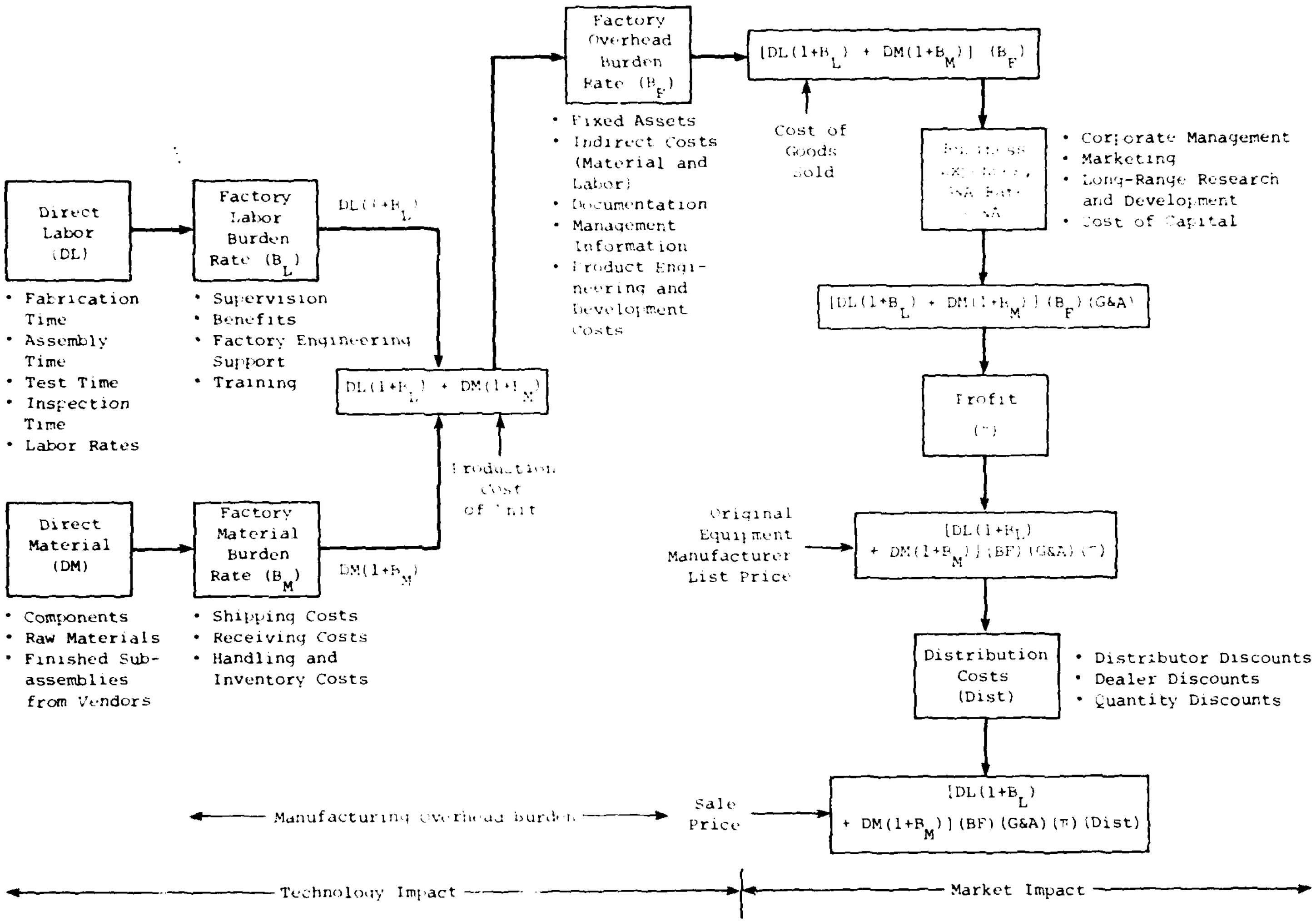

Figure 2-8. TYPICAL AVIONICS PRICING STRUCTURE

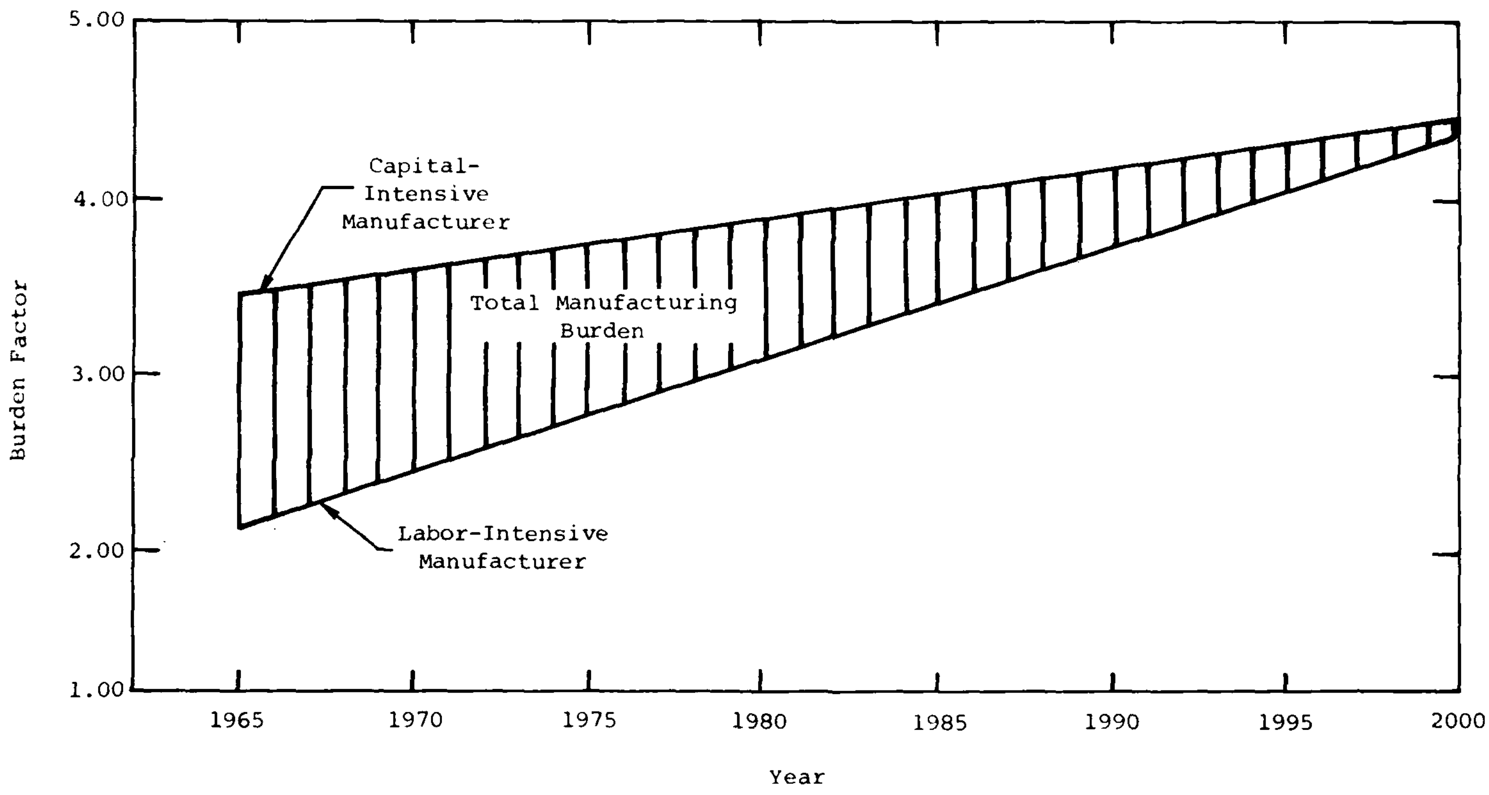

Figure 2-9. MANUFACTURING OVERHEAD TREND

the industry as the production of avionics becomes more capital intensive. Several other factors also drive burden rates up for both capital-intensive and labor-intensive manufacturers. For example, the labor reductions made possible by automation make it necessary to prorate the essentially fixed or growing overhead over fewer production labor hours. Moreover, the design complexity of avionics demands more extensive product engineering and development, and this effort is also prorated over the fewer direct labor hours.

The manufacturing burden is generally applied to direct labor cost only. The basic business expenses, represented by general and administrative (G&A) costs and profits, have not changed significantly, are not expected to do so, and are applied to the cost of goods sold. The distribution cost for low-priced avionics has remained at 100 percent of the original equipment manufacturer's list price and is not expected to change before the year 2000. The distribution cost allows for handling by the various levels of middlemen and the retail dealer. List price does not necessarily reflect the installation price, and variations in installation fees and discounts accommodate short-term market demand/supply fluctuations.

It is evident that overhead and distribution costs will make up a growing portion of the price of avionics, even if direct costs remain constant. This increase is partly the result of management efforts to reduce direct cost through automation. These direct costs are examined in more detail in Chapters Three and Four.

CHAPTER THREE

IMPACT OF TECHNOLOGY ON THE DIRECT COSTS OF AVIONICS

This chapter presents an overview of technologies in manufacturing and design which help to reduce direct material and labor costs. Section 3.1 describes the idealized cost trade-offs between technology and manufacturing. Section 3.2 surveys manufacturing technology and its influence on packaging technique. Section 3.3. reviews advances in component technology. Section 3.4 examines innovation and the process of technology diffusion as they apply to manufacturing and components.

3.1 IDEALIZED COST TRADE-OFFS BETWEEN TECHNOLOGY AND MANUFACTURING

The influence of technology is reflected in the manufacturing cost (i.e., cost of goods sold) of a piece of avionics. For any particular line of avionics, this cost exhibits a characteristic scalloped curve resulting from variations in labor hours, labor rates, material costs, and availability of alternate technology, as shown in Figure 3-1. The following scenario is an example of the influence of technology on the cost of avionics.

In most cases, a Model B avionics is introduced when the cost of manufacturing the Model A reaches comparable manufacturing costs of the new technology in Model B. Management makes this decision by evaluating such factors as the quantity of units sold, the manufacturing costs of the unit, the sales price, and the functional capabilities of the unit versus competitive offerings. The manufacturer generally will realize a reduction in the manufacturing costs for approximately the first two years of the typical eight-year production life of Model B. This reduction results from labor-hour savings caused by learning curve effects and savings resulting from the quantity price break of increased purchase volume. Soon, however, the increasing direct costs of the fixed technology increase above the continuing learning curve savings while the competition forces a reduction in sales volume by introducing more technologically advanced equipment that captures a larger market share. Suddenly, the manufacturer's costs begin to rise until another technology transition point occurs when the next generation techology becomes cost effective, about eight years after introduction of Model B. At this time, the manufacturer introduces the Model C. This cycle is repeated again and again as new manufacturing technologies become available.

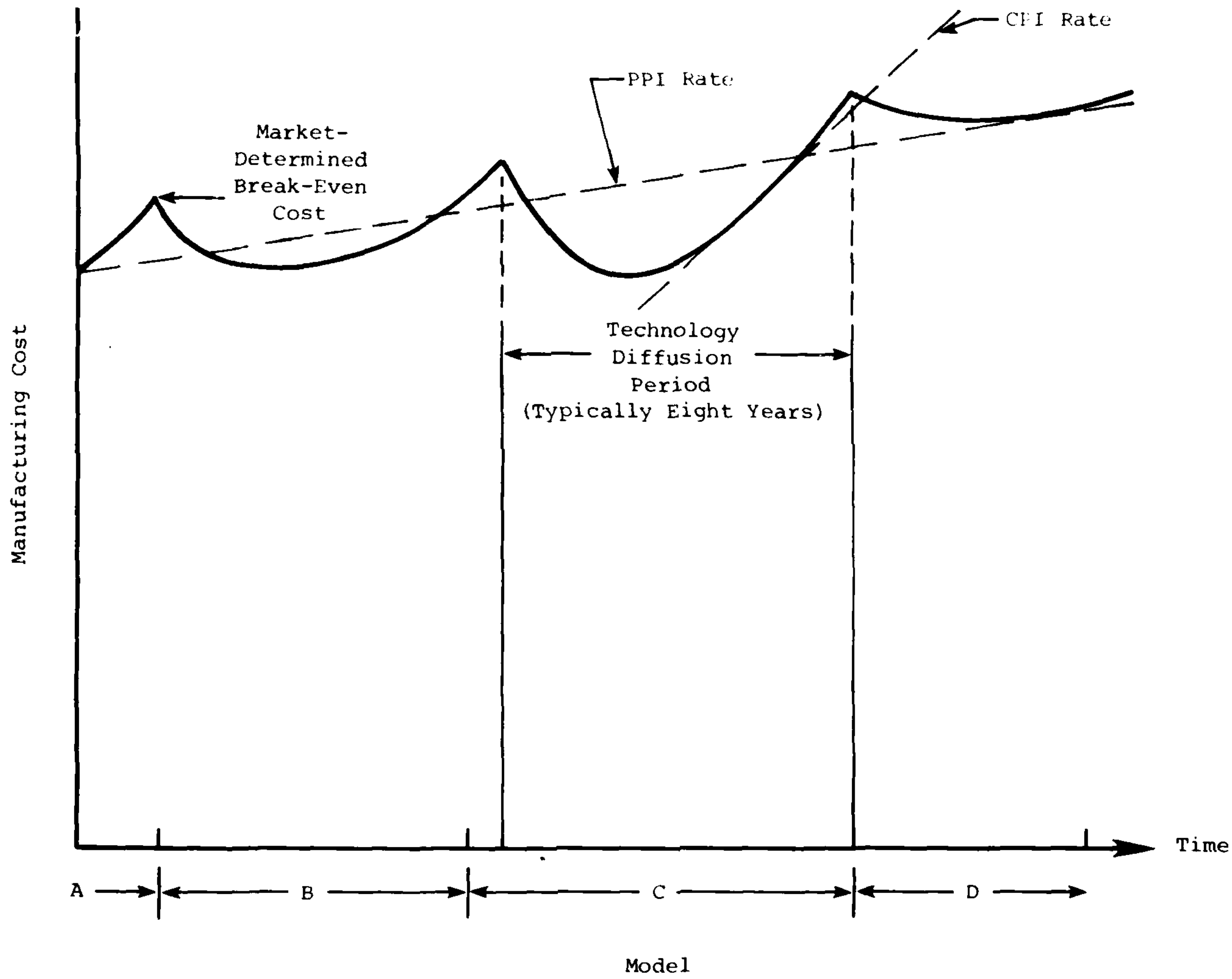

Figure 3-1. MANUFACTURING COST OF A TYPICAL AVIONICS PRODUCT LINE

Although savings from learning curve effects occur throughout the eight-year cycle, the inflationary increases in direct costs resulting from producing a unit with aging technology will begin to dominate in the third year and will mask any learning curve effects. Because new technology is always being introduced, the long-term average cost increases are only at the PPI rate, while short-term cost fluctuations may approach the CPI rate. (Good examples of this technology cycle are the Genave Alpha-10 in Figure 2-1 and the RNA-26C, RVA-33A, and RNA-34A in Figure 2-7 in Chapter Two). This cycle does not appear in all unit prices because recent, highly inflationary conditions have offset initial learning-curve savings, or only partial history data were available.

3.2 MANUFACTURING AND PACKAGING TECHNIQUES

Direct costs are broken into direct material costs and direct labor costs. Changes in the cost of materials are represented accurately by the PPI. Changes in labor costs are available from the Department of Labor, Bureau of Employment and Earning Statistics.

3.2.1 Labor, Manufacturing, and Packaging Techniques

Electronics production labor rates historically have increased faster than inflation (CPI or PPI) as was shown in Figure 2-2. For example, in 1967 the average communication equipment production worker earned $3.07 an hour. If inflated to 1978 dollars according to the CPI,* the wage is $6.00 an hour. In 1978, however, the average earnings were $6.67 per hour. Figure 3-2 depicts actual and predicted labor rates through the year 2000. The actual rates through 1978 were obtained from the Department of Labor;** the predictions are based on the anticipated CPI inflation rates. The PPI, representing concurrent increases in the cost of materials, is included for comparison. This actual and predicted growth in labor rates has forced avionics manufacturers to substitute less expensive materials, design concepts, and manufacturing techniques for manual assembly and fabrication.

Figure 3-3 shows the technology and labor trade-offs for a VHF receiver. In 1967, approximately 9 percent of the total manufacturing cost was direct labor (first pair of bars). If the VHF receiver was produced in the same way in 1978, labor would consume 15 percent of the total manufacturing cost of this same unit (second pair of bars). As a result, total labor content would have increased by 67 percent. The third pair of bars shows the effect of the introduction of newer materials, design concepts, and manufacturing techniques. Labor hours are reduced by about a third while total labor cost is maintained at about the 1967 level. Nevertheless, the cost of materials has dropped so that the labor contribution to total cost has increased from 9 percent in 1967 to 12 percent in 1978.

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*Composite of all items, including foods and beverages, housing, apparel and upkeep, transportation, medical care, entertainment, and other goods and services.

**SIC 355, "Communication Equipment."

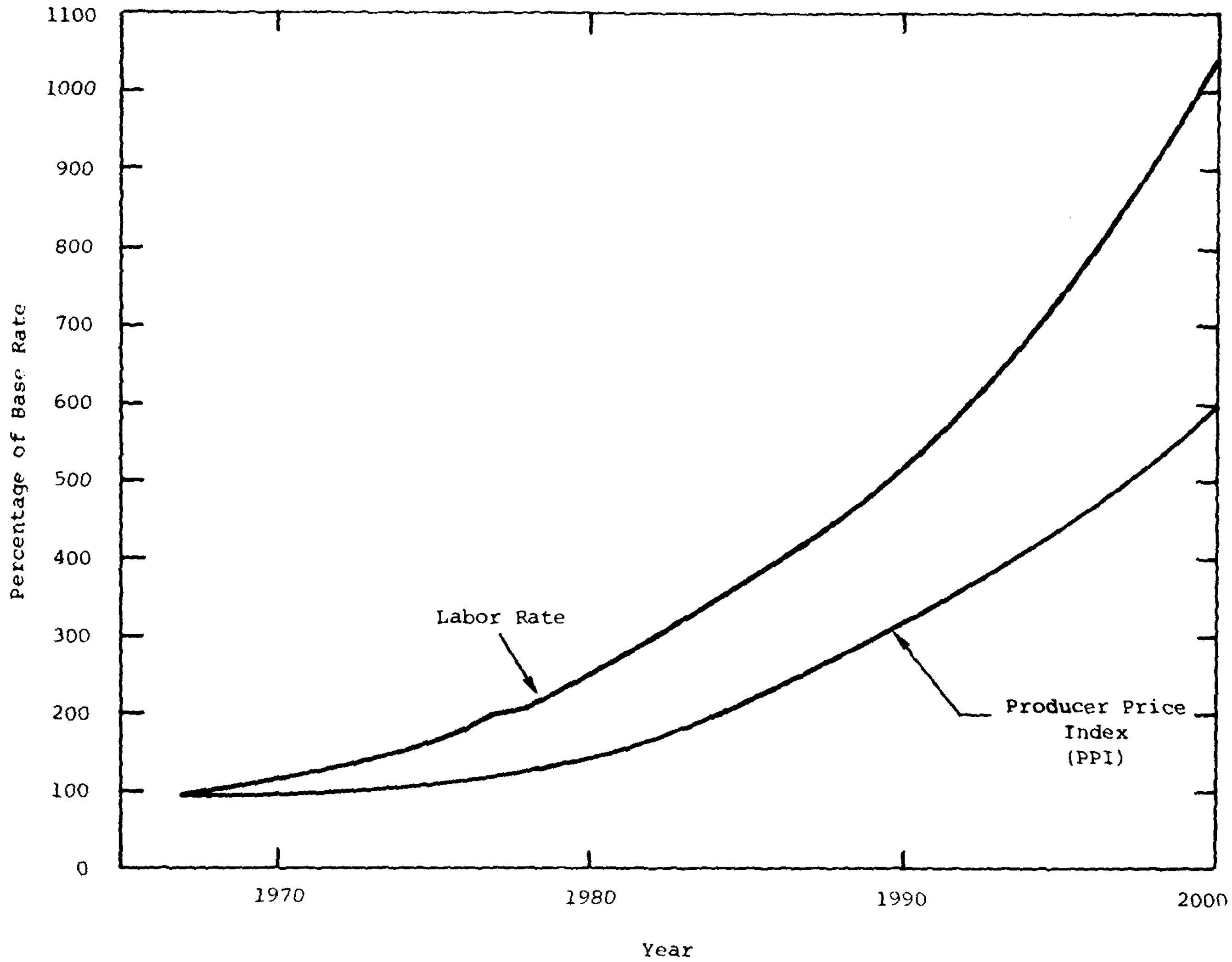

Figure 3-2. LABOR RATE TREND IN ELECTRONICS MANUFACTURING (BASE YEAR 1967)

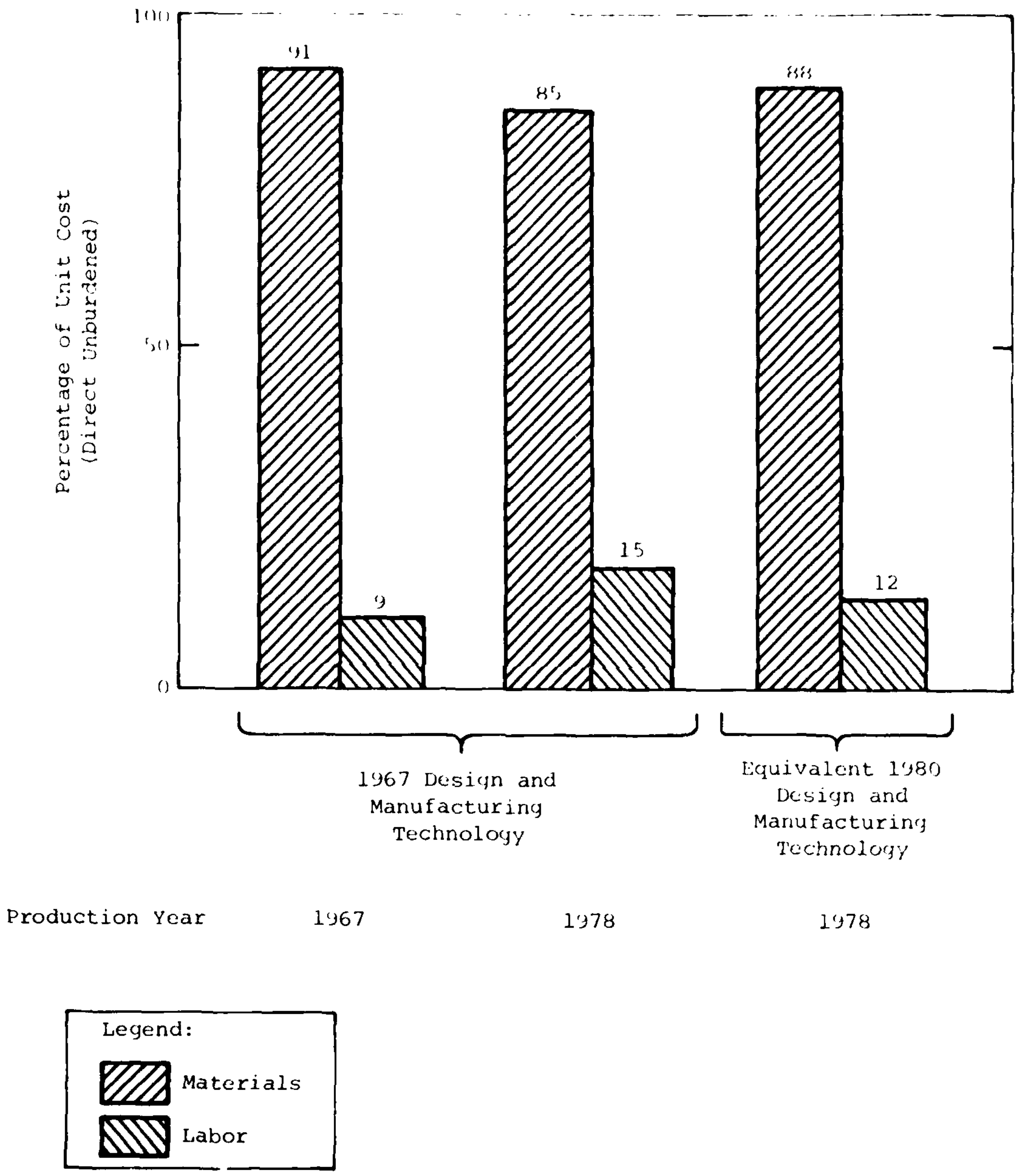

Figure 3-3. TECHNOLOGY AND LABOR TRADE-OFFS FOR THE VHF RECEIVER

3.2.2 Manufacturing Techniques

New manufacturing techniques are introduced mainly to reduce the labor contribution to a unit. Manufacturing technology and equipment packaging design mutually support cost-reduction efforts. For purposes of illustration, manufacturing and packaging technologies have been divided into decades and are described in the following paragraphs.

The manufacturing technology of the 1960s used manual, assembly-line technology. Most components were either chassis mounted or mounted on tie points and stand-offs requiring point-to-point wiring. In more complex units, subchassis were sometimes mounted on a main chassis.

Lead preparation and soldering were primarily manual procedures. Extensive use of mechanical and electromechanical devices required tedious, time-consuming fabrication, assembly, and adjustment. Calibration generally required many adjustments to potentiometers, capacitors, and inductors. Troubleshooting was a technical art using basic laboratory instruments. Testing was a slighly more rigid procedure but was still basically performed manually with laboratory instruments, and it provided little indication of the cause of failure. Semiautomated and, to a lesser extent, automated test equipment existed but this equipment was not yet cost effective for wide application in the industry.

In the 1970s, the printed circuit board dominated avionics manufacture and design. The introduction of transisitors increased wiring complexity, density, and number of connections significantly. As a result, a mass-producible wiring technique was required. The single-sided printed circuit board (PCB), introduced around 1970, could be manufactured in bulk quantities easily, and it significantly reduced wiring labor hours. Component lead preparation was simplified, and component mounting time reduced. Manual soldering was used initially, but PCBs lent themselves well to mass soldering when pot and wave soldering techniques were introduced. Only bulky or high-heat dissipation components were manually mounted on the chassis. Interconnection among boards was done by wire harnesses, which made point-to-point connections much easier to accomplish. The printed circuits boards were mounted on a chassis with stand-offs, while subchassis disappeared for the most part. Elimination of many bulky mechanical and electromechanical devices increased packing density and reduced assembly and adjustment time. Testing, although still performed manually, provided more information for use in troubleshooting. Some firms introduced semi-automated assembly techniques for PCBs and experimented with more fully automated techniques. Assembly and test time was cut drastically. For example, a typical navigation receiver required only 27 hours of labor in the 1970s compared with 50 hours in the 1960s.

Not only did labor hours decrease, but weight and volume also decreased as a result of increased packaging density. In the 1960s, a general aviation navigation receiver weighed about 10 pounds and had a volume of 400 cubic inches. In the 1970s, this same type of equipment weighed 6 pounds and had a volume of 200 cubic inches. The volume of air-carrier equipment did not exhibit comparable size reductions because they were manufactured in accordance with then-existing ARINC characteristic 500 series. The new ARINC characteristic 700 series will permit smaller unit volumes in the 1980s.

In the 1980s, technology will be dominated by dramatic advances in component technology and increasing board densities. The use of modular PCB layouts to suit varying customer requirements and to facilitate testing and troubleshooting is expanding. Point-to-point wiring has been all but eliminated. Ribbon cables, flex circuits, motherboards and backplanes, multiplexing techniques, and plug-in connectors have simplified assembly and encouraged the trend to modular design. Automatic soldering techniques have been improved to a batch process. Manufacturers who use automated component insertion into PCBs have proven savings of 5¢ per component if the automatic inserter equipment is used to full capacity. The cost of contemporary automated assembly equipment still exceeds some manufacturers' installation requirements at present market volumes, but automated inventory control and technical data management are commonplace. Equipment designs now include active internal calibration procedures that require, at most, minor attention during manufacture. Testing includes automatic component identification and value verification, and some functional tests are performed. Fully automated analog testing has not been implemented. Computer-directed troubleshooting has reduced the time required to find faults and does not require the level of skill it once did. Industry leaders who investigated automated assembly techniques in the 1970s are now experimenting with robotics. Robotics makes use of flexible, computer-controlled robots that are capable of as many as six degrees of freedom motion. These robots require minimal tooling to handle varied components and their operating procedures are easily modified through software changes. Consequently, robotics will offer a flexible production capability for short production runs and different operations without the need for a large inventory of dedicated tooling, machinery, and long set-up times required by conventional automated production equipment.

The rising cost of labor will motivate the acceptance of future technology changes. Labor hours will be decreased through continued reduction in component counts; mechanization of chassis assembly and PCB processing; and increased use of computer-controlled testing, calibration, and troubleshooting. Figure 3-4 shows this trend for a typical high-production volume unit such as a VOR. Unfortunately, the spread of automated processing equipment through the industry will continue to be hampered by a lack of market volume until the introduction of robotics. Robotics will reduce setup and tooling costs, which are critical in short production runs.

Figure 3-5 presents historical and anticipated volume of sales for a typical high-volume item such as a VHF transceiver. Actual data through 1976 were obtained from the Aircraft Electronics Association. Data to the year 2000 were obtained by using the FAA's projection of aviation fleet growth. On the average, the market will expand at approximately 2 percent per year through the end of the century, and no rapid increases in overall volume are expected. The dips in total industry turnover and new aircraft installations represent the impact of a recession on the industry. Figure 3-5 shows that during a recession retrofits increase as pilots upgrade

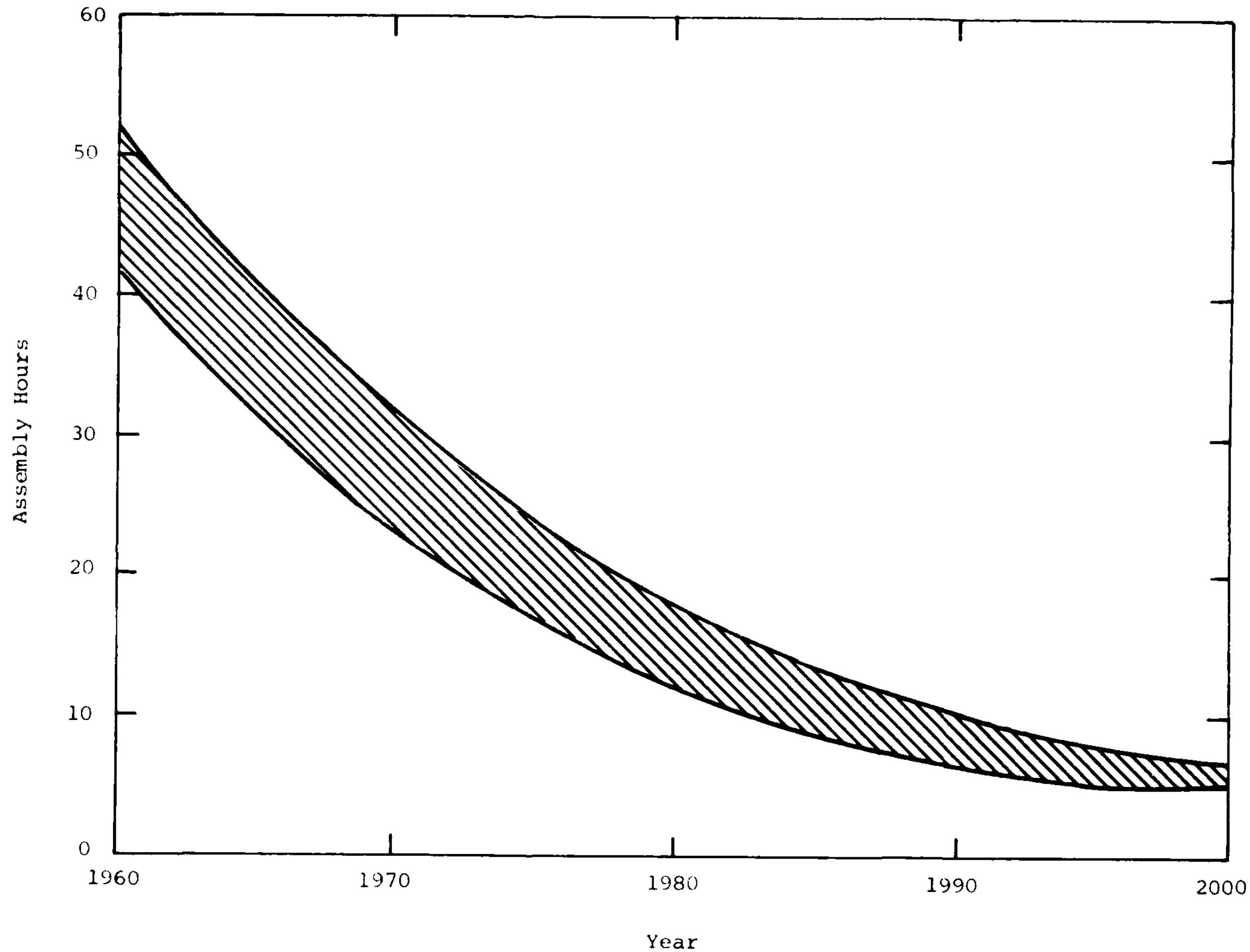

Figure 3-4. TRENDS IN VOR ASSEMBLY TIME

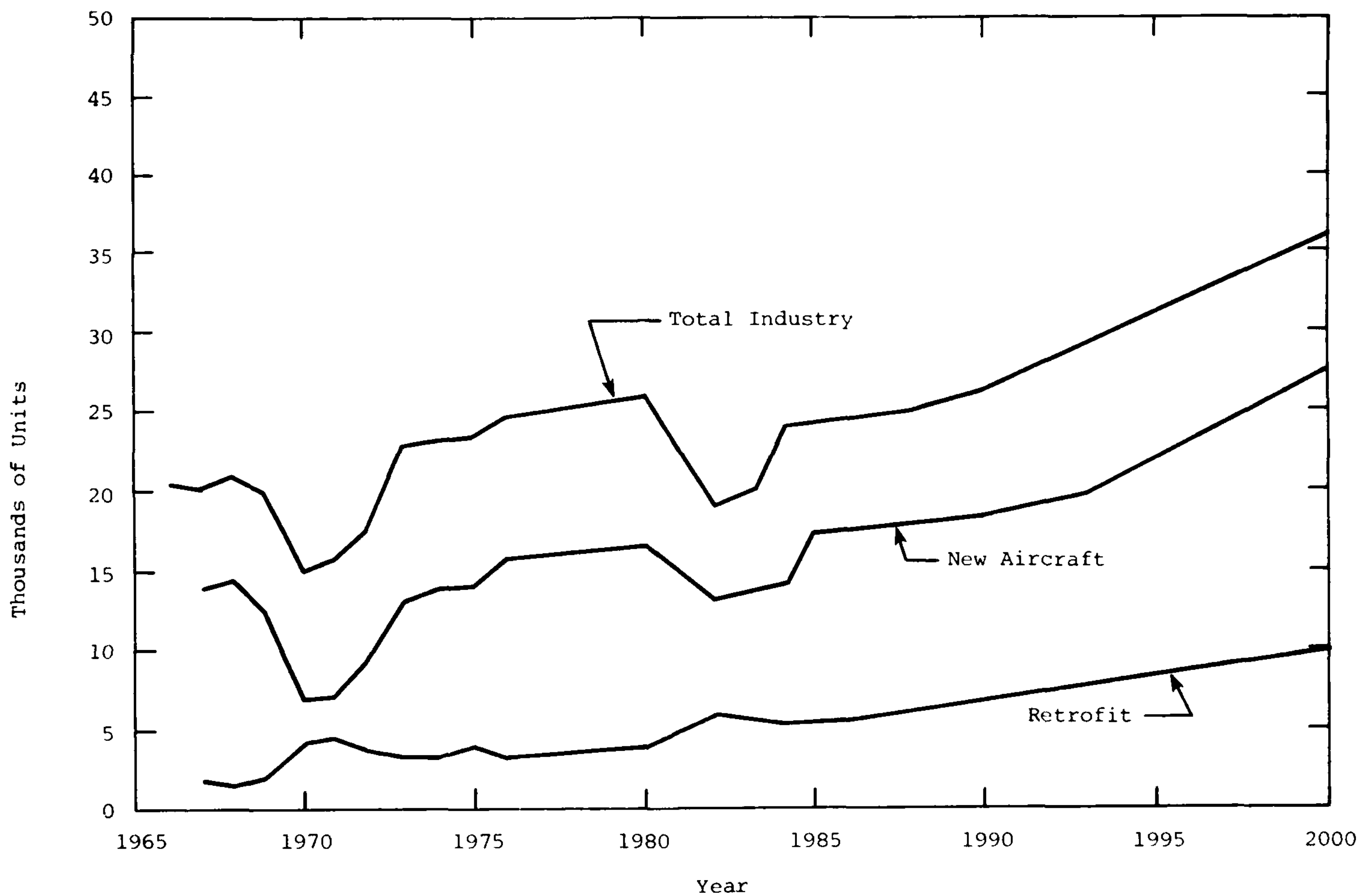

Figure 3-5. AVIONICS MARKET SIZE PER HIGH-VOLUME UNIT

existing aircraft. Since such an avionics market is typically dominated by about five manufacturers, average annual production quantity is less than 5,000 units per manufacturer. This volume is considered by the manufacturer to be just slightly below the required volume for a major investment in automated production and testing. However, robotics, with its inherent flexibility, moderate cost, and ease of setup, will make automatic insertion and assembly capabilities for short-run production available to many smaller avionics manufacturers.

Automation is introduced primarily to reduce labor hours, but it also provides other dividends such as reduced assembly effort, more accurate and thorough testing, and overall improved product quality. Fully automated assembly and testing are still about 5 to 10 years away for at least several manufacturers. By then, automated testing will be broadened from the present component verification to functional tests. Simple automatic digital fault detection and location techniques already exist in the avionics industry. Within ten years, digital sampling techniques will dominate analog functional testing and provide fault isolation capabilities.

Computers are being used increasingly in production processes; they will be applied more widely in other areas such as engineering, management functions, and production support. Computer-based inventory control and management information systems are widespread. Large-volume users already have integrated automated material handling systems with their inventory control and data management systems. Others foresee the need for similar levels of automation within the next five years. A totally integrated and and computerized inventory management system permits manufacturers to mount a drive for an effective parts standardization program. Parts standardization in turn will allow manufacturers to reduce material costs through scheduled buying in large quantities.

Computers can help to reduce product design engineering errors as some manufacturers have proven. Some applications of computers to specific engineering tasks are in the following areas: drafting, PCB layout design, test procedure preparation and sequencing, and circuit design and optimization.

Within the next five years the reduced cost of computers will make sophisticated information management systems available to smaller volume manufacturers. These systems will help to optimize administrative efforts and plant utilization. Table 3-1 summarizes manufacturers' estimates of potential savings from automation in these different areas.

3.2.3 Packaging and Design Techniques

Technology will continue to affect not only avionics manufacturing but also packaging and design. Increasing integration at the component level will continue to reduce component counts and, as a result, equipment volume. Figure 3-6 shows this trend in the volume of navigation receivers. The size reduction of navigation receivers is somewhat masked by continued functional enhancements. Transponders provide an example of what size

Table 3-1. POTENTIAL SAVINGS THROUGH THE USE OF AUTOMATION	
Application	Savings (Percent)
Automated Inventory Management	5 to 20
Components Bought in Quantities	5 to 25
Standardization of Quantities	10 to 25
Automated Administration (MIS)	5 to 10
Automated Insertion With Respect to Assembly	10
Automated Insertion With Respect to Test	15
Automated Insertion and Test (In Process and Final)	2
Warranty Reductions Due to Automation	2

reductions are possible with limited functional enhancements (see Figure 3-7). In conjunction with the size reductions of avionics, weight has been decreasing (see Figures 3-8 and 3-9). There is, of course, a limitation on the minimum weight and volume of a unit. This minimum is defined by the man-machine interface required for ease of control. The true projected volume can be realized only through multifunctional integration in a common package.

3.3 MATERIALS AND COMPONENTS

About 90 percent of the direct cost of avionics can be traced to the cost of materials. This ratio has remained comparatively constant during the last two decades. Figures 3-10 and 3-11 detail this trend for a VHF navcom receiver. A large part of this material cost initially was caused by the cost of mechanical and electromechanical devices. These devices now account for only 11 percent of total cost. The 1960s technology made extensive use of relay switching, servo-selected crystals, and analog mechanical displays. In the 1970s, crystal selection by diodes replaced servo-selection and relays were replaced by semiconductor devices. The only remaining mechanical parts were the controls and enclosure. Electronic displays recently replaced the simpler mechanical indicators (such as digital readouts for DMEs) and appear to be on the verge of replacing traditionally mechanical course deviation indicators (CDIs). Controls may eventually go to push button, but some resistance is foreseen because pilots tend to prefer knobs. Mechanical and electromechanical parts of electronics and packaging have been reduced to near minimum.

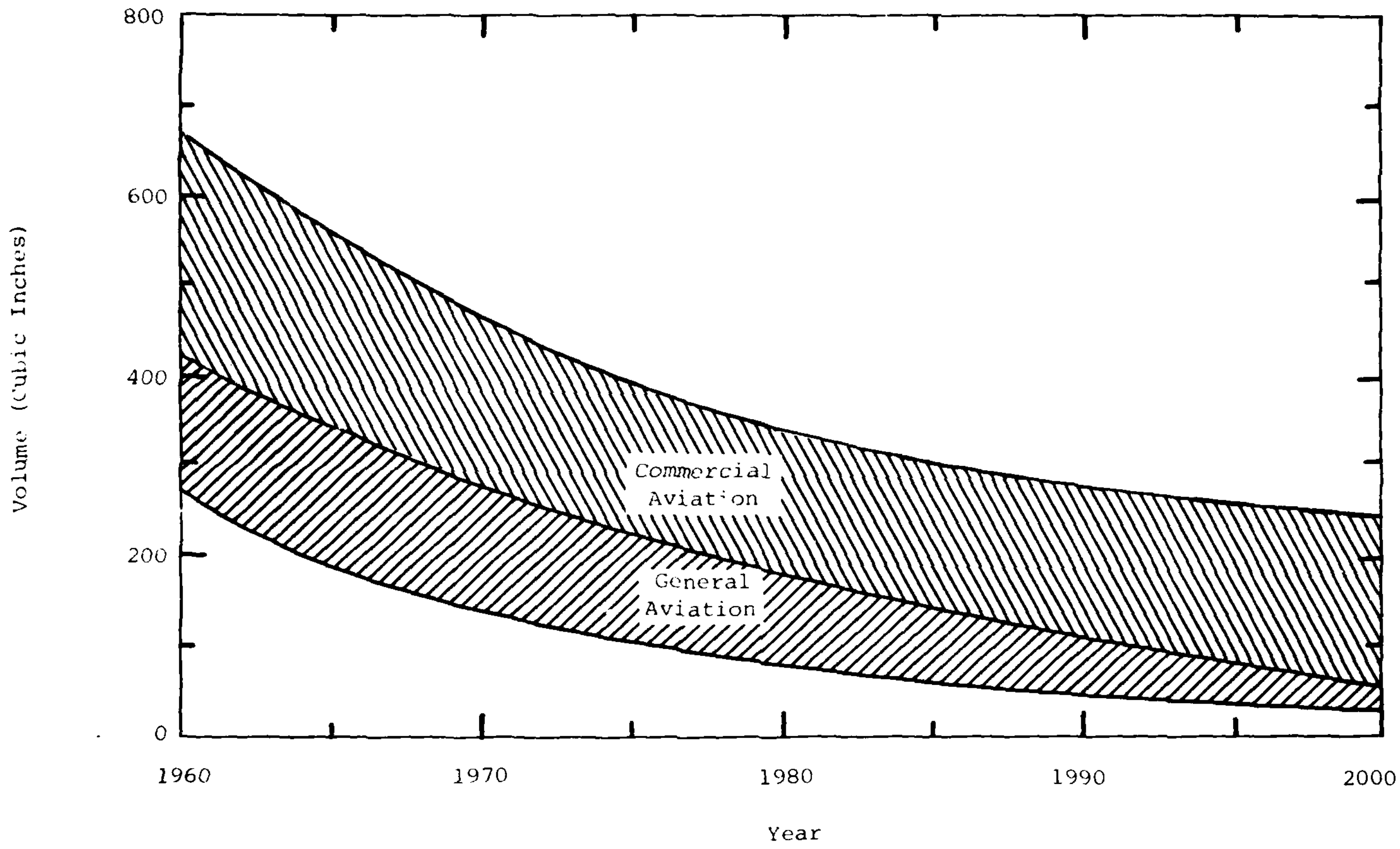

Figure 3-6. NAVIGATION RECEIVER UNIT VOLUME TREND

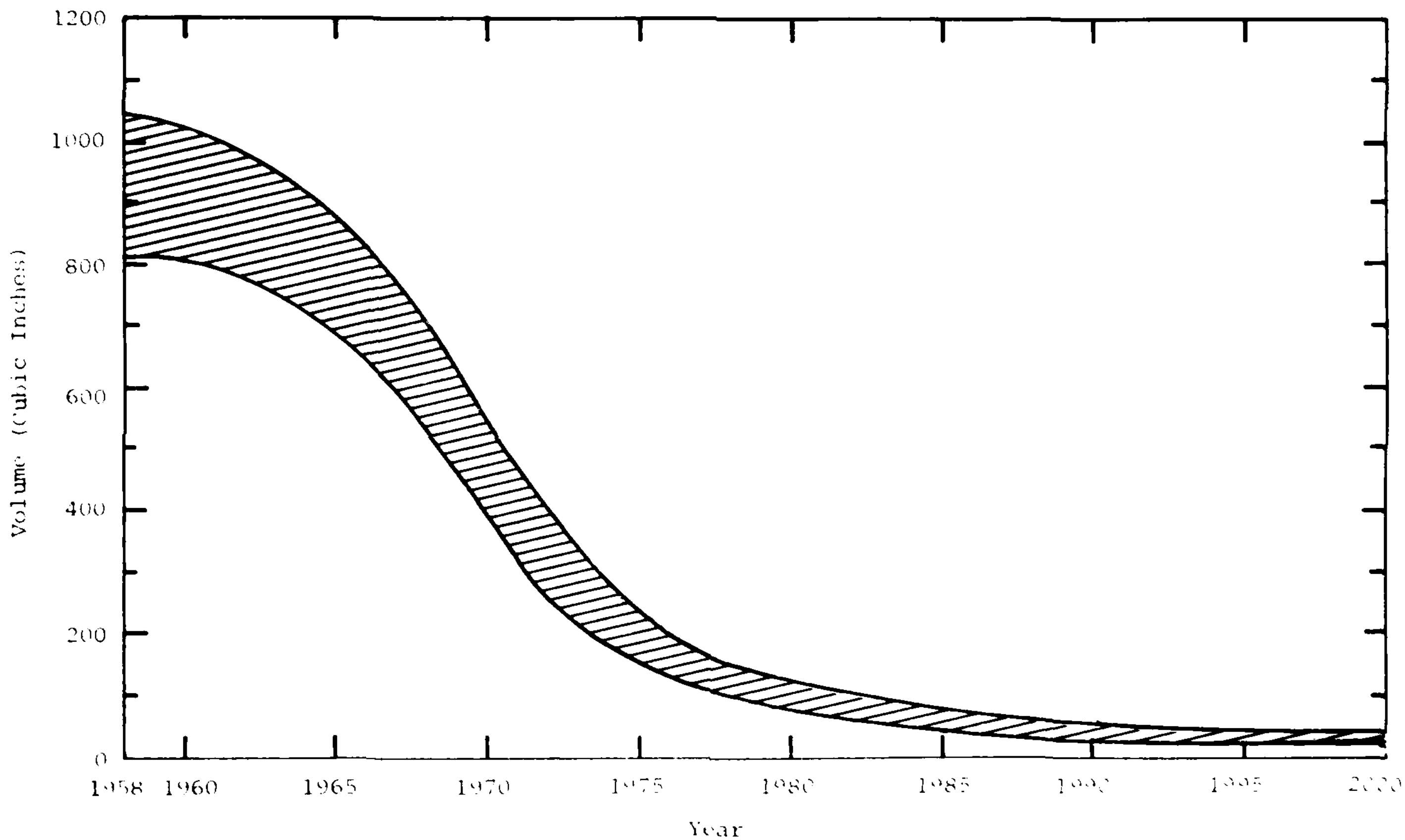

Figure 3-7. UNIT VOLUME TREND OF GENERAL AVIATION TRANSPONDERS

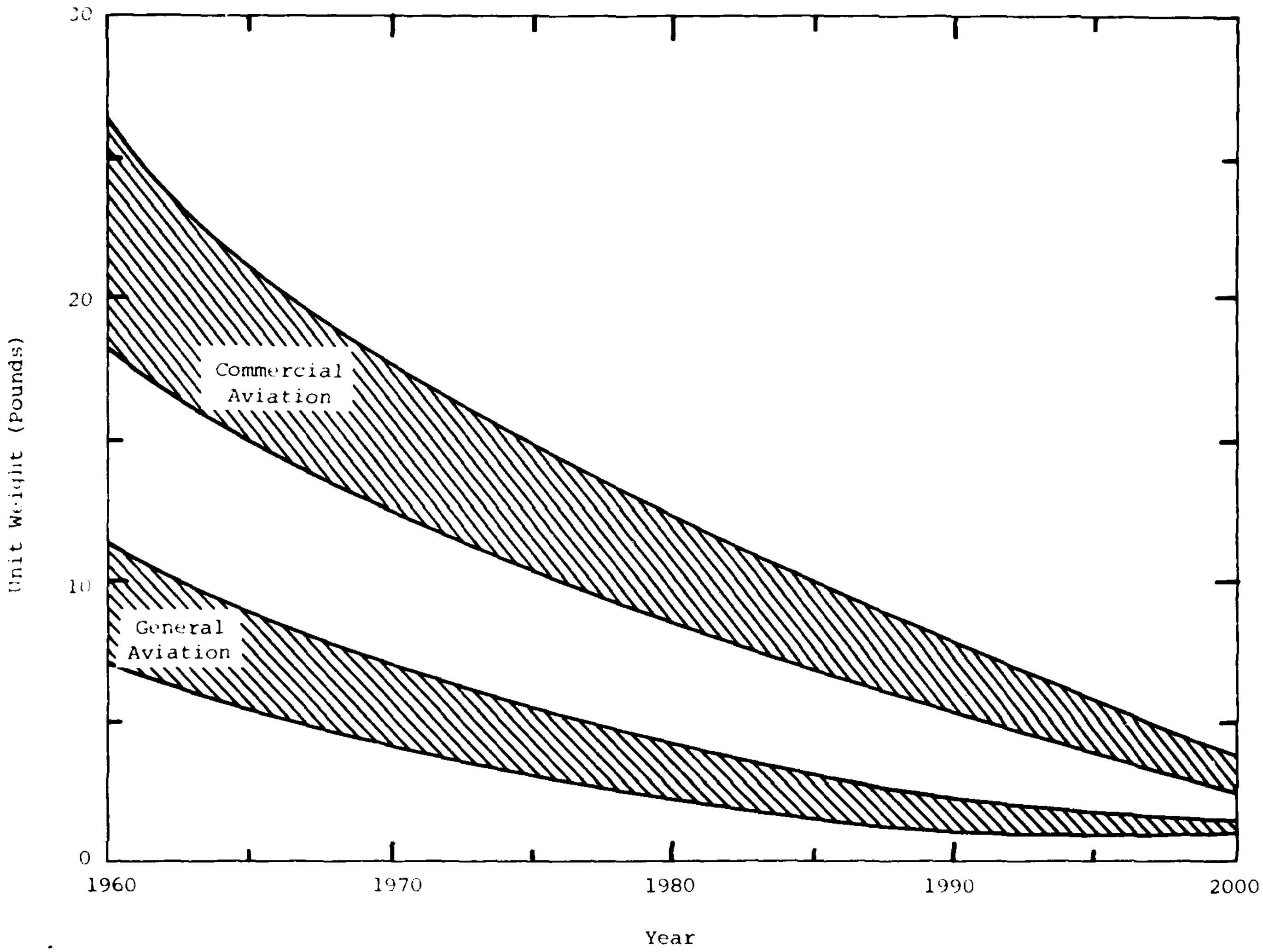

Figure 3-8. TRENDS IN UNIT WEIGHT OF NAVIGATION RECEIVERS

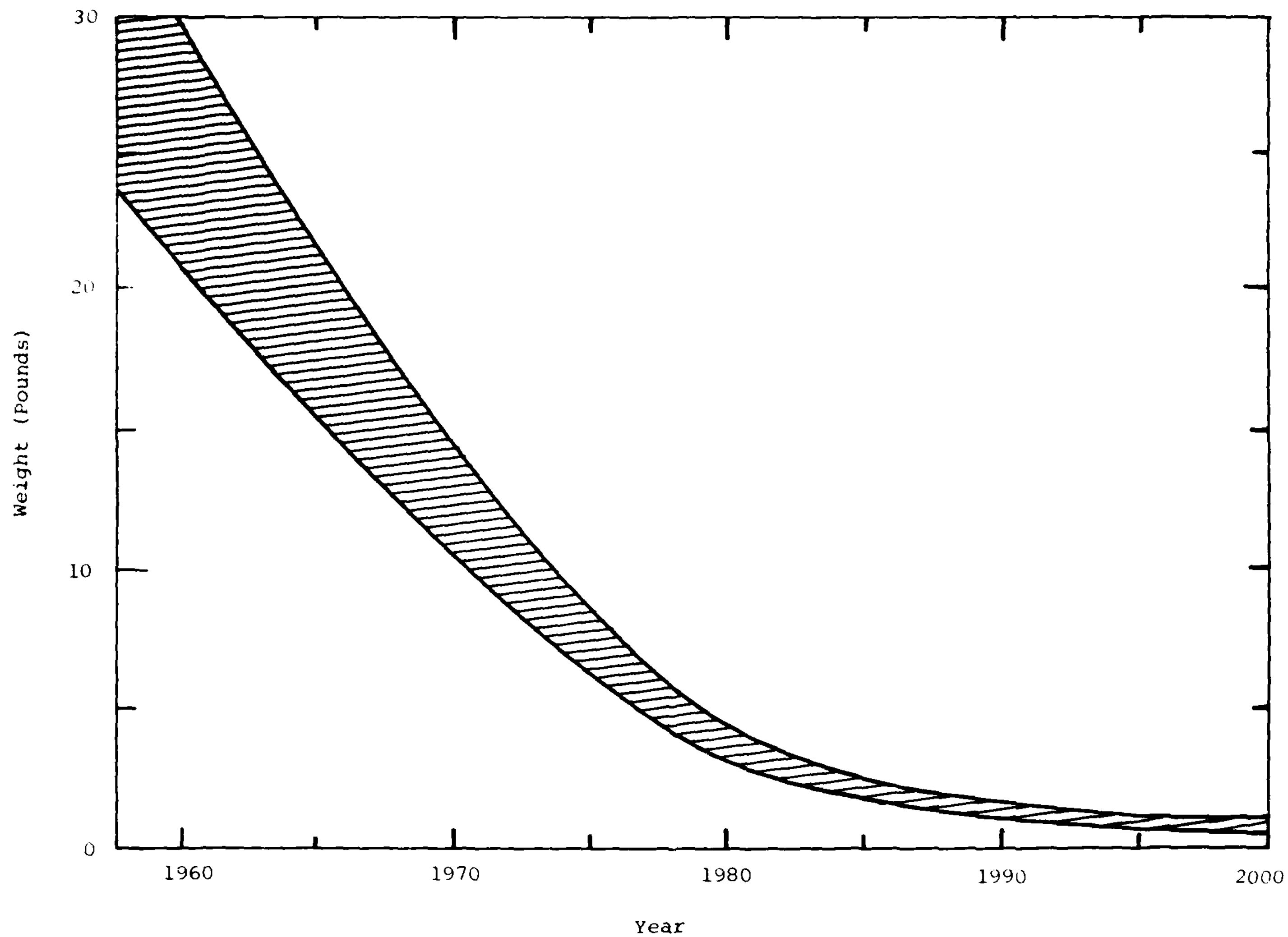

Figure 3-9. TREND IN UNIT WEIGHT OF GENERAL AVIATION TRANSPONDERS

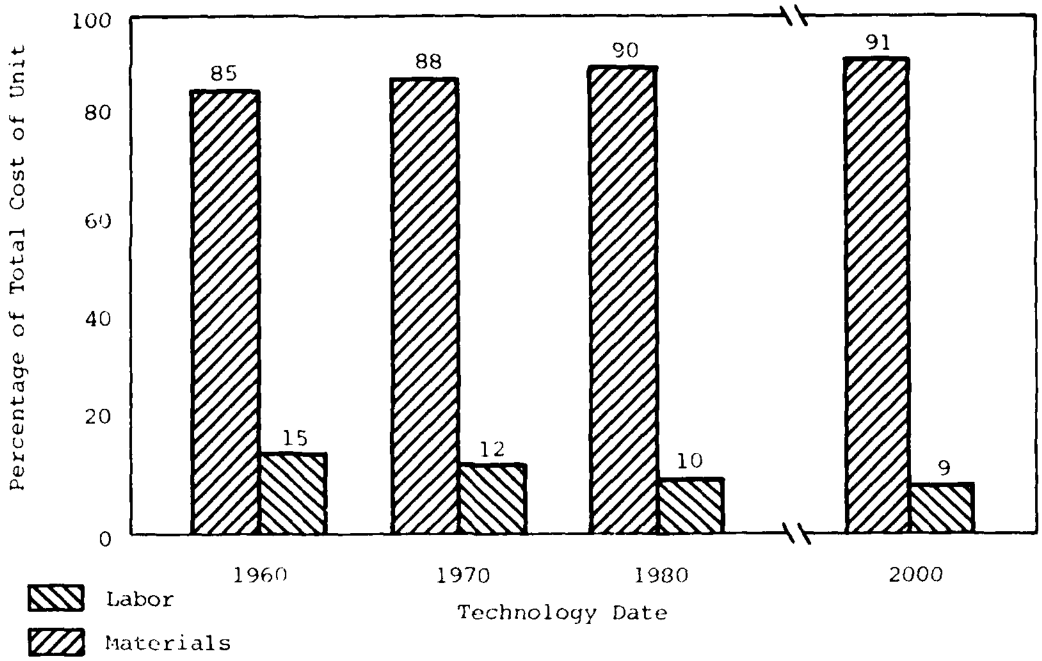

Figure 3-10. MATERIAL AND LABOR COSTS OF VHF RECEIVERS (UNBURDENED DIRECT COST)

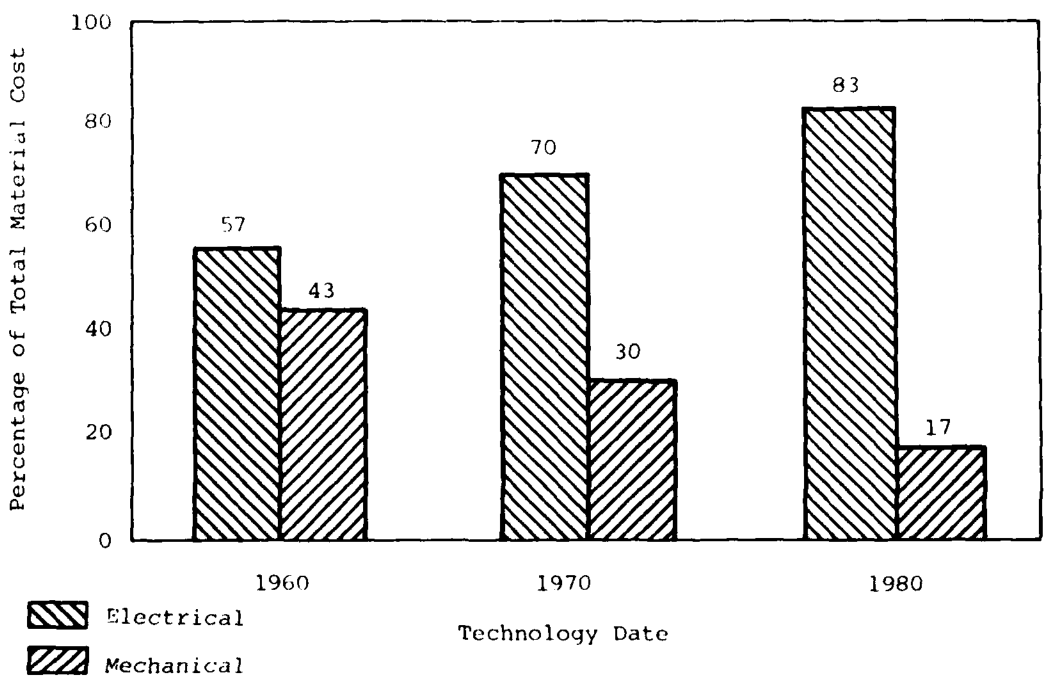

Figure 3-11. ELECTRICAL AND MECHANICAL PARTS COSTS OF VHF RECEIVERS

3.3.1 Discrete Components

The last two decades have seen a revolution in active device capability with the transition from tubes to discrete semiconductors, TTL integrated circuits (ICs), and now LSI and VLSI CMOS technology. The impact of ICs on electronics is obvious. Discrete active devices also have achieved significant improvements. For example, MOSFET devices have enhanced RF receivers, and power semiconductors have dramatically altered power supply and RF transmitter design.

There has been significant improvements in passive devices as well. For example, capacitors have been reduced in size without compromising capacity or voltage rating.

The use of semiconductors has lowered supply voltages and power consumption, permitting the use of more compact supplies and passive devices with lower ratings. For example 1/2- to 1-watt resistors of 20 years ago are now miniature 1/4- to 1/8-watt sizes that can be packed in higher density printed circuits boards. The size reduction that accompanies power reduction has become true of nearly all components, making a significant improvement in overall weight and size. Not only has size been reduced, but new component configurations have been designed specifically for automatic manufacturing (e.g., radial capacitors).

Components of older technology, such as tubes, inductors, and hardware items, tend to be more labor intensive and are generally increasing in cost more rapidly than contemporary devices such as ICs. Figure 3-12 shows the original equipment manufacturer price trends of components in constant dollars (Department of Labor data). Increases in hardware item prices (sheet metal, fabricated metal boxes, RF shielding) are increasing at the highest rate, reflecting the high labor content involved. Except for a few special-purpose items, tubes have been replaced with lower cost semiconductors. Tube prices are increasing nearly as rapidly as hardware prices.

Although the cost dropped initially as a result of such technological advancements as the introduction of tantalum and mylar film capacitors, market pressures from the computer and consumer industries have driven up capacitor costs. There is no sign that this demand will abate, but manufacturers say the threat of foreign competition will limit capacitor price increases in the future. Resistor prices on the other hand have been decreasing steadily over the past ten years and show signs of continued reduction. In part, this phenomenon results from reduced size, increased production volume, and from foreign competition. Semiconductors have experienced the greatest price cuts. Discrete semiconductors are being used mostly for power, high gain/low noise, and RF amplification, and they are still falling in price. Transistor price reductions, however, are not expected to be nearly as dramatic as those of integrated circuits.

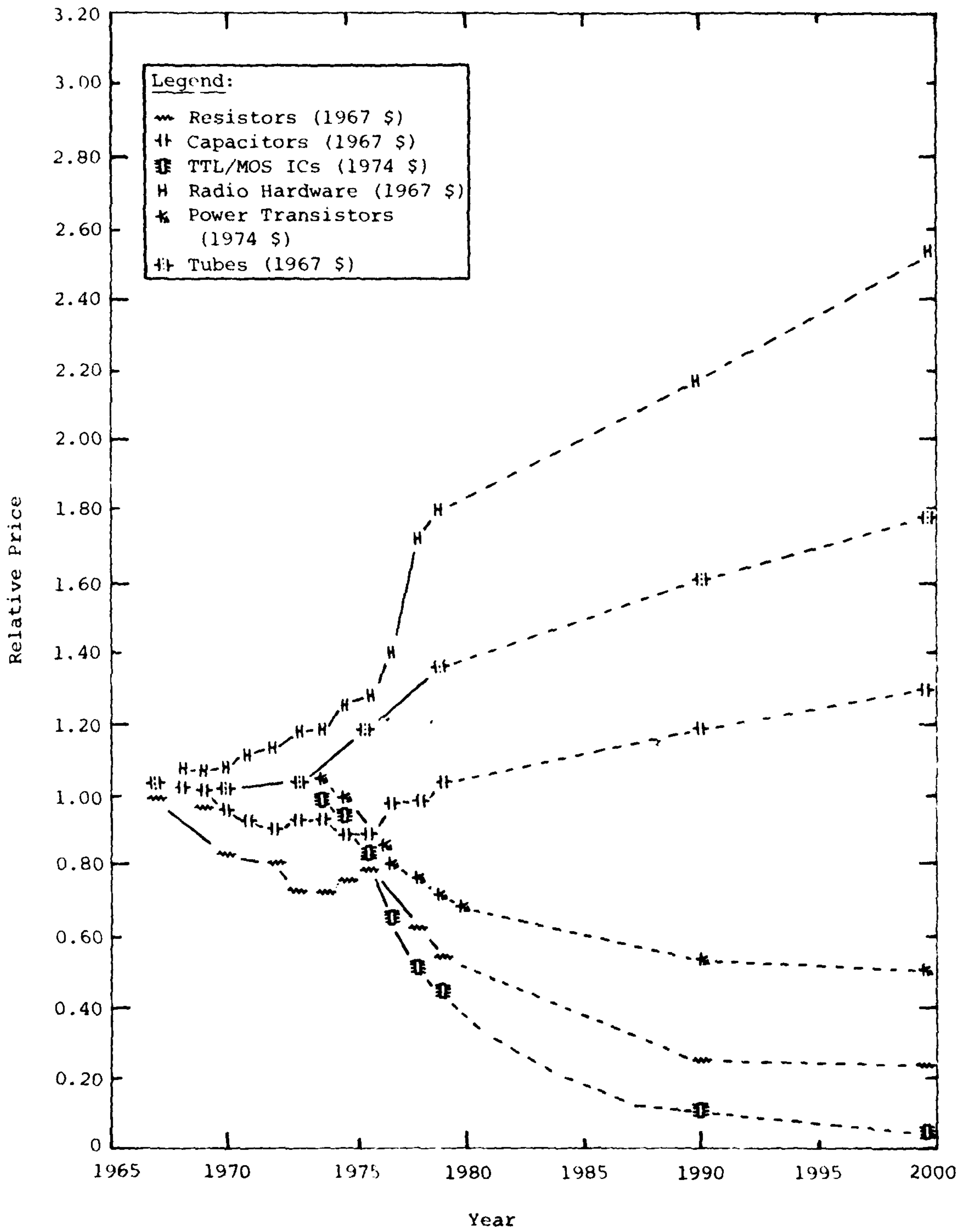

Figure 3-12. ORIGINAL EQUIPMENT MANUFACTURER COMPONENT PRICE CHANGES IN CONSTANT DOLLARS (REFERENCE PRICE = 1.00)

3.3.2 Integrated Circuits

Integrated circuits (ICs) have dropped to one-third their price in less than five years, while they have provided significant functional advancement. Obviously, integrated-circuit tec'hnology has and will continue to influence avionics design. Table 3-2 displays some of the most recent technology trends in integrated circuits and shows clearly the magnitude of improvements attained in some important characteristics.

Table 3-2. TECHNOLOGY TRENDS IN INTEGRATED CIRCUITS

Technology	Equivalent Number of Devices	Power per Bit	Failure Rate per Bit (Percent/ Hours)	Cost per Bit
Discrete Components (1960)	1,000	100 mW	0.01/1,000	$25.00
Bipolar IC (1970)	30	60 mW	0.002/1,000	$ 5.00
MOS IC (1977)	1	1 mW	0.005/1,000	$ 0.20

As a result of reduced overall power consumption biasing and support elements needed, ICs have revolutionized package density of avionics and improved reliability. Most ICs used in air carrier class equipment built in the 1970s required ceramic packaging. Now, the trend is toward less expensive plastic packaging.

Figure 3-13 tracks the future capability of large-scale integrated circuits to the year 2000. Complexity is measured by equivalent memory capacity of IC memories. The growth rate has been consistent over the last decade. This trend should continue because of the development of silicon on sapphire (SOS), charged coupled devices (CCDs), and Josephsen junction technologies.

Figure 3-14 shows the near-future trends in cost-per-bit of ICs. It should be noted that although the cost of avionics has basically followed the PPI, IC prices have fallen well below the PPI. This fact can be explained in part by the increase in overall functional capability available in each new avionics unit. However, complex function VLSIs may not prove to be cost-effective in many avionics units because the high setup costs must be amortized over short production runs. Rather, each VLSI device will have to be incorporated into a whole family of equipment or be adopted from commercially available devices. As an example, microprocessors represent a flexible VLSI with a large nonavionics market. Consequently, they are low in cost. The demand for CB radios and other commercial receivers in the middle of the 1970s created a strong demand for phased locked loops and frequency synthesizers. This demand permitted

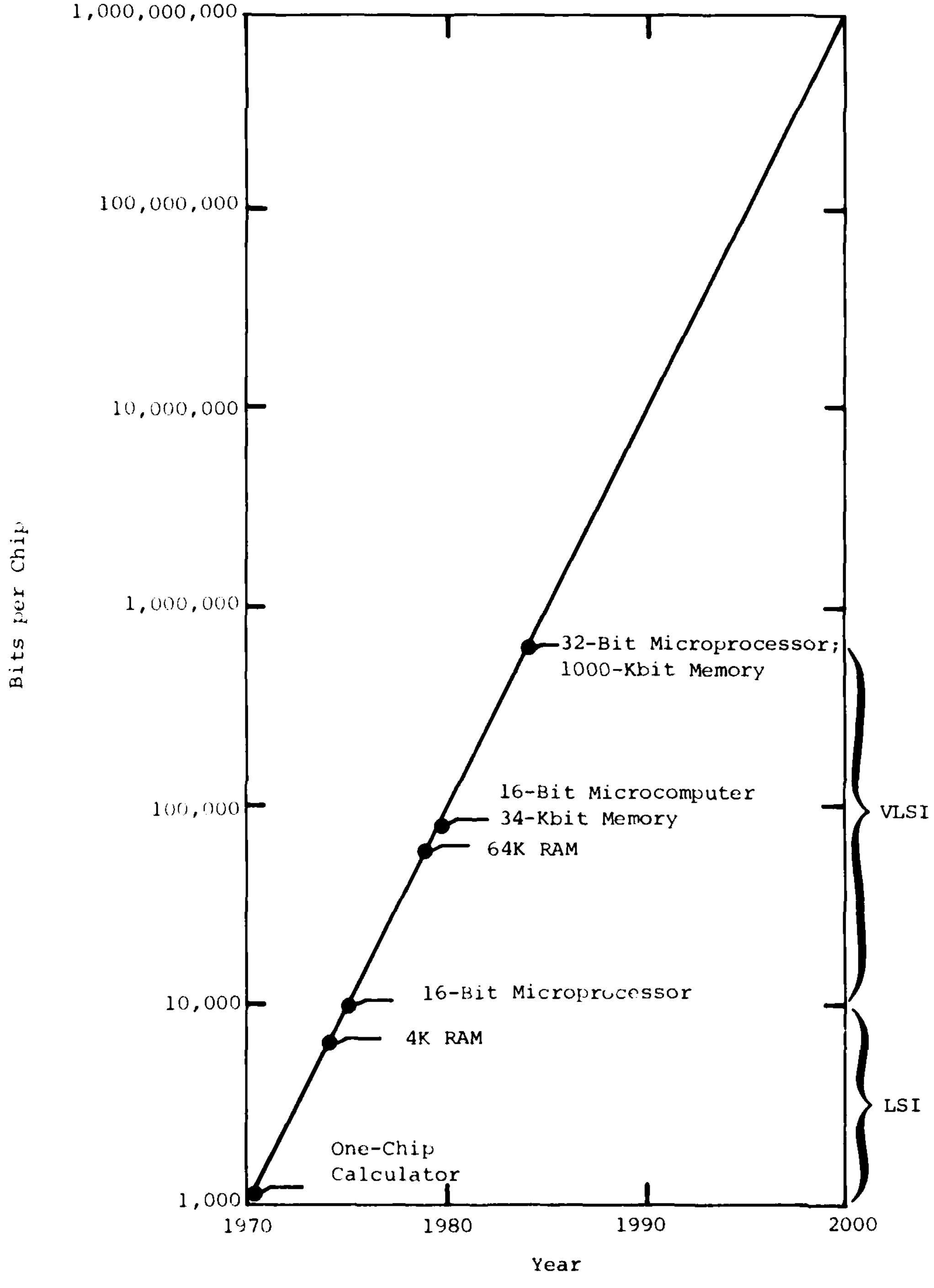

Figure 3-13. TREND IN INTEGRATED CIRCUIT CAPABILITY

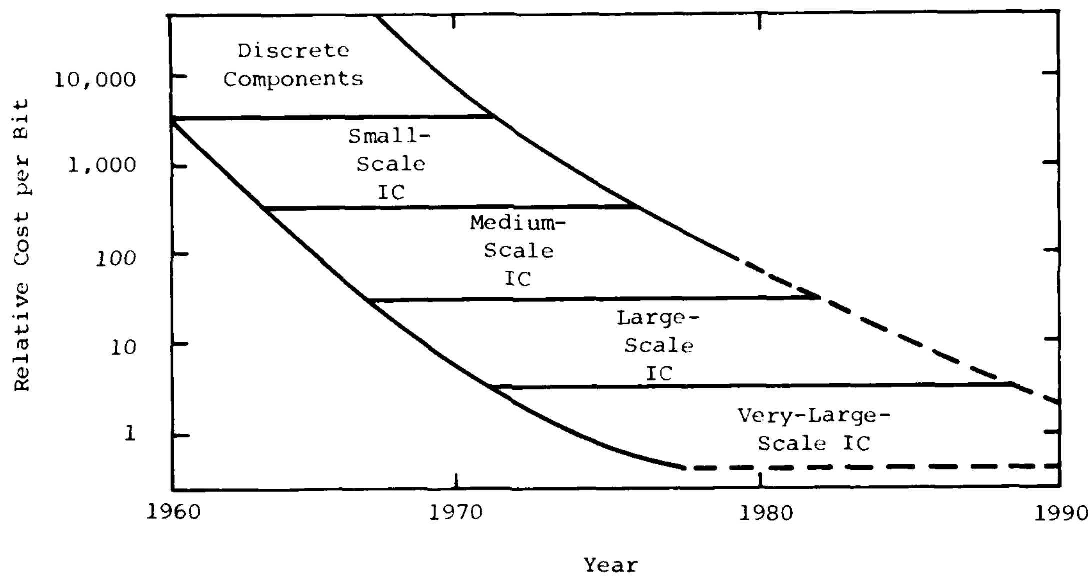

Figure 3-14. COST TRENDS OF INTEGRATED CIRCUITS

avionics manufacturers to incorporate these devices cost effectively. The future market, production, and development costs of VLSIs will determine how fast they are incorporated into avionics.

3.3.3 Component Usage Patterns

One would expect new equipment designs to emphasize use of the less inflationary components. This section shows how many components of each type were used in avionics over the last two decades and predicts how many would be used in a like piece of equipment by the year 2000. These predictions are based on past trends in component usage and future potential of integration techniques.

Figure 3-15 shows the component counts of various devices for transponders. The active-device category shows a typical trend from 25 tubes in 1960 to 120 transistors in 1970. This increase resulted in part from functional enhancement (described later), the replacement of multifunction tubes with single-function transistors, and simplistic design practices. The transition was still cost-effective, however, because tubes were much more expensive than transistors. Passive devices also increased over this period. The increase in passive components is partly the result of additional biasing elements that transistors require and additional diodes and passive components required for the increase from 64 to 4,096 address codes (the 4,096 code), implemented with diode logic. The majority of the increase in passive components is simply the result of the 5-to-1 increase in transisters over tubes.

Figure 3-16 is a graph of the number of transponder components weighted by cost. Between 1955 and 1975, the OEM piece-part price cost of components changed less than 10 percent in constant 1967 dollars. Therefore the component costs in Figure 3-16 reflect more changes in component count than in piece-part prices. Note that the total cost is nearly unchanged for the tube-to-transistor transition in spite of the fact that 120 transistors were used to replace 25 tubes. This transition was driven primarily by technical considerations. Some cost savings resulted from the manufacturing and packaging efficiencies possible through the use of newer solid-state components.

A transistor-to-IC transition is also evident in the early to middle 1970s. This transition was driven primarily by cost, although the technical benefits also were significant. The increased cost reduction achieved through substitution of ICs for transistors was possible because IC-based designs not only reduced manufacturing costs but also reduced total active and passive component costs.

This trend toward higher component level integration, lower component costs, and lower component counts will continue through the year 2000. A transponder in the year 2000 is anticipated to have one LSI for all functional computations and logic, 12 power transistors for the power supply and L-band transmitter, less than 10 inductors required for power chokes and special tuning purposes, and half the number of resistors and capacitors as required today.

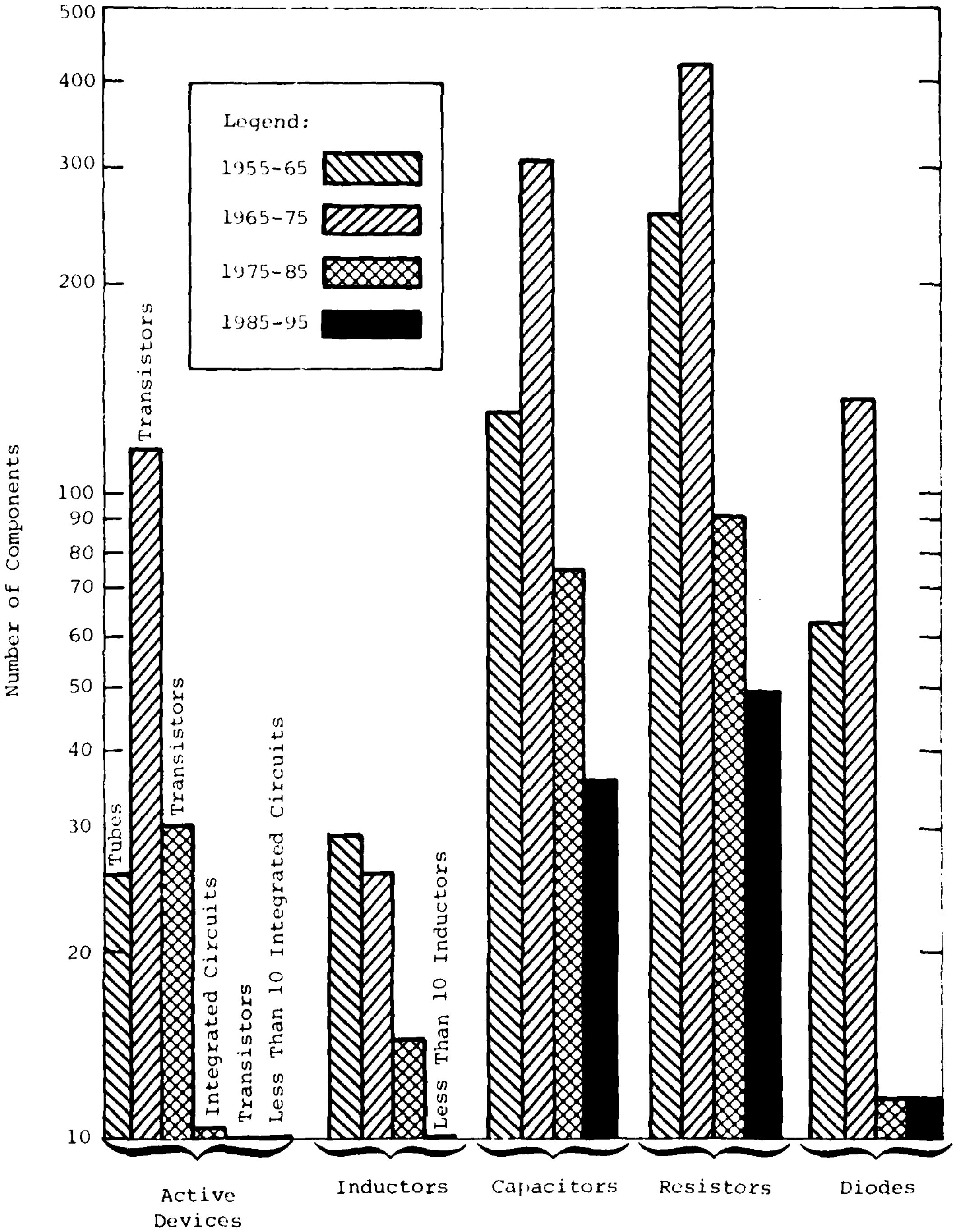

Figure 3-15. TRENDS IN QUANTITIES OF TRANSPONDER COMPONENTS

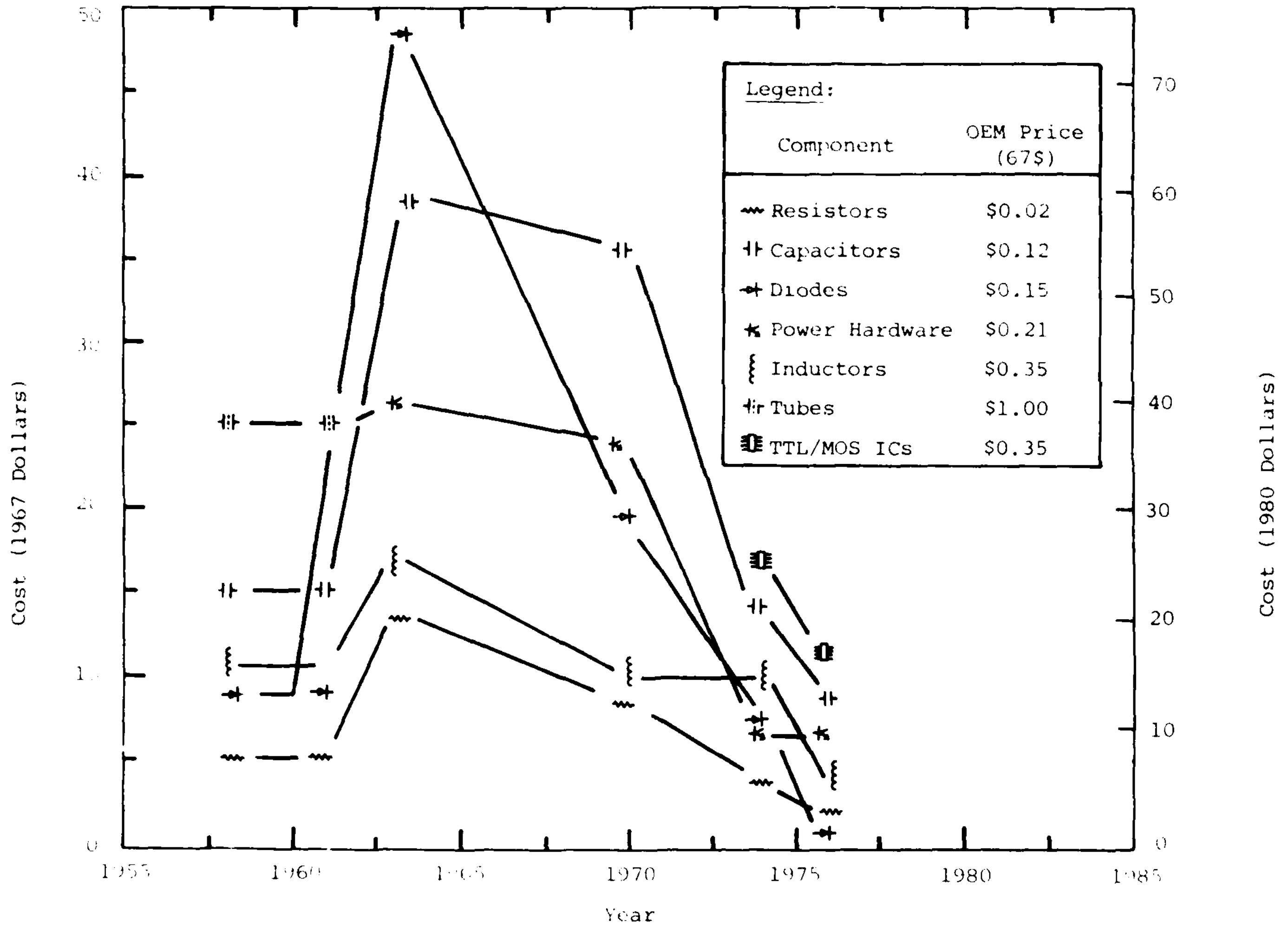

Figure 3-16. TRANSPONDER COMPONENT COSTS WEIGHTED BY QUANTITY OF COMPONENT TYPE

Components used in transceivers (Figure 3-17) and navigation receivers (Figure 3-18) exhibit the same characteristic trends. The 1960s period saw a similar transition from tubes to transistors as occurred in transponders. By the year 2000, discrete transistors will only be used in high-gain/low-noise RF receivers, power RF transmitters, and power supplies. Large-scale integration in navigation receivers by the year 2000 will comprise all baseband housekeeping and functions, including frequency selection with PLLs. There will be less than 10 ICs in navigation receivers and probably one or two in transceivers -- one chip for digital housekeeping and frequency selection and one for analog processing.*

In the 1960s and 1970s, inductors were used primarily for tuning. Today it is possible to emulate inductance with operational amplifiers and other passive devices within a limited range of inductance (inductor synthesis). Inductor synthesis may be routinely used by the year 2000 when high-gain devices are much cheaper. The number of discrete diodes will stabilize around 20 for power rectification (SCRs) and electronic varactor tuning. The capacitor count will range from 75 to 100, and the resistor count will be in roughly the same range. The capacitor and resistor estimates are derived from past reductions attributed to integration.

3.3.4 Display Devices

Display and indicating devices are not amenable to the type of component count analysis presented above. Two types of displays are used in today's equipment: alphanumeric and pictorial analog. LED arrays and gas discharge devices are used for display of such simple alphanumeric information as frequency selection. LCDs and plasma are being investigated as possible substitutes for LEDs and gas-discharge devices. The only improvement that seems practical is the integration of decoder and driving circuits into the display devices themselves. Pictorial analog displays mainly use electromechanical devices or CRTs. Both items are expensive and labor intensive. In the future, pictorial analog devices will be constructed as matrixes of LEDs, LCDs, etc., or will utilize CRTs. Basic stumbling blocks with matrix designs are resolution, power consumption, and interconnection and/or decoding complexity. Some two-dimensional special-purpose arrays and patterns already have been built and included in avionics equipment for CDIs. CRTs require high supply voltages, are expensive, and consume a lot of power. They are still the most popular means of pictoral display and will be used in the new Boeing fleet. Research into flat-plate technology is being pursued vigorously by other industries and may be commonplace in avionics by the year 2000.

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*Phillips already has developed a complete RF-to-audio single-chip FM receiver prototype.

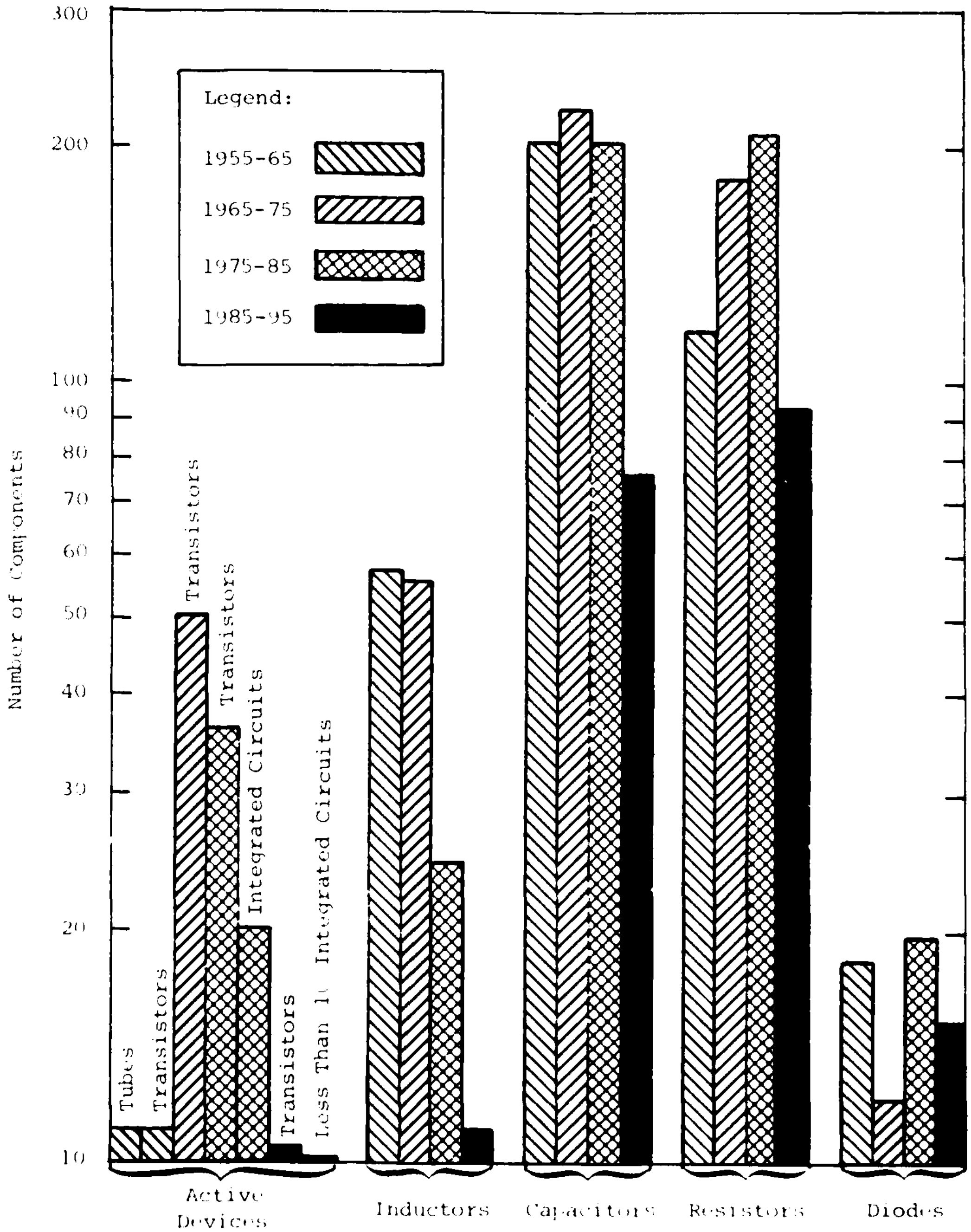

Figure 3-17. TRENDS IN QUANTITIES OF TRANSCEIVER COMPONENTS

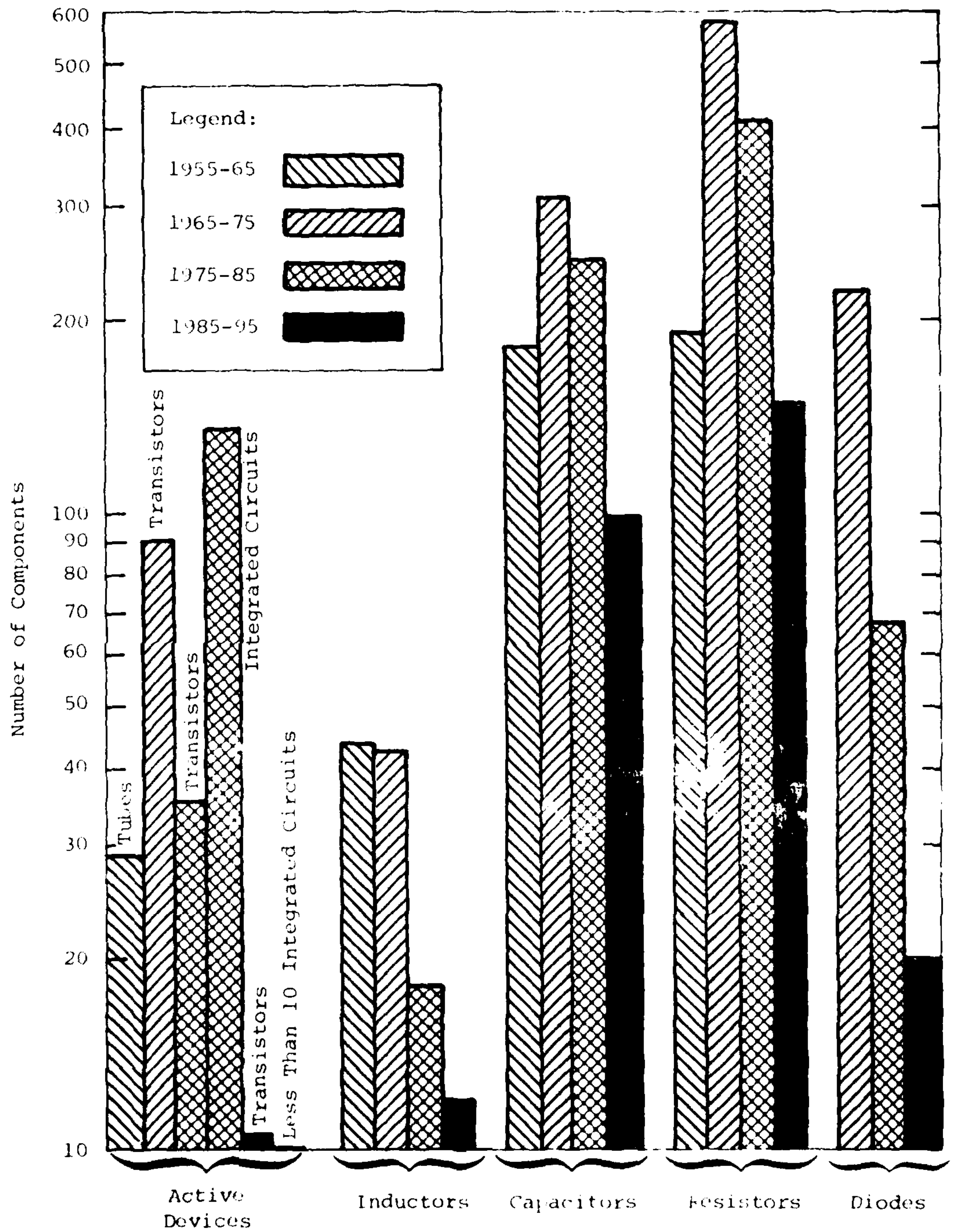

Figure 3-18. TRENDS IN QUANTITIES OF NAVIGATION RECEIVER COMPONENTS

3.4 INNOVATION AND TECHNOLOGY DIFFUSION

In order to predict the future of avionics technology, one must first gain an understanding of the rate of innovation in electronics in general and the time lag between occurrence of an invention and its general application in avionics manufacturing. It is impossible to foresee a spontaneous revolutionary innovation, but past experience may provide some clues to trends.

Categories of technology have been identified for investigation and traced from invention to the most current utilization. Components trace materials innovation, while wiring processes and assembly techniques trace manufacturing innovations.

Component innovation typically occurs in a research laboratory such as Bell Labs. After proof of principle and laboratory demonstrations, the military has traditionally adopted new technologies first. Sometimes the advanced research is sponsored by the military, as was the case with VHSLSI (very high speed LSI). Once manufacturers gain production experience with the device, they begin commercial production. Avionics manufacturers may or may not adopt the new device immediately thereafter.

During the last few years the computer and commercial electronics industries have been at the forefront of innovation in the area of component manufacturing technology. The military, however, is once again beginning to assert its traditional research leadership role.

Manufacturing technology proceeds differently from component innovation. Advances commonly originate in a large-volume manufacturing environment. Sometimes advances are driven by the need for better production control or a higher level of production capability. Manufacturing innovation frequently occurs in military programs, is applied rapidly, and filters out to industry as needed.

Figure 3-19 shows the trend of active component innovation and application trends in the 20th century. The horizontal scale defines the date of innovation or application, and the vertical scale defines the degree of application (e.g., invention, military application, nonavionic commercial use, and commercial avionics). The first major innovation was the invention of the triode. The second major technology change occurred 30 years later with the invention of the transistor. The subsequent innovations are principally an improvement of transistor technology, and thus the period of innovation is much shorter. One cannot infer from two data points (invention of triode and the invention of the transistor) that a revolutionary change in technology should be expected every 30 years, but some of today's inventions such as opto-electronic devices, surface acoustic wave, amorphous semiconductor technology, and new memory technologies may yet prove to be comparable to the major breakthrough of the transistor. The period of technological improvement of a familiar technology (e.g., the transistor) appears to be much shorter; an innovation occurs about every eight years. Therefore, a high probability exists that several more semiconductor advances will occur before the turn of the century.

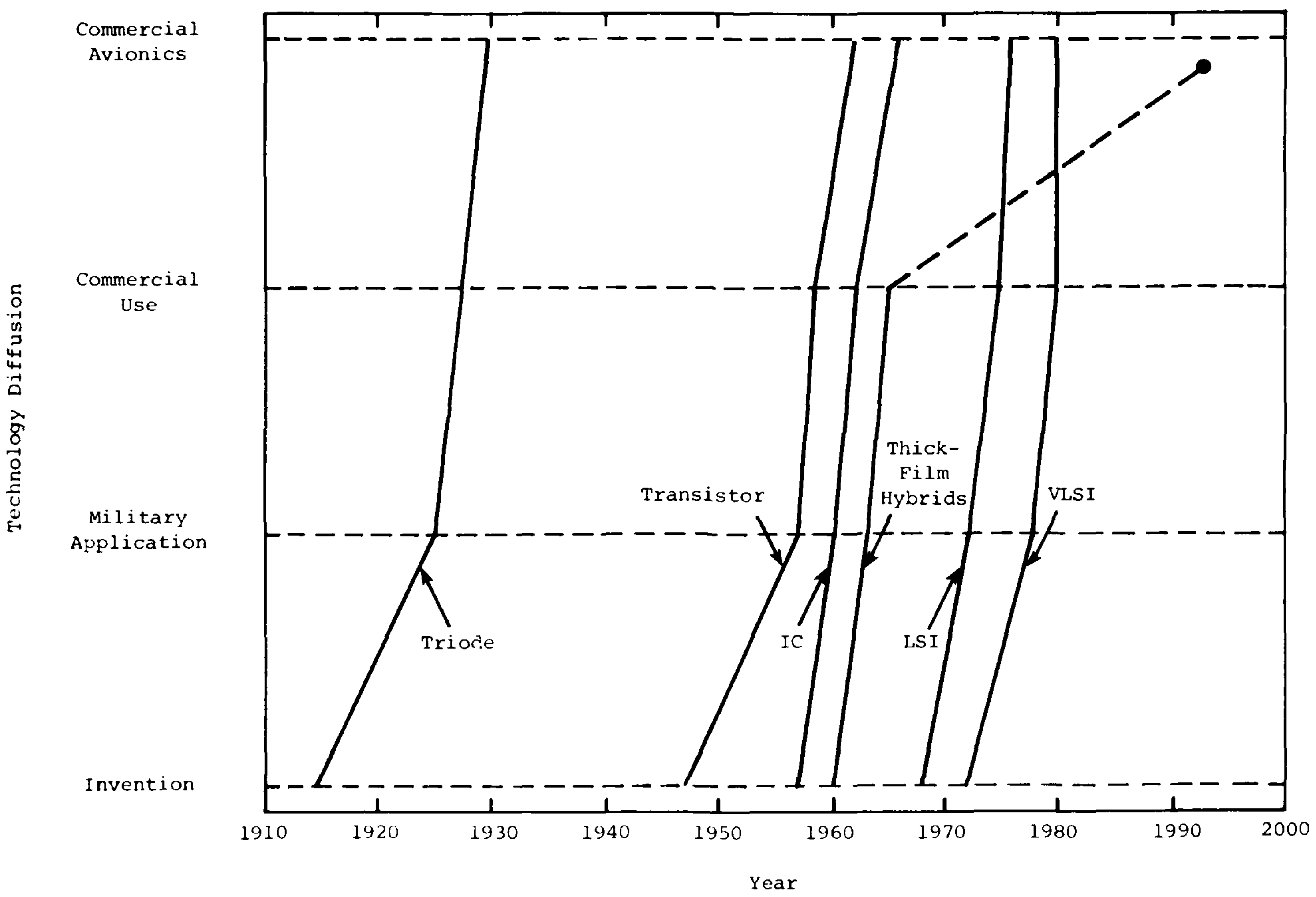

Figure 3-19. DIFFUSION OF ACTIVE COMPONENT TECHNOLOGY

Figure 3-19 shows that triode technology required 20 years to be adopted into avionics. The relatively long time lag can partly be attributed to a lack of requirements for adoption. The transition time for transistors was 18 years, and ICs were used in avionic equipment 5 to 10 years after invention. Figure 3-20 shows the future trend for solid-state devices. Gallium arsenide semiconductors that offer improved bandwidth will gradually replace discrete silicon devices in the middle of the 1980s. The capabilities of silicon have been exceeded by GaAs in laboratory experiments. Memory devices with capacities at least four times that of anything realized in silicon have been produced commercially. High-power RF transistors are available off the shelf but are not yet cost-effective.

Gallium arsenide and the superconducting materials of Josephson junctions are constrained at present by processing operating costs. Gallium arsenide undoubtedly will evolve into integrated circuitry, but because of problems with growing oxides, inexpensive gallium arsenide ICs will not be available for 15 to 20 years. Josephson junction devices that use lead alloys instead of semiconductors have potential for exceptional speed but currently require operation at near zero °K. However, some scientists think that room temperature Josephson junctions are possible. Josephson junctions may represent the next major revolution in device technology, but practical laboratory prototypes are not likely in the immediate future. Bubble memory technology has already seen commercial use, but it is cost prohibitive for most avionics equipment.

Manufacturing technology improvements have followed component technology revolution. Figure 3-21 shows the appearance of new wiring techniques after the advent of transistors in the 1950s. The lack of innovation in wiring techniques in the 1970s indicate that the technology is maturing and potential growth is limited. Interestingly, the diffusion time delay from invention to commercial avionics manufacturing use for both component and wiring technology is approximately eight years.

Figure 3-22 diagrams innovation and technology diffusion with regard to manufacturing and assembly techniques. Manual assembly and semiautomated assembly were adopted by avionics manufacturers within the traditional eight-year diffusion-delay time. Automated component insertion and soldering have been available since the 1950s but they are only now being applied. The reason for this slow acceptance is that the cost of the technology is just now beginning to break even with the cost of manual labor. Computer advances late in the 1960s and early in the 1970s helped to fuel a period of creativity in manufacturing techniques. Leading avionics manufacturers began incorporating sophisticated automatic test equipment (ATE) into their production processes 8 to 10 years after they became available. Robotics as we now know it was conceptualized and laboratory produced in the middle of the 1970s. Commercial industry, particularly automotive and commercial electronics manufacturers, rapidly embraced this new technology. Some avionics manufacturers just now are starting to experiment with robotics and production application is still several years away.

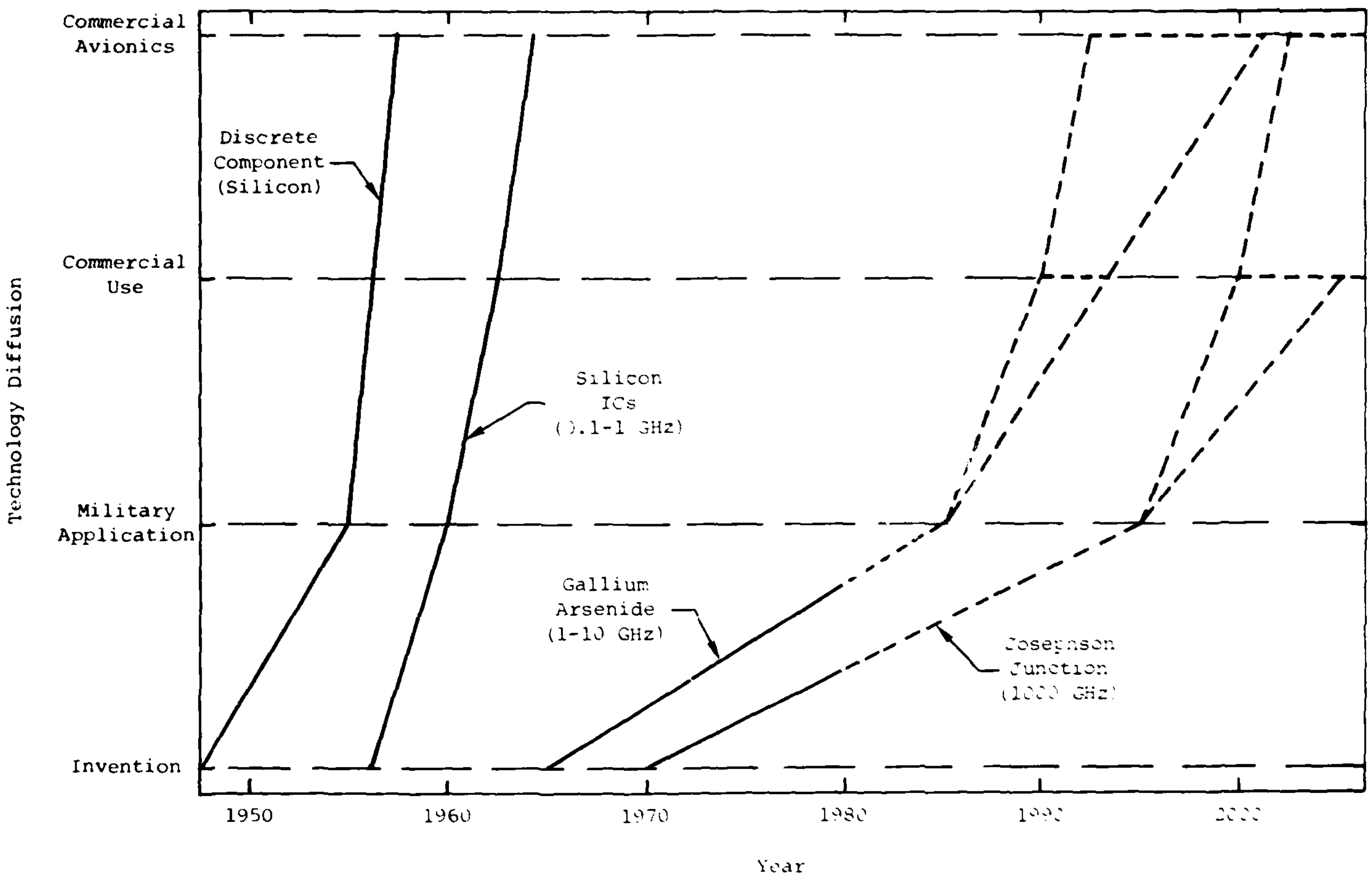

Figure 3-20. DIFFUSION OF SOLID-STATE TECHNOLOGY

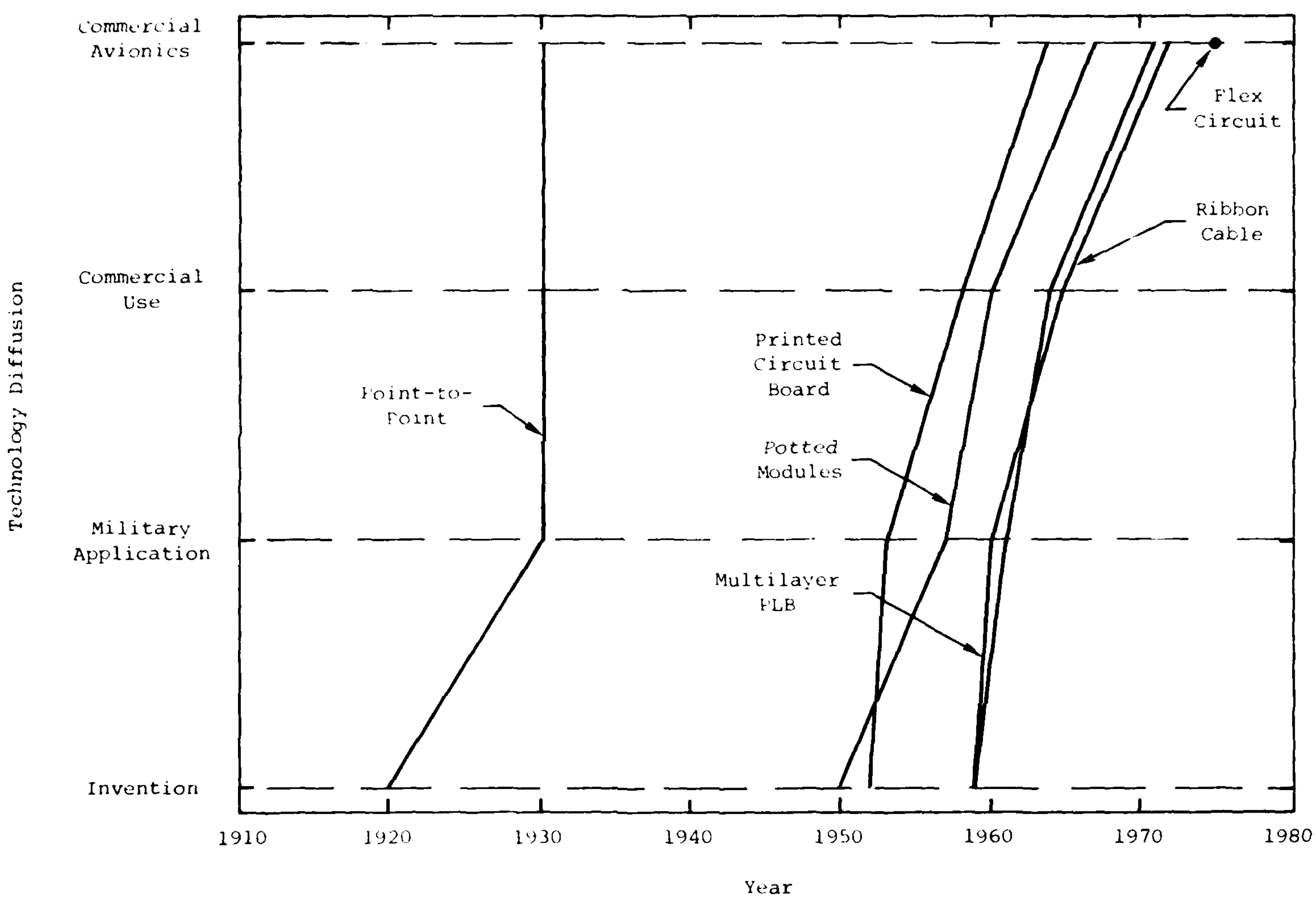

Figure 3-21. DIFFUSION OF WIRING PROCESS TECHNOLOGY

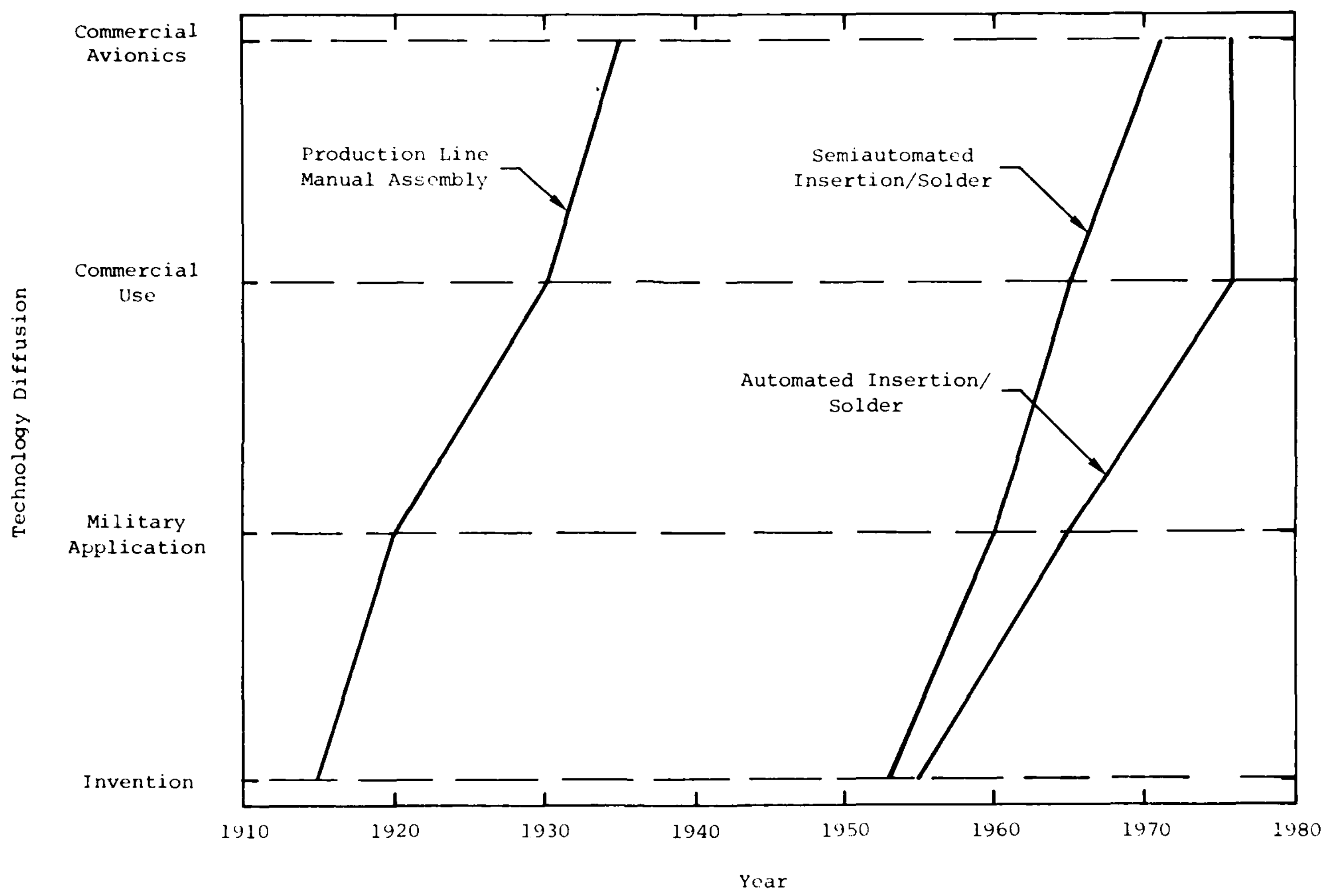

Figure 3-22. DIFFUSION OF ASSEMBLY TECHNOLOGY

CHAPTER FOUR

TRENDS IN FUNCTIONAL MODULE COSTS

Chapter Four describes cost trends in the manufacturing implementation of different functional building blocks commonly used in avionics. Historical costs are based on detailed analysis of functional complexity and allocation of estimated manufacturing cost on the basis of material content. Future trends are derived from trends presented in Chapters Two and Three, including the anticipation of technological innovation and diffusion. The unburdened total labor and material cost in this chapter should be representative of most existing and future equipment designs. However, some individual units with peculiar characteristics or requirements may fall outside the cost ranges presented.

4.1 PRIMARY AVIONICS FUNCTIONS

The principal uses of avionics for the foreseeable future will be communication, navigation, and surveillance. The majority of voice communications are achieved and will continue to be accomplished via VHF radio links. The principal elements of a VHF transceiver are the antenna, RF transmitter, RF receiver, audio (baseband) amplification, and power supply. Navigation is principally based on VOR/DME, although some other systems such as INS, LORAN, and OMEGA are used in limited quantity for special applications. A VOR unit consists of an antenna, a VHF RF receiver, an audio baseband processor that is slightly more complex than the comparable part of a VHF transceiver, a power supply, and an indicator. The DME is an L-band device that is composed of an antenna, an RF transmitter, an RF receiver, a baseband signal processor of significant complexity, a power supply, and an indicator. Surveillance is a ground-based activity that is enhanced through the use of transponders. A transponder consists of an antenna, an L-band RF receiver, an L-band RF transmitter, sophisticated decoding logic and baseband processing, and a power supply. The technology content of the transponder and DME baseband processing is similar, although the degree of complexity may be different between the two units. Controls for all units are considered to be mechanical equipments. (See Chapter Three for hardware cost trends.)

It is evident that an analysis of the following functional modules will be useful:

- VHF Receiver Module

- VHF Transmitter Module
- L-Band Receiver Module
- L-Band Transmitter Module
- Audio Baseband Processing and Signal Decoding Module
- Power Supplies
- Antennas
- Displays

Analysis of these modules will provide useful data on cost trends in most major avionics equipment at the major subassembly level. It must be stressed that the absolute cost of particular functions (e.g., the cost of VOR baseband versus VHF transceiver audio baseband) will follow similar trend curves but at different absolute values.

4.1.1 VHF Receivers

A VHF receiver includes the RF preamplifiers and IF strips between the antenna input and the detector. It also includes the local oscillator required for mixing. Figure 4-1 shows the cost trend of VHF receiver modules. The continuing downward trend reflects still further reduction in the cost of semiconductors and also the use of integrated circuitry in the receiver in the near future. The bottom line represents some of the least expensive general aviation VHF receivers, and the top line is more representative of air carrier equipment.

Present technology incorporates FET transistors for RF amplifiers and mixers. There will be no immediate change in transistor technology, but integrated VHF receivers are on the horizon. Bipolar technology already has produced a prototype of a complex, single-chip, integrated VHF receiver (RF to audio output) for commercial application. The nonavionic commercial consumer market will be the most likely impetus for development of technology required for such integrated VHF receivers. Eventual application to avionics will depend on ease of shifting the frequency band of the device to the aeronautical frequencies from commercial broadcasting frequencies.

Phase locked loops (PLLs) already used in navigation/communication receivers are still not integrated in a single chip. The integrated-circuit PLL has been used extensively in the consumer market in the VHF band (both in commercial stereo FM receivers and in CBs). It is only a matter of time before integrated PLLs are included in avionics.

4.1.2 VHF Transmitters

A VHF transmitter includes all the circuits required to produce a modulated RF signal at the antenna terminal. This includes the RF oscillator, modulator, predriver and final output stages, and harmonic filter.

VHF transmitter costs (Figure 4-2) will not decrease significantly after 1980 because the cost drivers are discrete power semiconductors, which have somewhat stabilized in price. Integration will not play a significant

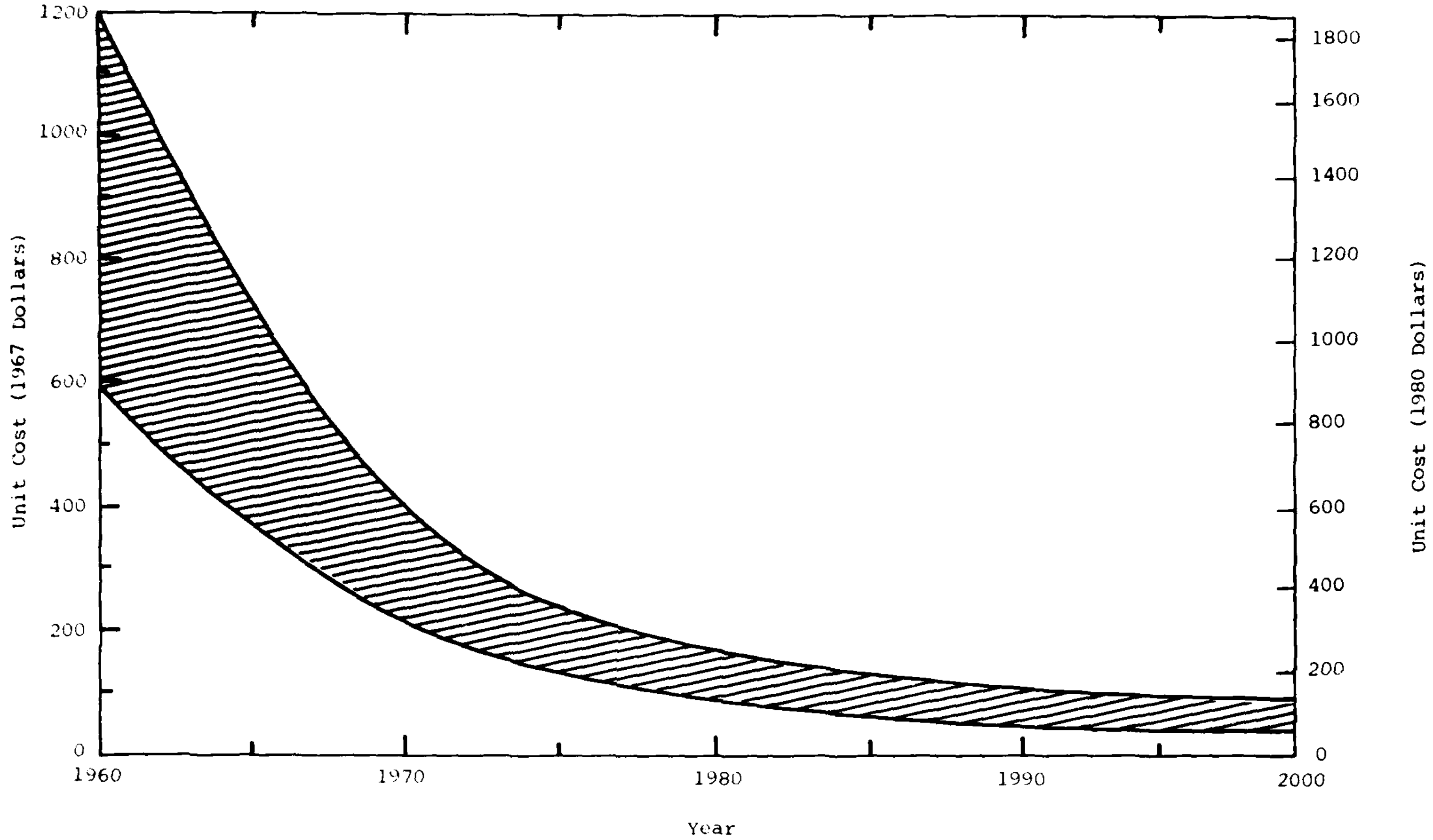

Figure 4-1. COST TREND OF VHF RECEIVERS

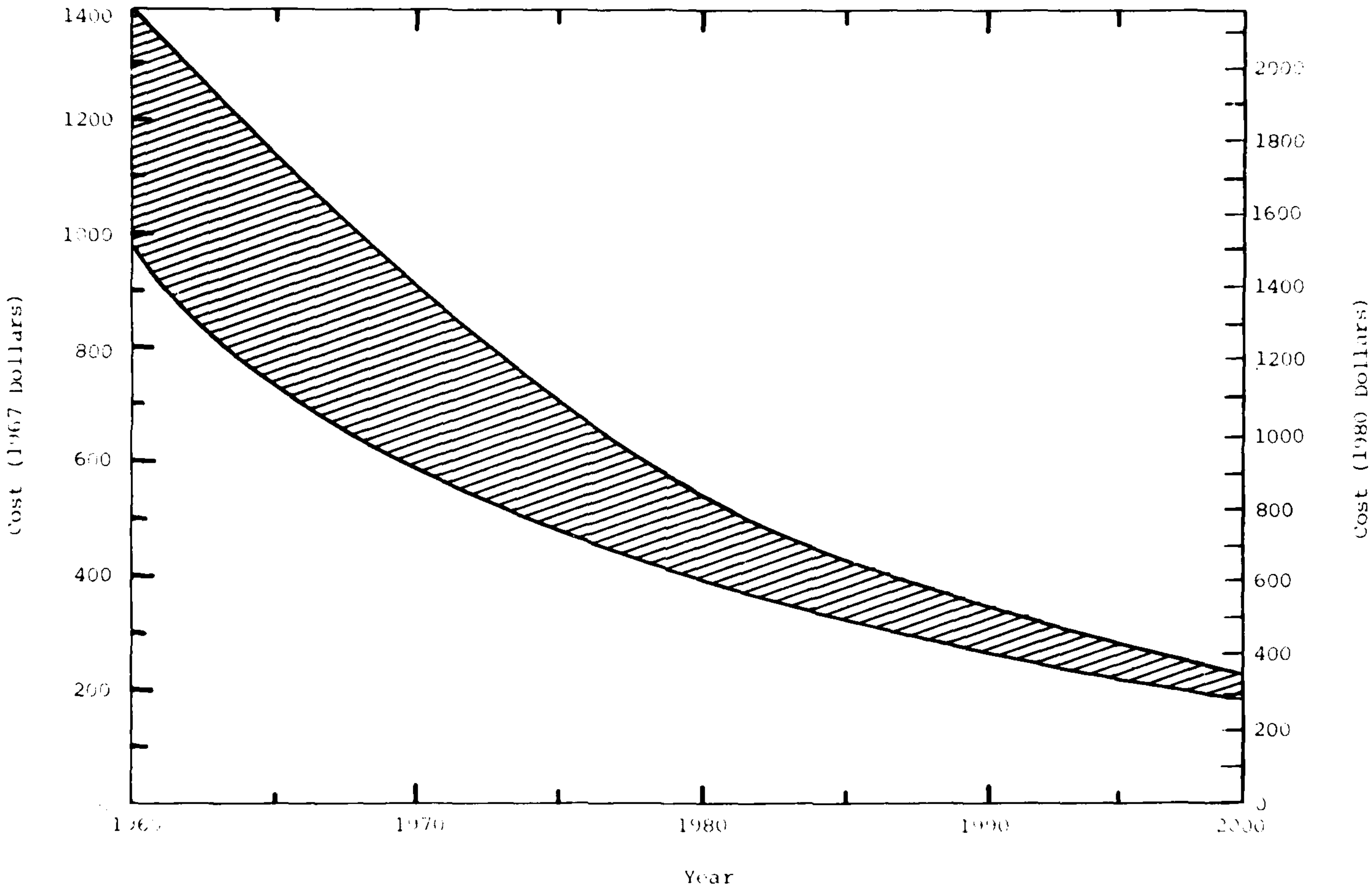

Figure 4-2. COST TREND OF VHF TRANSMITTERS

role. Although it is possible to manufacture a modulator on an IC with bipolar technology, the output level is still too low to drive an RF power amplifier. Should the gain of RF power transistors improve significantly, the use of integrated modulators may become viable. Late in the 1980s, thick-film hybrid technology might prove useful in meshing integration and high-output power levels successfully, but hybrids still suffer from high cost and poor reliability.

4.1.3 L-Band Receivers

An L-band receiver is functionally identical to a VHF receiver, but it is tuned to a higher frequency range. L-band receivers have been utilizing discrete semiconductors since early in the 1970s. Stripline technology appeared in the middle of the 1970s and leadless passive components late in the 1970s. These improvements, together with the rapidly dropping costs of RF transistors, have contributed to a large decline in costs (Figure 4-3). The design technology is now mature, and only minor changes and improvements are likely. Component prices are falling less rapidly, and manufacturers say prices would be stable were it not for the threat of foreign competition. Future L-band receivers will make more extensive use of leadless devices, particularly the new RF chip transistors available from Japan, but costs will not see another dramatic decline as in the 1960s and 1970s.

4.1.4 L-Band Transmitters

An L-band transmitter is functionally identical to a VHF transmitter, except that the final RF output frequencies are confined to the L band. The final output stage of an L-band transmitter still uses tube technology and the near-term trend will be for continuing cost increases at a rate comparable to hardware (Figure 4-4). The reason for this increase is that the cavity oscillator tube is a labor-intensive device. However, high-frequency, high-power semiconductors prices have been dropping and within 3 to 5 years should be competitive with the tube technology. As this high-frequency, high-power gallium arsenide and silicon technology matures and is incorporated into L-band transmitters, costs will continue to drop dramatically into the 1990s and finally start leveling off around the year 2000. The large differential in Figure 4-4 between low performance general aviation and commercial aviation is basically the power requirement differentials.

Use of stripline technologies in passive RF circuits has been increasing over the last five years and will dominate L-band transmitters. The introduction of leadless capacitors has simplified assembly of RF modules because of their ideal suitability to stripline techniques. Manufacturers have hinted that introduction of leadless transistors in the not too distant future is quite realistic and that future L-band transmitters will feature stripline designs with leadless active and passive component installation.

4.1.5 Audio Baseband Processing and Signal Decoding

Baseband circuitry contains all functions performed after the receiver detector and before the transmitter modulator. In transceivers, the baseband

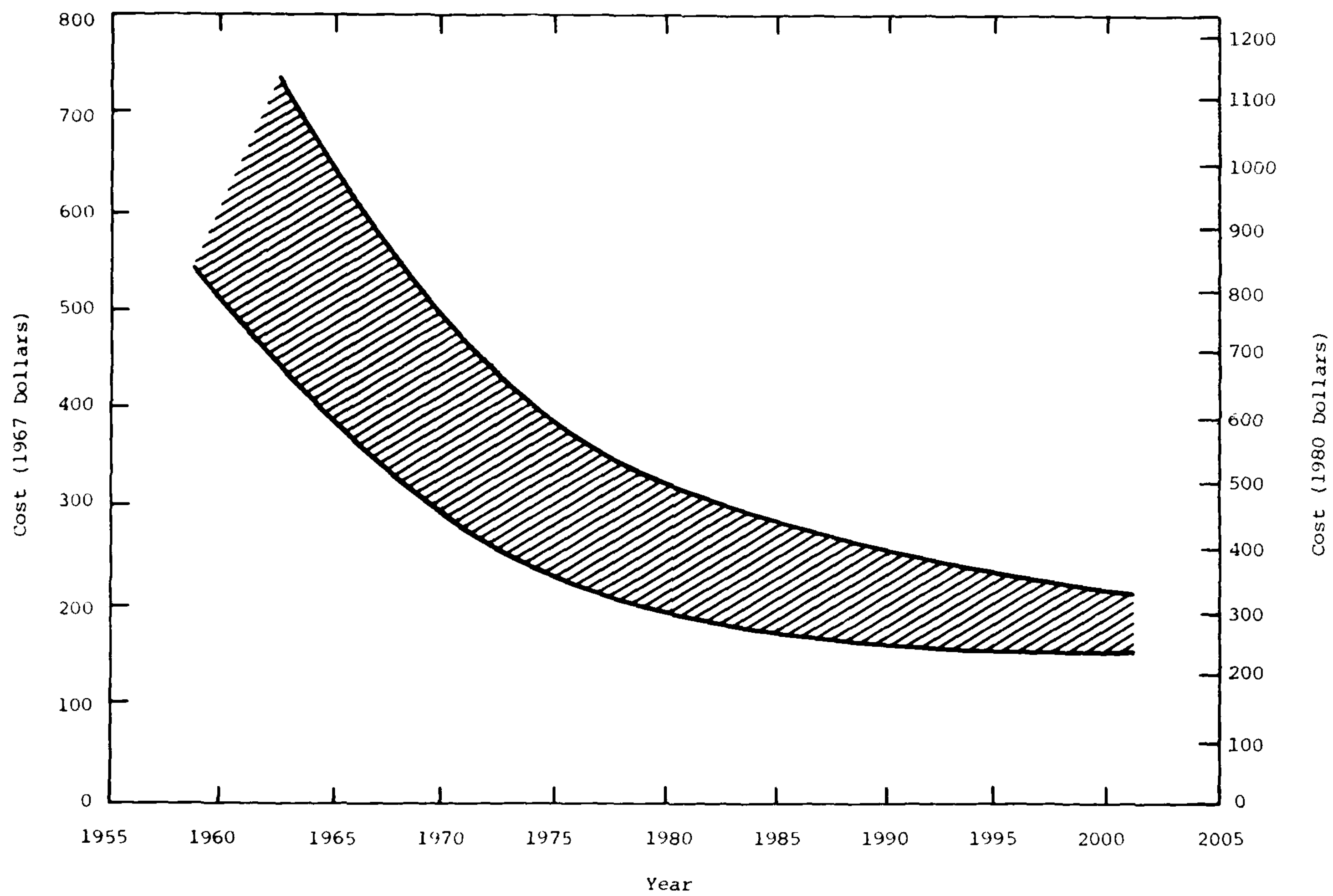

Figure 4-3. COST TREND OF L-BAND RECEIVERS

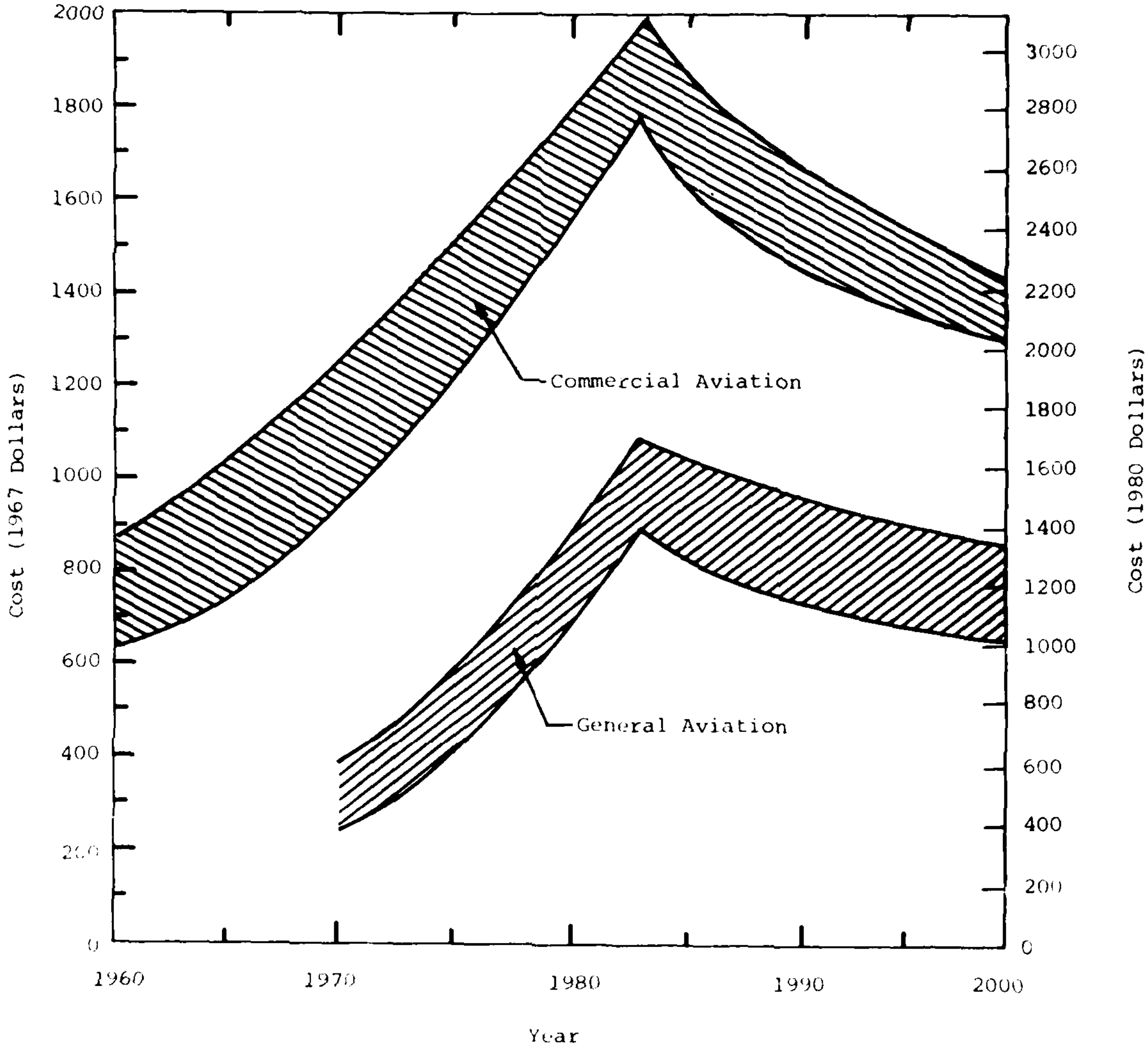

Figure 4-4. COST TREND OF L-BAND TRANSMITTERS

typically includes the AGC, the carrier override and squelch circuits, the audio output amplifier, and the microphone preamps that drive the modulator. In VORs, the baseband also includes bearing and localizer processors and the CDI interface. DME and transponder basebands are comparable in complexity but more complex than VORs. DME baseband contains the video processors, range circuitry, and monitor and self-test functions. Transponder baseband includes the decode/encode circuits, pulse generator, video processors, and self-test circuits.

With the exception of the transceivers, baseband processing, more than any other section, will benefit from advances in integration. The audio circuits of transceivers were converted to semiconductors a long time ago and are a mature technology: their circuits are essentially optimized at minimum cost. Any cost reductions will occur strictly because of reductions in material cost, particularly semiconductor components. These simple audio circuits form the lower boundary of the curve in Figure 4-5.

In VORs, the bearing and localizer functions lend themselves readily to digital techniques. In fact, the use of A/D conversion of detected audio, subsequent digital signal processing, and reconversion to analog are commonly used techniques in modern VOR receivers. This approach is sure to drive the cost of baseband processing down even further as A/D, D/A, and digital prices plummet. In DME, the range circuitry, monitor and self-test functions, and some of the video processors have been digitized for at least two generations of equipment. Transponder encode/decode and self-test circuits present a similar situation. The cost of these processing circuits will drop rapidly as digital IC costs drop.

The availability of low-cost, flexible VLSI devices (e.g., microprocessors) affects not only baseband design but also avionics architecture. Whereas past trends have emphasized functional separation, the tremendous capacity and capability of microprocessors allows designers to integrate the accomplishment of dissimilar functions in one central location. It is possible for a microprocessor to perform multiple functional calculations, housekeeping and control, self-test, and display driving concurrently. Frequency control can be accomplished through a digital interface between the microprocessor and the synthetic frequency generator. Analog outputs can be provided through D/As where necessary. A two-chip VOR that uses one receiver chip and one microprocessor may be available as early as 1990.

The versatility of VLSI provides other significant, if not necessarily tangible, benefits for design and manufacture. The part count is reduced and assembly time shortened. The addition of new functions is readily achieved through software. And, of course, providing digital output signals to other avionics becomes practically automatic, while digital built-in-test and self-calibration capabilities can be included in the units at a minimal cost to simplify production test time.

The future trends will continue to be toward higher levels of component integration within a given function and more integration of dissimilar

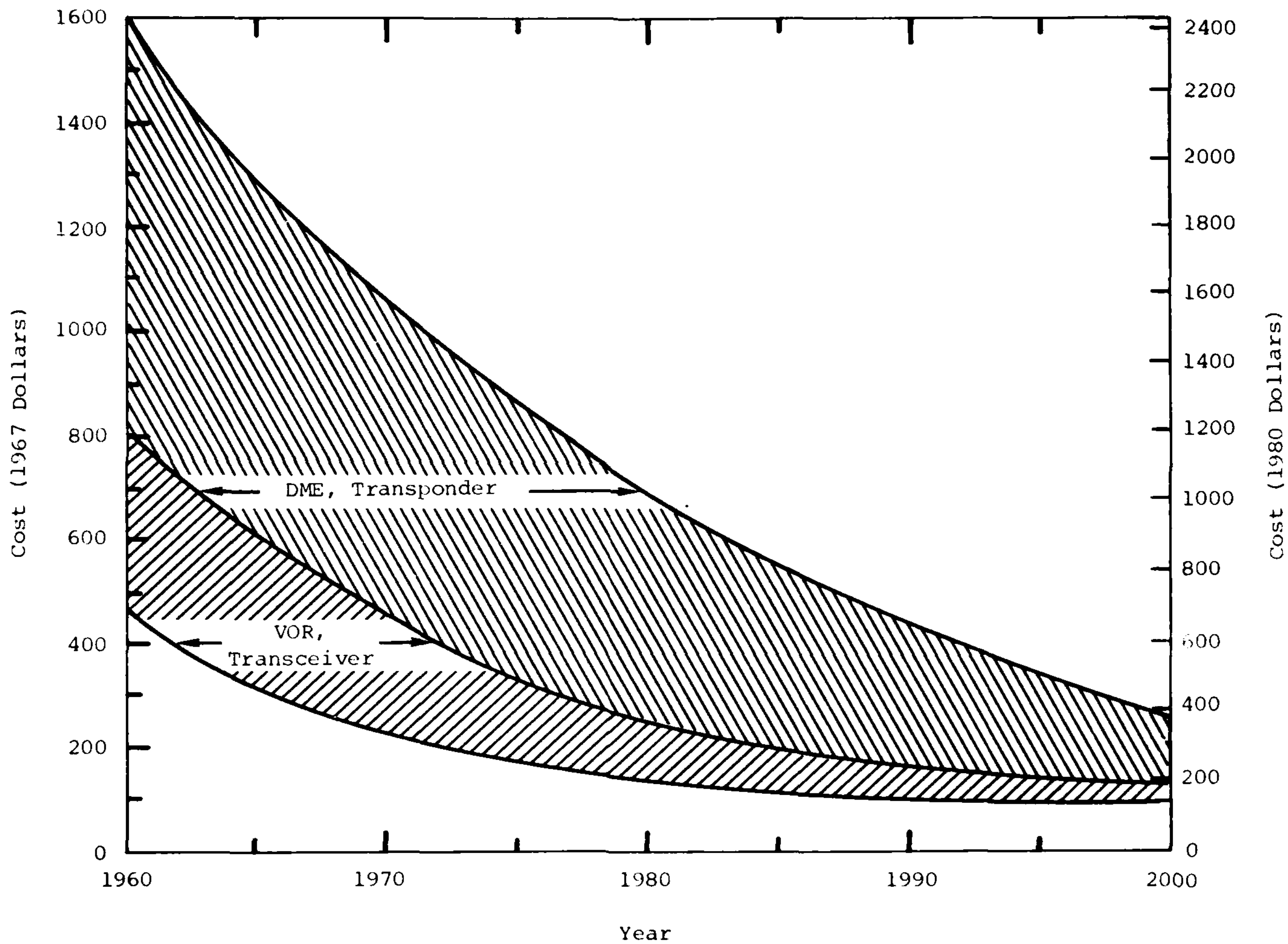

Figure 4-5. COST TREND OF AUDIO BASEBAND PROCESSING AND SIGNAL DECODING

functions, as the market permits. Several manufacturers of general aviation equipment have attempted such an approach. One, for example, offered a single package unit containing VOR, DME, marker beacon, localizer, and glide slope capabilities for a little more than the price of an independent DME. Another offered an expandable family of modules that, when integrated, provide capabilities similar to the previous example. Both product lines have been poorly received because they present problems in terms of interchangeability and interface with existing equipment in aircraft. Yet, in other applications, dissimilar functional integration is occurring. The new Boeing aircraft have a multipurpose common display for many functions. Flight management computers integrate navigation, flight data, and aircraft housekeeping data for pilots. RNAV systems use computers to integrate inputs from different sensors to provide pilotage. Functional integration will unquestionably reduce avionics costs by taking advantage of commonality of functions, but slow market response and the absence of a standard common data bus will impede such trends significantly.

4.1.6 Power Supplies

Power supplies have been shrinking in size, capacity, and cost as avionics power consumption levels have been reduced with the use of lower dissipation components. This trend has been accelerated by the increasing efficiency of designs (e.g., switching supplies versus linear regulators) and the compact size of components. For example, switching regulators operate at 20 kHz and require smaller, less expensive inductive elements.

Discrete solid-state devices have long been used in power supplies and will continue to dominate the market for the foreseeable future because the power-handling capability of integrated regulators is limited by packaging heat dissipation. Figure 4-6 shows the trend in power supply costs. The large power supplies were used mainly in air carrier equipment of much more sophisticated capability. Consequently, this equipment used a much higher content of power-consuming electromechanical devices and tubes. As these devices were phased out, air carrier equipment power consumption was reduced together with the price of power supplies. Small power supplies primarily serve general aviation equipment that have lower power dissipation, such as a transceiver. Their continued reduction in cost reflects mainly the anticipated drop in transistor prices during the next 20 years. Some additional savings may be achieved through the use of distributed, low-power integrated circuit regulators by 1990.

4.1.7 Antennas

Antennas are purely mechanical devices. Their costs will increase as rapidly as the cost of hardware increases. (See Figure 3-11.)

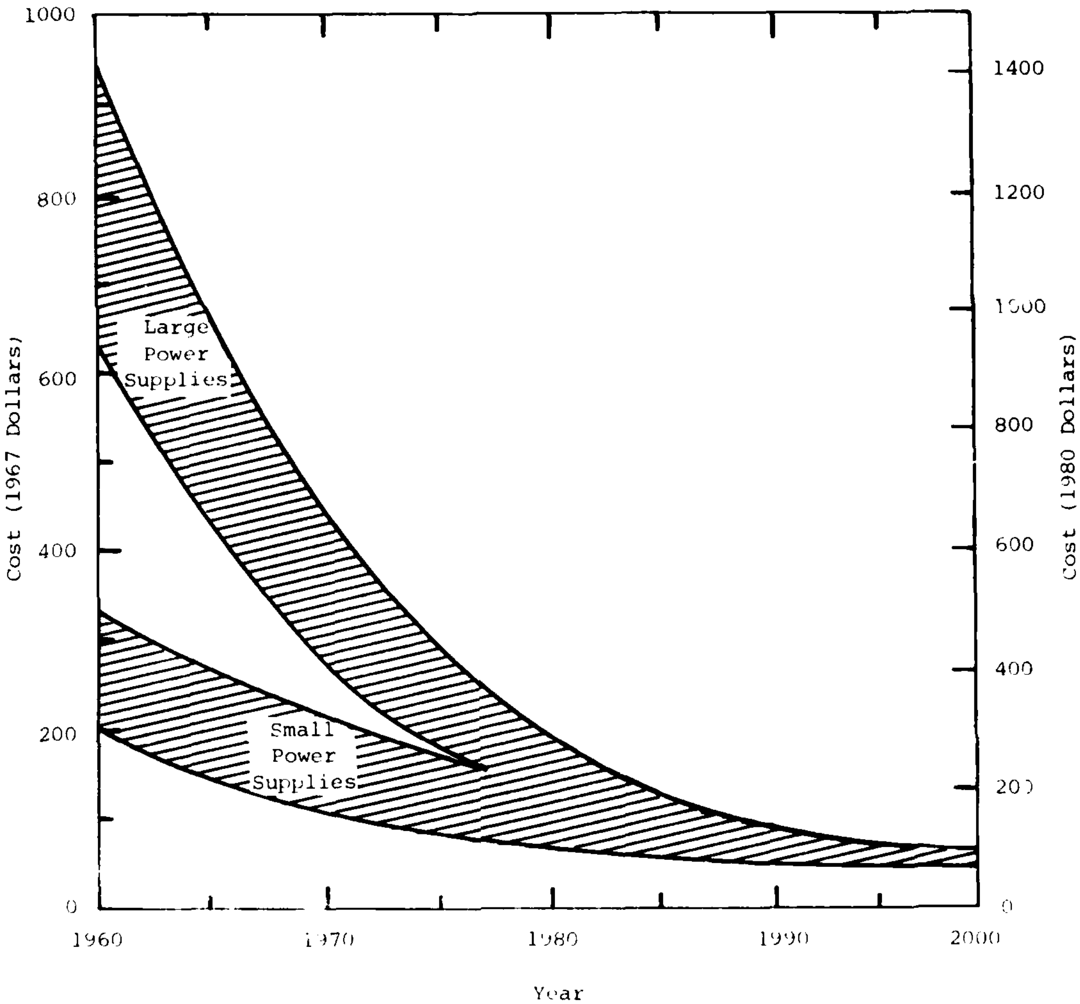

Figure 4-6. COST TREND OF POWER SUPPLIES

4.1.8 Displays

Display technology is bound for a revolution in the near future. Mechanical displays of analog information are labor intensive to produce and are rising rapidly in cost. Figure 4-7 shows that the newly introduced electronic CDIs cost about half as much to produce and that these costs are dropping. However, market acceptance of these new electronic displays has been slow; partly because they are incompatible with many older pieces of avionics and partly because their performance is limited in some respects. LED displays still wash out in a sunlit cockpit unless they are illuminated to a level of brightness which consumes excessive power. LCD displays are environment sensitive and have acquired a

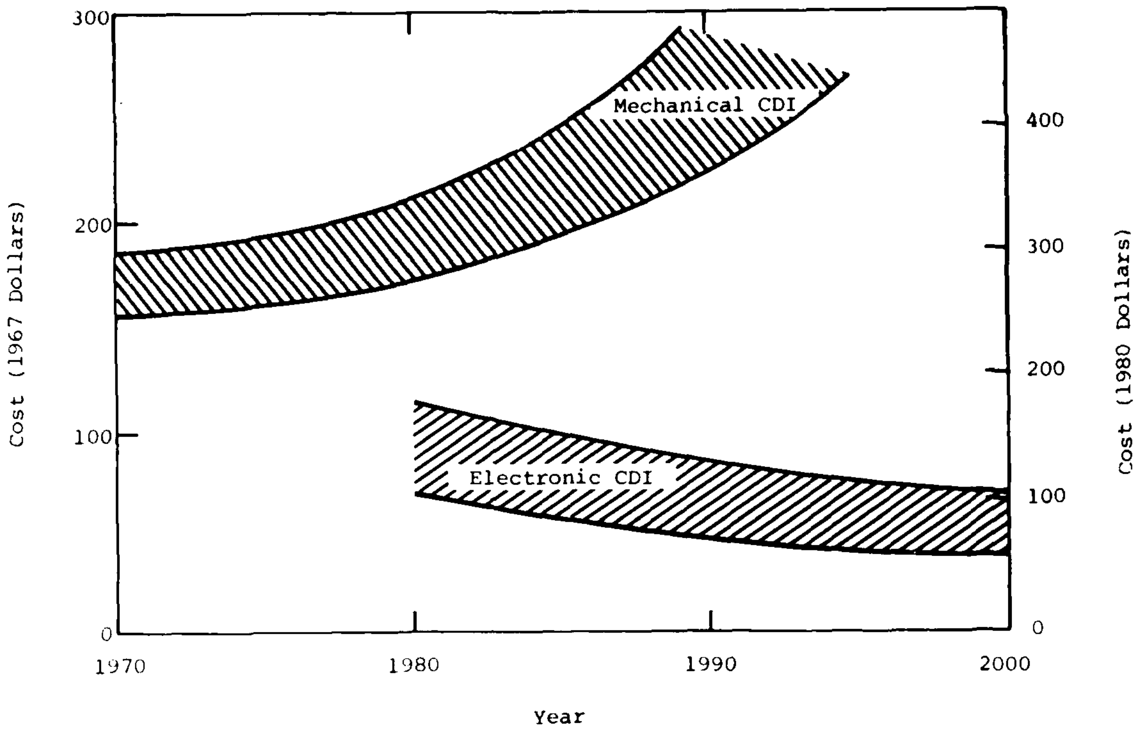

Figure 4-7. CDI COST TREND

reputation for a short lifespan. Some LED and LCD displays provide only a limited viewing angle. Gas-discharge tubes have exhibited reliability problems that primarily result from faulty manufacturing techniques. Finally, many pilots just are not comfortable with the new displays.

Nevertheless, the days of the mechanical display are numbered in spite of all these obstacles. An electronic CDI indicator introduced in 1978 is an identical replacement of many standard mechanical units. Automatic-intensity adjustment capabilities are being incorporated into LED displays to compensate for ambient conditions. The technology of LCD displays is improving: the newer LCDs are capable of storage and operation within a wider temperature range and during higher shock and vibration levels. Reliable gas-discharge tubes have been commonly used in DMEs after the manufacturing problems were corrected. In the new Boeing aircraft, CRT displays have replaced many individual mechanical indicators and are expected to reduce pilot workload and increase pilot efficiency.

Although the introduction of electronic displays into low-performance general aviation aircraft is being hampered by the absence of standard digital interfaces, the limited panel space available, and the dissatisfaction with performance, the available technology is improving. New 1024 × 1024 alphanumeric dot-matrix panels have been fabricated, and special patterns are available at reasonable cost. As the CB market made integrated phase locked loops available for frequency synthesis and the computer market made microprocessors available for baseband, the demand of the automotive industry will drive down the cost of future aircraft instrument panels. (It is noteworthy that some automotive manufacturers offer a completely electronic dashboard as an option today.) This transition should occur in the middle to late 1980s, and the cost of electronic displays will drop dramatically. The cost differential and acceptable performance level will hasten a transition in low-performance general aviation cockpits. Concurrently, additional functional enhancements will be provided through the display, which will reduce the cost of other avionics.

4.2 AVIONICS DESIGN ARCHITECTURE

With the exception of L-band power transmitters, which have not yet totally seen the benefits of solid-state devices, all modular circuits are settling down to the PPI rate and will show little deviation through the year 2000. Therefore, the greatest potential for cost reduction lies in new design concepts and standardization.

The recent advent of microprocessors has made available to avionics a digital computing capability and cost previously considered impractical. This capability has permitted the substitution of a single digital processor chip for functions previously performed by multiple analog circuits. Currently, this centralization is occurring at the single-function level; in the near future, the rapid growth of computing-power-per-chip may make such centralization possible on a multifunction level. Some benefits of this approach are to reduce costs by reducing signal processing redundancy, to provide for expansion of functional capability without purchasing additional hardware, and to improve the accuracy of all flight data through the availability of multiple sensors. Avionics architecture concepts must be examined as a possible means of significantly decreasing the cost of avionics beyond its present level, because it takes nearly 10 years before any new innovation in components results in a marketable application.

4.2.1 Possible Architecture Alternatives

The conventional distributed architecture used in general aviation is characterized by separate self-contained units such as VOR, marker beacon, ADF, and DME performing individual functions. If several of the individual tasks can be performed in a single microprocessor in a time-sharing manner, size and cost reductions may be possible by eliminating redundant processing capability. This concept, an example of classical centralized architecture, is illustrated in Figure 4-8. Additional savings may be achieved by integrating the components of the centralized architecture into a single unit (integrated architecture). A distinct variation of integrated architecture makes use of a multifunction electronic display as illustrated in Figure 4-9. In this configuration, several display functions and control panel functions are combined within a single input/output unit, reducing panel space requirements.

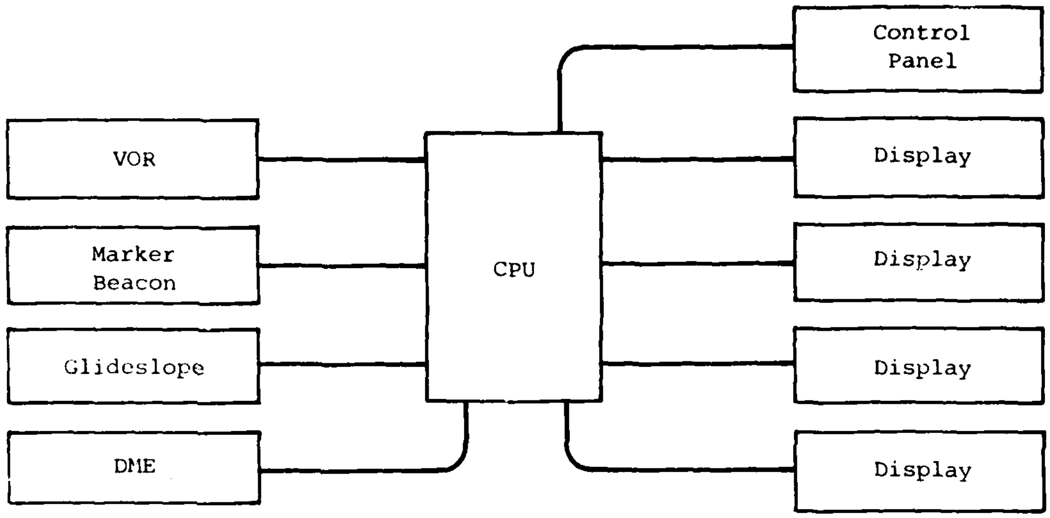

Figure 4-8. CENTRALIZED ARCHITECTURE

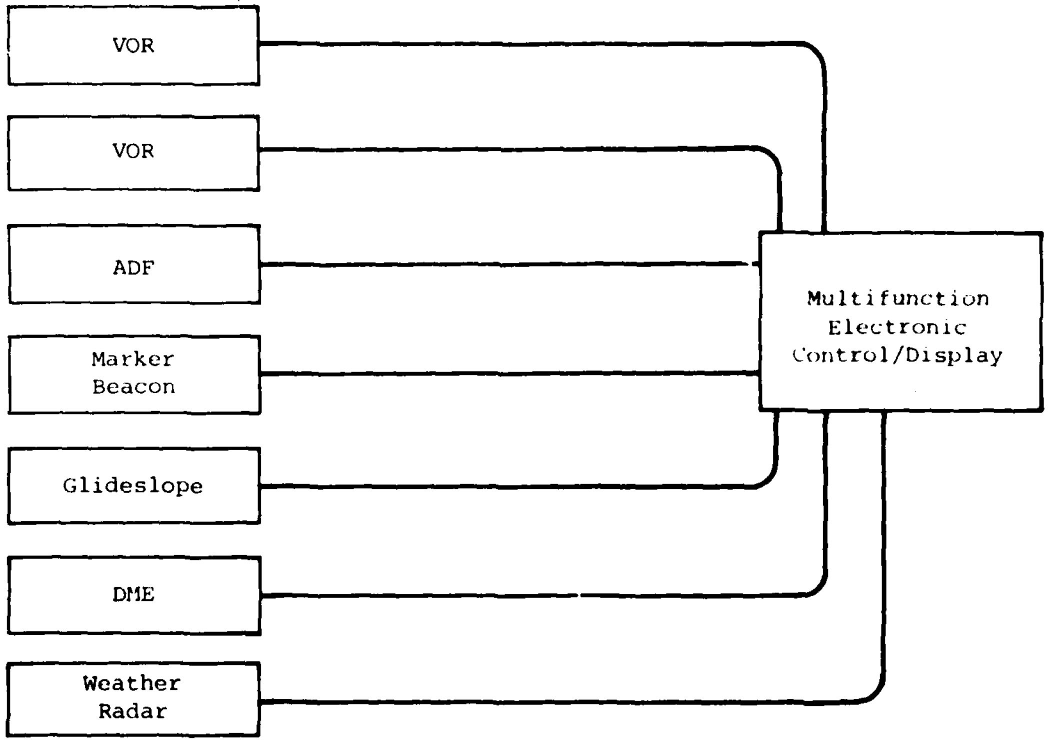

Figure 4-9. MULTIFUNCTION ELECTRONIC DISPLAY ARCHITECTURE

A totally different approach to cost reduction uses a data bus or a network of data buses to interconnect avionics units with each other, with cockpit controls, with displays, and with flight management computers. Such a bus architecture is illustrated in Figure 4-10.

The major potential advantages and disadvantages of each architecture alternative are summarized in Table 4-1. The comments reflect an assessment only of the potential effect on the costs of general aviation equipment and installation resulting from the adoption of various architectures structured according to today's technology and design practices. Architectures relying on radical innovations in design concepts, materials, processes, packaging, or components result from the technology diffusion forces discussed previously. These architectures are excluded from consideration. Factors not

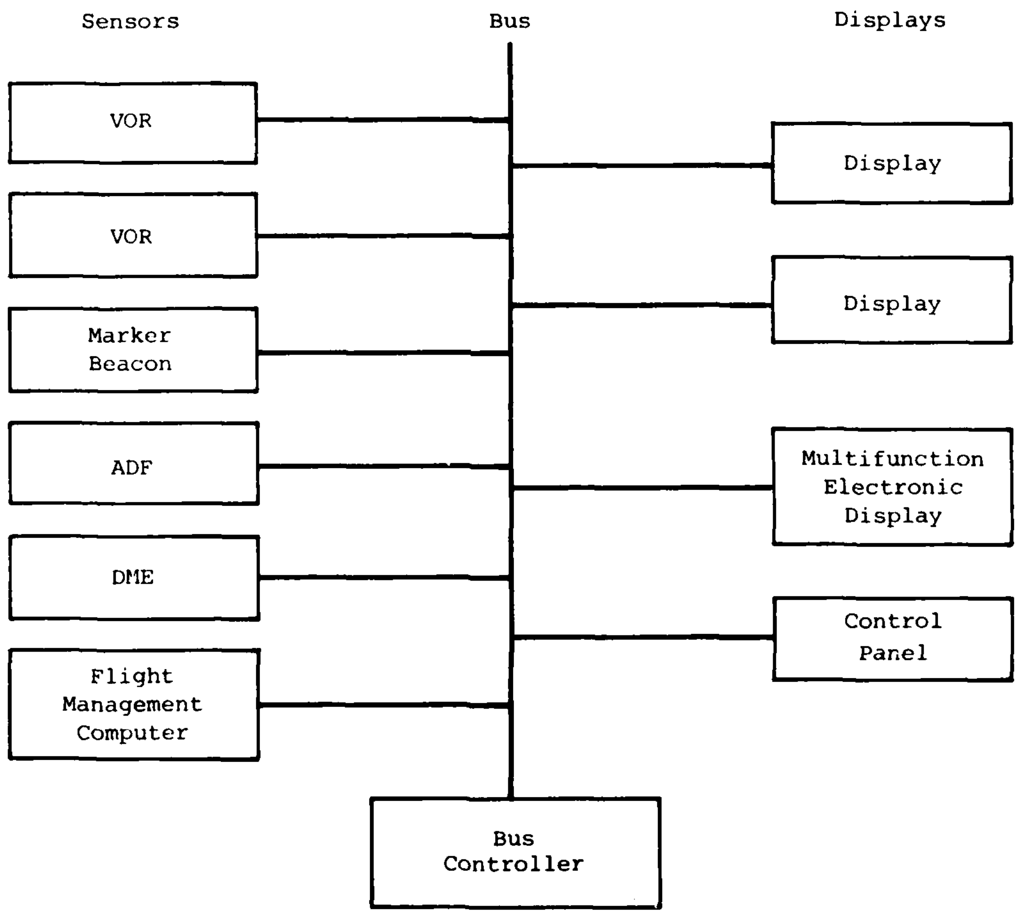

Figure 4-10. BUS ARCHITECTURE

Table 4-1. ALTERNATIVE ARCHITECTURE TRADE-OFFS		
Architecture	Advantages	Disadvantages
Distributed	Flexibility in building suite Integrity	Requires significant panel space
Centralized	Reduces cost and size through hardware sharing	Requires a standard interface Possibility of a single point failure
Integrated	Reduces cost and size through hardware sharing Further reduces size by locating functions together	Less suite-building flexibility Possibility of single point failure
Multifunction Electronic Display	Reduces size by locating displays together Provides centralized viewing location	Current high cost Requires standard interface Possibility of a single point failure
Bus	Flexibility in building suite Reduces cabling weight and complexity	Cost savings applicable to remote rather than panel-mounted installations Requires standard interface Possibility of a bus controller failure

directly related to costs but affected by the selection of avionics architectures (e.g., effect on pilot workload) also are not addressed because many of these factors depend on detailed, specific engineering design decisions.

4.2.2 Alternative Architecture Trade-Offs

Aspects that are unique to a particular architecture are discussed in this section. Barriers that affect any architecture alternative are highlighted in Section 4.2.3.

The conventional distributed architecture is based on self-contained equipment and therefore does not require electrical interfaces between the various avionics units. Consequently, units can be selected from the product lines of various manufacturers and can be purchased as needed, providing significant purchasing flexibility. Collectively, however, such individual units take up much of the available panel space in the cockpit.

Centralized architecture allows the central processor to perform some of the baseband functions of several of the avionics units. The use of a centralized architecture does not necessarily imply a reduction in the number of displays, only a reduction in the number of processors required to drive the displays. Therefore some redundant processing capability is eliminated and cost potentially reduced.

Integrated architecture reduces cost thorugh time-sharing processing as in centralized architecture and reduces the amount of panel space required for installation by locating several functions within a single unit. Several manufacturers of general aviation avionics units have used integrated architecture in a variety of functional combinations; that practice typically yielded fourteen percent savings in both cost and panel space when compared with equivalent capability using distributed architecture. The U.S. Air Force's multifunction multiband airborne radio system (MFBARS) avionics integration program has indicated potential cost savings of 67 percent and size reduction of 75 percent over a distributed architecture. These dramatic savings are due mainly to RF time-sharing processing of a significant number of L-band functions, which constitute about 70 percent of the size and cost of the proposed military equipment suite. The RF time-sharing techniques developed in the MFBARS program are not yet mature and will not be implemented by the military until the late 1980s.

A multifunction electronic display unit could combine t functions of many current displays, such as HSI, CDI, RMI, and weather radar. Much panel space could be conserved by using such a unit. CRT displays and other new displays are discussed in Section 4.1.8.

A bus architecture as defined in ARINC Characteristic 429-4 could provide a convenient interface between an RNAV computer and navigation sensor inputs, potentially providing the same flexibility in suite building that is currently available in distributed architecture. The use of a bus architecture provides a means by which a single electronic display can be driven by a number of processors, but does not preclude the use of separate, dedicated displays for some or all processors. Present systems use a combination of dedicated and multifunction electronic displays. Interfaces to future units such as data links and collision avoidance systems could also be facilitated by a bus architecture. If and when these capabilities become necessary, the interface convenience offered by a bus architecture could possibly be associated with a cost savings. Using a bus architecture in an application that uses extensive remotely mounted avionics could achieve a cost benefit primarily through reduced weight and maintenance associated with the cabling otherwise required to provide interfaces between cockpit displays and remotely located receivers and processors. However, cabling-related weight and maintenance problems are not dominant in general aviation because most units are self-contained and mounted in the cockpit panel.

4.2.3 Barriers to Use of Alternative Architectures

The following barriers can limit the acceptance of the alternative architectures:

- Lower perceived reliability and pilot confidence
- Possibility of single-point failure
- Incompatibility with sequential avionics purchasing practices (lack of flexibility in building suite)
- Small size of general aviation avionics market
- Lack of standard interface definitions

Pilots have grown accustomed to the feeling of reliability provided by the multiple redundancy of conventional distributed architecture. If the VOR receiver fails, the pilot can use the ADF to help determine the aircraft's position. If the ADF also fails, the radio can be used to communicate with a flight service station (FSS), the control tower, or an ARTC center. The transponder can also be used to indicate an emergency situation by using code 7700 even if all other systems fail. This hierarchy of highly visible back-up capability provides the pilot with a high level of confidence in the reliability of distributed architecture. The possibility of a single-point failure that could incapacitate all the associated avionics functions exists in each of the alternative architectures. The central processor in a centralized or integrated architecture, the bus in a bus architecture, and the CRT in a multifunction display architecture each presents a vulnerable point at which a failure could disable many functions. This potential diminishes pilot confidence in these alternative architectures. Although the reliability of the alternative architectures could be made to approach that of distributed architecture, this reliability would not be as highly visible as in distributed architecture. Also, the cost of improving the reliability would be prohibitive. In particular, redundancy, which is commonly used in air carrier aircraft to enhance reliability, would be too expensive for serious consideration by general aviation.

A second barrier is the typical practice of purchasing general aviation avionics sequentially. The avionics purchased with a new aircraft generally consists of the minimum suite. This suite might include a VHF navigation/communication transceiver and a transponder. Additional avionics units are subsequently purchased as enhanced capability is desired. Avionics units designed for an alternative architecture can not easily be combined with an existing suite that uses distributed architecture. Existing units (which may not yet be fully amortized) might have to be replaced to permit the incorporation of an alternative architecture as a retrofit installation. The purchasing flexibility inherent in the conventional distributed architecture is therefore not available with the alternative architectures without standardization of interfaces.

Another barrier is the small size of the general aviation avionics market compared to other markets in the electronics industry. It is harder to justify design and development costs for a new system concept when the potential market is small. Avionics units designed for an alternative architecture would primarily be sold as new installations rather than retrofit installations as described above. Eliminating any portion of an already small market will further reduce the potential acceptance of the alternative architectures.

A fourth barrier is the lack of interface standards among manufacturers of general aviation avionics. As an example, providing interfaces between current multifunction electronic displays (e.g., color CRT displays) and various sensor units can be difficult since standard interface definitions do not exist in general aviation avionics. The conventional distributed architecture used in general aviation allows the combination of different manufacturers' equipment in an avionics suite, but units designed for different alternative architectures could not be easily provided with interfaces with each other. The incompatibility among the various architectures has the potential of dividing the total general aviation avionics market even further. As stated above, this market is too small to be further divided. Even if all manufacturers were to use the same alternative architecture in new avionics designs, interchangeability could not be easily achieved without interface standardization.

As indicated in Table 4-1, no single approach provides dominant benefits over any other architecture without some significant drawbacks. At present, there is insufficient incentive for manufacturers to develop or implement new concepts in general aviation avionics architecture. In addition, existing barriers make changes from conventional distributed architecture undesirable or difficult to attain. However, as more functional capability is required in the cockpit, operational considerations and the need for additional avionics will ultimately force changes in current architecture regardless of cost effectiveness.

4.3 PROJECTED COSTS

Table 4-2 shows the projected costs of VHF transmitter and receiver modules through the year 2000. The modules are representative of an item with a moderately decreasing cost. The PPI is included for reference.

Table 4-2. PROJECTED COSTS IN CURRENT DOLLARS AND PPI INDEX

Equipment Module	1980	1985	1990	1995	2000
VHF Receiver Module	$560.00	$734.00	$840.00	$928.00	$921.00
Cost Factor	1.0	1.31	1.50	1.66	1.64
VHF Transmitter Module	$250.00	$328.00	$364.00	$371.00	$414.00
Cost Factor	1.0	1.31	1.46	1.48	1.66
Inflation Factor					
PPI Index	$ 1.00	$ 1.48	$ 2.18	$ 2.88	$ 3.61

Note: PPI index is provided for comparison.

CHAPTER FIVE

CONCLUSIONS

During the past 20 years the price of avionics at the unit level has increased on the average at a rate consistent with the PPI. The PPI has been increasing more slowly than wages. Consequently, the price of avionics reflects productivity and technology advancements achieved as a result of the semiconductor revolution. Silicon was to electronics what iron and steel have been to transportation. The functional enhancements and cost reductions caused by the semiconductor revolution will continue for many years but at an ever decreasing pace as transistors approach physical limitations. Although new component revolutions may occur tomorrow, it is unlikely that the avionics industry will be affected in this century because it takes 15 to 20 years for a major invention to be incorporated into production designs. Therefore avionics will continue to use basic refinements of today's semiconductor technology through the year 2000. Major revolutions in production technology may also occur, but they are unlikely to have a significant cost impact because about 85 percent of direct costs are attributable to materials.

The materials used in avionics have shifted from the heavy use of mechanical and electromechanical components to semiconductors. This shift has resulted in reduced power dissipation and size of all active and passive components. The trend in semiconductor components has been toward higher and higher levels of integration which has reduced component counts and power consumption dramatically. Table 5-1 shows the actual component counts for [illegible] and the projected component counts through the end of the century. Although the number of active components will be reduced dramatically, support and passive devices will limit the possible reductions in parts count.

Table 5-1. PROJECTED COMPONENT COUNTS

Component	[illegible]*	[illegible]	[illegible]	1995	2000
Transponder	[illegible]	[illegible]	[illegible]	[illegible]	120
VHF Transceiver	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*Estimated count based on actual.

Component costs have generally been increasing with the PPI. However, considerable variation exists among different types of components; labor-intensive mechanical items are the most inflation sensitive and technology-intensive semiconductors are the least inflation sensitive. Table 5-2 shows projected cost factors for various types of components through the year 2000, normalized to the 1980 cost factor. The PPI index is shown for purposes of comparison. Cost factors assume a PPI inflation curve as described in Chapter Two of this report. Component prices may be estimated by multiplying 1980 prices by the cost factor. For example, a tube that cost $5.00 in 1980 will cost $7.50 in 1985 ($5.00 × 1.5). All components, with the exception of resistors and integrated circuits (ICs), will increase in price. Resistor prices should remain stable through the 1980s and increase dramatically through the 1990s. IC prices will continue their present downward trend.

Table 5-2. PROJECTED COST FACTORS AND PPI INDEX FOR ESTIMATING COMPONENT PRICES THROUGH THE YEAR 2000

Component Type	1980	1985	1990	1995	2000
Cost Factors					
Hardware	1.0	1.5	2.4	3.4	4.6
Tubes	1.0	1.5	2.3	3.3	4.3
Capacitors	1.0	1.4	2.2	3.1	4.1
Transistors	1.0	1.2	1.6	1.9	2.3
Resistors	1.0	1.0	0.9	1.2	1.5
Integrated Circuits	1.0	0.9	0.6	0.5	0.3
Inflation Factor					
PPI Index	1.00	1.48	2.18	2.83	3.61

Note: PPI price inflation is assumed as follows: 1.00 for 1980.

The greatest potential for cost reduction for future avionics designs is in the elimination of inflation-sensitive components such as L-band power tubes, electromechanical displays, and mechanical items. Some power amplifiers and oscillators in L-band RF circuits of vintage tube technology, such as transponder cavity oscillators, do not yet have a cost-effective solid-state replacement. When RF semiconductor power devices become competitive with tubes, the cost of these L-band transmitters will be reduced as was the case with discrete solid-state devices. Most displays, such as course deviation indicators (CDIs), still use expensive electromechanical indicators. These servo-driven displays, although popular with pilots, will increase in price comparably to hardware. Electronic CDI displays, which now offer the same functional capability at half the price, still exhibit some technical drawbacks. These displays are also facing problems because of resistance to change by many pilots. However, the pressure of increasing price differentials and improved performance will eventually force the transition to electronic displays. Although mechanical items are inflation sensitive, only marginal additional savings are anticipated through creative new packaging concepts, size reductions, and functional integration.

The second potential for cost reduction lies in new design concepts and standardization. The recent advent of microprocessors has made available digital computing capability and cost previously considered impractical for avionics. This capability has permitted the substitution of a single digital processor chip for functions previously performed by multiple analog circuits. At present, this centralization is occurring at the single-function level. In the near future, however, the rapid growth of computing power per chip will make such centralization possible on a multifunction level. Some benefits of this approach are cost reductions by reducing signal-processing redundancy, expansion of functional capability without the purchase of additional hardware, and improvement in the accuracy of all flight data through the availability of multiple sensors.

The industry's limited market does not now and will not in the future provide a sufficient production base for large, basic research and development efforts. Consequently, avionics manufacturers will continue to depend on other segments of the electronics industry for proof of concept, initial production, and maintenance of production quantities for low material cost. New innovations will exist for nearly a decade before application to avionics hardware.

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