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ANALYSIS AND METHODOLOGY FOR AERONAUTICAL SYSTEMS TECHNOLOGY PROGRAM PLANNING

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16 Abstract

This report presents the results of a study performed by ARINC Research Corporation in support of NASA controls and guidance program planning. A structured methodology was developed that allows the generation, analysis, and rank-ordering of system concepts by their benefits and costs, indicating the preferred order of implementation. The methodology is supported by a base of data on civil transport aircraft fleet growth projections and data on aircraft performance relating the contribution of each element of the aircraft to overall performance. The performance data are used to assess the benefits of proposed concepts. The methodology includes a computer program for performing the calculations needed to rank-order the concepts and compute their cumulative benefit-to-cost ratio. The use of the methodology and supporting data is illustrated through the analysis of actual system concepts from various sources.

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January 1983

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under Contract NAS1-16261

by

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FOREWORD

This report is submitted in accordance with the provisions of NASA contract NAS1-16261. It presents the results of a multi-task study to examine present and future air transport operations, and to develop a structured methodology for the assessment and selection of research projects in that area.

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ARINC Research Corporation wishes to gratefully acknowledge the contributions made to this project by the many experts in the aviaiton community whose information and informed opinion were incorporated in this report.

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SUMMARY

The National Aeronautics and Space Administration (NASA) is chartered to support the development of aeronautical systems for the enhancement of aviation and related industries. Under that charter, NASA performs research and development on aircraft flight control and guidance systems under the program name of Controls and Guidance.

That program within NASA conducts research in a wide variety of areas relating to advanced flight controls and aircraft guidance systems aimed at enhancing the performance of aircraft of many types. In order to maximize the effectiveness of its research, the Controls and Guidance Program engages in careful planning to ensure that the projects selected for execution, from among all those available or proposed, are those that will provide the maximum benefit to the aviation community. This is a difficult planning task, given the large number of factors that bear on such a choice. Recognizing the need for a structured approach to the planning of the program, the NASA Systems Application Office contracted with ARINC Research Corporation for the development of a planning methodology that would provide a framework for generating and analyzing controls and guidance system concepts and for selecting concepts for execution in such a way as to maximize the benefit to the aviation community.

1. OVERVIEW OF PROJECT APPROACH

The project performed by ARINC Research had as its goal the formulation of a structured methodology for project selection based on the benefits and costs of the various independent proposed projects, supplemented by a base of aircraft performance data which could be used in the analysis and generation of specific controls and guidance concepts. The project concentrated on civil transport class aircraft, with some additional qualitative data provided on high-performance military aircraft. The methodology was illustrated through the analysis of actual controls and guidance concepts developed by ARINC Research, The Lockheed-California Company, and others.

This project was performed in four tasks. In the first task, we compiled the base of data containing fleet growth projections and information on aircraft performance. In the second task, we made projections as to the types of problems that will be encountered by the aviation community in the

future. In Task 3, we developed, implemented, and documented the structured methodology for generating and selecting controls and guidance concepts that address the problems identified in Task 2. In Task 4, we exemplified the methodology by analyzing actual controls and guidance concepts. Our approach to each of these tasks is outlined in the following paragraphs.

Task 1: Fleet Growth Projections and Aircraft Performance Data

The methodology developed in this project is intended to be useful not only in analyzing controls and guidance concepts, but also in guiding the planner in the generation of these concepts. To that end, the base of data created to support the methodology contains information on the expected growth of the civil aircraft fleet through the year 2010. Also included are "snapshot" scenarios of the civil aircraft fleet in 1990, 2000, and 2010. These data were used to formulate predictions as to the kinds of problems and limitations that are expected to be encountered by the aviation community in the future. The data on predicted problems serve as a guide for pointing out where controls and guidance concepts can be applied to best advantage. Using those data, planners can concentrate their efforts in areas predicted to pose problems to, or set limits on, the growth of aviation.

Growth forecasts were collected to project trends in total numbers of aircraft, revenue-passenger-miles, types of aircraft, and aircraft lifetimes. Through the use of these growth projections, the expected introduction dates of new aircraft were projected. Another factor considered was the availability of new technologies that could hasten the introduction of new types of aircraft. Finally, scenarios showing "snapshots" of the civil aircraft fleet in the next three decades were prepared from these data.

In Task 1, we also compiled information on the performance of aircraft for use in assessing the merits of proposed controls and guidance concepts. The data are used in the methodology to assess the benefits of the proposed concepts by determining the change in the total performance of the aircraft as the result of a change in the performance of a single element of the aircraft resulting from the application of a controls and guidance concept.

Task 2: Aviation Problem Areas

In the second task, we used the fleet growth and technology information developed in Task 1 to predict the problems that the civil aviation community will face in future decades. From those, we developed general goals and desired improvements for aviation through the year 2010.

Each of the problems identified was restated as a goal for the improvement of civil transport aviation. The relationship of each of those goals to the overall goal of enhancing aircraft performance and to intermediate goals was identified and quantified.

The statement of goals in this task, and their quantitative relationships, are intended to serve as a guide for the planner to help in identifying where controls and guidance concepts can be most effective in alleviating the problems of the aviation community.

Task 3: Project Methodology

In this task, we developed, implemented, and documented a structured methodology for the generation and analysis of controls and guidance concepts. The methodology comprises both conceptual and analytical parts, with the final step being automated.

This methodology was configured to provide a framework for the planner to use in selecting and refining a statement of goals and developing and analyzing specific concepts to achieve those goals.

The methodology relies heavily on the fleet growth projections, technology forecasts, and aviation scenarios developed in Task 1 and the goals definitions developed in Task 2. The data are used to determine the benefits of proposed concepts and their total impact on aircraft performance fleet-wide.

The final step in the methodology is a rank-ordering of the concepts under consideration by their ratio of benefit to cost. Since a large number of calculations are required to perform this ranking, the methodology provides a computer program for this function. This program is intended to be used in an interactive manner, allowing the planner to perform iterative calculations very quickly and thereby permit the planner to assess the sensitivity of the final results to changes in the input information.

The output of the program shows the cumulative benefit-to-cost ratio of performing the concepts in groups of one, two, three, etc., up to the number of concepts under consideration. This form of output was chosen because of the strong impact of the costs of broadly applicable generic technologies (such as high-reliability systems) on the final result. By computing the cumulative ratio, the advantages of pursuing concepts that share a group of generic technologies become evident. Optimal levels of research activity can also be identified in this way. The results are presented in both tabular form for precision and graphical form for easy interpretation.

Task 4: Methodology Example

In Task 4, we exemplified the use of the methodology through the analysis of real controls and guidance concepts. In some cases, the methodology was used to generate the concepts, while in other cases, the methodology was used to analyze concepts from other sources. Estimates of the benefits and costs of the concepts were obtained either through the use of the methodology or from the source of the concept. The concepts were then rank-ordered using the program developed in Task 3 as the final step in the methodology.

In this example of the use of the methodology, we attempted to use the most authoritative and accurate estimates of the concept benefits and costs available. The costs of the generic technologies assumed to be required were treated as they would be in a sensitivity analysis to illustrate that aspect of the methodology.

2. SAMPLE RESULTS

The remainder of this Summary highlights some of the key results generated by the various activities of this project.

As the first step in Task 1 of this project, ARINC Research identified the growth trends for civil transport aircraft over the next three decades. The number and type of aircraft expected to be in service or to be introduced into service from now through the year 2010 were identified.

A review of industry literature and discussions with the three major U.S. airframe manufacturers produced a diversity of opinion as to expected growth rates, ranging from 4 to 8 percent in terms of revenue-passenger-miles. Those figures were used to develop estimates of the growth in the number of aircraft, taking into account the trend toward increases in aircraft capacity and route lengths. That is, with a greater number of seats and longer routes, fewer aircraft are needed to fly the same number of passenger-miles. Thus, the growth rate for the number of aircraft in service is somewhat lower than that for passenger-miles. Figure S-1 shows the forecast growth in numbers of aircraft, taking into consideration aircraft retirements, purchases of new aircraft built with old (pre-1980) technology, purchase of new aircraft built with new (post-1980) technology, and the production capacity of the four major international airframe manufacturers.

From the growth forecasts and a knowledge of the projected lifetimes of the various aircraft types, we determined the expected introduction dates of new generations of aircraft. Considering those dates in light of the types of technologies expected to be available in those time frames enabled us to predict the characteristics of the aircraft to be introduced. The data clearly indicate that changes in aircraft over the next 30 years are expected to be evolutionary, rather than revolutionary. Table S-1 shows the predicted introduction dates and characteristics for a variety of future aircraft. These aircraft include short range (SR), medium range (MR) and long range (LR) designs. The number included with the range designation indicates the sequence of aircraft introduction. Table S-2 shows the mix of technology predicted for each aircraft type.

From the information on the projected growth of the civil aircraft fleet and the technology mix, we assembled scenarios showing "snapshots" of the fleet in the years 1990, 2000, and 2010. These scenarios are shown in Table S-3.

The information on fleet growth and the aircraft scenarios serve two purposes. First, they provide data on the numbers of aircraft to which a given controls and guidance concept might apply. This information is needed to compute the total benefits and costs associated with a concept. Clearly, all other considerations being equal, it would be better to apply a concept to a class of 1,000 aircraft than to a class of 100 or 10, so that the benefit would apply to more aircraft (e.g., B-727 versus Concorde SST). The second purpose of the growth forecasts and scenarios is to point out the kinds of problems that the aviation community will face in the future. Such information can guide the planner in selecting concepts that address problems offering large pay-offs.

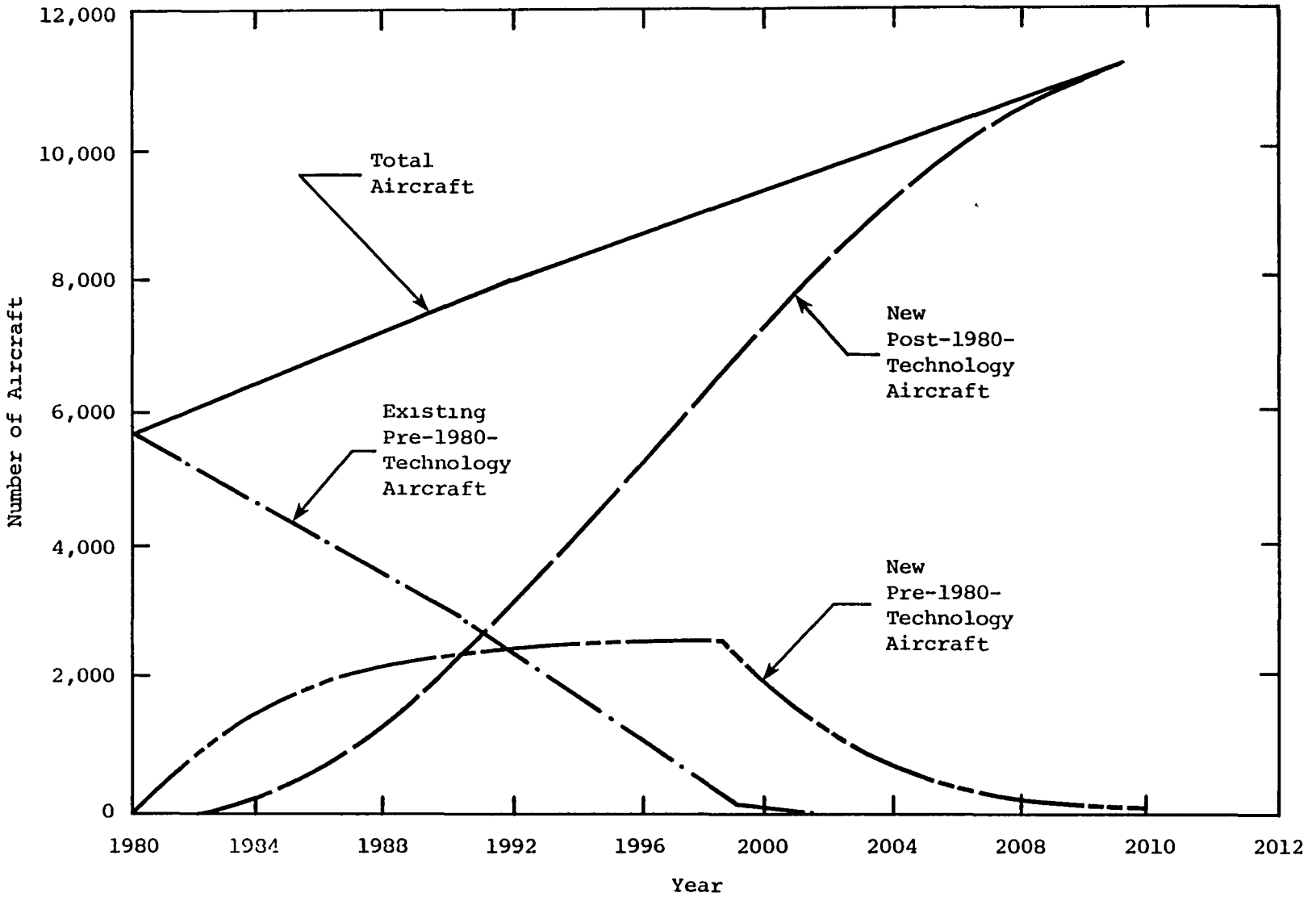

Figure S-1. CIVIL AVIATION FLEET GROWTH TREND

Table S-1. NEW AIRCRAFT DESIGN CHARACTERISTICS

Characteristic	Characteristic Values by Aircraft Type										
	SR1	LR1	SR2	MR1	LR2	SR3	MR2	LR3	SR4	MR3	LR4
Introduction Date	1987	1990	1995	1997	2000	2003	2005	2007	2008	2010	2010
Design Range (nautical mi)	2,200	5,000	2,000	2,500	5,500	1,700	2,500	6,500	1,700	2,500	7,500
Max L/D	20	22	20	22	30	22	20	35	22	35	12
Sfc at Cruise	0.66	0.62	0.63	0.61	0.58	0.45	0.58	0.50	0.42	0.52	1.25
Gross Takeoff Weight (1,000s of lb)	125	360	123	240	335	125	261	385	125	244	490
Operating Equipment Weight (1,000s of lb)	69	225	66	148	200	70	165	240	65	155	250
Max Fuel (1,000s of lb)	30	120	28	40	72	15	35	92	15	22	265
Max Zero Fuel Weight (1,000s of lb)	109	305	106	213	280	115	235	330	110	225	310
Max Payload (1,000s of lb)	40	80	45	65	80	45	70	90	45	70	60
Max Range (nautical mi)	3,100	7,000	3,150	3,850	7,300	3,000	4,500	9,800	3,200	4,000	10,000
Number of Passengers	150	300	150	240	300	175	275	350	175	275	275
Cruise Speed (knots)	435	465	435	450	460	450	460	450	460	460	1,460
at Altitude (1,000s of lb)	31	35	31	35	40	29	40	45	27	45	60
Fuel Efficiency (seat-miles per lb fuel)	15.5	17.5	16.9	23.1	30.4	35.0	35.4	37.3	37.3	50.0	10.4
Airframe Efficiency (payload per OEW)	0 58	0.36	0.68	0.44	0.40	0.64	0.42	0.38	0.69	0.45	0.24
Fuel Weight per Mile (pounds)	9.7	17.1	8.9	10.4	9.9	5.0	7.8	9.4	4.7	5.5	26.5

Table S-2. TECHNOLOGY MATRIX

Class of Technology	Level of Potential Use by Aircraft Type										
	SR1	LR1	SR2	MR1	LR2	SR3	MR2	LR3	SR4	MR3	LR4
Composite Materials	30%	40%	40%	40%	60%	60%	60%	75%	75%	75%	50%
Active Controls	30%	50%	50%	50%	70%	70%	70%	80%	80%	80%	80%
All-Electric Systems	30%	40%	50%	50%	50%	60%	60%	60%	75%	75%	75%
Laminar-Flow Control	-	-	-	-	A	-	A	P	-	P	-
Propfan	-	-	-	-	-	X	-	-	X	-	-
Variable-Cycle Engine	-	-	-	-	-	-	-	-	-	-	X
System Monitoring	30%	30%	50%	50%	50%	75%	75%	75%	80%	80%	80%
Self-Adjusting Wing	-	-	-	-	-	-	-	X	X	X	-
Digital/Electronic Flight Deck	30%	35%	55%	60%	75%	75%	80%	80%	90%	100%	100%
Electronic Engine Controls	10	13	13	16	16	18	18	20	20	20	20
New Conventional Airfoils	-	-	-	X	-	X	-	-	X	-	X
Fuel-Efficient Engines Compared with 1980	12%	12%	15%	15%	18%	25%	20%	23%	30%	28%	40%

*A - Active; P - Passive; X - Aircraft uses this technology.

Table S-3 AVIATION SCENARIOS

Scenario Factors	1990	2000	2010
Total Number of Aircraft	7,750	9,600	11,375
Number of New Pre-1980-Technology Aircraft	2,400	1,800	75
Number of New Post-1980-Technology Aircraft	2,350	7,800	11,300
Number of Old Pre-1980-Technology Aircraft	3,000	0	0
Number of Aircraft by Range			
Short Range	2,350	2,900	3,400
Medium Range	3,000	3,650	4,200
Long Range	2,400	3,050	3,765
Supersonic Transport	0	0	10
Composite Materials			
Maximum Usage	30% of potential	60% of potential	75% of potential
Fleet Average Usage	8% of potential	35% of potential	56% of potential
Active Controls			
Maximum Usage	30% of potential	70% of potential	80% of potential
Fleet Average Usage	6% of potential	38% of potential	65% of potential
Auxiliary Systems Converted to Electronic/Digital			
Maximum Usage	30% of potential	50% of potential	75% of potential
Fleet Average Usage	3% of potential	25% of potential	55% of potential
Level of Aircraft System Monitoring Automated	30%	50%	80%
Propulsion Efficiency Improvement vs 1980 Levels			
Maximum Improvement	12%	18%	30%
Fleet Average Improvement	6%	11%	20%
Number of Engine Control Functions Converted to Electronic/Digital	7 to 10	10 to 16	16 to 20
Fuel Costs per Gallon in 1980 Dollars (1980 = $1 05)	$1.05	$1 10	$1 15
Fleet Mix	SR1 2% B767/B757/A310 28% DC9-80/B737-300/ B747/DC10 31% B727-100/DC-8/etc 39%	SR1, LR1, SR2, MR1 80% LR2 1% DC9-80/B747, B727. 19%	SR1, LR1 retired SR4 2% SR2 (being retired). 10% LR4 0 1% LR3, MR3 10% SR3, LR2, MR1, MR2. 78%
Typical Flight Deck Electronics	DABS, ETIS, ATARS, 4D-RNAV, BCAS, CDWI, CDTI, HUD, Multifunction Switches/ Panels	DABS, CDTI, ATARS, CDWI, BCAS, MLS, ETIS, HUD, 4D-RNAV, Multi-function Switches/Panels	DABS CDTI, ATARS CDTI, BCAS MLS, ETIS, 4D-RNAV HUD, Color Flat Panels, Civilian GPS, Speech Recognition and Synthesis, Category III c Autoland, Multi-function Switches/Panels
Air Traffic Control System Capability	Able to Accommodate Above-Listed Systems	Above-Listed Electronics Required	Above-Listed Electronics Required
Noise Levels Vs FAR Part 36	Equal	-3 dB	-6 dB

Also as a part of Task 1, we performed a qualitative analysis of the factors that influence the performance of high-performance military aircraft. Those data will serve as a starting point for later studies of this class of aircraft. High-performance aircraft were of interest because they are almost always the first to include advanced controls and guidance concepts in their design. Thus, they represent the leading edge of technology in this area and are some of the most advanced aircraft in operation today. The characteristics of those aircraft were compiled and their missions analyzed. We concluded that the single overall goal of these aircraft is that of ordnance delivery, either through the actual firing of ordnance or through support functions such as EW or reconnaissance. Our analysis revealed six principal elements that contribute to the ability of the aircraft to accomplish its mission: aerodynamic performance, armament systems, survivability, turnaround ability, cost, and navigation/communication/identification capability. Each of those factors is, of course, made up of many subfactors. More than 80 individual elements and their qualitative relationship to each other were identified.

As a final part of Task 1, we quantified the relationships between the various factors that make up civil transport aircraft performance and the overall performance of the aircraft. These relationships are used to determine the benefits of the proposed concepts by assessing the effect of changes in an individual element on overall performance. For instance, fuel consumption, maintenance, and crew costs contribute a great deal to the cost performance of the aircraft. Thus, a concept that changes one of those factors will have a corresponding effect on cost. The functional relationships between those and other performance factors were analyzed and presented in a variety of forms. Some relationships were expressable as exact equations. In other cases, the relationships were best shown in the form of sensitivity graphs, showing the percent change in a factor as a function of changes in the various factors that make it up. The format is shown in Figure S-2. Still another way of displaying the analytical relationships is by means of a tree structure. In the case of the civil transport aircraft analyzed in this study, the performance tree was quantified, showing the percent contribution of each of the individual elements. A portion of the performance tree structure is shown in Figure S-3 (additional data of this type appear in the body of the report). An example would be a controls and guidance concept that increases the lift-to-drag ratio of the aircraft wing by 25 percent. Figure S-3 shows that the lift-to-drag ratio makes up 23 percent of the fuel consumption of the aircraft, which in turn makes up 42.8 percent of operating costs. Thus, such a concept would reduce costs by 25 percent of 23 percent of 42.8 percent, or about 2.5 percent. Since annual operating expenses for a large aircraft are in excess of $10,000,000, that is a significant savings. The data showing the analytical relationships are used in this way to analyze the effect of concepts.

In Task 2 of the study, we used the information developed in Task 1 to identify problems that the aviation community will face in the coming decades. This assessment of problems is intended to serve as a guide for the planner to help identify where controls and guidance concepts can best be applied to address the problems faced by the aviation community. Examining the number

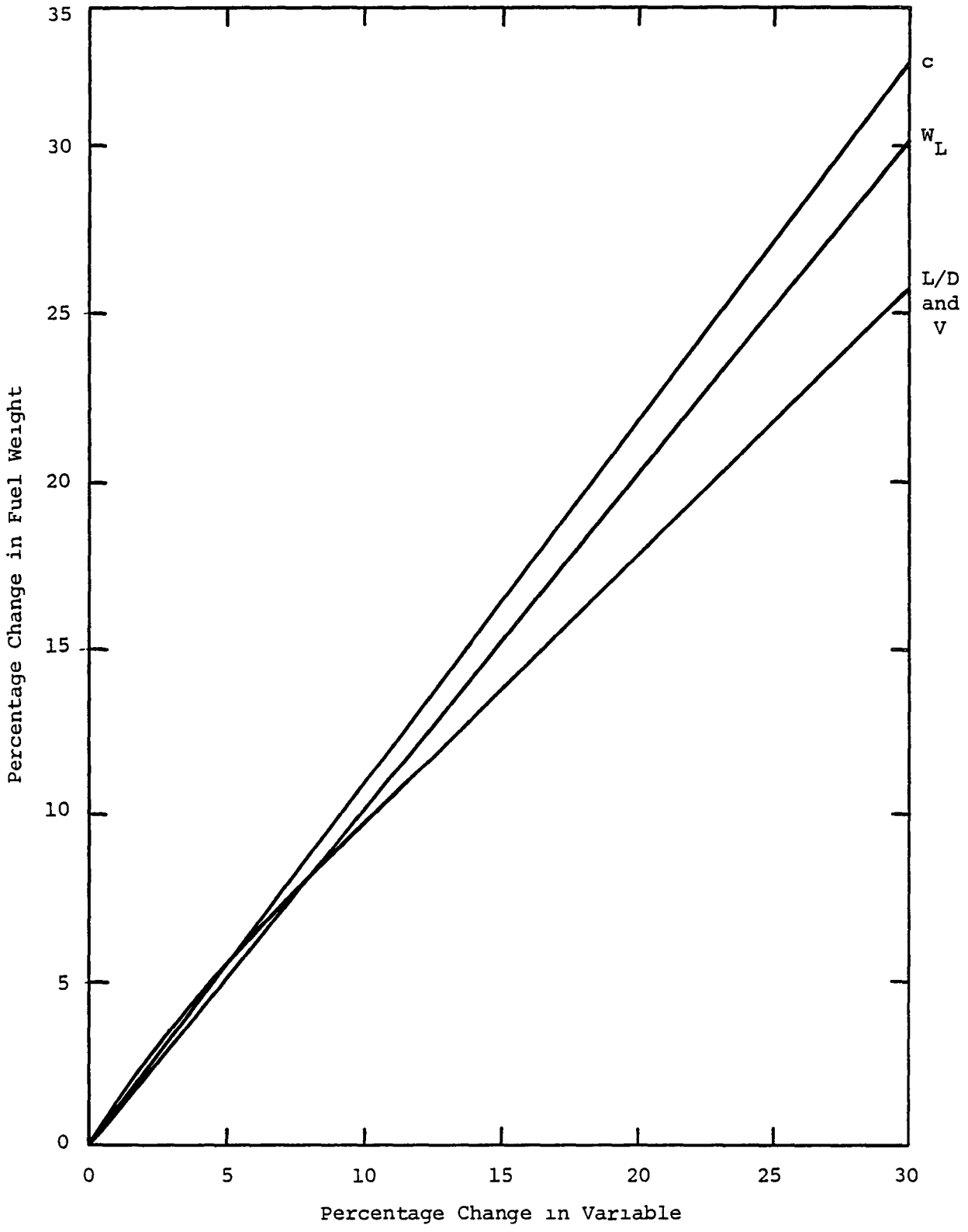

Figure S-2. FUEL USAGE: SHORT- AND MEDIUM-RANGE AIRCRAFT

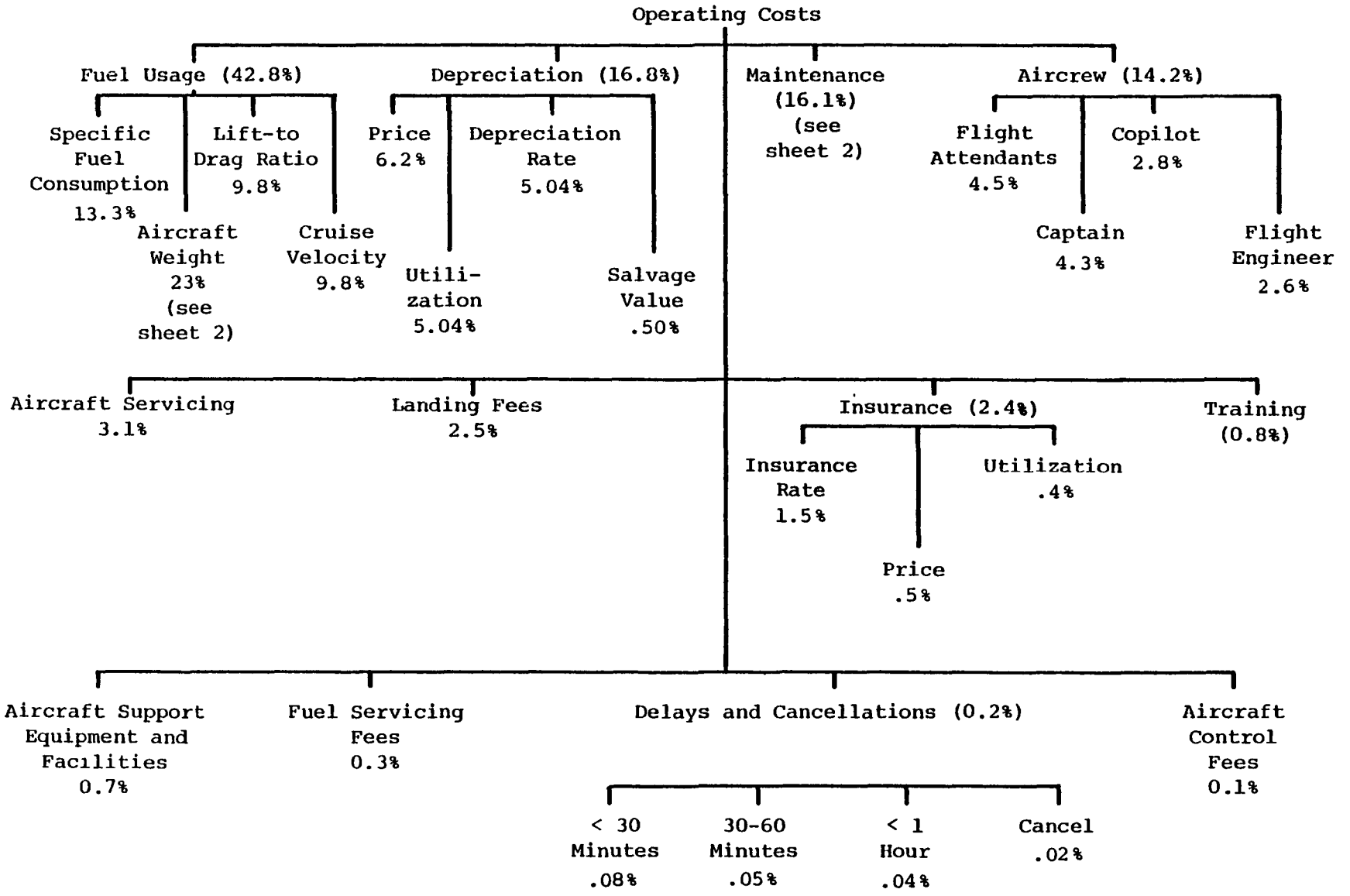

Figure S-3. OPERATING COSTS PERCENTAGE TREE

and types of aircraft expected to be in use, forecasts of operating costs (especially for fuel), and the expected state of the air traffic control system, we identified specific problems and types of problems. On reviewing all of the problems, we realized that they were all part of three fundamental problems that are, and will continue to be, problems for the aviation community. They are high costs of operation, safety of flight, and the social acceptability of the environmental impact of aircraft. Those three general problems were then restated as general goals for aviation: improve the economic performance of aircraft, enhance the safety of aircraft, and enhance the social acceptability of aircraft.

Each of the basic goals was analyzed and broken down into its component parts; that is, all of the individual elements that contribute to performance in relation to those goals were identified and stated as subgoals. Those were in turn broken down into their component parts, with each of the components stated as a goal. A portion of the result of that process is shown in Figure S-4. As the figure shows, the goal of reducing operating costs has as its component parts the goals of reducing fuel usage, reducing depreciation, reducing maintenance costs, reducing aircrew costs, and so forth. These are then broken down as shown into component goals. For instance, the goal of reducing fuel usage is composed of the component goals of reducing aircraft weight, increasing lift-to-drag ratio, increasing engine efficiency, etc. Attainment of any of these component goals will in some measure achieve the goal of, in this case, reducing fuel usage, which in turn will reduce the operating costs of the aircraft.

A planner using these data can thus see what specific changes will affect the goal or goals he is interested in attaining through the use of a controls and guidance concept.

In Task 3, we developed the methodology by which the planner can create and analyze independent controls and guidance concepts, and rank-order them to help structure his research program. The methodology is broad and open-ended, allowing the analysis of many different kinds of concepts. The analysis relies heavily on the fleet growth statistics, aviation scenarios, and analytical relationships discussed earlier. There are nine basic steps to the methodology, as summarized below:

Step 1: Choose the overall goal to address from among the three general goals of cost, safety, and social acceptability.

Step 2: Choose the area in which to apply controls and guidance concepts.

Step 3: Estimate the maximum possible benefit that could be attained.

Step 4: Choose a specific function to improve.

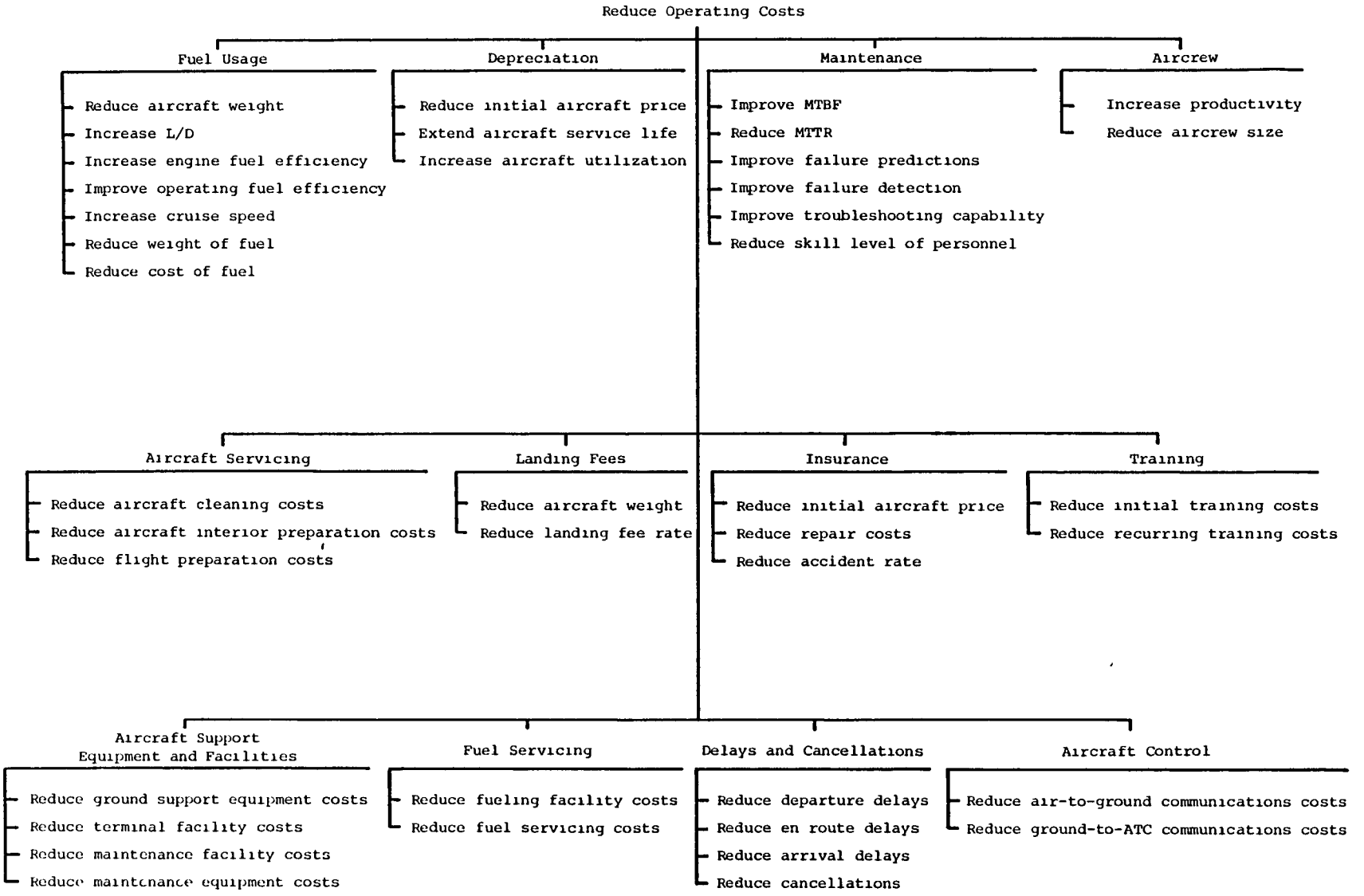

Figure S-4. IMPROVEMENT AREAS AND DESIRED CAPABILITIES

Step 5: Devise a specific controls and guidance concept that will effect an improvement in the selected area of performance.

Step 6: Uses the data provided in Task 1 of this study to estimate the benefit of the concept under consideration.

Step 7: Develop estimates of the costs of the concepts under consideration.

Step 8: Order the concepts by their benefit-to-cost ratio. This ordering must include the generic technology costs and must also assure that generic technology costs accounted for in a previous concept are not added again.

Step 9: Compute the cumulative benefit-to-cost ratio obtained by considering executing the concepts in their ranked order in groups of one, two, three, etc. up to the number of concepts under consideration.

To aid the planner in the final step, we have developed a computer program that enters the benefits and costs of controls and guidance concepts and the costs of generic technologies, sorts the concepts into descending benefit-to-cost ratio order, and computes the cumulative benefit-to-cost ratio.

The program is called ARCEM, for ARINC Research Concept Evaluation Methodology. The ARCEM Program is configured to accept up to 100 concepts and 20 generic technologies for analysis. The program will compute the cumulative benefit-to-cost ratio for the set of concepts in the order in which they were entered, or will first sort them into descending benefit-to-cost ratio for the set of concepts in the order in which they were entered, or will first sort them into descending benefit-to-cost ratio order, taking into account the costs of the generic technologies. The results are shown in both tabular and graphic form. The ARCEM Program was used extensively in Task 4 of this study to analyze the group of example concepts.

In the fourth task, we exemplified the methodology by analyzing a set of actual controls and guidance concepts. The example concepts were selected to address the goals of reducing operating costs and enhancing safety. There were three sources for the concepts used: internal ARINC Research activities, the industry literature, and a NASA study performed by the Lockheed-California Company. These concepts are summarized below:

1. Airborne Wind-Shear Detector: This concept, obtained from the industry literature, involves a laser-based system that could detect the presence of wind shear by sensing the Doppler modulation of a laser beam caused by the relative motion of particulate matter in the air-mass involved in the shear. If such a system were both highly effective and highly reliable, then shear could be avoided, reducing shear-related accidents. Also, some portion of the strength of the wing and airframe associated with absorbing shear loads could be eliminated from the design of the aircraft. This

would result in a lighter aircraft, which in turn would save fuel. More fuel would be saved by eliminating go-arounds necessitated by shear conditions. Thus, this concept addresses the two goals of enhancing safety and reducing operating costs. However, due to the problems associated with evaluating the cost benefit of increased safety, only the operating cost reductions made possible by this concept were used in the comparative analysis with the following seven concepts.

2. Active Landing Gear: This concept was generated by the project team as a result of inspecting the performance tree structures. A portion of the strength of the landing gear is associated with hard-landing loads and with side loads generated during cross-wind landings. An active system that would monitor the touchdown, adjust the flare of the aircraft, and control the angle at which the landing gear touches the runway by swiveling the gear to keep all loads longitudinal could reduce the hard-landing loads and reduce or eliminate the sideloads in a cross-wind landing. Thus, the strength and weight of the landing gear could be reduced, saving fuel and costs.

3. Reduced Number of Flight Attendants: This concept was also generated as a result of inspecting the performance tree structure. Flight attendants constitute a major element of the cost of aircraft operation. Regulations presently require one attendant for each 50 seats. The function of the attendants, aside from serving food and drinks, is to open the doors and inflate the escape slide in an emergency and to direct the passengers to the exit. If part of these functions, such as slide inflation, could be automated, it might be possible to reduce the number of attendants required. This would result in salary and benefits savings and savings in training costs.

4. Advanced Flight Control Systems: This and the subsequent concepts were taken from a report by the Lockheed-California Company. This concept replaces the conventional hydraulic-actuated flight control system with a fly-by-wire system using electromechanical actuators relaxed static stability, and a full authority stability augmentation system. The concept results in lighter, more reliable aircraft, which are cheaper to build.

5. Advanced Secondary Power Systems: Advanced, light-weight generators are used in this concept to provide all secondary power requirements of the aircraft, reducing or eliminating the need for inefficient bleed air systems. Engine efficiency and power system reliability are enhanced, resulting in a lower operating cost.

6. Advanced Avionics Components: At present, each avionic system is housed in a separate box, requiring separate power and cooling, adding to the weight of the aircraft. This concept would configure the avionics to have each functional element as a card or cards in a

large card box. This reduces the power and cooling requirements and eliminates much of the weight of the boxes. Replacement of avionics is simplified also, requiring only the removal of a card instead of an entire box.

7. Advanced Cockpit Systems: Flat panel electronic displays are used in this concept to simplify data presentation to the pilot. Multipurpose controls whose function and labels are under software control are used to simplify and streamline the cockpit control panel. This results in more efficient operation and fewer flight crew errors.

8. Advanced Air Traffic Control Systems: This concept employs advanced cockpit systems for communication and traffic display in conjunction with ground-based ATC systems to achieve better traffic flow and more direct routing. That will result in fuel, and hence cost, savings. Safety is also enhanced by reducing the chance of mid-air collisions.

The benefits and costs of the first three concepts were estimated using Steps 5, 6, and 7 of the ARINC Research methodology. The remaining five were taken from the Lockheed report. These data were then used to rank-order the concepts and compute the cumulative benefit-to-cost ratio by means of the ARCEM computer program. Tables S-4, S-5, and S-6 and Figure S-5 show the results of the analysis. Table S-4 lists the concepts with their benefits, costs, and technology line showing which generic technologies are required by each concept. (The generic technologies are listed in the body of the report.) A "1" indicates that a technology is needed, a "0" indicates that it is not. Table S-5 shows the estimated costs of the generic technologies. All benefit and cost figures are in millions of dollars and represent total benefits and costs over the life of the concept.

Table S-4. INPUT DATA FOR COMPUTER RUN

No.	Name	Benefit (In Millions of Dollars)	Cost (In Millions of Dollars)	Generic Technology Number 1	2	3	4	5	6	7	8
1	SHEAR	304	213	1	1	0	0	0	1	1	0
2	ACT. LG	91	96	1	1	1	0	0	0	1	0
3	RED. FA	4,355	207	1	1	1	0	1	0	1	0
4	AFC	361.9	0.001	1	1	1	1	1	0	1	0
5	ASP	542.9	0.001	1	1	0	0	0	0	0	0
6	AA	45.3	0.001	0	0	0	1	1	0	0	0
7	AC	271.5	0.001	1	1	0	1	1	0	0	1
8	ATC	542.9	0.001	1	1	0	1	1	0	0	1

Table S-5. GENERIC TECHNOLOGY COSTS	
Generic Concept Number	Cost (In Millions of Dollars)
1	500
2	500
3	100
4	100
5	50
6	150
7	50
8	50

Table S-6. SORTED ORDER OF CONCEPTS		
Rank	Name	Cumulative Benefit/Cost Ratio
1	RED. FA	3.09
2	ASP	3.48
3	ATC	3.49
4	AFC	3.72
5	AA	3.75
6	AC	3.93
7	SHEAR	3.34
8	ACT LG	3.23

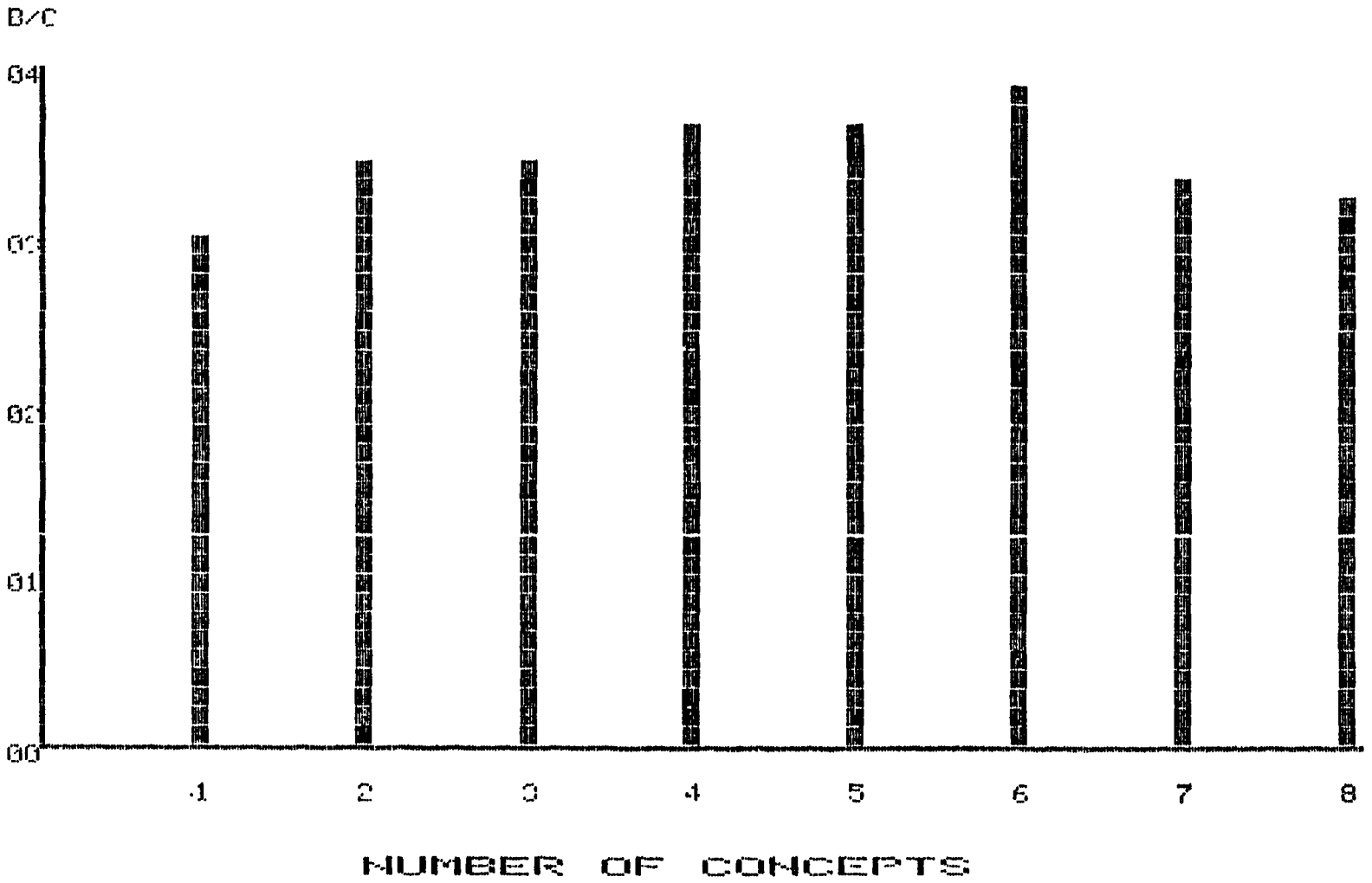

Figure S-5. CUMULATIVE BENEFIT-TO-COST RATIO AS A FUNCTION OF THE NUMBER OF CONCEPTS PERFORMED IN SEQUENCE

Using the ARCEM Program, the concepts were sorted into descending order of benefit-to-cost ratio, and the cumulative benefit-to-cost ratio was computed. The results are shown in Table S-6. The ratios shown with each concept represent the cumulative ratio obtained by implementing that concept after the previous concepts have been implemented. For instance, the ratio of 3.848 associated with concept No. 4 is the ratio obtained by performing the first four concepts in the order listed. The cumulative ratios are shown graphicially as a function of number of concepts in Figure S-5. The sensitivity of these results to the input data could readily be determined by using the editing capability of the ARCEM Program to change factors of interest and observing the change in the results. Such a sensitivity analysis is carried out in Chapter Four of this study report.

The information and methodology presented in this report provide the program planner a set of useful tools to use in configuring a program in such a way as to obtain the maximum benefit from the research and development program. The methodology can be used end-to-end, starting with only basic goals, and, using the data from Task 1, identifying improvement areas and desired capabilities, leading to the generation of specific concepts. These concepts can be combined with concepts from other sources, and their benefits and costs can be estimated by using the performance data and analytical relationships provided. Other concepts that include outside estimates of their benefits and costs can be included in the final steps of the methodology in which the ARCEM Program is used to rank-order the concepts and compute the cumulative benefit-to-cost ratios to identify minimum and optimal levels of activity.

The entire methodology, including the ARCEM Program, is not specific to controls and guidance concepts or even to aviation. We expect that this methodology will find broad application in many areas of NASA program planning.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The National Aeronautics and Space Administration (NASA) is chartered to support the development of aeronautical systems for the enhancement of aviation and related industries. Under this charter, NASA performs research and development in such areas as jet engine technology and the aerodynamic design of wings and other structural aircraft components. Also under this charter, NASA performs research and development studies related to aircraft flight control and guidance systems, under the program name of Controls and Guidance.

This program within NASA conducts research in a wide variety of areas relating to advanced flight controls and aircraft guidance systems aimed at enhancing the performance of aircraft of many types. Past efforts have dealt with technologies such as cockpit displays, fly-by-wire control systems, stability augmentation systems, and active flight control systems. Each of these efforts was aimed at improving the performance of aircraft in an important area.

In order to maximize the effectiveness of its research, the NASA Controls and Guidance Program engages in careful planning to ensure that the projects selected for execution, from among all those available or proposed, are those that will provide the maximum benefit to the aviation community. This is a difficult planning task, given the large number of factors that bear on such a choice. It is often necessary to compare projects and concepts that have benefits in different areas and that have differing cost elements. Recognizing the need for a structured approach to the planning of its program, the NASA Controls and Guidance Office contracted with ARINC Research Corporation for the development of a planning methodology that would provide a framework for generating and analyzing controls and guidance system concepts and selecting concepts for execution in such a way as to maximize the benefit to the aviation community realized by the program.

1.2 OBJECTIVES

The project performed by ARINC Research had as its goal the formulation of a structured methodology for project selection based on the benefits and

costs of the various proposed projects, supplemented by a data base on aircraft performance that could be used in the analysis and generation of specific controls and guidance concepts. The project concentrated on civil transport class aircraft, with some additional qualitative data provided on high-performance military aircraft. The methodology was illustrated through the analysis of actual controls and guidance concepts developed by ARINC Research, the Lockheed-California Company, and others.

1.3 APPROACH

This project was performed in four tasks. In the first task, we compiled the base of data containing fleet growth projections and information on aircraft performance. In the second task, we made projections as to the types of problems that will be encountered by the aviation community in the future. In Task 3, we developed, implemented, and documented the structured methodology for generating and selecting controls and guidance concepts. In Task 4, we illustrated the methodology by analyzing actual controls and guidance concepts. Our approach to each of these tasks is outlined in the following paragraphs.

1.3.1 Task 1: Fleet Growth Projects and Aircraft Performance Data

The methodology developed in this project is intended to be useful not only in analyzing controls and guidance concepts, but also in guiding the planner in the generation of these concepts. To that end, the data base created to support the methodology contains information on the expected growth of the civil aircraft fleet through the year 2010. Also included are "snapshot" scenarios of the civil aircraft fleet in 1990, 2000, and 2010. Those data were used to formulate predictions as to the kinds of problems and limitations that are expected to be encountered by the aviation community in the future. The data on predicted problems serve as a guide for pointing out where controls and guidance concepts can be applied to best advantage. Using those data, planners can concentrate their efforts on problems that may limit the growth of aviation. In this way, the controls and guidance concepts developed can provide greater benefit to the aviation community for the research funds expended.

In this task, growth forecasts were collected to project trends in total numbers of aircraft, revenue-passenger-miles, types of aircraft, and aircraft lifetimes. Included in the growth projections were aircraft retirements, purchases of new aircraft produced with old technology, and purchases of aircraft produced with new technology.

Through the use of growth projections, aircraft lifetimes, and projected retirements, we predicted the introduction dates of new aircraft. Another factor considered in projecting the types of aircraft to be introduced was the availability of new technologies, such as laminar-flow controls or the introduction of efficient prop-fans, which could hasten the introduction of new types of aircraft. These technology forecasts were also used to predict the types of technology expected in future generations of aircraft.

Finally, the scenarios showing "snapshots" of the civil aircraft fleet in the next three decades were prepared from these data.

In Task 1, we also compiled information on the performance of aircraft for use in assessing the merits of proposed controls and guidance concepts. The analytical relationships between the various factors that make up aircraft performance in the areas of interest were defined and presented in tree form, in equations, and in graphs. The data are used in the methodology to assess the benefits of the proposed concepts. This is accomplished by determining the change in the total performance of the aircraft as the result of a change in the performance of a single element of the aircraft resulting from the application of a controls and guidance concept.

1.3.2 Task 2: Aviation Problem Areas

In the second task, we used the fleet growth and technology information developed in Task 1 to predict the problems that the civil aviation community will face in future decades. From those, we identified general goals and desired improvements for aviation through the year 2010.

Both general types of problems and specific problems were considered. We also considered whether there were any problems unique to one of the aviation scenarios developed in Task 1.

Each of the problems identified was restated as a goal for the improvement of civil transport aviation. The relationship of each of these goals to the overall goal of enhancing aircraft performance and to intermediate goals was identified and quantified.

The goals and their quantitative relationships recognized in this task are intended to serve as a guide for the planner to help in identifying where controls and guidance concepts can be most effective in alleviating the problems of the aviation community. By applying concepts to areas which may yield large improvement in overall performance, the money and effort expended on research and development of controls and guidance concepts will achieve the greatest benefit.

1.3.3 Task 3: Project Methodology

In this task, we developed, implemented, and documented a structured methodology for the generation and analysis of controls and guidance concepts. The methodology comprises both conceptual and analytical parts, with the final step being automated.

This methodology was configured to provide a framework for the planner to use in selecting a goal for consideration, refining the statement of the goal until a single element of performance is identified for improvement, generating a concept that effects the desired improvement, assessing the merit of the concept in comparison to other concepts under consideration, and determining the effect of the requirement for generic technologies to support the implementation of the concept in light of the technologies required by the other concepts under consideration.

The methodology relies heavily on the fleet growth projections, technology forecasts, and aviation scenarios developed in Task 1, as well as the goals defined in Task 2. These data are used to determine the benefits of proposed concepts in terms of their total effect on aircraft performance fleet-wide. The methodology also identifies and describes a number of sources of techniques for estimating the costs of the concepts under study, as well as the cost effects the concepts have on the aircraft directly.

The final step in the methodology is a rank-ordering of the concepts under consideration by their ratio of benefit to cost. This ordering shows the preferred order of implementation of the concepts. Obviously, it is desirable to implement the most beneficial concept first. This ranking takes into account the estimated costs of the generic technologies required for implementation of the concepts. Generic technologies are those that are broadly applicable, and may be developed outside the specific concepts under consideration. For instance, the technology of high-reliability systems is generic rather than specific to a concept. Such a technology has many applications and may be developed independently of the concepts under study. If the concept in question requires such a technology, it must somehow be acquired, either through direct involvement in the technology's development, or through adaptation if the technology is already available. Since a large number of calculations are required to perform a ranking taking this factor into account, the methodology provides a computer program for this function. The program is intended to be used in an interactive manner, allowing the planner to perform iterative calculations very quickly and thereby permit the planner to assess the sensitivity of the final results to changes in the input information. This feature of the methodology is intended to recognize that analyses such as those contemplated here must often be performed with scarce or poor-quality data; often, only rough estimates of benefits and costs are available. Permitting the planner to quickly judge the sensitivity of the results to the input data facilitates identification of those data items important enough to warrant further refinement. Also, such iterative techniques can be used to address the analysis parametrically, determining the range of the results as a function of the range of the input.

The output of the program shows the cumulative benefit-to-cost ratio of performing the concepts in groups of one, two, three, etc., up to the number of concepts under consideration. This form of output was chosen because of the significant effect of the costs of generic technologies on the final result. By computing the cumulative ratio, the advantages of pursuing concepts that share a group of generic technologies becomes evident. Optimal levels of research activity can also be identified in this way. The results are presented in tabular form for precision and graphic form for easy interpretation.

1.3.4 Task 4: Methodology Example

In Task 4, we exemplified the use of the methodology through the analysis of actual controls and guidance concepts. In some cases, the methodology was used to generate the concepts, while in other cases, the methodology was used to analyze concepts from other sources. Estimates of the benefits and costs of the concepts were obtained either through the use of the

methodology or from the source of the concept. The concepts were then rank-ordered, using the program developed in Task 3 as the final step in the methodology.

Two of the concepts considered were developed internally by ARINC Research. A third was obtained from the industry literature. The remaining five were obtained from a previous NASA study performed by the Lockheed-California Company. This variety of sources was used to exemplify the various ways in which the methodology can be used.

In performing this example use of the methodology, we attempted to use the most authoritative and accurate estimate of concept benefits and costs available. The costs of the generic technologies assumed to be required for implementation of these concepts were treated as they are in a sensitivity analysis to illustrate that feature of the methodology.

1.4 REPORT ORGANIZATION

The remaining chapters of this report are organized as follows: Chapter Two contains the results of Task 1, showing the growth forecasts and aviation scenarios. The analytical relationships between aircraft performance factors are discussed; detailed data related to commercial aircraft are provided in Appendix A. High-performance military aircraft performance factors are described in Appendix B.

Chapter Three presents the results of Task 2. The problem areas and aviation goals are listed and discussed.

Chapter Four presents the project methodology developed in Task 3. Both the conceptual and automated portions of the methodology are discussed, and the methodology is described step-by-step. The complete cost models are provided in Appendix C. Detailed run instructions for the computer program are given in Appendix D and the program listing is given in Appendix E.

Chapter Five presents the results of Task 4. The example concepts are analyzed, and the basic results are presented. Additional output generated by the sensitivity analysis is presented in Appendix F.

A glossary and list of references are presented in Appendixes G and H, respectively.

CHAPTER TWO

CIVIL AVIATION SCENARIOS

This chapter presents the base of data developed to support the identification of aviation problems and goals and to assess the effectiveness of controls and guidance concepts in attaining these goals. Overall growth trends are discussed, and individual "snapshots" of the civil aircraft fleet are presented for the years 1990, 2000, and 2010. Also presented is the qualitative data developed for high-performance military aircraft and the analytical relationships used to assess the effect of specific concepts on aircraft performance.

2.1 PURPOSE

The scenarios fill three purposes. First, they provide a baseline against which system improvements can be judged; the overall impact of a system is, of course, a function of the number of aircraft to which it will apply. Second, the scenarios provide a means of determining the problems the aviation community will face in the future. Identification of these problems will make it possible to define specific areas where improvement is needed and specific new capabilities that will be desirable. From these capabilities, systems concepts that produce the desired results can be developed. Third, they provide a data base for computing concept benefits and costs.

2.2 GROWTH TRENDS

A review of industry literature and discussions with the three major United States airframe manufacturers (References 2, 3, 4) produced a diversity of opinion on growth rates and the method of measuring the growth. The forecast by the FAA (Reference 1) for the years 1981 through 1992 is made in terms of revenue-passenger-miles; it predicts a growth rate of 4 percent a year, while a forecast by I.S. MacDonald (Reference 6) predicts growth for the next ten years at 6 percent in terms of revenue-passenger-miles. Forecasts by three airframe manufacturers (References 2, 3, 4, 5) predict growth rates of 4 to 6 percent for the next 15 years in terms of number of aircraft and 8 to 10 percent in terms of revenue-passenger-miles. NASA's own task report (Reference 7), which formed the framework for the Aircraft Energy Efficiency Program, predicted growth of 4 percent through the early 1990s in terms of revenue-passenger-miles.

Review of the available data made it apparent that there were no forecasts completely covering the time period of interest. A review of historical data showed that the growth in numbers of aircraft had been proportionately smaller than the growth in revenue-passenger-miles. The difference is due to several factors -- primarily the increase in aircraft productivity and the fact that as aircraft capacities have increased, there has been less than a one-to-one replacement ratio. Because it more directly serves the purposes of this study to determine aviation scenarios and benefits in terms of numbers of aircraft instead of revenue-passenger-miles, a growth forecast of numbers of aircraft was developed by using a growth rate somewhat lower than that predicted for revenue-passenger-miles. The forecast considered aircraft retirements, purchases of new aircraft with old technology, purchases of new aircraft with new technology, and the production capacity of four major international airframe manufacturers.

The product of this development, Table 2-1 shows the cumulative number of active aircraft by the different production categories, as well as the number of aircraft produced each two years. The following forecast considerations were used in deriving the data in Table 1:

1. The growth rate will be 1 percent until 1990 and then increase to 3 percent per year. The slow growth for the first ten years is anticipated because of the current slump in the world economy, which will prompt airlines to delay purchasing new aircraft and attempt instead to increase the average load factor. (Reference 1)

2. Aircraft purchases for the next decade will be predominantly pre-1980-technology aircraft (B727, B737, B747, DC-9/80, DC-10, L1011, A300), because of slow growth and the desire on the part of the manufacturers to offer derivative aircraft instead of totally new aircraft. (References 2, 3, 4)

3. Most first-generation aircraft (B707, B720, DC-8, CV880 and 990, B727-100, and DC-9-10) will be retired by 1990; most second-generation aircraft (B737-200, B727-200, DC9-30, BAC-111) will be retired by 2000. The first-generation aircraft will be retired by 1990 because of economics, relative inefficiency of airframes and engines compared with those of later aircraft, and old age. The second-generation aircraft will be retired by 2000 for the same reasons, although the primary reason will be old age. (Reference 6)

4. New aircraft built with pre-1980 technology will have an average lifespan of 16 years compared with the 12 to 15 years currently experienced. Because of economics (i.e., more expensive airframes and low profits), the airlines are flying aircraft longer and refurbishing them. The trend recently has been to fly aircraft more toward the fifteenth year of the spectrum than to the tenth or twelfth year. The airlines have indicated a desire for longer life spans in their aircraft. (References 5, 6)

5. New aircraft built with post-1980 technology, such as the B-767/757, will have an average life span of 18 years up to the year 2000, and 20 years thereafter. Advances in active controls and

Table 2-1. FORECAST AIRCRAFT PRODUCTION

Year	New Pre-1980 Aircraft* (Cumulative)	New Post-1980 Aircraft (Cumulative)	Existing Pre-1980 Aircraft**	Total Aircraft	Aircraft Retired in Preceding Two Years	Total Aircraft in Preceding Two Years	Pre-1980 Aircraft Produced in Preceding Two Years	Post-1980 Aircraft Produced in Preceding Two Years
1980	0	0	5,800	5,800	-	-	-	-
1982	825	25	5,250	6,100	550	850	825	25
1984	1,525	225	4,675	6,425	575	900	700	200
1986	2,025	725	4,100	6,850	575	1,000	500	500
1988	2,250	1,500	3,550	7,300	550	1,000	225	775
1990	2,400	2,350	3,000	7,750	550	1,000	150	850
1992	2,525	3,325	2,250	8,100	750	1,100	125	975
1994	2,575	4,375	1,500	8,450	750	1,100	50	1,050
1996	2,600	5,450	750	8,800	750	1,100	25	1,075
1998	2,625	6,625	25	9,250	750	1,200	25	1,175
2000	1,800	7,800	0	9,600	850	1,200	-	1,200
2002	1,100	8,800	0	9,900	900	1,200	-	1,200
2004	600	9,700	0	10,300	1,000	1,400	-	1,400
2006	375	10,325	0	10,700	1,000	1,400	-	1,400
2008	225	10,875	0	11,100	1,000	1,400	-	1,400
2010	75	11,300	0	11,375	1,125	1,400	-	1,400
Totals					11,675	17,250	2,625	14,625

*Built after 1980 with pre-1980 technology.
**Built prior to 1980.

composite materials will enable aircraft to fly longer because of reduced fatigue and flight stresses. Moreover, the ease of updating flight avionics with revised software will prolong the useful life spans of most aircraft.

Figure 2-1 is the result of plotting the number of aircraft from Table 2-1 by year for the different categories of aircraft and the total aircraft. Although there is a significant difference in the assumed growth rates between the periods 1980-1990 and 1990-2010, the plot of total aircraft is nearly linear, with only a slight bend at 1990. This is probably due to three factors: (1) the retirement rate for existing pre-1980-technology aircraft, (2) the purchase rate for new pre-1980-technology aircraft, and (3) the manufacturing capacity of the airframe manufacturers. The four major international airframe manufacturers are limited to a maximum of 750 airframes per year because of capital investment limitations. However, the current rate of production is about 400 to 425 aircraft per year, owing primarily to slackened demand and to supply problems associated with long lead times for materials. According to the manufacturers (Reference 6), these problems can be resolved with time, although there do not appear to be any plans to expand capacity beyond the current limits.

2.3 AIRCRAFT TYPES

Once the growth projections were developed, aircraft lifetimes and predicted retirements were examined to determine when new aircraft would be introduced. Figure 2-2 shows the projected lifetimes of current aircraft and derivatives, and the expected introduction dates for new-technology aircraft. The DC9/BAC-111 listed are the advanced versions just now entering production, while the B737/A300B2 classes do not include advanced derivatives for the aircraft that have been discussed but are not firm commitments. The classes of aircraft are numbered within each range category in chronological order, with some overlap of the aircraft being replaced. For example, from Figure 2-2, the SR1 aircraft, which will be a follow-on to the B737/A300B2-type aircraft, is expected to be introduced in 1987; it will compete with the DC-9/BAC-111-type aircraft until the SR2, follow-on to the SR1, is introduced in 1995. Thus, for the short-range aircraft, there is considerable overlap between the different classes of aircraft, primarily because the recent derivatives of the DC-9/BAC-111 aircraft are delaying introduction of new aircraft.

Significant advances in aircraft technology can often "speed up" the expected introduction of new aircraft. The introduction of the four-engine jet transport in 1958 was a significant jump in technology just a few years after introduction of the "latest" reciprocating-engine aircraft. The wide-body aircraft introduced in 1969 represented a significant advance over existing aircraft. Historically, significant-advancement craft designs have been introduced approximately every 12 years, with shorter-range aircraft being introduced in the intervening time. This trend will probably continue for the next 30 years, with two exceptions. The availability of mature technology to support both active and passive laminar-flow control aircraft will permit such aircraft to be introduced earlier than the 12-year cycle would

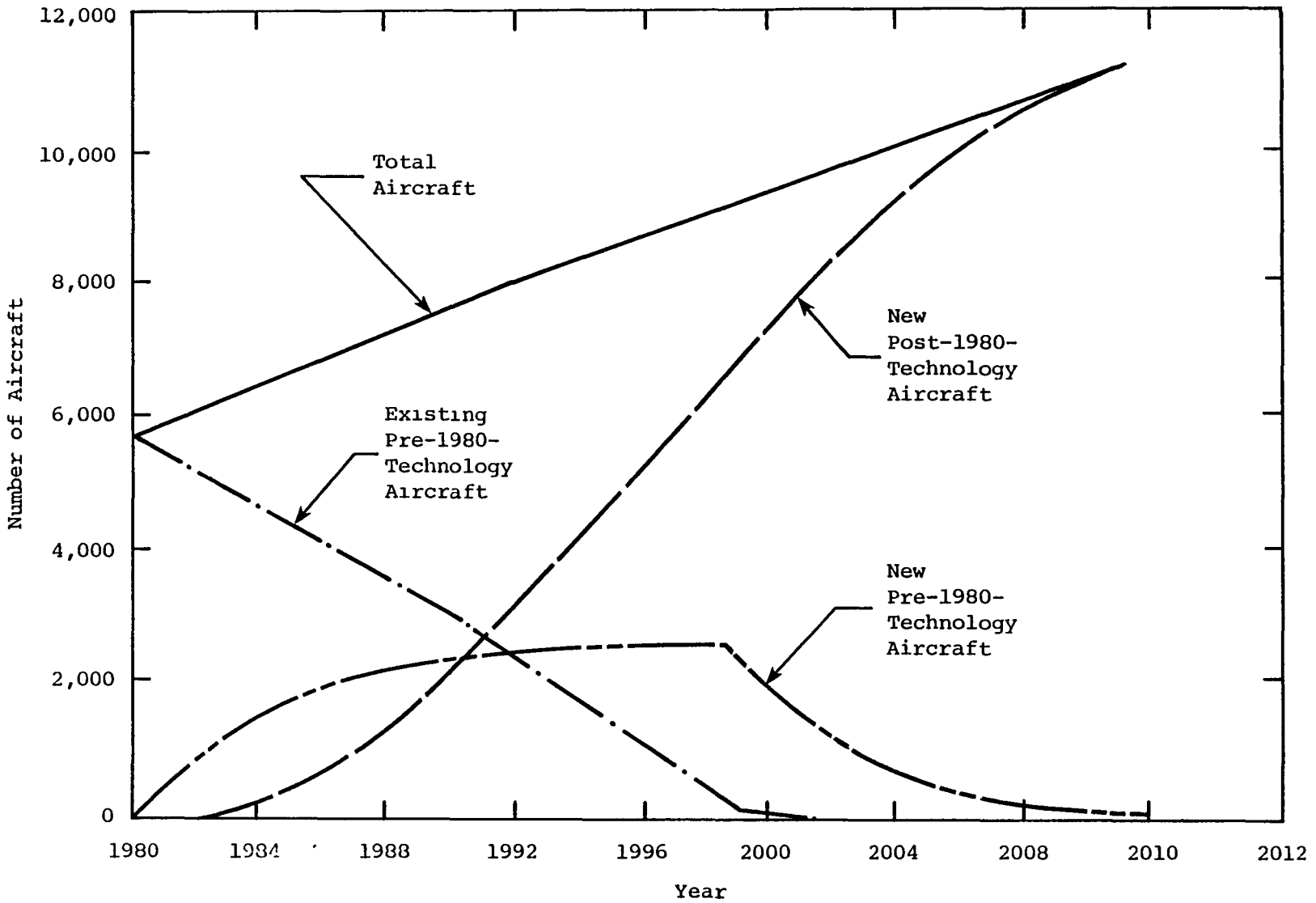

Figure 2-1. CIVIL AVIATION FLEET GROWTH TREND

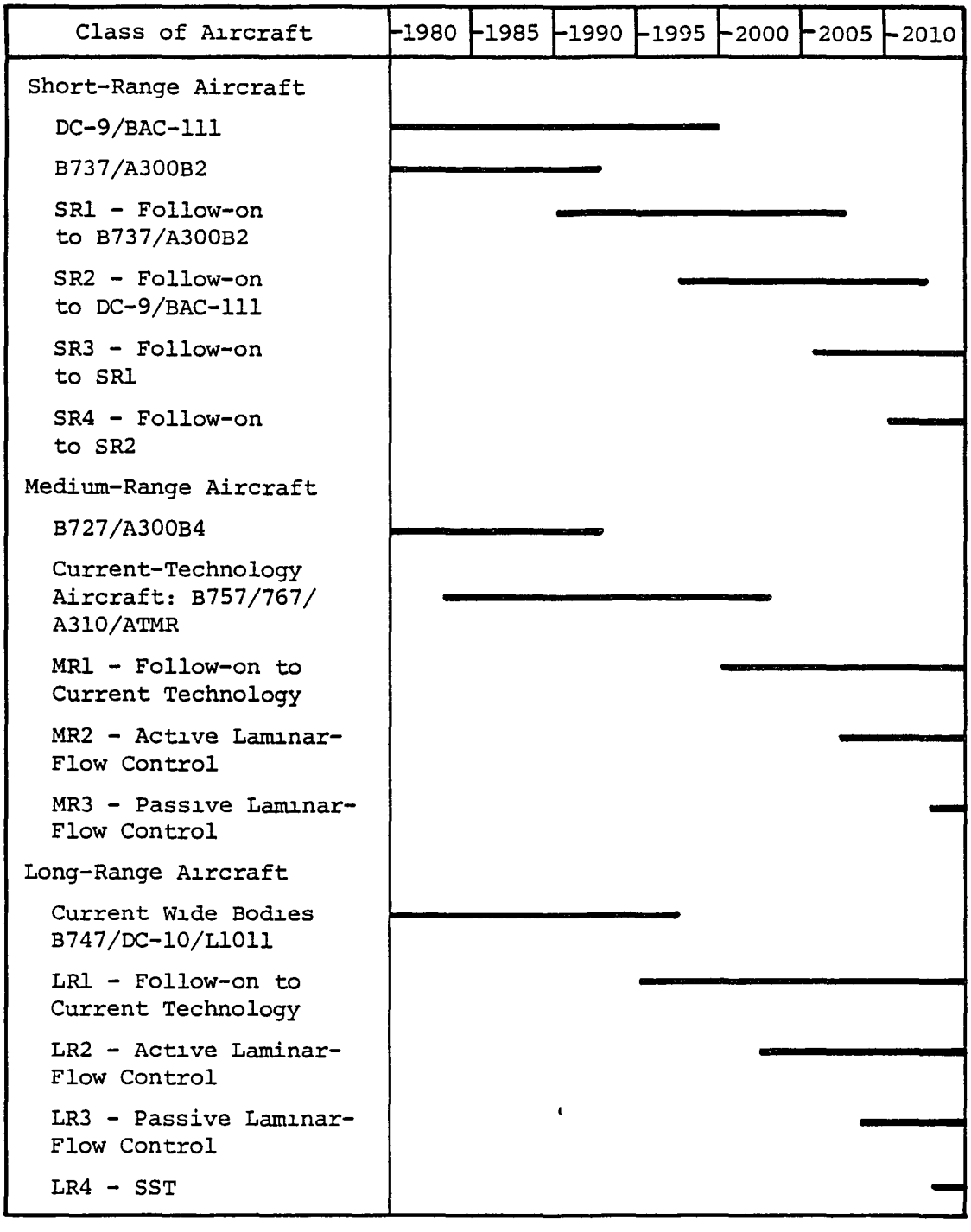

Figure 2-2. PROJECTED NEW AIRCRAFT INTRODUCTION DATES AND LIFETIMES

indicate. The significant improvement in operating economics associated with the technology encourages early introduction of aircraft with laminar-flow capability. Similarly, the supersonic transport, LR4, will be introduced shortly after the LR3 because of its unique performance, providing very-long-range, high-speed transportation.

2.4 TECHNOLOGY FORECASTS

If the predicted types of aircraft are known, the classes of technology and the level of achievement can be predicted for each type. Matching technologies with types of aircraft serves two functions: (1) it permits an accurate description of the aviation environment for use in developing the aviation scenarios, and (2) it permits development of a baseline against which the concepts to be developed in Task 2 can be evaluated. The degree of improvement above this baseline will be the basis for determining the benefits of avionics, controls, and human-factors concepts.

Table 2-2 is a technology matrix matching the predicted types of aircraft with the classes of technology predicted to be available to aircraft manufacturers and airlines during the next 30 years. The values presented in Table 2-2 represent the level of potential use of a particular technology. For example, for aircraft SR1, composite materials will be used in 30 percent of the airframe structure; 30 percent of the controls will be converted to active controls; 30 percent of the auxiliary systems will be converted from hydraulic, mechanical, or pneumatic to electric/electronic; 30 percent of the monitoring of aircraft systems operation, normally monitored visually by the flight crew, will be automated; 30 percent of the systems that will eventually make up the digital/electronic flight deck will be in place; 10 of the electromechanical engine control functions will be converted to electronic control; the engines will be 12 percent more fuel-efficient than comparable 1980 engines.

Active-controls technology involves the application of electronics to flight control systems to produce neutral or negative static stability and reduce wing loads. The use of active controls on transport aircraft is not limited to ailerons, but includes horizontal and vertical stabilizers, flaperons, spoilers, slats, and flaps. These devices can be used in a number of load-reduction techniques, including ride smoothing, flutter suppression, maneuver, gust, and general load alleviation and relaxed static stability. All of these applications generally result in weight reductions -- because reduced stress on the airframe reduces the amount of structural material needed to resist stresses -- and the synergistic effects of smaller control surfaces, which also produce a weight reduction. It appears that initially most aircraft will have triple or quadruple redundant systems because of the extremely high reliability requirement of 1×10^{-9} failures per flight hour (References 27 and 39) necessary for aircraft to fly with relaxed static stability. As the reliability of electronic systems improves, and fault-tolerant microprocessors are proven, the number of systems required will be reduced until the ultimate goal of a single system is reached.

Table 2-2. TECHNOLOGY MATRIX

Class of Technology	Level of Potential Use by Aircraft Type										
	1990 SR1	LR1	1997 SR2	2000 MR1	LR2	2006 SR3	MR2	LR3	SR4	MR3	LR4
Composite Materials	30%	40%	40%	40%	60%	60%	60%	75%	75%	75%	50%
Active Controls	30%	50%	50%	50%	70%	70%	70%	80%	80%	80%	80%
All-Electric Systems	30%	40%	50%	50%	50%	60%	60%	60%	75%	75%	75%
Laminar-Flow Control	-	-	-	-	A	-	A	P	-	P	-
Propfan	-	-	-	-	-	X	-	-	X	-	-
Variable-Cycle Engine	-	-	-	-	-	-	-	-	-	-	X
System Monitoring	30%	30%	50%	50%	50%	75%	75%	75%	80%	80%	80%
Self-Adjusting Wing	-	-	-	-	-	-	-	X	X	X	-
Digital/Electronic Flight Deck	30%	35%	55%	60%	75%	75%	80%	80%	90%	100%	100%
Electronic Engine Controls	10	13	13	16	16	18	18	20	20	20	20
New Conventional Airfoils	-	-	-	X	-	X	-	-	X	-	X
Fuel-Efficient Engines Compared with 1980	12%	12%	15%	15%	18%	25%	20%	23%	30%	28%	40%

*A - Active; P - Passive; X - Aircraft uses this technology.

All-electronic flight systems are an area recently studied (Reference 21) in an effort to reduce the weight of auxiliary systems on aircraft. The main advantage to eliminating the many mechanical, hydraulic, and pneumatic systems is the weight saving achieved by replacement with light-weight electrical and electronic systems. Possible applications considered include closed-cycle recirculating environmental control system (i.e., no bleed air), electric brakes, electric operation of high-lift devices, electrically operated landing gear, electric thermal deicing, higher-voltage electrical system, and stored-energy auxiliary power units.

The application of laminar-flow control techniques to transport air-aircraft will produce significant improvements in operational economy. The initial application will be an active wing on long-range aircraft in situations where route structure could produce a 20 to 40 percent reduction in operating costs (References 8, 11, 14, 15, 26). The wing will have extensive plumbing and a control system, as well as a complex sensor system to detect the location of the transition point. Natural laminar-flow airfoils, or passive laminar-flow control, should be introduced a few years after the active systems. The natural laminar-flow airfoils will rely on their shape to maintain laminar flow over 70 percent of the airfoil surface. In addition, the use of a self-adjusting wing, which automatically changes shape to maintain an optimum profile, will simplify maintaining laminar flow over the wing during different cruise conditions while still retaining the capability for turbulent flow when necessary. The self-adjusting wing will enable aircraft to maintain the optimum airfoil shape throughout the flight regime from takeoff to landing.

New conventional airfoil shapes are expected to provide further improvement. Most new airfoils, although improvements over previous jet airfoils, are still compromises with the ideal airfoil shape because of strength requirements of wings. As composite-materials technology matures and experiences wider use, it will be possible to manufacture airfoils that are considerably closer to the ideal shape.

Microprocessors can be used to decrease the flight crew's workload by automating the display of most system operation indicators so that the indicators are available upon demand or are displayed automatically in an emergency. The level of automation is shown in Table 2-2.

The number of engine control functions that can be converted to digital electronics is also shown in Table 2-2. To develop the more fuel-efficient engines needed for the next 30 years, more engine functions must be controlled more precisely to provide for optimum performance. New techniques being explored by the engine manufacturers include active control of blade clearances, self-adjusting optimized inlets, variable fan and compressor geometry, and more accurate fuel-flow metering.

Table 2-3 lists the advanced digital/electronic systems expected to be available on the flight deck of future aircraft. Most of these systems are currently planned for implementation, and extensive research and development efforts are under way in support of them; the other are just entering the research and development phase. The number of systems available for use is

Table 2-3. DIGITAL/ELECTRONIC FLIGHT DECK SYSTEMS*		
System	Initial Operation	General Use
Beacon Collision Avoidance System (BCAS)	1983	1988
Discrete Address Beacon System (DABS)	1984	1990
Enhanced Terminal Information Service (ETIS)	1985	1992
Automatic Traffic Advisory Resolution Service (ATARS)	1986	1992
Multifunction Switches/Panels	1987	1995
Microwave Landing System (MLS)	1987	2000
Heads Up Display (HUD)	1987	2000
Cockpit Display of Weather Information (CDWI)	1988	1993
Cockpit Display of Traffic Information (CDTI)	1988	1995
4-D RNAV	1990	2000
Speech Synthesis and Recognition	1995	2005
Color Flat Panel Displays	1998	2005
Category III c Autoland	1995	2005
Civilian Use of Global Positioning System (GPS)	2000	2010

*Reference 10.

shown in Table 2-2 as a percentage of the total number of systems. As systems become available, they will be introduced at varying rates, depending on the economic benefits derived from the introduction of each system.

With the information from Figure 2-2 and Table 2-2, Table 2-4 was developed to describe the major items of aircraft performance. The design characteristics shown are predominantly related to airframe and range, inasmuch as these seem to be the most important parameters of interest in determining the costs and benefits of aircraft. The three measures of efficiency at the bottom of the table -- fuel efficiency, airframe efficiency, and fuel weight per mile -- are commonly used in the aircraft industry as a measure of design efficiency. Fuel efficiency is measured in terms of seat-miles per pound of fuel for maximum range in nautical miles; it is approximately eight to nine seat-miles per pound for current aircraft. Airframe efficiency, expressed as maximum payload divided by operating equipment weight, is used by airframe manufacturers to measure the efficiency of their designs. Fuel weight per mile measures how efficiently an airframe engine combination is designed.

The values in Table 2-4 were derived by using the predicted technology levels from Table 2-2 and the forecast ratios of aircraft and structural

Table 2-4. NEW AIRCRAFT DESIGN CHARACTERISTICS

Characteristic	Characteristic Values by Aircraft Type										
	SR1	LR1	SR2	MR1	LR2	SR3	MR2	LR3	SR4	MR3	LR4
Introduction Date	1987	1990	1995	1997	2000	2003	2005	2007	2008	2010	2010
Design Range (nautical mi)	2,200	5,000	2,000	2,500	5,500	1,700	2,500	6,500	1,700	2,500	7,500
Max L/D	20	22	20	22	30	22	20	35	22	35	12
Sfc at Cruise	0.66	0.62	0.63	0.61	0.58	0.45	0.58	0.50	0.42	0.52	1.25
Gross Takeoff Weight (1,000s of lb)	125	360	123	240	335	125	261	385	125	244	490
Operating Equipment Weight (1,000s of lb)	69	225	66	148	200	70	165	240	65	155	250
Max Fuel (1,000s of lb)	30	120	28	40	72	15	35	92	15	22	265
Max Zero Fuel Weight (1,000s of lb)	109	305	106	213	280	115	235	330	110	225	310
Max Payload (1,000s of lb)	40	80	45	65	80	45	70	90	45	70	60
Max Range (nautical mi)	3,100	7,000	3,150	3,850	7,300	3,000	4,500	9,800	3,200	4,000	10,000
Number of Passengers	150	300	150	240	300	175	275	350	175	275	275
Cruise Speed (knots)	435	465	435	450	460	450	460	450	460	460	1,460
at Altitude (1,000s of ft)	31	35	31	35	40	29	40	45	27	45	60
Fuel Efficiency (seat-miles per lb fuel)	15.5	17.5	16.9	23.1	30.4	35.0	35.4	37.3	37.3	50.0	10.4
Airframe Efficiency (payload per OEW)	0.58	0.36	0.68	0.44	0.40	0.64	0.42	0.38	0.69	0.45	0.24
Fuel Weight per Mile (pounds)	9.7	17.1	8.9	10.4	9.9	5.0	7.8	9.4	4.7	5.5	26.5

weights. The ratios of structural component weight to gross takeoff weight were developed from data in References 22, 36, and 37. Comparisons between similar aircraft show the steady improvements in airframe design that accompany the improvements in capabilities. Design characteristics and the predicted growth trends in Table 2-2 provide the essential elements for developing the aviation scenarios. These scenarios will form the baseline for defining the problem areas in aviation, determining how to solve these problems, and measuring the degree of success.

2.5 AVIATION SCENARIOS

With the civil aviation growth forecasts (Subtask 1A) and aircraft technology forecasts (Subtask 1B) completed, the tools were available to project the civil aviation environment over the next 30 years. The projections through the year 2010 will describe the numbers and types of aircraft and the technologies that will be available to build and operate aircraft. Table 2-5 presents these descriptions for the years 1990, 2000, and 2010. Over the next 30 years, 17,250 aircraft will be built, with 85 percent of these using technology under development in 1980. The scenarios in Table 2-5 will be further examined in Chapter Three to identify the goals of civil aviation and the capabilities that will be needed to solve future problems. Potential controls and guidance concepts were evaluated against these baseline scenarios.

Improvements to the different aircraft will depend on potential use and the practical limits of such use. Although building an airframe totally from composite materials would provide a 30 percent weight reduction (Reference 34), there are several parts on an aircraft that would probably continue to be fabricated from metal to meet stress requirements. These parts would amount to 15 to 20 percent of the airframe; thus an airframe that was 80 percent composite materials would be at 80 percent of potential, although it would be near the practical limit for the foreseeable future. Similar comments apply to the use of active controls and the conversion of auxiliary aircraft systems to electrical and electronic systems.

The percentage breakdown by aircraft type (SR, MR, LR) is based on the current distribution of aircraft populations of each type, applied to the total number of aircraft projected for each decade. Although the distribution of ridership will change, it will be absorbed more by changes in aircraft seating capacity (mission optimization) than by changes in the percentage of aircraft. This is a further demonstration of the fact that evolutionary rather than revolutionary changes in the airline industry are predicted.

2.5.1 The 1990 Aviation Scenario

The 1980s will be marked by slow growth for the aviation industry, the growth rate averaging 1 percent per year. Almost 5,000 aircraft will be produced, with production evenly divided between pre-1980-technology aircraft and post-1980-technology aircraft. Although there will be a net increase

Table 2-5 AVIATION SCENARIOS

Scenario Factors	1990	2000	2010
Total Number of Aircraft	7,750	9,600	11,375
Number of New Pre-1980-Technology Aircraft	2,400	1,800	75
Number of New Post-1980-Technology Aircraft	2,350	7,800	11,300
Number of Old Pre-1980-Technology Aircraft	3,000	0	0
Number of Aircraft by Range			
Short Range	2,350	2,900	3,400
Medium Range	3,000	3,650	4,200
Long Range	2,400	3,050	3,765
Supersonic Transport	0	0	10
Composite Materials			
Maximum Usage	30% of potential	60% of potential	75% of potential
Fleet Average Usage	8% of potential	35% of potential	56% of potential
Active Controls			
Maximum Usage	30% of potential	70% of potential	80% of potential
Fleet Average Usage	6% of potential	38% of potential	65% of potential
Auxiliary Systems Converted to Electronic/Digital			
Maximum Usage	30% of potential	50% of potential	75% of potential
Fleet Average Usage	3% of potential	25% of potential	55% of potential
Level of Aircraft System Monitoring Automated	30%	50%	80%
Propulsion Efficiency Improvement vs 1980 Levels			
Maximum Improvement	12%	18%	30%
Fleet Average Improvement	6%	11%	20%
Number of Engine Control Functions Converted to Electronic/Digital	7 to 10	10 to 16	16 to 20
Fuel Costs per Gallon in 1980 Dollars (1980 = $1 05)	$1 05	$1.10	$1.15
Fleet Mix	SR1 2% B767/B757/A310 28% DC9-80/B737-300/ B747/DC10 31% B727-100/DC-8/etc. 39%	SR1, LR1, SR2, MR1 80% LR2. 1% DC9-80/B747, B727: 19%	SR1, LR1 retired SR4 2% SR2 (being retired) 10% LR4 0.1% LR3, MR3. 10% SR3, LR2, MR1, MR2 78%
Typical Flight Deck Electronics	DABS, ETIS, ATARS, 4D-RNAV, BCAS, CDWI, CDTI, HUD, Multifunction Switches/ Panels	DABS, CDTI, ATARS, CDWI, BCAS, MLS, ETIS, HUD, 4D-RNAV, Multi-function Switches/Panels	DABS CDTI, ATARS CDTI, BCAS MLS, ETIS, 4D-RNAV HUD, Color Flat Panels, Civilian GPS, Speech Recognition and Synthesis, Category III c Autoland, Multi-function Switches/Panels
Air Traffic Control System Capability	Able to Accommodate Above-Listed Systems	Above-Listed Electronics Required	Above-Listed Electronics Required
Noise Levels Vs FAR Part 36	Equal	-3 dB	-6 dB

of 2,000 aircraft, the only "new" aircraft introduced during this decade will be the SR1 (beginning in 1987). The new-technology aircraft introduced in 1982 and 1983 will use technology developed before 1980, although for the purposes of this study they are considered as post-1980-technology aircraft.

The typical aircraft of this decade will use a variety of new technologies, most in the early stages of maturity. Composite materials, such as boron or graphite epoxies, will be used for up to 30 percent of the potential structure -- mainly for secondary structures such as landing gear doors, access panels, spoilers, and floors -- and will have some initial use in vertical and horizontal stabilizers. Use of active controls will just be starting, the primary use being ailerons and elevators to alleviate gust and maneuver loads and smooth the ride for passengers. Conversion of aircraft auxiliary systems from hydraulic or pneumatic to electrical or electronic systems will reach the point where 30 percent of the systems have been converted; the most significant conversion will be fly-by-wire electronic flight controls for use with active controls.

While the airframe has been undergoing improvements, the engines and engine controls will be subject to technological improvements also. Engine efficiency for the decade will average 6 percent better in terms of specific fuel consumption compared with that of a 1980 engine. Beginning with SR1, fuel usage should improve by 12 percent as a result of the NASA Energy Efficient Engine Program started in 1975. At the same time, most of the primary engine control functions will be converted from electromechanical and hybrid control units to all-digital controls, with about one-half of the functions remaining to be converted.

Many of the air traffic control devices on which development was started in the 1970s will become operational during this decade, along with some of the newer electronic navigation systems. As Table 2-5 shows, DABS, ATARS, BCAS, and ETIS will be operational and widely used in the air traffic control system; CDTI and CDWI will have just been introduced into the system with the initial purchases of the system equipment and aircraft.

2.5.2 The 2000 Aviation Scenario

In the 1990s the growth rate will increase from the 1 percent of the 1980s to 3 percent. Of the 5,700 aircraft to be produced during this decade, only 225 (4 percent) will have pre-1980 technology, although 1,800 aircraft built with pre-1980 technology will still be flying. The net increase will be 1,850 aircraft, and the impact will be more significant than in the previous decade because almost all of the aircraft produced will have the major economic improvements of post-1980 technology. All the old pre-1980-technology aircraft will have been retired and many of the pre-1980 technology aircraft purchased after 1980 will be reaching retirement. The SR1, SR2, LR1, and MR1 aircraft will all be operating. The LR2 aircraft, with active laminar-flow control, will have just been introduced into production. This new aircraft should have a major impact on aircraft operating economics because of the significant improvements in performance possible with laminar-flow airfoils.

New technologies being applied during this decade will be basically the same as during the 1980s, although more mature. The average aircraft will use composite materials in approximately 35 percent of the airframe structure in the quest for a lighter-weight, fuel-efficient aircraft. Active controls will be used for 38 percent of the control surface systems, with the primary areas of emphasis being control augmentation, improvement of ride quality, maneuver and gust loading, lessening of fatigue loads, and flutter suppression. Nearly one-half of the aircraft monitoring systems will be automated.

Propulsion systems and their associated controls will also improve. Using the NASA Energy Efficient Engine Program as a baseline, the engine manufacturers will reduce fuel usage of engines by an additional 5 percent over that of the typical 1990 engine. Most of this improvement will come from better engine controls, with two-thirds of the engine controls converting from electromechanical to electronic. Greater control accuracy will be possible, and some control functions not previously possible will be available.

The electronic systems that interface with the air traffic control system, having been under development since the 1970s, will be fully developed and in use by most aircraft. Some, such as 4D-RNAV, HUD, and MLS, will finally be reaching a level of general use, while others will have been in general use for some time and will be undergoing improvements. At the same time the air traffic control system will be improved and updated so that it can provide the services required to utilize the new avionics.

2.5.3 The 2010 Aviation Scenario

Growth in civil aviation will continue at 3 percent during the first decade of the 21st century. Nearly 9,000 aircraft will be produced during this third decade, while fewer than that will be retired producing a net increase of 1,775 aircraft. All the pre-1980-technology aircraft will be retired by now, along with the first generation of the post-1980-technology aircraft. The addition of the retired aircraft to the supplemental and charter airlines should improve the economic outlook for these airlines.

The ten years between 2000 and 2010 will be years of substantial change for civil aviation because of the number of new and significant improvements in aircraft technology. In addition to the LR2 aircraft with active laminar-flow control, an MR2 aircraft will be introduced with active laminar-flow control, followed by new aircraft using passive laminar-flow control (natural laminar-flow airfoils). The two short-range aircraft introduced will utilize the high-speed turboprop, or propfan, and a very-long-range supersonic transport will be introduced to provide fast, economical service over long distances. The concept of the self-adjusting wing will be introduced on the LR3, MR3, and SR4 aircraft in an effort to extract maximum economic performance from existing technologies.

Airframe technologies developed during the 1980s will reach maturity during this decade. The average airframe will use composite materials in nearly 60 percent of the structure, with the remaining components being the primary load-carrying structures. Similarly, the use of active-controls technology will reach the 65 percent level, with the exploitation of aircraft center-of-gravity control and some static stability relaxation. Further expansion in these two fields will come with increased experience, confidence, and reliability. Conversion of aircraft auxiliary systems from hydraulic and pneumatic to electric/electronic will average 65 percent of the systems as further improvements await development of alternative energy sources to replace the auxiliary power unit. The automation of aircraft system monitoring will reach 80 percent, with further gains awaiting the reliability and confidence achieved through experience before reaching the fully automated state.

Propulsion systems and their control units will probably be approaching the physical limits of the technology for conventional turbofan and turboprop engines. The turbofan engines will reach a level of about 28 percent improvement in fuel efficiency compared with 1980 engines, and a 30 percent improvement in turboprop efficiency compared with 1980 engines. The number of engine control functions converted to digital/electronic will be 20, the maximum that can be accommodated without a significant impact on engine complexity or maintainability.

The electronic systems available to the flight crew and the air traffic control system will be extensive and complex. All of the electronic systems shown in Table 2-3 will be fully developed and available to civil aviation and the air traffic control system; true all-weather flight operations will be a standard procedure. As these electronic systems gain experience and improved reliability, they will be developed for general aviation and other nonscheduled aviation uses. The number of aircraft able to use many, or most, of the services of the air traffic control system will increase significantly, while remaining within the capability of the air traffic control system.

2.6 ANALYTICAL RELATIONSHIPS

2.6.1 The Need for Analytical Relationships

A critical step in the development and analysis of system concepts is to identify the relationships between aircraft performance parameters and each of the elements that make up the parameter; for instance, the relationship of overall aircraft operating cost to fuel use. Such relationships are necessary for quantitative assessment of the impact of a specific system concept. For example, we consider the goal of reducing fuel consumption. It is necessary first to know the factors that contribute to fuel consumption and their quantitative relationships. With this information, a system concept that will, say, reduce aircraft weight by 1 percent can be analyzed in terms of its impact on fuel consumption and hence on total operating cost. Thus one important use of analytical relationships is in quantifying the benefits of system concepts.

A second use for the analytical relationships to be presented in this chapter is in identifying "leverage" points in the various aircraft operating parameters -- that is, factors that have the strongest influence on a particular improvement area. For example, fuel use has a much greater influence on total operating cost than does upholstery cleaning. Thus a 1 percent reduction in fuel costs is much more desirable than a 1 percent reduction in upholstery cleaning costs. This is, of course, a trivial example, but it illustrates the need for leverage information: if we identify those factors which have the largest leverage, we can concentrate our efforts in areas offering the largest potential payoff.

2.6.2 Analytical Data

Three types of data on analytical relationships are presented in this chapter. Diagrams presented in "tree" format show the factors that constitute each operating parameter and the percentage breakdown of their relative contributions. Sensitivity diagrams are also presented to show the percentage change in parameter as a function of percentage change in each factor. Finally, where exact functional relationships are known, relationships are shown in equation form. The percentage trees will show at a glance the major factors in each area for leverage identification, while the sensitivity diagrams and analytical equations will give quantitative measures of system concept effectiveness. Examples of use of the data presented are given at the end of the chapter, together with a discussion of the overall analysis methodology.

2.6.3 Information Sources

A number of sources were used in obtaining data on the analytical relationships shown in this chapter. These include *A New Method for Estimating Current and Future Transport Aircraft Operating Economic,* by American Airlines (Reference 34); *Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations, 1977,* by the National Transportation Safety Board (Reference 29); *Aircraft Noise Reduction Technology: A Report by NASA to the Environmental Protection Agency for the Aircraft/Airport Noise Study* (Reference 32); and *Economic Analysis of Transportation Noise Abatement,* by Jon P. Nelson (Reference 33).

The American Airlines Study (Reference 34) was particularly useful because of its breakdown of aircraft operating costs and descriptions of the cost elements that contribute to those costs. By incorporating data from the Boeing Company, the study was able to examine industry averages instead of relying totally upon American Airlines data. As a result, for each of the cost areas examined in the study a parametric equation was developed to express operating costs in terms of aircraft design parameters. These parametric equations are useful as a planning and evaluation tool in addressing future aircraft from the aircraft operator's viewpoint.

The *Annual Review of Aircraft Accident Data* (Reference 29) reviews not only 1977, but also the previous nine years, to discern the accident trends for commercial aircraft. Accident data are presented for the

different categories of air carriers (scheduled, nonscheduled, supplemental, cargo) as well as the aircraft types involved in more than 90 percent of the accidents. The report includes a summary of the causes of all accidents during the period 1968 to 1977, as well as accident rates in terms of aircraft hours and departures. This information is useful in determining where the emphasis should be placed in safety-improvement efforts.

Aircraft Noise Reduction Technology (Reference 32) addressed the sources of aircraft noise, both engine and airframe, and what research was planned or under way to develop an understanding of the causes of noise on an aircraft. It contained some descriptions of the types of noise and the parts that contribute to engine noise, as well as a discussion of the component contributions to airframe noise.

Economic Analysis of Transportation Noise Abatement (Reference 33) describes how the aircraft noise levels set forth in Federal Aviation Regulation (FAR) Part 36 were derived, together with the impact of their implementation. It also addresses the economic impact of building quieter JT8D engines, the extent of noise reduction, and the economic benefits derived from quieter jet aircraft. The discussion of the jet aircraft noise cost/benefit analysis is particularly useful because it addresses how to determine the benefits of noise reduction.

2.6.4 Unit Values of Relationships

Analytical relationships must be expressed in terms of a unit. Operational costs were, of course, expressed in dollars, but the areas of safety and social acceptability did not lend themselves to the same treatment. There have been attempts to assign a dollar value to lives lost in accidents and to noise and air pollution. The dollar value of an accident has been equated to the cost of the accident itself, including the lost aircraft and lawsuits, plus the total projected lifetime earnings of those persons whose lives were lost. Values have been assigned to clean air and low noise on the basis of questionnaires distributed to persons in the affected area and of fees paid for the use of quiet/clean-air areas such as parks and other recreation areas.

Such measures may be useful in providing economic justification for pollution-control programs, but for the purposes of this study, we chose to use a more direct measure. Our safety values are stated in terms of total accidents, an accident being defined as any event in which passengers or aircrew are injured or the aircraft is damaged to the extent that it must be repaired.

In compiling data on social acceptability for the analytical relationships, we learned that definitive data were not available. The difficulty lies in not being able to quantify the benefits of factors such as clean air or lower noise levels, or the degree of contribution of specific factors. How much is clean air worth? Individuals in an affected area will give different answers to this question. Such difficulties in quantifying social benefits are not unique to this study. Exactly these same questions are being debated at the highest levels of government with

regard to environmental issues in general, and it is beyond the scope of this study to resolve such far-reaching issues. Instead, in cases for which numerical data are not available, we have listed noise and pollution sources in the order of their relative contributions to measured levels, without specifying their percentage contributions to social unacceptability.

2.6.5 Data Presentation

2.6.5.1 Percentage Trees

The percentage trees presented in Appendix A show the factors that contribute to costs, social acceptability, and safety.

Figure A-1 shows operating cost factors as a percentage of total dollar operating costs.

Figure A-2 shows the factors that contribute to safety problems as a percentage of total accidents during the ten-year period ending in 1977. Figure A-3 shows the same data broken down by flight phase.

Figure A-3 shows the factors that contribute to social acceptability. As discussed earlier, they are not ranked as to percentage contribution to social unacceptability, but are presented in the order of their contributions to measured levels.

2.6.5.2 Sensitivity Diagrams

This section presents sensitivity diagrams for the factors that influence operational cost and safety, showing percentage change in total factor as a function of percentage change in factor component. It should be noted that these graphs are unsigned; they apply equally to negative changes and positive changes.

Several graphs are required for fuel usage, reflecting the fact that the relationships change somewhat among the various aircraft postulated in the scenarios. Aircraft for which parameters differ by less than 5 percent are plotted together in the interest of clarity.

Fuel usage charts are presented as follows:

Figure	Aircraft
A-4	Short and Medium Range
A-5	Long Range
A-6	Supersonic Transport

Other cost elements are presented in Figures A-7 through A-12. Safety elements are presented in Figure A-13.

2.6.5.3 Equations

Fuel usage is an area for which there is an exact relationship between individual parameters and the total factor. Fuel usage is defined by the Breguet Range Equation (Reference 35) as

$$R = (L/D) \left(\frac{V}{C}\right) \ln \frac{W_{takeoff}}{W_{landing}}$$

where

R = range in nautical miles

L/D = lift-to-drag ratio (total drag)

V = cruise velocity, knots

C = specific fuel consumption (pounds of fuel/pounds of thrust)/hour

$W_{takeoff}$ = takeoff weight, pounds

$W_{landing}$ = landing weight, pounds

We solve for fuel weight, $W_{takeoff} - W_{landing}$:

$$W_{fuel} = W_{landing} \left[E^{\frac{R}{(L/D)\ (V/C)}} - 1 \right]$$

where W_{fuel} = fuel weight, pounds.

This relationship will give fuel required as a function of aircraft landing weight (aircraft + crew + passenger + cargo) and distance flown (R). (The lift-drag ratio, cruise speed, and specific fuel consumption are aircraft-specific parameters.) The relationship does not take into account climbs and descents. Its usefulness is in comparing system concepts that affect weight, L/D, cruise speed, and specific fuel consumption. By comparing different concepts over cruise route segments, differing impacts may be assessed.

2.7 EXAMPLES OF DATA USE

This section provides examples of the use of each of the three types of data presented in this chapter. The examples are for illustration only and do not represent actual system-concept values.

2.7.1 Percentage Tree Example

We consider the overall goal of enhancing the economic performance of aircraft. Figure A-1 shows that fuel usage is the largest element of operating costs. Thus a given percentage improvement in fuel use will have a greater impact on overall cost than the same percentage change in any other area. We have identified the cost factor with the most leverage. By ranking the different cost factors in declining order of percentage contribution, we obtain a ranking according to leverage.

An improvement area, then, is identified as "decrease fuel consumption" without, of course, affecting the number of passengers that can be carried. Following the percentage tree down, we see that aircraft weight is a major factor in fuel consumption. Thus a desired capability is "reduce aircraft weight." Sheet 2 of Figure A-1 breaks aircraft weight down into its various component parts. Using these data, we may wish to refine the desired capability to, say, "reduce landing gear weight," or "reduce wing weight."

Returning to Figure A-1, we see that maintenance is also a major cost element. The figure shows a breakdown of maintenance costs by area; the costs are dominated by propulsion system maintenance. Thus "reduce propulsion maintenance costs" is identified as a desired capability.

Returning once again to Figure A-1, we see that fuel servicing fees account for only 0.3 percent of operating expenses and thus have a low leverage value; even if all such costs could somehow be eliminated, the impact would be minimal. This area, then, is not a prime candidate for a desired capability.

2.7.2 Sensitivity Diagram Example

Figure A-5 shows the percentage change in fuel burn for a given distance flown as a function of percentage change in specific fuel consumption, aircraft landing weight, L/D, and cruise speed. For example, we consider a system concept that somehow effects a 25 percent improvement in L/D, such as might be achieved by a laminar-flow wing. Figure A-5 shows that the 25 percent improvement in L/D translates into a 22 percent improvement in fuel consumption.

2.7.3 Equation Example

The Breguet Range Equation is used to quantify the effects of changes in aircraft parameters on fuel use. We consider an aircraft flying a route segment of 1,000 nautical miles (R = 1,000) with the following parameters:

W = 225,000 pounds

L/D = 22

V = 468 knots

C = 0.62 pounds of thrust per pound of fuel per hour

The equation yields a fuel consumption value of 14,058 pounds for that segment. If the L/D could somehow be improved by 25 percent to 27.5, the equation would indicate a fuel burn of 11,177 pounds, an improvement of 2,881 pounds. The impact of changes in other factors can be computed in similar ways.

2.8 ACTIVE CONTROLS EXAMPLE

As a further example of the use of the data presented in this chapter, we consider the system concept of using active controls for wing-flutter suppression and gust-load alleviation. This is a system concept that is under active consideration for wide-body aircraft. In the proposed application, the active controls will allow the addition of about 5 feet of wing span without modification to the load-bearing wing box or other structural parts. This additional wing span increases the area and aspect ratio of the wing, enhancing the L/D, leading to a reduction in fuel consumption. Another way in which this system concept might be applied is to retain the same wing size but reduce the strength, and hence the weight, of the wing. The benefit of the weight reduction could be taken in reduced fuel burn or in extra payload capacity at the same rate of fuel burn.

Clearly, complex trade-offs are involved in making a choice between these alternatives, especially considering the "ripple" effect discussed earlier. The addition of wing area increases L/D, but it also increases aircraft weight, possibly requiring a heavier landing gear, larger tires, and possibly the strenghening of other components. On the other hand, the second alternative, weight reduction, might allow lighter landing gear and other structural parts. The data in this chapter and the cost models presented in Chapter Four can aid in evaluating these trade-offs. Figure A-6, for example, shows the relationship of L/D and aircraft weight to fuel usage. Estimates of L/D increases and weight decreases could be applied to this graph to determine which would have the larger impact. The cost-estimating models could then be used to determine the overall impact of the system concept on aircraft cost (as well as the cost of the control system itself, of course) to permit determining the most beneficial and cost-effective implementation of this system concept. It is precisely that process, for this and many other system concepts, that will be followed in subsequent tasks to produce a rank-ordering of concepts.

2.9 HIGH-PERFORMANCE MILITARY AIRCRAFT

The information in the preceding sections of this chapter was specific to the civil transport class of aircraft. High-performance military aircraft are also of interest. Such aircraft typically are the first to employ advanced controls and guidance concepts in their design. Thus, they represent the leading edge of technology.

As part of this study, we performed a qualitative assessment of the missions of those aircraft and identified the factors that influence their performance. The assessment can serve as a starting point for later in-depth studies of this class of aircraft.

The primary function of high-performance military aircraft is to deliver ordnance. The mission of all such aircraft is to deliver ordnance to a specified target or to support that delivery through such functions as electronic warfare and reconnaissance. Our analysis revealed six major elements of performance that determine the ability of high-performance aircraft to complete their mission: Aircraft aerodynamic performance, armament systems, survivability, turnaround capability, cost, and navigation/communication/identification capability. Each of these factors is in turn made up of a number of subelements, each of which contributes an increment of performance in the various areas.

A description of each of these elements is presented in Appendix B, along with their graphic presentation in tree form.

In order to be useful in the context of the project methodology, the contribution of the individual elements of the tree must be quantified. Although the present study addressed these factors in only a qualitative way, we were informed by knowledgeable sources that there is no clear consensus as to a relative ranking of these factors; all of the factors are important for mission completion. The relative importance of the various elements depends on the viewpoint of the person doing the ranking and on the phase of the mission being considered. For this reason, the percentage values for the performance elements shown in Appendix B are left blank. The user's own interpretation of the relative importance of the factors needs to be supplied. A first estimate might be to apply equal weighting to all of the six principal factors and then compute the individual contributions of the subordinate elements on the basis of that assumption.

2.10 SUMMARY

This chapter has presented information that relates changes in individual operating parameters to changes in overall aircraft operating performance. This information will be used in subsequent tasks to identify and analyze controls and guidance concepts.

CHAPTER THREE

AVIATION GOALS AND DESIRED IMPROVEMENT AREAS

The development of goals for civil aviation through the year 2010 and how those goals might be realized through the achievement of specific desired improvements are addressed in this chapter. This information can be used to identify where controls and guidance concepts can best be applied so as to address the most important needs of the aviation community and thus obtain the maximum benefit.

3.1 APPROACH

Aviation growth forecasts, aircraft technology trends, and the aviation scenarios were examined to define potential problem areas associated with future commercial transport operations. ARINC Research used the problem areas to establish aviation goals that must be met for civil aviation to remain a viable transportation system in the future. From these aviation goals a number of specific improvement areas were identified. Specific desired capabilities that might produce improvement in the various areas were then defined. Measurement parameters were assigned to permit quantitative evaluation of the degree to which a desired capability would alleviate a problem. The Goals, Improvement Areas and Desired Capabilities are summarized in Table 3-1.

3.2 PROBLEM AREAS

The three commercial aviation scenarios described in Chapter Two were used to identify problem areas that commercial aviation can be expected to encounter through the year 2010. The general problems identified, found to be common to all three scenarios, are shown in Table 3-2. The problems listed can be grouped in three major problem areas: operating costs, safety, and social acceptability.

3.2.1 Operating Costs

The first nine items in Table 3-1 are related to the operational aspects of aviation. Fuel and maintenance costs, reliability, and weather are problems encountered daily. Initial aircraft costs and the cost of avionics are problems that airline management must resolve on the basis of utilization and return-on-investment decisions. Flight crew workload is a problem which the flight crews encounter every day and in which

Table 3-1. GOALS, IMPROVEMENT AREAS AND DESIRED CAPABILITIES		
Problem Area/Goal	Improvement Area	Desired Capability
Reduce Operating Costs [3.3.1]		
	Fuel Usage [3.3.1.1]	Reduce Aircraft Weight Increase L/D Increase Engine Efficiency Improve Operational Fuel Efficiency Increase Cruise Speed Reduce Weight of Fuel Reduce Cost of Fuel
	Depreciation [3.3.1.2]	Reduce Initial Aircraft Price Extend Aircraft Service Life Increase Aircraft Utilization
	Maintenance [3.3.1.3]	Improve MTBF Reduce MTTR Improve Failure Prediction Improve Failure Detection Improve Troubleshooting Reduce Skills Levels
	Aircrew [3.3.1.4]	Increase Productivity Reduce Aircrew Size
	Aircraft Supply [3.3.1.5]	Reduce GSE Costs Reduce Terminal Facilities Costs Reduce Maintenance Facilities Costs Reduce Maintenance Equipment Costs
	Training [3.3.1.6]	Reduce Initial Training Costs Reduce Recurring Training Costs
	Aircraft Servicing [3.3.1.7]	Reduce Aircraft Cleaning Costs Reduce Aircraft Interior Preparation Costs Reduce Flight Preparation Costs
	Delays and Cancellations [3.3.1.8]	Reduce Departure Delays Reduce En Route Delays Reduce Arrival Delays Reduce Cancellations

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Table 3-2. AVIATION PROBLEMS		
Specific Problems	Problem Area	Improvement Area
1. Fuel Costs	Cost	Reduce fuel costs
2. Maintenance Costs		Reduce maintenance costs
3. Initial Aircraft Costs		Reduce aircraft costs
4. Reliability		Increase reliability
5. Avionics Costs		Reduce avionics costs
6. Weather		Reduce weather-related costs
7. Flight Crew Workload		Reduce flight crew workload
8. Airport Saturation		Reduce airport crowding
9. Flight Crew Costs		Reduce flight crew costs
10. Safety	Safety	Reduce accidents
11. Information Management		Enhance information management
12. Software Control		Implement software control
13. Noise	Social Acceptability	Reduce noise
14. Air Pollution		Reduce air pollution
15. Pilot Acceptance		Enhance pilot acceptance

management must strike a balance between underutilization and overwork in attempting to increase productivity. While airline planners are addressing the problem of flight crew workloads in a more complex air traffic control (ATC) system, they must also plan for future operations when many functions will become automated and flight crew proficiency in nonautomated situations will be a serious concern. A final operational problem is airport saturation; as air traffic grows, more airports will reach the limit of the number of aircraft that can be handled either by the ATC system or by the available airport terminal facilities. All of these problems are directly related to flight operations and are considered under the problem area of operational costs.

3.2.2 Safety

The next three problems listed in Table 3-1 are safety-related. Safety is a primary concern because of the chance of accidents whenever aircraft fly. Although there were no fatal accidents in 1980, the first such year since 1928 for the major airlines, there were still a number of nonfatal accidents (Reference 28), and the large number of reported and unreported near misses shows that the potential for disaster still exists. Reducing

the number of accidents and near misses will significantly reduce the potential for loss of life and property. Information management is also a safety concern because it affects the way information needed for appropriate decisions is presented to the flight crew. Presenting information in a haphazard and confusing manner, without inputs from all the data systems in the aircraft, significantly increases the potential for indecision or a wrong decision by the flight crew. Presenting information in a clear, concise, and readily understood manner will permit proper decisions.

The third safety-related problem concerns software control, the process of maintaining the identical sets of programming instructions in all microprocessors, as well as standardizing interfaces and data formats. As the number of microprocessors used on commercial transports increases during the next 30 years, so too will the software to control them. The development of fault-tolerant computers and reliance on airborne electronics to handle control situations automatically requires great emphasis on fault detection and fail-safe operation by these microprocessors. Although computerized control devices will be thoroughly checked and tested, hidden errors in the software could produce malfunctions that the designers failed to anticipate. Only through software control and thorough validation and verification of the software will the potential for this problem be adequately diminished.

3.2.3 Social Interaction

The last three problems listed in Table 3-1 are related to concerns of the American public about commercial aviation. The noise problem has been highlighted both by the public's annoyance with noise levels near airports and by engine and airframe designers' dissatisfaction with federally mandated noise levels and the design problems they create. As society strives for a quieter, more peaceful environment, there will be increased emphasis on reducing the noise level of civil aviation to make it more compatible with the environment. There will also be continued emphasis on improving the air pollution characteristics of aircraft.

3.2.4 Unique Problem Areas

The problems discussed in the preceding subsections were found not to constitute unique problems for the three aviation scenarios developed in Chapter Two. Private discussions with airframe manufacturers and published articles predict that there will be no exotic new aircraft designs over the next 30 years. The designs and improvements will be mostly evolutionary, the only possible exception being the development of laminar-flow aircraft. Although aircraft with laminar flow will offer significant improvements over aircraft with conventional or supercritical airfoils, they will still represent primarily an evolutionary development of a known technique. Supersonic or hypersonic transport or large-capacity V/STOL aircraft would be revolutionary because of the radically different circumstances associated with their operation. However, by the time they are developed and operational the civil air transport system will have advanced in sophistication to the point where the introduction of the aircraft will have little effect on the system.

Further, the economics of operating an airline will always constitute a problem regardless of the aviation scenario or types of aircraft. The FAA aviation forecasts (Reference 1) used the Wharton Long-Term Industry and Economic Forecasting Model, which assumes that there will be no long-term shortages of materials or supplies, but only a general increase in costs due to inflation. In addition, the model assumes that "noise and pollution standards will continue to be implemented, and there will be no new environmental or policy constraints on aviation" (Reference 1). Thus it appears that the economic and social problems that airlines must contend with today will continue to exist in the future.

Finally, the primary problem is, and will continue to be, fuel costs. The FAA forecast and the supporting Wharton economic model assume that aviation fuel will be available, with only occasional spot shortages, and that the cost of fuel will act to ration this commodity among users.

Thus it appears that there will be no unique problems within the next 30 years. Although a new supersonic transport will become operational in the year 2010, the air traffic control system will be developed to the point where it can support this new type of aircraft.

3.2.5 Relationship of Problem Areas To Aviation Goals

Each of the three major problem areas discussed above is directly related to a specific aviation goal. The problem of operating costs, the first major problem area, is restated as the goal of reducing operating costs. Safety, the second major problem area, is restated as the goal of improving safety. Interaction with society, the third problem area, becomes the goal of enhancing social acceptability.

3.3 IMPROVEMENT AREAS

The aviation goals were examined to determine potential improvement areas -- i.e., specific factors that constrain performance in a particular area were identified. The improvement areas were then interpreted as measurable desired capabilities to determine the benefits achievable through the application of controls and guidance technology.

Under the goal of reducing operational costs there are 12 improvement areas and 31 desired capabilities. Safety as a goal has 5 improvement areas and 17 desired capabilities, and the enhancement of social acceptability has 6 improvement areas and 17 desired capabilities.

3.3.1 Reduce Operating Costs

3.3.1.1 Fuel Usage

Fuel cost, the major element of aircraft operating cost, is the first improvement area under the goal of reducing operating costs. Seven

desired capabilities are associated with this reduction. The first is a reduction in aircraft weight; if aircraft weight is reduced, less fuel will be used to fly a given route.

The second desired capability is an increase in the lift-to-drag ratio (L/D), which will increase the range of an aircraft or, conversely, permit flight to the same range with less fuel.

The third desired capability is an increase in engine fuel efficiency, that is, a decrease in the specific fuel consumption of an aircraft's engines. The fourth desired capability is an improvement in the operating fuel efficiency of the aircraft. This improvement would be the result of decreased use of auxiliary power units, optimum routing, less taxiing, and a general reduction of auxiliary activities that use fuel.

The fifth desired capability is an increase in the cruise speed. With medium-range and long-range aircraft, an increase in cruise speed above that required for minimum fuel consumption can produce a decrease in the direct operating cost. The sixth desired capability is reduction of the weight of the fuel used by aircraft. This would require establishing new specifications for use in producing aviation fuel. The reduced weight of the fuel would lessen the weight carried by aircraft, thus permitting the use of less fuel.

The last desired capability is reduction of the costs of producing fuel through such new techniques as relaxed aviation fuel specifications, synthetic fuels, alternative fuel sources, cheaper production methods, or other technologies. All seven desired capabilities could reduce the costs of aviation fuel usage and thereby contribute to the goal of reducing operating costs.

Measurements will be made of the reduction in the amount of fuel used, whether from reduced specific fuel consumption, improved operational fuel efficiency, or increased cruise speed. Weight will also be measured, because reduced aircraft weight will result in a reduction in the amount of fuel used. Improvements in the L/D ratio will also produce fuel savings because an increase in the L/D ratio of an aircraft will permit it to fly farther on the same amount of fuel or, conversely, to fly the same distance with less fuel. The last two parameters to be measured are the weight of fuel and the cost of fuel. It is necessary to use fuel to carry fuel; thus a lighter fuel would require less fuel to carry it. The cost of fuel can be altered by reduced specification or by less expensive methods of producing fuel.

3.3.1.2 Depreciation

In the future, depreciation costs will be the second major expense of aircraft operations. This expense can be reduced by three methods: (1) reducing the initial cost of aircraft, (2) extending the service life of aircraft, or (3) increasing the aircraft utilization. Reducing

the initial cost of aircraft would have the largest impact, because initial cost is the largest single factor influencing depreciation costs. Aircraft weight reduction, new materials, and new fabrication techniques all contribute to reducing the initial costs of aircraft. If the service life of aircraft could be extended from the current 12 to 15 years to more than 20 years, the airlines would gain an extra five years of service and a reduction in depreciation. Greater aircraft utilization would also reduce the depreciation costs because these costs would be spread over more flight hours per year, with a corresponding reduction in the cost per flight hour.

Aircraft productivity in terms of hours per day will be measured to determine if increases will produce significant savings in depreciation costs. Aircraft wieght, materials used, and fabrication techniques can result in decreased aircraft purchase price. These also will be measured. Since initial aircraft costs can be related to aircraft weight, reductions in aircraft weight should produce savings in aircraft costs, which in turn will reduce depreciation costs.

3.3.1.3 Maintenance

There are six desired capabilities within the maintenance category. Extended mean time between failures (MTBF) would decrease the cost of maintenance by reducing the frequency at which components fail and must be replaced. Frequent replacement of equipment necessary for flight operations incurs large expenditures for spares and supply lines needed to replace equipment at intermediate stops on aircraft routes.

The second desired capability is reduction of the mean time to repair (MTTR) equipment that has failed. Repair time increases geometrically in proportion to the complexity of new equipment. New techniques should be developed that will significantly decrease the time necessary to repair failed equipment producing significant cost savings for the airlines.

The third desired capability is improvement of the accuracy of failure predictions. More accurate predictions of failure times and failure modes could save a significant number of the man-hours now expended in costly inspections. Improved failure detection is also needed. Many man-hours are spent inspecting equipment both to predict when it will fail and to detect when it has failed. By improving or changing failure-detection methods, many nonproductive work efforts could be eliminated. Complex and miniaturized equipment is difficult to troubleshoot, even with much of the built-in test equipment available. Built-in test devices usually identify a failed line replaceable unit (LRU), and occasionally the particular printed circuit board or module within an LRU, but usually the repair technician must troubleshoot the cause of failure below that level.

The last desired capability, reduction of personnel skill levels, could contribute to reduced maintenance cost. Reduced repair times, improved failure detection, and improved troubleshooting capabilities could be combined with improved automatic test equipment to simplify the task of equipment repair and perhaps reduce the skill level needed to effect repairs.

Repair times will be estimated to determine the number of man-hours required to perform repair as well as the cost of materials. Failure times (MTBF) will also be estimated because longer MTBFs will result in decreased maintenance costs over the life of an aircraft. Improved failure prediction/detection will be measured by using the amount of time required for inspection for maintenance. Troubleshooting capabilities will be measured in terms of man-hours required to determine the cause of a failure.

3.3.1.4 Air Crew

There are basically two methods of reducing air crew costs: increasing air crew productivity and reducing air crew size. If air crew productivity could be increased, the airlines would be able to use the crews more hours per day. It may be possible, for example, to increase the number of hours per day a flight crew can work by virtue of the reduced cockpit workload brought about by automation of aircraft systems.

Reduction of air crew size would also reduce other operating costs. Changing the flight crew from three crew members to two not only reduces personnel costs but decreases the weight of the cockpit with respect to seats, instruments, cockpit size, and baggage, as well as the extra crew member, all of which extract a fuel penalty. Similarly, the Federal Aviation Administration recently proposed reducing the criterion for number of flight attendants from one per each 50 seats to one per each 50 passengers. With load factors currently averaging 55 to 60 percent, such a move could produce significant weight, fuel, and personnel savings.

Air crew costs can be measured with two parameters: (1) the actual cost per flight hour, which considers the size of an aircraft crew (both flight crew and flight attendants) and the productivity of the air crew; and (2) the weight of the air crew and associated equipment, which is directly related to fuel usage because of the weight/fuel relationship.

Training costs can be measured with several parameters: (1) cost of aircraft flight hours saved as a result of improved simulator training; (2) cost in terms of man-hours and facility time required to train personnel (flight crews, flight attendants, ground crews, and maintenance) to current levels of achievement either for new or refresher training; (3) cost in terms of man-hours and facility time required to train personnel to new levels of achievement (which may be reduced by better training techniques or reduced requirements); and (4) cost of training facilities, primarily simulators.

3.3.1.5 Aircraft Support Equipment and Facilities

In the improvement area of aircraft support equipment and facilities there are four desired capabilities for reducing operating costs. The first is reduction of ground support equipment costs. The number of items necessary to support aircraft on the ground or at a ramp can be quite

3.3.1.5 Aircraft Support Equipment and Facilities

In the improvement area of aircraft support equipment and facilities there are four desired capabilities for reducing operating costs. The first is reduction of ground support equipment costs. The number of items necessary to support aircraft on the ground or at a ramp can be quite large depending on an aircraft's size and degree of independence. There are baggage carts, baggage conveyor-belt trucks, tow tugs and pusher tractors, auxiliary power trucks, and other vehicles. If their number could be decreased, significant savings in capital equipment, fuel, and manpower might be realized. If methods could be devised to reduce the number of gates, ramps, and passenger lounges, the reduction in capital expenditures for partially used facilities could be significant, permitting expansion of airport capacity at those airports which are, or soon will be, limited because of congestion at ramp/gate facilities. Ideally, an airline could serve more passengers with fewer facilities.

The aircraft support improvement area must also address the cost of maintenance facilities and maintenance equipment. It is necessary to reduce the cost of these facilities and equipment, especially as aircraft equipment complexity increases and the amount of equipment required to troubleshoot LRUs increases. In many cases, the automated test equipment for checking and troubleshooting avionics equipment is several times more expensive than the equipment being tested. As minicomputers and microprocessors proliferate, the investment in test equipment also increases. The purpose of the desired capabilities in this area is to reduce the cost of this new maintenance equipment and the facilities in which aircraft and the associated avionics are repaired.

3.3.1.6 Training

The aviation community has made significant progress in reducing training costs (Reference 40), although there is room for further improvement. The cost of time and facilities for training of air crew members is substantial, whether the training is for initial flight duties or transition to a new position. Several weeks of training are needed, together with hours of simulator time and several hours of actual hands-on time in the aircraft. In addition, there is extensive training for maintenance and ground support personnel, who also use simulators and numerous other training devices. The costs incurred become even larger when new aircraft are introduced into an airline fleet, with the consequent expenses of flight crew downtime, training, and route familiarization. Another training cost that can be reduced is that of the recurring training needed to maintain and verify proficiency. The costs associated with such training might be reduced by using small, low-cost simulators.

3.3.1.7 Aircraft Servicing

Aircraft servicing encompasses cleaning an aircraft, resupplying it, and preparing it for flight. Aircraft cleaning is labor-intensive, consisting of cleaning the aircraft exterior, waxing it,

and repainting it when necessary. Another aircraft servicing expense is the cost of preparing the aircraft interior. It includes the cost of servicing the toilets, emptying and restocking the galley, cleaning the aircraft interior, and stocking the passenger compartment with headrest covers, magazines, and brochures. Most of these efforts also are labor-intensive, although the weight of the items carried could be reduced, thus producing a fuel saving.

Aircraft support equipment and facilities costs can be measured with two parameters: (1) the number of facilities and amount of ground support equipment required, and (2) units costs of the facilities and equipment. Cost of the support equipment will be the more reliable measurement parameter.

Aircraft servicing costs can be measured primarily by man-hours and materials required to service an aircraft, as discussed in Section 3.3.1.7. Reductions in flight preparation cost can be measured in terms of the man-hours or computer time expended in preparing flight plans.

3.3.1.8 Delays and Cancellations

Reduction or elimination of delays and cancellations affect two of the civil aviation goals -- operating costs and social acceptability. The expenses of delays and cancellations are directly related to aircraft operations, while the irritation and distrust associated with delays and cancellations are related to social acceptability. The costs associated with departure, en route, and arrival delays are primarily in fuel and time. Time can be significant, especially when a delay causes an insufficient amount of "crew time" to remain prior to completion of a route and a standby crew must be called out for the remainder of the route to be completed. In the case of cancellations, not only are revenues lost because passengers must be rescheduled on other airlines or accommodated at a hotel, but there is the expense of paying flight crews and flight attendants when a flight is canceled. All these are expenses that could be alleviated through improvements in aircraft reliability, flight operations, air traffic control system route smoothing, and ATC system planning.

Delay and cancellation costs have fuel usage and time as measurement criteria. Most delays result in using additional fuel or carrying it in anticipation of delays. In addition, extra time is used for flight crews, airframe flight time, and awaiting ground personnel, and there is a decrease in air crew productivity due to a smaller number of flights permitted per crew workday.

3.3.1.9 Landing Fees

Landing fees, charged by the agency responsible for an airport, are assessed against an aircraft to pay for the operation of an airport and associated facilities. Although they are usually assessed on the basis

of maximum landing weight, other factors may be combined with landing weight to produce a landing fee rate. Costs may be reduced by reducing the landing fee rate or reducing the weight of the aircraft. Thus a 10 percent reduction in the landing weight of an aircraft would produce a 10 percent reduction in the assessed landing fee.

Landing fees are measured by the landing-fee rate and aircraft landing weight. Reduction of either will reduce the cost of landing fees.

3.3.1.10 Fuel Servicing

Fuel servicing fees can be reduced through two desired capabilities, reduction in the costs of fueling facilities and reduction in the cost of fuel delivery. The cost of fuel servicing might be reduced by any of several methods, ranging from placing the fuel storage facilities underground instead of above ground, to automating the fueling process, and to eliminating the fueling services completely. This type of expense is normally encountered at airports where the fueling facilities are not privately owned, but leased or handled completely by the airport governing agency.

Fuel servicing costs are measured by the cost of the fueling facilities and the man-hours necessary to carry our fuel servicing.

3.3.1.11 Aircraft Control

Aircraft control fees include air-to-ground communications via the ARINC networks and ground-to-ATC communications necessary for flight plan filing and preflight information. The major expense for these communications systems is the cost of the equipment and leasing of the communication lines. Reductions in these two areas could be accomplished through data links or other advanced technology methods, thus contributing to a reduction of the operating costs.

Fees for aircraft control, which consists of air-to-ground communications and airline-to-ATC communications, are measured primarily by the costs of leasing or purchasing these services. These costs encompass equipment, communications lines, and the manpower to provide 24-hour facilities and interface with the air crews.

3.3.1.12 Insurance

The costs of insuring aircraft is an operating expense based on the initial purchase price of the aircraft, the cost of repairs, and the prevailing accident rate. Reducing any of these three factors could reduce the cost of insurance to the airlines. Reducing the initial aircraft purchase price was discussed in Section 3.3.1.2, and the reduction of the number of accidents will be discussed in Section 3.3.2 in more detail. Ideally, if there were no accidents, the only need for insurance would be to cover those "acts of God" which periodically occur;

accidents such as wind damage to parked aircraft, hail and lightning damage, birdstrikes, and other such natural occurrences would be the only events needing coverage, and the cost of insurance would thus be lessened.

Clearly, a reduction in accident history also reduces insurance costs for a particular type of aircraft. Overlap between improvement areas is one of the factors to be evaluated in subsequent tasks.

A reduction in the cost of repairing damaged aircraft could greatly reduce the cost of insurance as an operating expense. Inexpensive materials and repair techniques, damage-limiting design, and simplified repair are all methods that could be used.

The effect of reduced insurance costs can be measured in several ways. A reduction of the initial aircraft purchase price was discussed in Section 3.3.1.2 Reduced repair costs are measured in terms of man-hours to effect a repair and the cost of materials necessary to make that repair. Finally, the cost of insurance can be reduced by a record of fewer accidents, as discussed in Section 3.3.2.

3.3.2 Improve Safety

The safety goal has five improvement areas in which achievment of the desired capabilities would result in a reduction of accidents and a corresponding improvement in safety. Four of the five improvement areas were cited as a cause or factor in 95 percent of the certificated rout air carrier accidents between 1968 and 1977 (Reference 29), whereas the fifth improvement area is a potential future problem. The five improvement areas are: (1) reduction of accidents due to human error, (2) reduction of accidents due to aircraft operations, (3) reduction of accidents due to weather, (4) reduction of accidents due to the air traffic control system, and (5) reduction of accidents due to software errors.

3.3.2.1 Human-Error Accidents

Associated with the goal of reduction of accidents due to human error are four desired capabilities. This category includes accidents attributed to pilots, flight instructors, ground support personnel, maintenance personnel, weather personnel, ATC personnel, supervisory personnel, and even passengers and flight attendants.

The first desired capability is reduction of errors in judgment that cause accidents; accidents of this sort are caused when people exceed the limits of safe operation of an aircraft. Flight management systems of the future might be linked with the flight control system to prevent entering stall or spin conditions. A recent example was the case of an Aeromexico DC-10 that stalled during climb to cruise altitude after being commanded into a constant airspeed and constant rate of climb (Reference 30). The aircraft stalled and fell 11,000 feet before recovering, with some minor structural damage, because the pilots were relying on the autopilot. If the on-board aircraft computer had had the logic to determine that the

two input parameters were incompatible, the accident might have been prevented. Achievement of the desired capability to reduce errors in judgment could reduce or eliminate accidents of this kind.

A second desired capability is optimization of the workload of flight crews. Although considerable effort has been made to reduce workload, future workload levels still need to be reduced even more. Future airline transport operations will be carried out in a complex, busy environment where the risk of accidents must be greatly reduced. In addition to reducing the level of work within the flight deck, it will be necessary to improve the display and utility of information presented to the flight crew. Achievement of this desired capability would aid the flight crew in making decisions based on accurate data with a minimum of judgment errors. Research is just beginning on how best to display information and on what information must be displayed during each portion of flight.

The last desired capability is reduction of errors due to training. The quality and content of training courses must be examined to eliminate objectives that do not pertain to current technology or that could contribute to inappropriate actions or errors in judgment. Better training equipment or techniques that more accurately present actual situations may be the best method of attacking the problem.

3.3.2.2 Aircraft Operation Accidents

The second improvement area is the reduction of accidents due to aircraft operations. This area is concerned primarily with failures and malfunctions of the airframe, powerplant, landing gear, systems, instruments, and associated accessories. The first desired capability is improvement in malfunction/failure predictions; although related to maintenance and reliability, this capability seeks to improve the predictability of malfunctions and failures so that they can be avoided.

The second desired capability is improvement in malfunction/failure detection so that hidden faults can be detected before they cause an accident. It may be possible to develop techniques that could monitor the condition of an aircraft and alert the flight to a malfunction or failure before it occurs.

A third desired capability is reduction of the effects of system malfunctions. This capability is related to both redundancy and reliability; when an aircraft system fails, it may affect the performance of other systems. For example, the failure of an air data computer affects not only the flight instruments directly but also the navigation system and the flight management system. Isolation of malfunctions to individual units or elimination of malfunctions would greatly reduce the accidents attributed to this area.

The last desired capability is improvement in the crash survivability of transport aircraft. Many passengers are killed by the crash dynamics of the aircraft and not the initial impact. It is necessary to develop techniques that will enhance the survivability of airplane crashes in the same way passenger protection has been developed for automobiles.

3.3.2.3 Weather Accidents

The third improvement area addresses the problem of reducing accidents due to weather through four desired capabilities. The first desired capability is improvement in the prediction methods for different types of weather that affect aviation. Many types of weather cannot be predicted accurately more than a few minutes in advance of occurrence, especially severe weather, and frequently probable location is inaccurately predicted. If severe weather could be accurately predicted, flight paths could be rerouted, or flight times changed, to avoid a possible accident.

Associated with this desired capability is the need for improved weather detection. Although significant advances have been made in weather detection devices and methods in the last 15 years, with airborne color radar and improved ground stations, there are still many types of severe weather that cannot be adequately detected. Once again, detection of these types of weather conditions could prevent an accident.

The third desired capability is penetration of weather in a manner that is not damaging or destructive to the passengers or aircraft. A prime example is the manner of encountering wind shear; the current method is to increase airspeed, and "hang on for the ride." With active controls and new designs, it may be possible to develop a penetration technique that will not be so potentially damaging.

The last desired capability is improvement in the timeliness of weather information so that flight crews and ATC personnel can have up-to-date information. More than once an accident has occurred because timely weather information was not available to permit avoiding a dangerous situation (Reference 29).

3.3.2.4 Air Traffic Control System Accidents

The fourth improvement area concerns accidents attributed to the air traffic control system (ATCS), primarily airport and airways facilities, and airport conditions. These accidents generally are due to mechanical problems and a lack of proper equipment at facilities, rather than inadequate facilities personnel. This area can be improved through three desired capabilities. The first is improvement in the system reliability of the ATCS. Many system outages, however brief, have been reported to Congress and in the public media in the last few years, and these are indicative of problems with system reliability. Improvements must be made if public confidence is to be restored and more complex operations begun.

A second desired capability is the provision of integrated backup equipment in an arrangement by which there would be immediate switchover to a backup system in case of failure of the primary system, with no degradation in performance or lengthy transition times.

The last desired capability is improvement in airport facilities to eliminate accidents attributed to airport conditions. Activities designed to address this capability include better approach lighting systems, different runway lighting schemes, low-cost reliable instrument landing systems for small and medium airports, automatic unattended control towers, and ground location devices to guide aircraft for ground movement in poor visibility.

3.3.2.5 Software Accidents

As more minicomputers and microprocessors are used on the flight decks of future aircraft, the reliability of the software controlling those devices must be addressed. Future avionics systems will be tested to verify that they can handle a myriad of problems with a fail-safe or fail-operational capability. However, two problems remain: (1) the "what if", or out of the ordinary, problem and how the system would deal with it; and (2) the problem of latent errors in the software, which usually are detected only after some outside stimulus has triggered the wrong response to a situation.

To deal with these problems, there are three desired capabilities. The first is improvement in software error detection. It is necessary to devise new techniques that will permit extensive testing of electronic devices to detect latent errors and determine how a device will respond to unanticipated problems. Attainment of this capability could eliminate the chance of a catastrophic failure on some future aircraft.

The second desired capability is reduction of the effects of soft defects so that the effects of latent and unanticipated errors are mitigated. This would be similar in concept to fault-tolerant computers, except that it would attempt to eliminate or attenuate an unanticipated error that could be present in all electronic devices built by the same manufacturer. This technique is directed toward developing an internal tolerance for errors and a way of dampening the effects of error.

The last desired capability is improvement in software integration. As the number of electronic devices in use on aircraft increases, a problem can arise from the different programming languages used in different computers and the different techniques for inputting, outputting, throughputting, and erasing data. With RAMs, ROMs, PROMs, EPROMs, and various other devices, the problem of communication between devices can become enormous. The magnitude of the possible problem was illustrated in the launch of the first space shuttle, when the five main computers on board the spacecraft were unable to "talk to" each other because of a synchronization problem. Standardization of languages and

integration of the sfotware within an aircraft are essential, especially when the avionics must communicate with ourside systems. Achievement of these desired capabilities could prevent the risk of a catastrophic accident due to software errors.

Safety benefits can be calculated by estimating the accident rate attributed to each of the categories in terms of accidents per departure, instead of the usual rate of number of accidents per seat-mile. Using accidents per departure is a better method of expressing the likelihood that an aircraft will be involved in an accident each time it takes off, rather than expressing it in seat-miles; every seat on an aircraft has the same chance of being involved in an accident. In addition, using accidents per departure permits meaningful comparisons between scheduled airlines, air cargo carriers, and commuters.

3.3.3 Enhance Social Acceptability

The goal of enhanced social acceptability of civil aviation has five areas of improvement, the attainment of which would improve the acceptability of aviation as an industry that tries not to irritate its neighbors. Millions of people enjoy airline travel and consider it an essential means of transportation, while those living near airports consider aviation a threat to their lifestyles. Many air travelers are irritated by the delays in schedule. Although it is the goal with the smallest number of tangible benefits and the greatest potential for increased cost, social acceptability is nevertheless important in the future as people strive for a better quality of life.

3.3.3.1 Engine Noise

The first improvement area, reduced engine noise, has three desired capabilities. A reduction of power requirements would enable small, lighter, quieter engines to be used. As technological improvements are made in aircraft design, with the emphasis on weight reduction, aircraft will become smaller and lighter, thus needing less thrust for flight; a reduced thrust requirement for flight can be directly translated into reduced power requirements.

A second desired capability is reduction of the engine noise level. Although there are currently federally mandated noise levels that must be reached by 1986, it appears that there will be an effort to lower those limits even more in the future.

The third desired capability is location of engines on the aircraft in a way that minimizes the noise reaching ground observers. NASA and the engine manufacturers have conducted some experiments to seek reductions of noise levels, but nothing has been committed to production. The techniques examined include mounting engines on top of the wing, above the wing, and in the tail in an attempt to use aircraft structures for shielding purposes. All of these desired capabilities seek to decrease the engine noise heard by ground observers to the "whisper" level.

3.3.3.2 Airframe Noise

If engines become much quieter, airframe noise will be the major source of noise. This source can be minimized through six desired capabilities, all related to the noise produced as an aircraft passes through the air. The first desired capability is reduction of the noise from high-lift devices, primarily flaps. Because flaps cause turbulence, especially when in an approach or landing configuration, they increase the noise level. Techniques for reducing the size of flaps or delaying their use, or even eliminating flaps completely, could be considered.

Reduction of the noise produced by landing gears is another desired capability. The rumble from turbulence around the landing gear is very noticeable to most people in an aircraft during approach to landing. If landing gears could be made smaller or more aerodynamic, or if their extension could be delayed until the last few moments before landing, the noise levels could be significantly reduced. If the landing gear itself could be replaced by some other system, such as landing bags, the noise associated with the landing gear might be virtually eliminated.

A third desired capability, closely associated with the first two, is reduction of aircraft skin friction. If the skin were made more "slippery," the aircraft would be able to fly with less turbulence, reducing airframe noise.

The fourth desired capability is the reduction of aircraft weight. Aircraft noise measurement tests have shown that there is almost a linear relationship between aircraft weight and aircraft noise levels. In fact, the Federal Aviation Regulations, Part 36, establish noise limits based on aircraft weight. Reduction of aircraft weights would decrease the average noise level of aircraft without decreasing aircraft capability.

Another desired capability would be an increase in the lift-to-drag (L/D) ratio of aircraft. Generally the higher the L/D ratio, the smoother the airflow about an aircraft, resulting in less airframe turbulence and, consequently, less noise.

The last desired capability is a reduction of landing and approach speeds to reduce noise levels. Research by NASA with the QRSA (Quiet Research STOL Aircraft) has shown that reduced airspeeds contribute to reduced noise levels. If future aircraft could fly approach and landing speeds 20 or 40 knots lower than present speeds, the airframe noise levels could be significantly reduced.

3.3.3.3 Airport Noise

The third improvement area encompasses methods of reducing airport noise levels. The noise generated at many airports can be heard for some distance, and those people who live under the flight paths to airports complain about infringement because the airport did not exist when they purchased their homes. Airport noise levels can be reduced through four

desired capabilities, which are associated mainly with flight operations techniques. The first desired capability is the use of curvilinear approaches to airports, a technique that will be possible with the Microwave Landing System (MLS). Although it still funnels aircraft to a central point for final approach to landing, the MLS provides wide, fan-shaped approaches instead of stringing aircraft out as the current system does. While not reducing total airport noise, curvilinear approaches redistribute it so that the noise is not concentrated over one area.

A second desired capability is the use of power-off descents by aircraft during approach. This technique would permit aircraft to descend from cruise altitude almost to landing with the throttles at flight idle, thus using minimum fuel and creating minimum noise.

Steeper takeoff and approach paths constitute the third desired capability needed in reducing airport noise. With steeper flight paths, aircraft more quickly reach altitude, where noise is attenuated before reaching ground observers. Combined with power-off descents and curvilinear approaches, this capability might permit making landings with the same precision exhibited by the first space shuttle, which used similar techniques.

The last desired capability is the reduction of noise from aircraft ground operations -- the constant whine of jet engines during peak hours as aircraft taxi. If techniques were developed to eliminate the ground operation of engines from the time the aircraft turns off of the runway upon landing until it taxies onto the active runway for takeoff, the noise level would be significantly reduced.

3.3.3.4 Air Quality

The fourth improvement area is the lessening of air pollution by reducing either the levels of pollution or the types of pollutants. Reduction of the levels of pollution would eliminate one of the major criticisms of civil aviation by those concerned about the quality of the environment. Although the visible aspects have been eliminated, there is still concern about the long-term environmental effects of pollution. At the same time, there is concern about the types of pollutants emitted by jet aircraft. Concern about aviation's contributing to "acid rain" or a worsening of the "greenhouse effect" because of carbon dioxide, sulfur, nitrogen oxide, or other hydrocarbon emissions has created diverse groups acting to minimize the effects of or change the types of pollutants emitted. Improvements in both of these areas would reduce air pollution and enhance the social acceptability of aircraft.

3.3.3.5 Airline Punctuality

Although punctuality was addressed in Section 3.3.1.8 in the discussion of methods for reducing usage costs, it also applies here because it is a factor that affects the social acceptability of civil aviation. Many travelers are irritated because of delays in arrivals or departures and thus fly only when necessary. Alleviation of these problems could encourage travelers to fly more often than only when necessary.

The social acceptability of civil aviation can be qualitatively measured by three parameters: noise level, air pollution level, and punctuality. The contribution of an aircraft to overall noise levels can be measured and the reduction in these noise levels determined for each of the components producing noise. Similarly, the level of air pollution and the type of air pollutants can be determined and the changes in these two areas measured and quantified. However, determination of the quality of these changes is a political decision that is beyond the scope of this effort. The last parameter of social acceptability, punctuality, can be measured as a deviation from published arrival and departure times. This deviation can be related to what social research has shown to be "acceptable" to a majority of travelers.

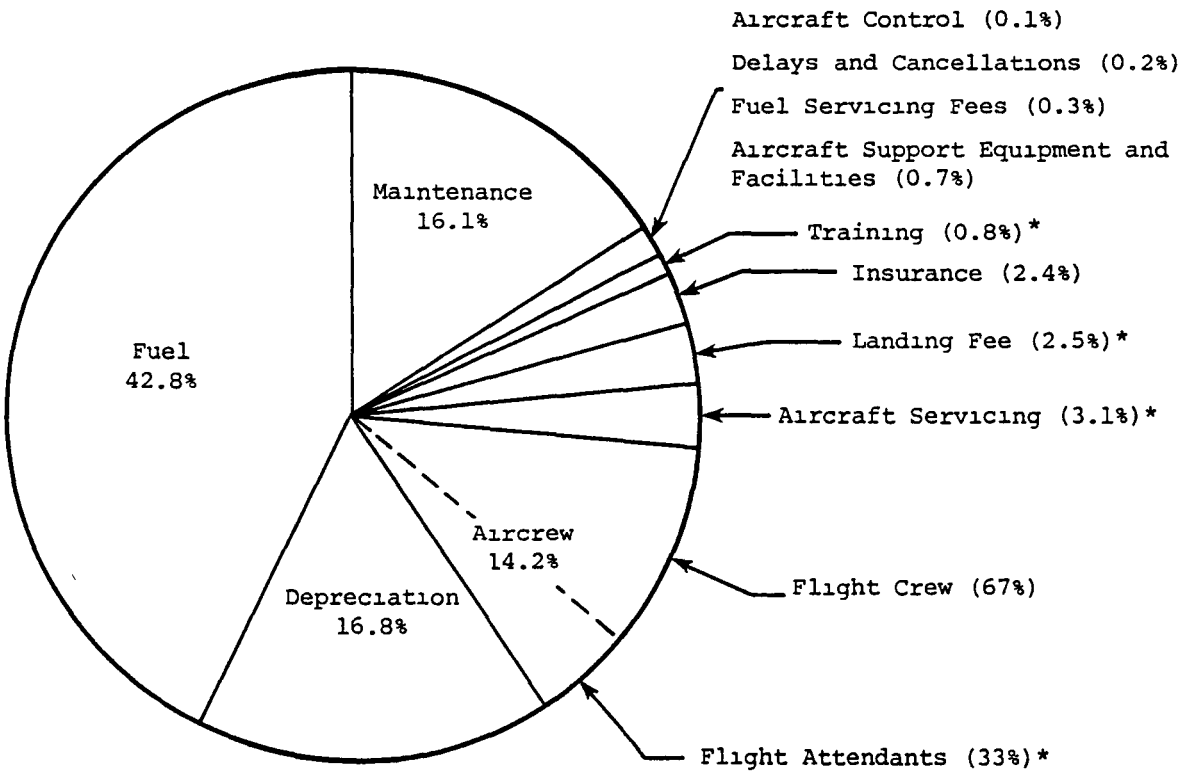
3.4 RELATIVE WEIGHTING OF IMPROVEMENTS

Each improvement area within each aviation goal was ranked according to its relative contribution to achievement of the goal. This ranking is necessary so that the efforts of this study can be focused on those areas which would have the largest impact on costs.

3.4.1 Aircraft Operating Cost Assessment

In a 1977 study for NASA/Langley (Reference 34), American Airlines developed a method for assessing the operating costs associated with commercial air transport aircraft. These costs, which are more inclusive than the standard method developed in 1967 by the Air Transport Association (ATA), include the cost of some ground support facilities for determining the direct operating costs (DOC) of aircraft. According to the study, and actual American Airlines experience data, the top five categories contributing to DOC in 1976 were fuel costs, 28 percent; depreciation costs, 23 percent; maintenance costs, 22 percent; flight crew pay, 13 percent; and flight attendant pay, 7 percent.

Figure 3-1 shows the representative distribution of the operating costs based on American Airlines data. It also shows that nearly 25 percent of the items that American Airlines considered as part of the DOC of an aircraft are not included in the ATA model for determining the cost of operating an aircraft. CAB Form 41, which the airlines are required to file annually with the Civil Aeronautics Board, also describes the operating costs by combining both aircraft operating costs and airline operation costs. For example, the form combines landing fees with commission fees to create a fees category. Thus,



*Not included in 1967 ATA standard method of calculating direct operating costs.

Figure 3-1. DISTRIBUTION OF AIRCRAFT-RELATED OPERATING EXPENSES

according to CAB Form 41, the top five operating cost categories for 1979 were fuel costs, 25 percent; landing fees, commissions, 13 percent; flying labor, 11.4 percent; purchased goods and services, 9.5 percent; and depreciation, rental, and insurance, 7.4 percent. It can thus be seen that the CAB and the airlines use different categories of expenses when considering operating costs.

For purposes of this study, we use the definition of aircraft-related operating expenses shown in Figure 3-1, as defined in Reference 34. Fuel costs are the costs attributed to the fuel used in flying a route and supporting the aircraft during ground operations. Maintenance costs are the costs associated with maintaining an aircraft in a safe and efficient manner. Depreciation costs are the expenses associated with the amortization of the initial aircraft and engine purchase price, plus the cost of initial spares and related aircraft improvements occurring after purchase. Insurance costs are primarily the costs of hull and liability insurance

and any claims in excess of these limits. Flight crew and flight attendant salaries are the costs associated with the air crew and the benefits accruing to them. Control fees are the costs associated with leasing, maintaining, purchasing, or operating the equipment or facilities necessary to maintain control of aircraft through an independent air-ground communications network. This communications network includes radio, telephone, teletype, and data link systems. Landing fees are those fees levied against an aircraft for landing at an airport. Aircraft service costs are the costs associated with preparing an aircraft for flight, including passenger-compartment cleaning, aircraft cleaning, galley preparation, and pre-flight preparation.

Using the cost categories described above, the American Airlines projected rates for labor and materials, and the inflation rates employed in the FAA aviation forecasts (Reference 1), ARINC Research projected that the operating cost distribution as of 1980 is as follows: fuel costs, 43 percent; depreciation costs, 18 percent; maintenance costs, 17 percent; flight crew pay, 10 percent; flight attendant pay, 5 percent; other costs, 7 percent. This differs considerably from the 50 to 60 percent fuel estimate often used, primarily because of the indirect costs that have been included to define aircraft-related operating costs. The inclusion of these costs provides a clearer picture of the cost of operating and supporting an aircraft.

3.4.2 Technology Impact

Parametric studies by Boeing (Reference 31) and American Airlines (Reference 34) have shown the impact that technology improvements can have on the economic parameters of aircraft operations. Figure 3-2, based on the Boeing study, shows the impact on aircraft direct operating costs of improvements in aircraft technologies. The figures gives the relative rankings of technological improvements: drag reduction produces the largest benefit, followed by flight time, aircraft weight, specific fuel consumption, and aircraft price, with minor contributions from maintenance.

The parametric study by American Airlines using both their data and Boeing data, examined the effect of changes in basic aircraft design parameters on typical figures of merit. Figure 3-3, based on that study (Reference 34), shows the effects of improvements in drag on five basic design parameters. For example, it shows that a 5 percent reduction in drag will produce a 6 percent reduction in fuel use for a typical medium-range aircraft. The figure also shows that an improvement in drag of 10 percent will produce a 5 percent reduction in airframe weight. In combination with the data from the Boeing study, it shows the synergistic effects of technology improvements; a 10 percent reduction in drag will produce a 6 percent reduction in DOC, plus a 5 percent reduction in aircraft weight, which itself will produce a 2 percent reduction in DOC.

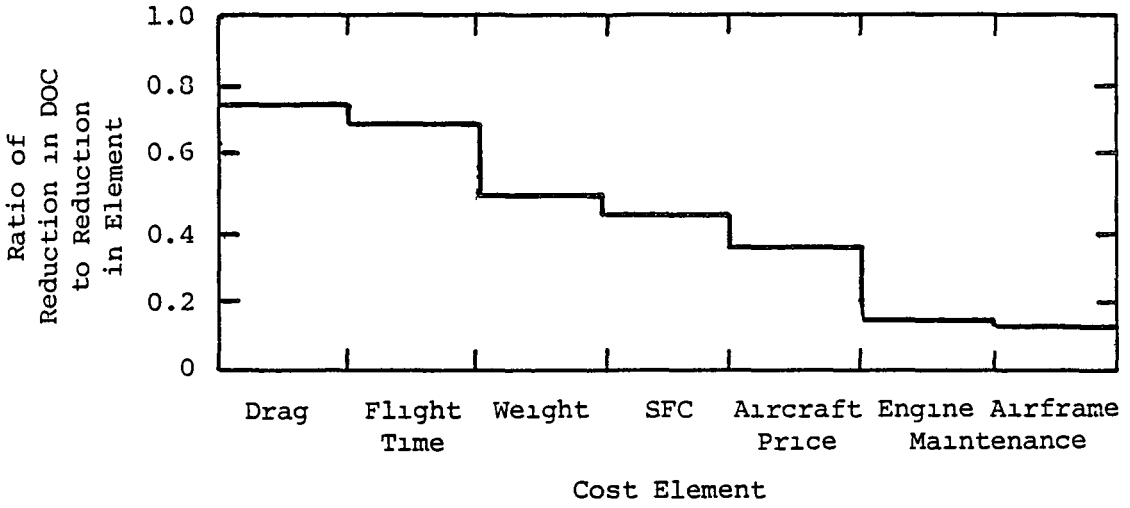


Figure 3-2. EFFECT OF TECHNOLOGY ON DIRECT OPERATING COSTS

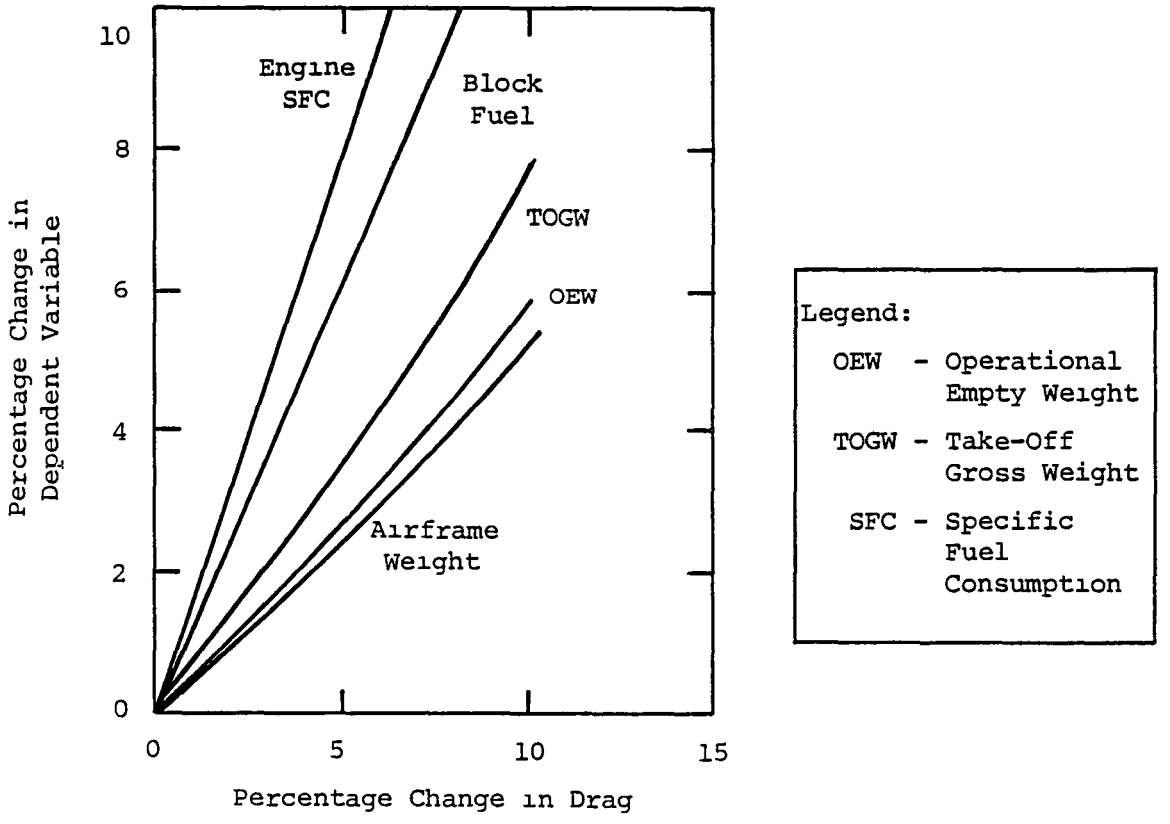


Figure 3-3. SENSITIVITY STUDY: EFFECT OF CHANGE IN DRAG

3.4.3 Relative Importance

Assessment of the relative importance of technological improvements requires two levels of attack. Fuel is the most important cost, followed by depreciation, maintenance, flight crew, and flight attendants. Within each of these categories, the technologies that contribute to costs are drag, flight time, aircraft weight, specific fuel consumption, aircraft price, and maintenance. Thus, in assessing the benefits of any concept, the evaluation must first examine the factors contributing to fuel usage, then those contributing to depreciation, and so on.

3.5 SUMMARY

The aviation scenarios developed in Chapter Two were examined to identify potential problems for future commercial aviation operations. These problems were grouped in three problem areas -- operations, safety, and social -- which were then restated as aviation goals. Each goal comprises a number of improvement areas, which are further divided into desired capabilities. The content of the improvement areas and their associated desired capabilities were discussed. The parameters that will be measured to determine the quantifiable benefits were also developed. Finally, the improvement areas were ranked by their order of importance.

CHAPTER FOUR

ANALYSIS METHODOLOGY

This chapter describes the structured methodology developed by ARINC Research for the generation and analysis of controls and guidance concepts. This methodology draws on the base of information presented in Chapter Two, and the breakdown of aviation goals presented in Chapter Three.

The methodology has been kept general and open-ended to accommodate the extremely wide range of subject areas to be addressed and the likelihood of encountering unanticipated ideas and concepts. This approach provides maximum flexibility in identifying problem areas, developing system concepts that address the problems, and analyzing system-concept benefits.

This chapter describes the general methodology to be used in identifying and analyzing the benefits of the various system concepts. The steps constituting the methodology, as discussed in the following sections, are as follows:

1. Identify needs and establish goals
2. Establish improvement goals
3. Estimate maximum potential benefits
4. Define a specific desired capability
5. Devise a system concept to provide desired capability
6. Determine effectiveness of system concept
7. Estimate costs of system concept
8. Rank concepts
9. Compute cumulative benefit-to-cost ratio

This methodology was used in Task 2 to analyze system concepts and establish priorities for them according to their potential payoffs.

4.1 STEP 1: IDENTIFY NEEDS AND ESTABLISH GOALS

The needed changes identified in Step 1 are likely to be general statements of requirements covering large areas of concern, such as reductions in operating costs or improvements in safety.

The approach taken in defining general goals was to examine all the factors that limit or constrain aircraft operations. After consideration of the entire range of aircraft and airline operations, it was concluded that all of the general goals fell under one of three basic goals:

- Enhance economic performance of aircraft
- Improve safety of aircraft operations
- Enhance the social acceptability of aircraft operations

It is clear, of course, that these three general goals are related; the accident rate of an aircraft certainly affects that aircraft's social acceptability, for example. Still, division of goals along profit/cost, safety, and social lines was considered to be useful in the present and foreseen civil aviation environment.

4.2 STEP 2: ESTABLISH IMPROVEMENT GOALS

For each general goal area, the factors that limit or constrain performance in that area are identified. Each of these factors becomes an improvement goal. It is these improvement goals that appear in the percentage trees of Chapter Five. For example, we consider the general goal of improving the economic performance of aircraft. Economic performance is ultimately reflected in the profit a carrier can make by operating the aircraft. Profit is determined by the following relationship:

$$P = R - FC - VC$$

where

R = revenue

P = profit

FC = fixed costs

VC = variable costs

Like any business, a carrier will seek to maximize its profit in the long run. To this end, the carrier will attempt to maximize revenue and minimize fixed and variable costs. We can consider the individual elements that make up each of the factors in this profit equation:

- Revenue
  - Ridership
  - Fare Structure
- Fixed Costs
  - General Operating and Maintenance
  - Insurance
  - Overhead

- Depreciation*
- Advertising

- Variable costs
  - Fuel
  - Crew Costs
  - Aircraft Maintenance
  - Depreciation*
  - Landing Fees
  - Servicing Costs

Improvement in any of these factors will improve profit. Factors that can be addressed by controls and guidance technology are identified as improvement areas. For instance, an improvement area might be a reduction in fuel consumption.

4.3 STEP 3: ESTIMATE MAXIMUM POTENTIAL BENEFITS

As a first test of an improvement area, it is useful to compute the maximum possible benefit that could be derived in that area. This procedure helps to identify areas in which further study is merited and areas in which it is not. For example, we consider the improvement goal of reducing fuel servicing fees. Fuel servicing fees account for only 0.3 percent of total operating costs. Thus, even if it were somehow possible to eliminate all such fees completely, the result would be only a 0.3 percent reduction in total cost. Considering that it probably would not be possible to eliminate all fuel servicing fees, it is clear that this is not a high-priority goal. Fuel use, on the other hand, accounts for more than 40 percent of total operating cost. Thus even a relatively small reduction in fuel use would have a profound impact on overall costs, making this a high-priority goal. This comparison is an example of low-leverage and high-leverage items and illustrates one of the important uses of the information presented in this report.

This step is straightforward in cases where detailed data on performance factors is available. Special attention must be paid to this step, however, in cases where less detailed, or estimated data is used.

4.4 STEP 4: DEFINE A SPECIFIC DESIRED CAPABILITY

Each of the improvement areas that pass the maximum-potential-benefit "test" are then restated as desired capabilities. For instance, the result of the fuel usage example would be the establishment of a desired capability of "reducing specific fuel usage."

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*Depreciation appears twice because it is a factor both in ownership and in operation; a five-year-old aircraft with zero flight time is worth less than a new aircraft (constant dollars) but is worth more than a five-year-old aircraft with 10,000 hours of flight time.

4.5 STEP 5: DEVISE A SYSTEM CONCEPT TO PROVIDE DESIRED CAPABILITY

A system concept is a specific means of attaining a desired capability. Again, the specific factors that contribute to, limit, or constrain a given desired capability are identified as potential areas of improvement.

Two basic sources of system concepts are used in this methodology. The first is the large body of literature that exists in the aviation community. Many of the improvement areas and desired capabilities discussed in this report are also being discussed and debated in the industry at large. The methodology thus calls for a continuing review of literature, periodicals, papers, and proceedings for ideas that apply to the various goals under consideration. The second source of system concepts is the internal development of new ideas.

It is at this point in the process that the creative element enters. Ideas are obtained from industry literature or new ideas are "thought up" for applying controls and guidance techniques to the desired capabilities.

The technique we have used in this methodology is the idea-generating process known as brainstorming. We used this technique in generating the system concepts described in Chapter Five. We found brainstorming to be a highly useful and efficient means of generating and analyzing system concepts.

Literature review and brainstorming were used to generate the system concepts that appear in Appendix F.

4.6 STEP 6: DETERMINE EFFECTIVENESS OF SYSTEM CONCEPT

In Step 6 the degree to which a system concept alleviates a problem or improves an area of operation is determined. It is, of course, desirable to quantify the benefit wherever possible. Cost improvements are naturally expressed in terms of dollars. Safety improvements can be expressed in terms of the reduction in the number of accidents, but the relationship between safety improvements and details of system concepts is not easily definable. (For instance, how do we calculate the reduction in accidents resulting from, say, better cockpit displays? No precise relationship exists.) Similarly, improvements in the area of social acceptability elude easy quantification. Benefits are measured in a number of ways as discussed in the following subsections.

It is possible that some concepts can be implemented in varying degrees, rather than in their entirety. In such cases, the planner should consider a few representative degrees of implementation and determine their respective benefits and costs. Each of the cases can then be considered as a separate concept during the remainder of the methodology. For example, consider the concept of active controls. This concept can be applied to just the ailerons, the ailerons and elevators, or the ailerons, elevators, and rudder. Each degree of implementation carries with it benefits and costs, both increasing

as the degree of implementation increases. The user of the methodology should determine the benefits and costs of each case, as discussed in this report, and treat each as a separate concept.

4.6.1 Costs

Benefits related to cost reduction are determined by reference to the analytical relationship data presented in Chapter Five and aircraft performance data presented in Chapter One. The percentage improvement in a particular area can be related to a percentage improvement in overall cost by means of the analytical relationships. This percentage can in turn be related to an absolute dollar saving by reference to the aircraft performance data for the time period under consideration. In some cases, the percentage improvement effected by a specific system concept can be calculated precisely; in other cases, the percentage improvement will be estimated on the basis of engineering judgment. In questionable cases, several different estimates will be analyzed to obtain a measure of the sensitivity of the result to the estimates of percentage improvement. The total industry benefit can be obtained by multiplying the dollar saving by the number of aircraft predicted for each scenario.

4.6.2 Safety

As mentioned earlier, the relationship between aircraft system features and reduced accidents is not a direct one. This is partly a reflection of the fact that most accidents result from some form of human error; the human element is perhaps the least predictable of all aircraft systems.

The impact of various concepts on human-error-related accidents can be judged only on a case-by-case basis. An engineering estimate of the degree to which a given concept improves a particular system, coupled with an understanding of how such systems have contributed toward human errors in the past, can be used to estimate the impact of changes in the system. For example, errors in reading altimeters have led to accidents. An easier-to-read altimeter could reduce such errors and hence reduce accidents. To quantify the effect, we would first determine the number of accidents attributed to misreading of altimeters in the past and then estimate the degree to which the new altimeter is easier to read. The percentage improvement in readability can then be related to a reduction in accidents.

This is, of course, only a first-order estimate and is somewhat crude. The variability in skill among pilots makes it difficult to issue blanket statements concerning safety-related items; some pilots would never have made an error using the old-type altimeter, while others will still make errors using the new type. At best, conclusions can be made about the *probability* of human-error-related accidents. The estimate of performance improvement of the system concept may be critical; an analysis should be performed to determine the sensitivity of the result of the assumption. If the analysis indicates a high degree of sensitivity, a more detailed assessment of the effect of the system is indicated, possibly including actual testing to determine human reactions statistically.

Other categories of safety-related systems that do not involve human actions can be quantified to a somewhat greater degree. The engineering estimates of performance enhancement can be directly related to decreases in accidents without concern for human variability.

4.6.3 Social Acceptability

Assessing the benefits of environmental improvements is a subject of considerable controversy among environmentalists and regulatory agencies. It is often difficult to quantify benefits of actions such as reducing noise levels, since there is no quantitative "price" being paid for the noise. Rather, the impact of the noise is in the form of personal irritation and annoyance, which do not lend themselves to quantification.

Even among those affected by noise or air pollution, there is no agreement as to the "price" being paid for pollution. Some are only slightly annoyed and generally willing to put up with a certain level of pollution, while others find the same level of pollution extremely offensive and will take action to stop it. Still others, more sensitive in some way, find that their health suffers from this level of pollution. The question is how best to quantify these impacts.

Past efforts to determine the "price" of pollution have actually attempted to assign a dollar value. Techniques include circulating questionnaires that simply ask how much a victim would be willing to pay to have the pollution removed, and studying property values in areas subject to pollution and comparing them with values of similar properties in nonpollution areas. Still another technique is to determine the amount of money spent by visitors to travel to clean, noise-free recreation areas such as national parks.

Such techniques can of course be used to associate dollar values with various levels of pollution, but within the environmentalist and regulatory community the validity of such results is being called into question. Clearly, numerous extraneous factors have a bearing on the results of these studies, such as individual prejudice, nonenvironmental forces in the real estate market, and recreational attractions other than clean air and quiet. With regard to the question of airplane-induced noise and air pollution near airports, there is the added concern of "fairness," since in most cases the airport was there first and people chose to live near it. There is also the question of the greater public good; the air and noise pollution around an airport affect only a relatively small number of people, but the cost of pollution must be borne by all, in the form of higher taxes and fares.

The point of the foregoing discussion is that there is no clearly adequate means of quantitatively assessing the benefits of reducing noise and air pollution. This issue is one of the most serious challenges facing the environmentalist community, and is the subject of continuing study and debate at the highest levels of government. It is far beyond the scope of this study to settle such issues. However, our methodology will employ a semiquantitative measure based on previous industry experience.

A recent study (Reference 33) indicates that the U.S. airline industry spent $726 million between 1968 and 1976 to achieve a fleet-wide average noise reduction of 4 to 8 dB. (The study also estimates a total benefit to society of $643 to $919 million this century, based on a set of arbitrary assumptions concerning the per-dB impact of noise on property values and on an "annoyance factor.") This noise reduction is that which is mandated by FAR Part 36 (1976 levels). Since it must be assumed that these regulations in some broad sense reflect the will of the American people, it must also be assumed that the price to be paid is in some broad sense "worth it"; that is, the American people as a whole are willing to pay this price for this amount of noise reduction. This datum, then, can be used as a reference: any scheme that affects noise reduction at a total cost of $90 to $180 million per dB fleet-wide will be judged as cost-effective. Different noise-reduction schemes can be ranked on the basis of how much better they perform or how much less they cost than the reference.

4.7 STEP 7: ESTIMATE COSTS OF SYSTEM CONCEPT

There are two elements to be considered in estimating the cost of the system concept: the actual cost of the controls and guidance system itself, and the effect that implementation of the system will have on aircraft cost. We consider, for example, the system concept of using active controls for gust alleviation, allowing a lighter wing structure. The active control system will clearly increase aircraft acquisition cost, but changes in the wing structure will add to or diminish the cost of the aircraft structure itself. Thus each of these elements must be determined to estimate the total cost effect of the system concept.

4.7.1 Aircraft Costs

The total cost of an aircraft is determined by the individual costs of the millions of required component parts plus the labor to assemble them into an aircraft. Added to these costs are design, overhead, supervision, and certification costs, as well as profit. It would be an enormous task to estimate the cost of a new aircraft by enumerating the costs of each part and process. In answer to this, the industry has developed techniques for estimating aircraft production costs on the basis of overall parameters such as aircraft weight, number of seats, number of engines, speed, and range. These techniques are based on cost-estimating relationships (CERs) derived from historical information on airplane production. They are in wide use today in industry planning activities. Our methodology will employ these CERs to evaluate the impact of system concepts on aircraft production costs.

We have identified four specific models that lend themselves to our methodology:

- Oman, B.H., *Vehicle Design Evaluation Program: A Computer Program for Weight Sizing, Economic, Performance and Mission Analysis of Fuel-Conserving Aircraft, Multibodied Aircraft and Large Cargo Aircraft Using Both JP and Alternative Fuels*, NASA CR-145070, January 1977.

- Levenson, G.S., *et al.*, *Cost Estimating Relationships for Aircraft Airframes*, The RAND Corporation, RM-4845, February 1966, and R-761-PR, December 1971.
- Large, J.P., Campbell, H.G., & Cates, D., *Parametric Equations for Estimating Aircraft Airframe Costs*, The RAND Corporation, R-1693-1-PA&E, February 1976.
- American Airlines, *A New Method for Estimating Current and Future Transport Aircraft Operating Economics*, NASA CR-145190, January 1978.

It should be noted that these models are, in general, valid only for more or less conventional aircraft. Being based on historical data, they may not be accurate for aircraft designs that depart radically from the traditional. This should not pose a problem for our methodology, since our forecasts of aviation growth show an evolutionary rather than revolutionary trend. Such changes can be accommodated in the model by changes in coefficients; these are continually updated by the model's authors to reflect the latest data and trends. Engineering judgment should nevertheless be applied in all cases in which advanced technology is being analyzed to assure applicability.

These models will be used in subsequent tasks to determine the benefits of system concepts as they apply to aircraft cost. For instance, in the active-controls example mentioned above, one of the potential benefits is the ability to built a lighter wing. This change, however, would have impacts that would "ripple" through the entire aircraft design; the aircraft could have, say, lighter landing gear because of the reduced load-bearing requirement. These models take such relationships into account, and they will be used to estimate the total benefit of system concepts.

A more detailed discussion of these cost-estimating models appears in Appendix C. The general constraints, inputs, and outputs are described in that appendix.

4.7.2 System Costs

The difficulty encountered in estimating the costs of future avionics, controls, and human-factors systems varies greatly with the type of system. The cost of those similar to existing systems can be estimated quite accurately; those which are radically different are much more difficult to estimate. Many technical and economic variables are at work, some quite imponderable. For example, no one can accurately predict the rate of currency inflation for the next 20 years, or the exact state of technology. In such cases, we must ultimately depend on engineering judgment in estimating cost.

There are, however, a number of tools and techniques available to users of this methodology that can aid in the estimating process. The planner can use these in our methodology to narrow considerably the range of our cost estimates for future systems. It is emphasized that cost figures arrived at are only estimates and that uncertainty does exist. It is incumbent upon the user of this methodology to perform several iterations, using a range of cost estimates, to gain an understanding of the sensitivity of the result to the cost assumptions.

One of the tools available for use in cost estimating is the RCA PRICE model. RCA developed the PRICE computerized model in the early 1960s to assist in deriving cost estimates for electromechanical equipment and systems. RCA then used the model for about 10 years to estimate avionics and space system costs before permitting commercial use of the model. More than 500 companies and businesses now use the PRICE model.

PRICE is an acronym for Programmed Review of Information for Costing and Evaluation. It can be used in all phases of hardware acquisition, from development and production to purchase or modification, estimating the costs associated with design, drafting, project management, documentation, sustaining engineering, tooling, system testing, labor, materials, and overhead. Field operations and software development costs are not estimated by PRICE, since it is a hardware model.

The PRICE model employs a parametric method of estimating costs that can use a minimal amount of input or be refined with more accurate data. Data used in developing the parametric cost equations include quantities of equipment to be produced; development and production schedules; hardware geometry, consisting of size, weight of electronic and structural components, and electronic packaging density; amount of new design required; hardware design repetition; type and manufacturing complexity of the hardware; production fabrication processes to be used; technological improvement; and yield considerations for hardware development. Missing data can be computed by using existing cost-estimating relationships that are available in the model.

Output from the PRICE model consists of itemized costs for both development and production, as well as cost ranges for total development and production costs. In addition, the PRICE model can be used to determine these costs on the basis of minimal design detail inputs plus a target cost. These costs are all presented in terms of manufacturer's cost and do not include profit. This flexibility of parametric cost estimating permits versatility of operation.

A second technique used to estimate systems costs is component cost estimating. Some "new" systems are actually new combinations of existing subsystems. By studying the present costs of these subsystems, and estimating the amount of R&D needed to combine them into a system, we can obtain an estimate of the total cost. The R&D estimate is based on experience with similar systems and on engineering judgment. Again, iterative calculations based on a range of R&D cost estimates will show the sensitivity of the result to the assumptions.

A third technique is comparison with similar systems. We consider, for example, the desired capability of 1,000-foot vertical separation, allowing selection of more nearly optimal cruise altitudes. Such a scheme may require a more accurate means of altimetry than that now available. One system concept, then, is a refined barometric altimeter. Study of existing altimeter costs, coupled with an estimate of the expenditures needed to enhance accuracy, would yield an estimate of the new system cost. The

"similar" system need not be used in the same area addressed by the system concept. In our example, another system concept might be an inertial altimeter. Inertial reference systems are currently employed in navigation, but not in altimetry. By studying the design and cost of these systems, however, and estimating R&D costs, a cost estimate for an inertial altimeter can be developed.

4.7.3 Generic Technology Costs

In most cases, in order for a specific concept to be implemented, one or more generic technologies must be available. A generic technology is one that enables the implementation of a broad range of specific concepts. For example, in order to implement the concept of active ailerons, it is necessary to have available actuators to move the aileron control surfaces. Such actuators, however, have very broad application beyond the specific application of active ailerons. Electromechanical actuators will apply, for instance, to active elevators, spoilers, landing gear, and so forth. This broad applicability means that the cost of generic technologies can be offset by the benefits of the multiple concepts which they enable.

There are several ways in which the cost of a generic technology may be viewed. The simplest case is that in which the generic technology is developed entirely by the same organization or program that develops the concepts. In that case, the cost associated with the generic technology is the entire cost of its development program. If the generic technology is being developed by some other organization, it may be necessary for the organization developing the specific concepts to support or participate in the development of the generic technology. In this case, the cost associated with the generic technology is that portion of the developement costs of the generic technology borne by the concept program.

Finally, if the generic technology is already developed, the cost associated with the generic technology is that of adapting the technology to the specific concept. It is recognized that it will often be difficult to obtain accurate estimates of the costs of these generic technologies. In such cases, a planner often resorts to performing a sensitivity analysis to determine the degree to which changes in input parameters affect the results. The project methodology addresses this requirement by providing the ARCEM microcomputer program, which allows a planner to determine quickly the sensitivity of benefit/cost ratio results to assumptions about generic technology costs.

4.8 STEP 8: RANK CONCEPTS

Thus far in the methodology we have identified a specific need or established a broad goal, identified an improvement area within that goal and verified it by computing maximum potential benefits, identified a specific improvement area, and developed a system concept that will address that area. We then determined the expected benefits and estimated the costs. It now remains to determine the relative desirability of the concepts by ranking them.

Concept ranking is based on a composite of conservative and optimistic rankings. Conservative rankings will favor low-risk concepts, while optimistic rankings will favor high-payoff concepts. By combining these two in light of an understanding of industry needs and priorities, a composite ranking of controls and guidance system concepts will be derived, showing which concepts best address industry needs while permitting a relatively high level of confidence in the feasibility of the concepts.

As an aid to the ranking process, we have developed a form that summarizes each of the important factors. It will be used in Chapter Five in identifying, analyzing, and ranking system concepts. This form is shown in Figure 4-1. It is used to organize the data to be entered into the automated portion of the project methodology, referred to as ARINC Research Concept Evaluation Methodology (ARCEM). The ARCEM Program performs the computations needed to calculate the benefit-to-cost ratios associated with the implementation of the various concepts. The ARCEM Program is described later in this chapter.

4.9 STEP 9: CALCULATE CUMULATIVE BENEFIT TO COST

Step 9 is intended to address the question of how to consider the costs of generic technologies in specific programs. For example, the use of active control systems for gust load alleviation may require the availability of electromechanical actuators and high-reliability computer systems. These two are examples of generic, or pacing, technologies -- technologies that have broad application in many areas and are being developed independent of a specific controls and guidance concept. Some means of factoring into the cost of a concept a portion of the development cost of a required generic technology is needed. However, the more concepts that share a need for a generic technology, the broader the base over which the cost of the generic technology can be amortized. For example, let us consider a concept such as active controls. We will assume that this concept requires electromechanical actuators and high-reliability computers. Let us further assume that $100 million of the development cost of electromechanical actuators can be apportioned program-wide to the active controls concept, as well as $500 million of the cost of high-reliability computer developement. If only the active controls concept is implemented, the $600 million developmental costs must be added to any unit cost of acquisition and installation, probably yielding a benefit-to-cost ratio of considerably less than one. However, if a second concept that requires the same generic technologies is instituted, the entire benefit is accrued, with only the unit costs added; the costs of the generic technologies have already been figured in. Thus the net benefit to cost for the two concepts goes up. As more concepts using the same generic technologies are added, the cumulative benefit to cost increases, at some point exceeding unity. At this point, the total benefit equals the total cost, and implementation of those concepts is economically justified. Depending on the details of the particular mix of concepts and generic technologies, the cumulative benefit-to-cost curve may reach a peak and then descend because of the increasing number of singular application generic technologies indicating an optimal number of concepts.

Concept Number	Concept Name	Benefit	Cost	Generic Technologies																		
				1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
			Costs																			

Figure 4-1. ARCEM WORK FORM

When considering a large number of concepts and generic technologies, it is unlikely that every concept would require every technology. The relationship between concepts and required generic technologies can be represented in matrix form, as shown in Figure 4-2. Concepts are listed on the horizontal rows of the matrix in order of project execution. Generic technologies are listed in the vertical columns, with the apportioned cost of the program listed at the bottom of each column. The apportioned cost represents some "fair share" of the generic technology development costs to be borne by the controls and guidance program, or alternatively, the cost of adapting a generic technology to the specific requirement of a given concept. At each row-column intersection, a notation is made indicating whether the concept on that row requires the generic technology in that column; a "1" indicates that the technology is required, a "0" indicates that it is not. Benefits of each concept, expressed numerically (in dollars, if possible), and unit costs are also included in the matrix.

A cumulative benefit-to-cost curve can be prepared from the data in the matrix. Since the concepts are listed in order of their benefit-to-cost ratio, they will be executed in that order. Starting with the first concept, the costs of all generic technologies needed for that concept, as indicated by 1's in the matrix, are added to the unit cost of the concept. The benefit of the concept is then divided by the total cost to arrive at the benefit-to-cost ratio. For the second concept, the benefit is added to the benefit of the first concept, and the unit cost is added to the total cost. The costs of the required generic technologies for this concept, however, are added to the total cost only if they were not added for the first concept; that is, the cost of each generic technology is added only once, the first time the need for it is encountered. Thus if the technology costs are already accounted for, the entire benefit of the second concept is accrued without adding any technology costs. In this way, the cumulative benefit-to-cost ratio increases as generic technologies are shared by more and more concepts.

The results of this procedure can be plotted to show the cumulative benefit-to-cost ratio as a function of the number of concepts implemented. In most cases, the relatively large costs of generic technologies will render the benefit-to-cost ratio less than one for the first few concepts. The added benefits of additional concepts using the same technologies drive the cumulative benefit-to-cost ratio upwards.

This part of the ARINC Research methodology provides a powerful tool for the organization and planning of research activities. It shows which concepts can provide the greatest benefit for the investment and also shows the number of concepts that must be implemented to economically justify expenditures for development of generic technologies. The technique will also reveal the existence of an optimal number of concepts for which the benefit-to-cost ratio is maximized, as indicated by a peak in the cumulative benefit-to-cost curve. The methodology can also provide important results by being used "backwards." The generic technology cost figures can be adjusted until the break-even or optimal point occurs at a number of projects consistent

Concept	Benefits	Costs	Electro-Mechanical Activator	High Reliability Components	Generic Technology No. 3	...	...	...
1. Active Ctrls			1	0	1	...	...	...
2. Wind-Shear Det			0	1	1	...	...	...
3. ⋮			⋮	⋮	⋮			
4. ⋮			⋮	⋮	⋮			
⋮			⋮	⋮	⋮			
Apportioned Costs			$	$	$			

Figure 4-2. CONCEPT MATRIX

with prevailing budget constraints. The technology cost figures then indicate the maximum amount that can be spent on generic technology and still achieve economically justified operation at the desired number of projects.

ARINC Research Corporation has developed a computer program that directly enters the data from the matrix form in Figure 4-2 and computes a cumulative benefit-to-cost curve. The program is written for the TRS-80 desk-top computer, but could easily be adapted to any computer using the BASIC or FORTRAN computer language. Full documentation of the program appears in Appendix D. A listing of the program, called ARCEM for ARINC Research Concept Evaluation Methodology, appears in Appendix E.

4.10 METHODOLOGY WALK-THROUGH

In this section of the report, we provide a "walk-through" of the methodology, showing in general terms how it is used. Specific numerical examples of the use of the methodology appear in Chapter Five. This preliminary walk-through is intended to acquaint the reader with the features of the methodology without requiring him to read the detailed step-by-step descriptions in Chapter Five.

The methodology begins with the selection of an improvement area to consider from among the three identified in the methodology: cost, safety, and social acceptability. For the purposes of this example, we will consider safety. We begin the use of the methodology by examining the information in Figure A-2 in Appendix A. This figure shows the various elements that make up the safety goal. These include human error, weather, aircraft equipment, the air traffic control system, software errors, and others, and are the various factors that can cause or contribute to accidents. We can concentrate our efforts by observing in Figure A-1 the elements that contribute the most to the goal, that is, the elements that cause the most accidents. This is referrred to as identifying the areas of greatest leverage, where a given percent of improvement will have the greatest effect. Examining Figure A-2, we see that human error is by far the largest contributor to accidents, and that flight crew errors are the largest element of human error. That is to say, mistakes made by the flight crew are the single largest cause of accidents. Thus, a concept that would somehow reduce flight crew errors could materially reduce the number of accidents, thereby enhancing safety. This, then, becomes our desired capability, to reduce flight crew errors resulting in accidents. We must now generate a specific system concept that will permit us to do that. For the purpose of this example, let us assume that using the creative techniques discussed previously, we have developed a suitable system concept. It might be an enhanced display to provide the crew with better information, or it might be an on-board computer that monitors aircraft systems and allows the crew to determine the results of planned changes to the status of the aircraft before they actually make the change, through high-speed simulation. Many other concepts in this area are possible, but let us consider the concept of enhanced display of information for the purposes of this example. The crew of a large aircraft must gather and assimilate a vast amount of information and base decisions and actions on that information. Any concept that improves the speed and accuracy with which they can do this would let them base their decisions and actions on better, more complete information, and thus reduce accidents resulting from unavailable or misinterpreted data. Many sources of detailed information on causes of accidents are available to the concept planner, such as those listed in references 10 and 29. We will assume that study of such data indicated that 25 percent of all accidents attributed to human error were caused by lack or misunderstanding of cockpit information. We might then estimate that our concept may be 50 percent effective in eliminating such errors. If such were the case, Figure A-2 shows that the concept, in eliminating half of the flight crew-induced accidents, would reduce accidents by about 13 percent, and hence offer a 13 percent improvement in safety (50 percent of 56 percent of 47.5 percent).

Having estimated the benefit of the concept, we must now estimate its cost. The cost models described in Appendix C are available to the planner to aid in this estimation. Another approach is to estimate the concept costs by comparison with similar existing systems whose costs are known. With an estimate of the cost per airplane of the concept in hand, we must now identify the generic technologies that must be available in order to implement this concept. The example concept clearly requires advanced display technologies and may require advanced sensors to gather higher quality

data on the status of aircraft systems. The costs of these technologies can be obtained through analogy with similar systems, or they can be treated parametrically to obtain estimates of the sensitivity of the economic merit of the concepts to the costs. The costs can be the entire cost of developing the required technology, they can be the apportioned costs in a shared development project, or they can be the cost of adapting an existing technology to the specific application. For the sake of this example we will assume that these costs have been estimated. The generic technology costs can then be added to the per-aircraft costs estimated earlier to obtain an estimate of the total cost of the concept.

At this point in the methodology, we can now compute the benefit-to-cost ratio of the concept. To do this, we divide the benefit (13 percent) by the cost. The generic technology costs are usually considered as "up-front" costs early in the program, and are typically nonrecurring. The per-aircraft costs apply once to each aircraft at the time of installation. The benefit, however, is accrued year after year for as long as the aircraft is in service. When computing dollar benefits, this can be taken into account by computing the present value of the benefits in a base year used for computation and comparison. In the case of the safety example, we must view the ratio of benefit to cost in light of these considerations.

The total benefit and costs over the years under study can be obtained by multiplying the benefits and per-airplane costs by the number of aircraft to which the concept will apply. This information can be found in Chapter Two of this report.

In this walk-through of the methodology, we have examined how a single concept is considered. It is important, however, to consider the entire set of concepts under consideration as a set, because of the possible interaction of generic technologies. It is possible that a second concept will share the generic technologies required by the first, making the pair of concepts, taken together, more attractive than either taken alone. The ARCEM computer program described in this report calculates the cumulative benefit-to-cost ratio of the set of concepts being considered, allowing the effects of sharing generic technology costs to be taken into account in the planning activity.

A note is in order concerning the rank-ordering of concepts by their benefit-to-cost ratio. Ranking is, of course, dependent on the particular combination of concepts selected for consideration. It is, however, possible for the ordering to be dependent on the number of concepts considered. For instance, if from a group of ten concepts, ranked in order from one to ten, we select and rank a group of only five of the concepts, in rare cases the five concepts selected will not be in the same order as before. This is due to the interaction of the generic technology costs with the benefits and costs of the concepts. Our experience indicates that this situation is rare and should not pose a serious problem for the user, but users should be aware of this limitation, and should use the iterative capability of the ARCEM Program to explore such dependencies.

4.11 THE ARCEM COMPUTER PROGRAM

The project methodology discussed in this chapter is designed to culminate in a rank-ordering of the concepts generated by the various techniques included in the methodology according to their cumulative benefit-to-cost ratio. The process by which the rank-ordering takes place lends itself to an automated approach. Performing the various computations on a desk-top computer permits the user to complete a large number of calculations in a short period of time. This is, of course, inherently more efficient; but the advantage of this approach goes beyond just efficiency. In many cases, decisions as to concept selection must be made with less-than-complete data. Often, only estimates of various program costs and benefits are available; in some cases, even estimates may be unavailable. In such cases, the planner must resort to a parametric or iterative analysis to determine the sensitivity of the plan to the input assumptions about costs and benefits. By using a computer to analyze the data, the planner can quickly analyze a number of sets of data to arrive at the desired indication of sensitivity and parametric assessment of the results.

Recognizing the desirability of this approach, ARINC Research has developed a computerized concept ranking algorithm and has implemented it on a suitable microcomputer. This tool allows the planner to rapidly perform the iterative calculations needed to arrive at the final concept ranking, and acts as an electronic work-sheet to simplify and streamline the entire process. The program has been designed to be as flexible and as "user-friendly" as possible.

4.11.1 Program Structure

The program, called ARCEM (ARINC Research Concept Evaluation Methodology Program), is configured in modular form. There are six modules, each specialized for a different function. The user selects the desired functions through the use of a light pen. The light pen was selected as the means of choosing options because of its direct interface with the data on the screen of the computer. This leads to quick operation and ease of relating user actions to the data being manipulated.

The six sections of the program include input, editing, listing, sorting, computing, and storing. The function and importance of each of these sections is discussed in the following paragraphs.

4.11.1.1 Input

The input routine allows for the entry of concept data to be analyzed. Up to 100 concepts and 20 generic technologies can be entered for analysis. Two methods of entry are available: keyboard and disk. The keyboard is used for initial entry of the data into the computer. The input routine prompts the user for the appropriate data and displays the data as they are entered for verification. Erroneous data can be corrected then, or later through the use of the edit routine. Disk input is used to enter concept data that have been previously entered and stored on magnetic disk.

4.11.1.2 Editing

In order for the program to be of maximum use in iterative, parametric, and sensitivity analyses, it contains the ability to edit, change, or delete all of the data that have been entered. This allows the user to adjust the concept data to represent the various configurations desired for the analysis. The edit routine includes the ability to change all of the data fields of the concepts, to add or delete concepts from consideration, or to change the order of the concepts. The last is of particular importance, since the order of the concepts as they are analyzed is of paramount importance in computing the cumulative benefit-to-cost ratio of the group of concepts under consideration. The ability of the user to change this order at will is a powerful means of determining the optimal ordering.

4.11.1.3 Listing

The program includes the capability to list the concepts and their associated data as they currently exist as the result of having been entered or edited. This provides the user with the means of verifying that the intended data have been entered. If errors are detected, they can be corrected by use of the edit routine. If desired, the user can obtain a printed copy of the concept data.

4.11.1.4 Sorting

This function is of key importance to the methodology. This is the section of the program that sorts the concepts into their optimal order. If the sort routine is not used, the concepts are analyzed in the order in which they are entered, or the order into which they have been edited. The sort routine provides the means of automatically sorting the concepts into descending order of benefit-to-cost ratio on the basis of the values of concept benefits and costs and generic technology costs as they are presently entered in the program. The program selects from among the concepts the one with the highest ratio of benefit-to-cost as the first ordered concept. The second is then chosen with the program taking into account that the first selected concept has provided the generic technologies associated with it. Generic technology costs associated with the second selection are not added if they were included in the first selection. This process continues through all of the concepts. At the end of the process, the concepts will be sorted into order of benefit-to-cost ratio.

Following the sort, the program displays the concepts in their sorted order. The user can obtain a printed copy of this list if desired.

4.11.1.5 Computation

The computation routine computes the cumulative benefit-to-cost ratio of the set of concepts as they presently exist, or in their entered, edited, or sorted form. The results are displayed in tabular form for all concepts. The first 25 concepts are presented graphically in bar chart form to aid in interpretation of the results. The user can obtain a printed copy of the tabular and graphical results if desired.

4.11.2 Storage

The concepts and associated data can be stored on magnetic disk for later retrieval by the input routine. This allows the user to analyze a set of data over several sessions without the need to manually re-enter the data at the beginning of each session. The stored data are identified by a file name, allowing more than one year to keep files and so share the computer facility for analysis of concept data.

Benefits and costs are not usually one-time events, but are, instead, applied over the course of several years. In such cases, it is necessary to convert the series of benefits or costs to an equivalent present value for computation. The calculation of present value applies the time value of money over the period in question at a discount interest rate specified by the planner. For example, the present value of a series of benefits of $100,000 a year for ten years is not equal to $1,000,000 as would be arrived at by simple addition. The value of the series of benefits is diminished by the fact that one cannot use money until one has it in hand. The money saved by the benefit in later years is less valuable than the money saved in earlier years, because the operator of the aircraft has the earlier savings to invest, or use in other ways, sooner than the later savings. The difference between the total return he gets on this earlier money, and the total return he gets on the later money, is the difference in present values.

The series of values is reduced by the present value calculation to a single value that is the equivalent of the series of values. To aid the user of the methodology in reducing a series of benefits and costs to a present value, a utility program has been included that performs the needed calculation. The user can run this program as he fills out the work form that contains the concept data and compute the present values from the value series. Both uniform and nonuniform series of values can be calculated. The user may specify a discount rate, or the program will supply a default value of 10 percent.

The ARCEM Program adds the needed element of flexibility and ease of computation required by the iterative type of planning usually associated with program selection activities. Using the program the planner can quickly see the consequences of his assumptions and decisions and tailor his actions accordingly.

Complete run instructions for the ARCEM and the present value utility programs appear in Appendix D. The appendix can be removed or reproduced for use at the computer. A program listing is provided in Appendix E.

CHAPTER FIVE

METHODOLOGY EXAMPLE

In the preceding chapters of this report, we have discussed the context of this study, and have described the structured methodology created in response to the requirements of the study and the body of data needed to support the analysis of civil air transport concepts. We have also presented the ARCEM computer program, which provides a powerful and flexible tool for the final analysis of the concept data generated and organized by the methodology. In this chapter, we will discuss a set of actual concepts and show how they are analyzed using the methodology. The discussion presented in this chapter will serve two purposes: it will exemplify the methodology and at the same time present a number of potentially beneficial system concepts.

In the discussion that follows, we will analyze eight concepts. Of the eight, two were developed as the result of internal ARINC Research creative activities, and one was obtained from industry literature. The remaining five are the result of a study performed for NASA by the Lockheed-California Company.* In the Lockheed study, a large number of specific technologies were examined as candidates for advanced applications. A subset was chosen for analysis by means of a proprietary Lockheed model and were combined into five system concepts. The Lockheed study identified eight concepts for consideration, but two of them were subsets of two others, and a third was an "all of the above" concept that included all of the other seven concepts. Since the methodology developed by ARINC Research is configured to analyze only independent concepts, the interdependent concepts in the Lockheed list were removed from consideration, retaining in each case the broader concept. The all-inclusive concept was also removed from consideration, leaving the five distinct cases which we will examine in this chapter.

In the sections that follow, each of the eight concepts will be discussed. We will show how the ARINC Research-generated concepts were developed by use of the project methodology, and we will discuss the relevance of the concepts from outside sources vis-a-vis the hierarchy of goals set forth in the ARINC Research methodology. Each of the concepts will be

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*Howison, W., and Cronin, M. J., "Electronic/Electric Technology Benefits Study," Lockheed-California Company, Burbank, California, May 1982, NASA Report No. 165980, prepared under Contract No. NAS 1-16199. (Reference 22)

analyzed in the manner described by the methodology, using the data provided in the previous chapters of this report. Finally, the group of eight concepts will be ranked by use of the ARCEM analysis program. Unless otherwise noted, the cost estimates for the various components of the ARINC Research concepts were developed by means of comparison of the proposed system elements with elements of existing systems.

5.1 CONCEPT EVALUATION

Each of the following concepts was evaluated by means of a combination of techniques to determine its benefits and costs. The data that appear in Chapter Two were used to determine the cumulative effects of individual performance factors. We used 1980 as the base year for the determination of all cost and benefit dollar figures. Where some costs and benefit data had been previously established for similar efforts, they were projected to the 1980 baseline using consumer price index data.

5.1.1 Airborne Wind-Shear Detection System

One of three overall goals identified for civil aviation is the enhancement of safety. Aircraft accidents, even nonfatal ones, are extremely expensive, not only because of the loss of a valuable aircraft but also because of damage to property on the ground and injury to passengers, crew, and ground victims. The expense of the loss of the aircraft is usually compounded by damage suits from injured parties and the inevitable bad publicity, which can lead to a loss of customers. In fatal accidents the prime concern is, of course, the loss of human life.

In considering controls and guidance concepts that would enhance safety, we came across the concept of an airborne wind-shear detector in the industry literature. Wind shear is an abrupt change in wind speed or direction, or both, over a very small distance or altitude increment. Rapidly descending columns of air called downbursts are also associated with wind shear. An aircraft encountering such conditions can be subjected to aerodynamic forces that cause extremely high sink rates. If the aircraft does not have sufficient performance capability to counter such forces, an uncontrolled descent will occur, possibly ending in a crash. Several crashes in recent years have been attributed to wind shear. The concept of a wind-shear detector is not new; such systems have been contemplated for years and several are in use today. These provide only a few seconds warning of shear conditions, however, and more advanced sensors capable of giving more warning time are postulated.

Upon discovering this concept in the industry literature, we used the project methodology to determine its potential benefits and projected costs. We began by relating this concept to the improvement goals established for civil aviation.

Review of the safety improvement goal revealed that weather was an improvement area to which flight electronics could make significant contributions to improving safety. This improvement could be realized by

achieving two desired capabilities: improved weather detection and improved ability to fly safely in the vicinity of wind shear. Referring to Figure A-2, in Appendix A, we see that various types of turbulence account for about 60 percent of the weather-related accidents, which, in turn, account for nearly 27 percent of all accidents. Thus the maximum potential benefit is a 16 percent reduction in accidents -- a significant figure. Clear air turbulence, storms associated turbulence, wake vortexes, and wind shear are the four types that produce almost all of these accidents. Wind shear is the most dangerous of the four because it occurs during landing, the most vulnerable portion of a flight. Thus an airborne wind-shear detector would be most valuable, especially if it could also detect clear-air turbulence and storm-associated turbulence.

We next describe the concept in question. The concept of an airborne wind-shear detection system would be to develop an airborne system that could detect wind shear and all other turbulence phenomena and direct an aircrew to avoid the occurrence, or if it is unavoidable, guide the aircraft through the least stressful route. A lightweight LIDAR (light detection and ranging) device appears to be the most promising method of detecting wind-shears at appropriate distances (J. R. Connel in Reference 1). Assuming that an infallible wind-shear and turbulence detection system could be developed as an enhancement to safety, it might also be possible to reduce the amount of structural strength required for an aircraft to survive turbulence. This could be accomplished by either reducing maximum g-load ratings or reducing the ultimate load factor used in design.*

Once the concept had been described, it was possible to determine the goals, improvement areas, and desired capabilities that would be affected by the implementation of such a concept. The goals that were established were to reduce operating costs and improve safety. Looking at the desired capabilities under each of the improvement areas, the improvement areas that were identified as being applicable to this concept were fuel usage, depreciation, maintenance, landing fees, insurance, weather accidents, and accidents due to human error. These areas are highlighted on Figures 5-1, 5-2, and 5-3.

Among the seven improvement areas were six desired capabilities. These desired capabilities, which the proposed concept should attempt to provide, were to reduce aircraft weight, reduce initial aircraft price, increase mean time between failure (MTBF), reduce judgment errors, improve weather detection, and improve ability to avoid weather.

The concept of a wind-shear detection system is applicable to all aircraft, both present and future, although only future aircraft could benefit from a lightened structure. The concept of an airborne wind-shear detection

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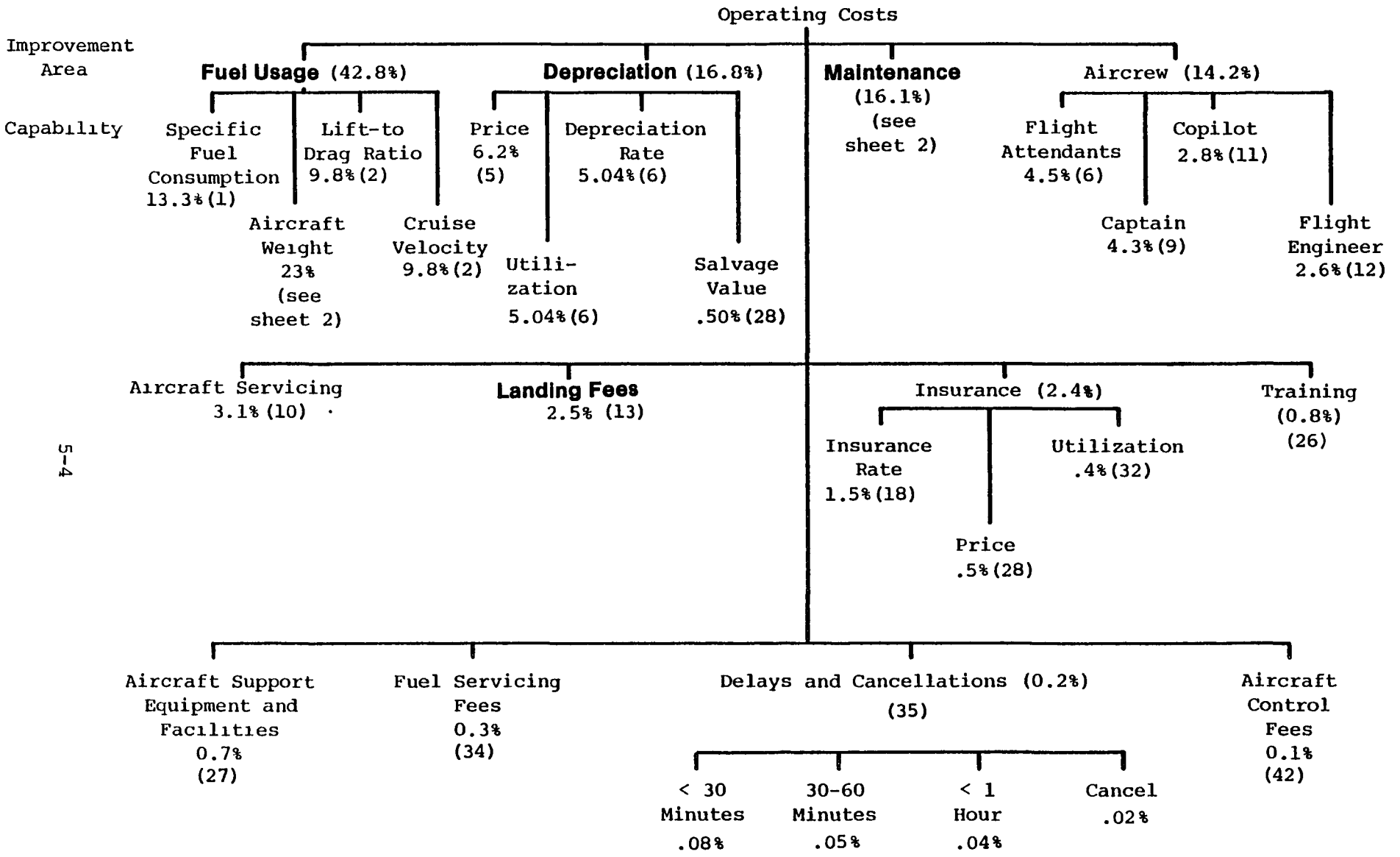
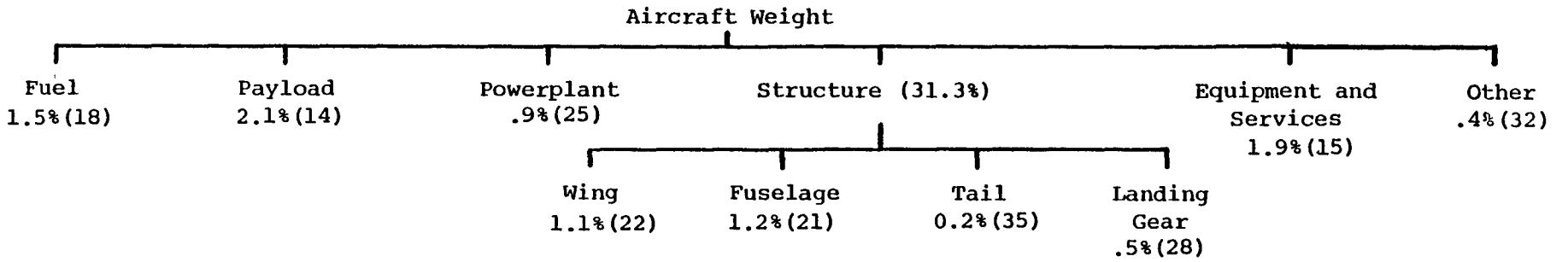
*In this context, load factor refers to the degree to which the aircraft is built to survive stress in excess of the maximum expected stresses. A 1.0 load factor indicates that the aircraft is designed to survive expected loads but no more.



(continued)

Figure 5-1. OPERATING COSTS PERCENTAGE TREE



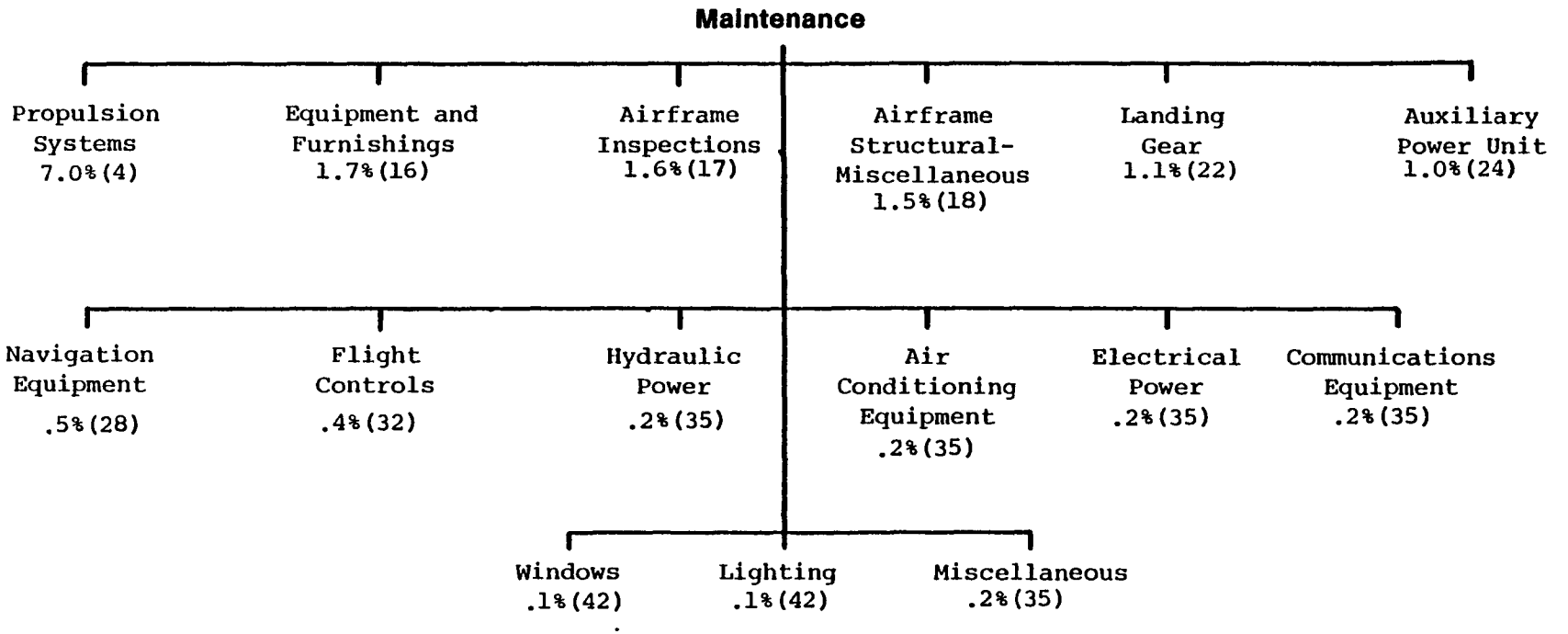


Figure 5-1. (continued)

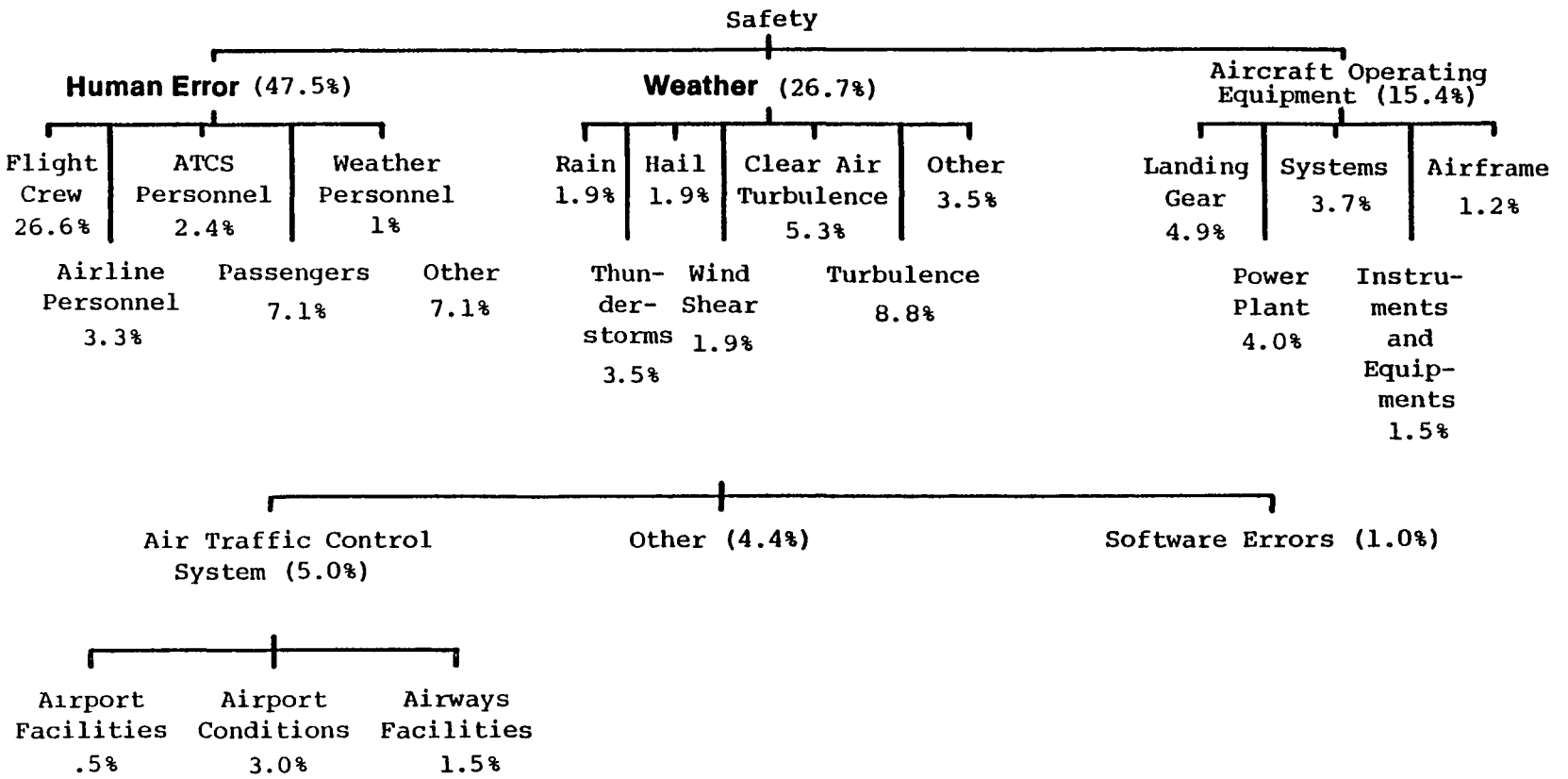


Figure 5-2. SAFETY PERCENTAGE TREE

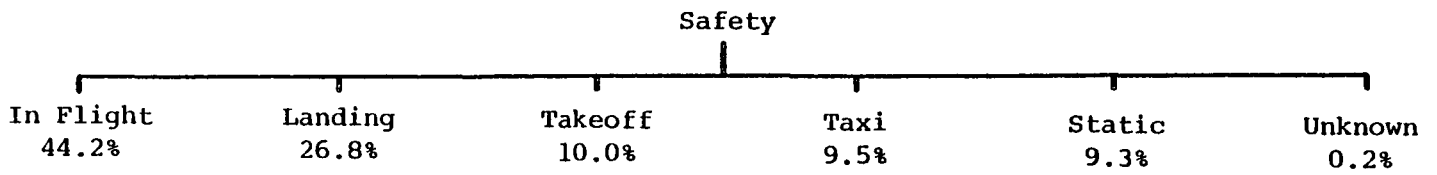


Figure 5-3. SAFETY PERCENTAGE TREE BY PHASE OF OPERATION

system has several facets that must be considered in its design. Ground-based wind-shear detectors work along current instrumented landing approaches, but as microwave landing systems come into use those systems may be ineffective because of the curved landing approaches. Moreover, the current ground-based systems relay the necessary information to the control tower where the warning of a wind-shear condition must be verbally relayed to the flight crew. Even then there is no direction to the flight crew on how to avoid the wind shear -- only a general approximation as to its location and intensity. Moreover, there is no approved clear-air or storm-associated turbulence detector available for aircraft.

An airborne wind-shear detector would alleviate many of the shortcomings of the ground-based designs. Within the framework of our methodology, the specific factors that would be affected by this concept are aircraft landing weight, initial aircraft price, airframe inspection costs, airframe structural maintenance costs, flight crew errors, wind-shear accidents, clear-air turbulence accidents, storm-related turbulence accidents, and airframe noise.

The benefits of the airborne wind-shear detection system can be divided into three categories: reduced aircraft operations costs, improved safety, and avoided costs due to aborted landings. The first of these, reduced aircraft operations costs is a result of reduced aircraft structural weight. Assuming that this concept would allow reducing the ultimate load factor from 1.5 to 1.4, Reference 3 indicates that such a change would result in a 3.25 percent reduction in the aircraft's structural weight. Using Figure 5-1, we can follow the effect of the weight reduction through to a reduction in overall operating costs. Using the aircraft described in Reference 6 as typical for the future, we determined that the 3.25 percent reduction in aircraft structural weight would produce a 1.85 percent reduction in aircraft empty weight. This reduction would produce a 0.27 percent reduction in fuel usage, which would produce a 0.12 percent reduction in aircraft operations costs. Similarly, the 3.25 percent reduction in aircraft structural weight which produces a 1.85 percent reduction in aircraft empty weight also results in a lower initial cost, which can be calculated by using the following equation from Reference 12:

$$\text{Cost} = \frac{W_i^{0.96} - W_f^{0.96}}{W_i^{0.96}}$$

where

W_i = initial operating equipment weight

W_f = final operating equipment weight

This results in a 1.77 percent reduction in initial aircraft price which, from Figure 5-1, produces a 0.65 percent reduction in depreciation costs, which in turn produces a 0.11 percent reduction in aircraft operations costs.

Some data exist that relate various aspects of aircraft maintenance costs to aircraft weight; lighter aircraft are, in general, cheaper to maintain. Some of the costs-estimating relationships discussed in the references are based on such a relationship. However, in this specific instance, the lighter, less strong airframe may in fact require as much (if not more) maintenance than a heavier structure, in addition to whatever maintenance on the wind-shear detection system is required. Thus, for the purposes of this example, we will assume no reduction in maintenance costs as the result of implementation of this concept.

The net reduction in operating costs, then, is estimated to be 0.12 percent due to net airframe structural weight reduction, and 0.11 percent due to reduced initial price, for a total 0.23 percent reduction in aircraft operations costs.

In order to obtain a dollar-value benefit, the percentage reduction above must be applied to the annualized cost of operating the aircraft. Reference 4 contains detailed data on all aspects of aircraft operations costs. That source indicates a total annual operating cost for U.S. air carrier aircraft of $\$23.118 \times 10^9$ over the 1980 fleet of about 2,200 aircraft. Thus, on average, a typical aircraft costs about $10.5 million per year to operate. Applying the 0.23 percent reduction to this figure yields a savings of about $24,000 per aircraft per year. Multiplying this figure by the number of aircraft on which this concept is installed yields the total annual cost-reduction benefit of the concept.

The second benefit of an airborne wind-shear detection system is improved safety. We estimated that development of an encounter system such as described would produce an 85 percent reduction in wind-shear accidents, a 75 percent reduction in clear-air and ordinary turbulence accidents, and a 25 percent reduction in storm-related turbulence accidents. Figure 5-1 shows that such reductions would produce a 49 percent reduction in weather-related accidents, which would yield an overall 13 percent improvement in safety.

The third benefit of a wind-shear encounter system is a reduction in the number of aborted landing approaches. Current airborne wind-shear warning devices do not warn of impending wind shear; instead they warn the flight crew that a wind shear has been encountered which may result in inadequate performance to continue the approach. This warning enables the flight crew to abort the landing approach and initiate a "go-around" while there is still an adequate performance reserve. The proposed concept would warn of an impending wind shear or turbulence encounter and provide guidance to avoid the encounter or penetrate it safely. The ability to penetrate or avoid wind shear safely has an additional economic benefit to the airlines -- the aborted approach and "go-around" which does not occur. Reference 2, estimates that a wind shear related go-around may occur once every 2,000 to 3,000 landings. Thus, there are an average of 5 to 7 aborted approaches per day due to wind-shear conditions, or about 1,800 to 2,600 per year. Assuming that an aborted approach requires an additional ten minutes to reestablish the approach and land, the additional fuel used

varies from 900 to 3,850 pounds, depending upon the aircraft. Using a weighted average of 1,850 pounds of fuel for an aborted approach, the use of an airborne wind-shear encounter system would save between approximately 500,000 and 700,000 gallons of fuel per year worth about $1 per gallon.

When the three benefits are combined, the total benefit is approximately $24,500 per aircraft per year averaged over the base year fleet plus 13 percent improvement in overall safety.

The next step in evaluating the wind-shear detection system is to estimate the costs to develop purchase, and install such a system. Development of an airborne-wind shear detection system will be dependent upon two pacing items. Development of such a system, which would be similar in design and function to conventional radar, would require several more years for miniaturization and reliability development. The system would have to detect the doppler shift in the scattered laser beam caused by the relative motions of particulate matter in the air-mass involved in the shear effect. The second pacing item is wind-shear and turbulence prediction software for a microprocessor. This development is necessary because of the predictive nature of the concept. On the basis of current efforts in this area (Reference 1), it appears that it will be 1990 at the earliest before this concept would be capable of operational use.

The proposed concept of an airborne wind-shear detection system would consist of a pulsed Doppler laser radar, signal processing equipment, dual integrating accelerometers, and a microprocessor. Assuming that a pulsed Doppler laser radar would be about as complex as existing radar sets and would be able to use existing weather radar scopes for information display, the approximate cost of the laser radar and signal processing equipment in 1980 dollars is estimated to be approximately $20,000 (Reference 22), including amortized development costs. The cost of dual integrating accelerometers is approximately $5,000 while the cost of the microprocessor used to determine wind-shear conditions and provide guidance for avoiding or penetrating the condition is estimated at $20,000. Thus the total cost for the system is estimated to be approximately $45,000 per aircraft.

We must now consider the effect of increasing aircraft efficiencies. Aircraft of the future are predicted to be inherently more efficient to operate than the baseline 1980 aircraft. Thus, a given percentage benefit will produce a smaller constant-dollar savings on a year 2000 aircraft, for instance, than on a 1990 or 1980 aircraft; 10 percent of $1 million is larger than 10 percent of $750K. In order to accurately assess the value of the benefits, we must consider this increase in efficiency. Table 2-4 in Chapter Two showed the predicted fuel efficiencies for future aircraft. Since fuel costs are predicted to remain a major cost element of about 50 percent of direct operating cost, we may use that figure as an indication of aircraft efficiency. As the fuel efficiencies figures in Table 2-4 in Chapter Two show, this factor will aproximately double by 2010; short range aircraft will go from 15.5 to 35 seat miles/lb. fuel, medium range from 23.1 to 50, and long range from 17.5 to 37.3. Considering the predicted introduction dates and lifetimes of these aircraft, as shown in Table 2-4 and Figure 2-2, and considering that fuel efficiency accounts

for about half of direct expenses, let us assume for the purposes of our example calculations that the following efficiency factors will apply to concept benefits:

Period	Factor, Percent of 1980 Costs
1980 to 1990	100
1990 to 2000	90
2000 to 2110	75

That is, direct operating costs, and hence the value of a given percent reduction for an aircraft in the 2000 to 2010 time frame will be 75 percent of those values in the base year of 1980. Similarly, a factor of 90 percent will apply in the period from 1990 to 2000. We will assume no changes for the remainder of that decade, yielding a factor of 100 percent. With this approach, we can use base year (1980) data to compute benefits and apply these factors to obtain results for future years.

It now remains to determine the number of aircraft to which this concept will apply. We have estimated that a LIDAR-based wind-shear detector will be operational by about 1990. The aviation scenarios in Table 2-5 in Chapter Two, project a total of 7,750 aircraft to be in use at that time. The fleet will be composed of both aircraft built prior to 1980 and new aircraft. Pre-existing aircraft will obtain the benefits of reduced go-arounds and enhanced safety, while the aircraft built after 1990 could have the added benefit of a lightened structure, as discussed earlier.

The data in Table 2-1 provide the means of determining the number of aircraft in each year after 1990 that can benefit from the availability of a LIDAR-based wind-shear detector. Beginning with the period from 1990 to 1992, Table 2-1 shows that of the 7,750 aircraft in existence, 1,000 will have been built that year.

We will apply the base year per-period benefit of $49,000 per aircraft to half of the 1,100 aircraft built in this time period, giving the effect of averaging the benefit over the production of the period. This takes into account in our calculations the fact that an aircraft produced on the first day of the period accrues benefit for the whole period, while an aircraft produced on the last day of the period accrues no benefit at all in that period.

Applying the base year per-period benefit of $49,000 to half of the 1,100 aircraft produced from 1990 to 1992 yields $49,000 × (1,100/2) = $26.95 million in benefits for this period. Added to this is the lesser benefit accrued by virtue of a reduction in go-arounds only, which will apply to the 6,750 pre-existing aircraft. The base year value of this benefit, computed from data in Reference 2, is about $550 per aircraft per two-year period. Multiplying by the 6,750 aircraft to which the benefit applies yields an annual benefit of $3.72 million. To the new-aircraft benefit we apply the correction factor reflecting the increase in inherent aircraft

efficiency. As discussed earlier, this factor is 90 percent for the 1990 to 2000 time frame. Thus, our total computed benefit for the 1990 to 1992 period is $26.95 million × 0.9 = $24.25 million, plus $3.72 million for the pre-existing aircraft = $27.97 million.

In the second period, 1992 to 1994, we know that 1100 of the 8100 aircraft in service were equipped with the shear detector at the time of manufacture and so will accrue the entire benefit. We will assume that all aircraft retired in the previous two years were built prior to 1990, so that there will be 7000 aircraft equipped with the shear detector without any weight reduction, 1100 equipped with weight reduction, and 1100 new aircraft produced in this time period. As before, we will apply the benefit to half of the new production. Thus, the benefit for the 1992 to 1994 period is:

$$(7{,}000 \times \$550) + (1{,}100 \times \$49{,}000) + \frac{1{,}100}{2} \times \$49{,}000) = \$84.7 \text{ million}$$

Applying the 90 percent efficiency factor yields a benefit for this period of $76.2 million.

The remaining periods are computed in the same way:

Period	Number of Aircraft With Weight Reduction	Number of Aircraft Without Weight Reduction	Number of New Aircraft	Benefit (Baseline) (Dollars)	Benefit (Include Factor) (Dollars)
1994 to 1996	2,200	6,250	1,100	138.18	124.36
1996 to 1998	3,300	5,500	1,200	194.13	174.71
1998 to 2000	5,500	2,750	1,200	300.41	270.37
2000 to 2002	6,700	2,900	1,200	359.30	269.47
2002 to 2004	7,900	2,000	1,200	417.60	313.20
2004 to 2006	9,100	1,200	1,400	480.90	360.60
2006 to 2008	10,500	200	1,400	548.90	411.70
2008 to 2010	11,375*	0	1,400	591.67	443.75

In order to be able to apply these benefit data to the methodology, it is necessary to reduce the data to a single benefit figure. We do this by using the net present value utility program provided with the methodology. In this specific instance, it is a two step process: we first determine the present value of the benefits in 1990, and then adjust that value to an equivalent value in the base year of 1980. Using the non-uniform option of the net present value utility program as described in Appendix D, we find that net present values of the benefits in 1990 are $789 million

*Some aircraft are being retired in this period.

total benefits, using a discount rate of 10 percent. We can now adjust these figures to their equivalent value in the base year of 1980 by again using the non-uniform option of the program. We enter 10 years (1990 - 1980) for the term, and then enter zero for the value for the first nine years, followed by the benefit value in the tenth year. We again use a discount rate of 10 percent. The answers represent the discounted, or equivalent, values of the benefits for the base year of 1980. This calculation gives us a total benefit of $304 million, representing the equivalent present value of the monetary benefits of an airborne wind-shear detector.

The next step is to calculate the costs of the concept. If we assume that the wind-shear detector will become available in 1990, we can assume that all aircraft then in existence will be equipped.* In following years, all newly made aircraft will also be equipped. Earlier, we estimated that the detector unit would cost $45,000 per aircraft, including installation and amortized development costs. Referring to the Forecast Aircraft Production Table (Table 2-1 in Chapter Two), we see that 7,750 aircraft will exist at the beginning of the 1990 to 1992 period. Multiplying this number by the unit cost yields an initial fleet equipage cost of $348.8 million. Applying the unit cost to the new production aircraft in each of the following two-year periods yields the following additional costs:

Period	Number of New Aircraft	Cost (Millions of Dollars)
1990 to 1992	1,000	45.0
1992 to 1994	1,100	49.5
1994 to 1996	1,100	49.5
1996 to 1998	1,200	54.0
1998 to 2000	1,200	54.0
2000 to 2002	1,200	54.0
2002 to 2004	1,400	63.0
2004 to 2006	1,400	63.0
2006 to 2008	1,400	63.0
2008 to 2010	1,400	63.0

Again, we use the net present value utility program to compute the net present value of these costs in 1990 using a 10 percent discount rate, and then bring this figure back to an equivalent value. The net present value in 1990 is computed to be $552.0 million. Using the net present utility program as before to obtain the equivalent 1980 base-year value, we obtain a value of $213.0 million.

*This is a simplifying approximation. In reality, they would be equipped over a number of years.

To summarize, considering the mix of old and new aircraft that can use the wind-shear detector and the rate at which use can be implemented, the present value (at a discount rate of 10 percent) of the benefits of the system totals $304 million. The present value of the costs is $213.0 million. All aircraft share in the safety benefits of the concept, so an across-the-board 13 percent reduction in accidents is also achieved.

At first glance, it might appear that the concept merits implementation, since the monetary benefits exceed the costs by a wide margin. However, we have yet to consider the generic technologies required for implementation of this concept, nor have we compared this concept to other concepts in light of those technologies. The reader should also bear in mind that even negative results can be of great value in an analysis such as this. For instance, had these benefit and cost figures been such that the costs exceeded the benefits the planner might decide to divide this concept into two concepts; one similar to the concept just analyzed, and another, similar in function, but built to less rigorous reliability specifications for use aboard existing aircraft, where the structural integrity of the aircraft does not depend on the wind-shear detection system. Such a unit would be producible at considerably lower cost. By adjusting the cost figure applied to the initial 1990 buy of detectors for the existing fleet of aircraft in an iterative fashion, the planner can learn what the price of the cheaper unit must be in order to obtain a satisfactory benefit-cost ratio. This determination would have to be made, however, in light of an understanding of the costs of the generic technologies required by the concepts, in relation to the generic technologies required by all of the concepts under consideration. The issue of generic technologies will be addressed at the end of this chapter, following the discussions of the various individual concepts.

5.1.2 Active Control Landing Gear System

The previous concept was an example of a "bottom-up" use of the methodology. In its application the effect of a specific concept on the overall performance of the aircraft was determined. In this example, we will use the methodology in a "top-down" fashion, starting with a statement of the most general goals and successively refining the statement of the goals until a specific concept can be identified. This use of the methodology involves the creative human element in "inventing" the system concept. The concept that we are about to describe is offered more as a means of demonstrating the use of the entire methodology than as a solidly researched concept that is ready for immediate implementation.

We begin by examining the overall goals: improve economic performance, improve safety, and improve social acceptability. For this example, we will select the goal of improving the economic performance of the aircraft.

The economic performance of the aircraft involves two fundamental factors: operating costs and revenues. The economic performance of the aircraft is improved by lowering costs or by increasing revenue. We will consider costs first. There are two elements that make up the cost of operating an aircraft: direct and indirect. Indirect costs are the general costs of doing business: administration, buildings, lights and heat,

clerical and support personnel, etc. Direct costs are those directly associated with the operation of the aircraft. It is these direct costs that we will consider.

Figure 5-1 showed the various elements of direct operating costs arranged in tree form. This form shows the relationships of the various elements of cost and their respective quantitative contribution. Figure 5-1 showed which elements are large cost drivers, and which contribute only a relatively small amount.

Since fuel usage is the largest single cost element, we will designate it as an improvement area, with the goal of reducing fuel usage (see Chapter Four). In examining the component parts of fuel usage, we see that aircraft weight plays a major part. The maximum potential benefit is large, as indicated by the percentage relation to cost (23 percent of 42.8 percent = 9.8 percent of total cost). Thus, a reduction in the weight of the aircraft will have a relatively large influence on the cost of operating the aircraft. We thus identify a desired capability: reduce aircraft weight.

We must now identify or develop a specific concept that will achieve this desired capability. To do this, we begin by examining all of the parts that make up the weight of the aircraft and consider the factors that determine their weight. Figure 5-1 shows the breakdown of the weight of the aircraft into its component parts.

In this example, we will consider the landing gear. The landing gear represents a significant part of the structural weight of the aircraft; 5 percent of the total. In examining the factors that determine its weight, we must identify the functions of the landing gear: to support the aircraft on the ground, to provide ground mobility, and to absorb the shock of landings. Let us consider the last function. (Note that each time we select a particular subject for consideration, we might just as easily have selected another area; those areas not selected are all subject for later consideration. This example is illustrating a chain of reasoning already followed to its conclusion.)

One of the principal functions of the landing gear is to absorb landing loads, acting as shock absorbers. The force of impact upon landing is absorbed by compression of fluids and gas inside the gear strut, and converted by the compression to heat, which is then dissipated to the surrounding air. There are two basic kinds of loads: longitudinal loads for which the force is along the axis of the gear strut, and side loads, which cause the gear to bend sideways. Much of the strength of the gear and hence, much of its weight, is associated with the structural strength needed to absorb these side loads, as well as unusual longitudinal loads in hard landings. Examining these factors that determine weight, suggests that reducing or eliminating side loads and hard-landing loads would remove the need for a portion of the strength, and hence the weight, of the landing gear. Therefore, we ask, "What are the factors that generate hard

landing and side loads, and what limits or constrains our ability to reduce them?" Large side loads occur principally during crosswind landings. When an aircraft lands in a no-wind situation or directly into the wind, the aircraft settles to the ground in a level attitude with both main gears touching the ground at the same time. Such landings produce little or no side loads if properly executed. When landing in a cross wind, however, the standard technique calls for banking the plane into the wind, countering the cross wind vector with a component of the lift vector of the wing. The aircraft is held on the centerline of the runway by the application of a small amount of opposite rudder. At touchdown, the upwind gear touches the ground first, followed by the downwind gear, and then the nose gear. Even if executed perfectly, this maneuver places considerable side loads on the landing gear, and if any side motion is present at landing, as is often the case, the side loads can be even greater. Hard landing loads result from abnormal sink rates at touchdown.

From these considerations a concept emerged. An active landing gear system could sense the sink rate and roll angle of the aircraft and automatically adjust the landing gear strut so that it remains perpendicular to the ground through touchdown and roll out and, at the same time, cushion the touchdown. With all landing loads longitudinal to the strut, side loads and hard-landing loads could be reduced or eliminated. Some portion of the strength and hence the weight of the landing gear could be eliminated. The active landing gear would also be operative during take-off and taxi, reducing loads encountered in those phases of flight.

The concept of an active control landing gear can affect both operating costs and safety. Thus the goals of an active control landing gear system would be to reduce operating costs and improve safety.

The goal trees (Figures 5-4, 5-5, and 5-6) show that the desired capabilities of such a system would be to reduce aircraft weight, reduce the initial aircraft price, and reduce maintenance costs. These desired capabilities provide improvements in the areas of fuel usage, depreciation, maintenance, landing fees, insurance, and aircraft operating equipment accidents. Such a concept, capable of making improvements in all these areas, would be applicable to all new aircraft with the primary consideration being that safety should not be degraded and that operation of the system should remain simple.

Several operational factors would be affected by the development and implementation of this concept. Those factors are landing weight, aircraft price, airframe structural maintenance costs, landing gear maintenance costs, and landing gear accidents. Achievement of the desired capabilities will permit reduction in each of these operational factors.

The technology matrix in Table 2-2, in Chapter Two, shows that large-scale use of active control systems and the associated advanced monitoring systems needed to ensure reliable operation will not take place until deployment of the short-range 1 (SR1) and short range 2 (SR2), medium-range

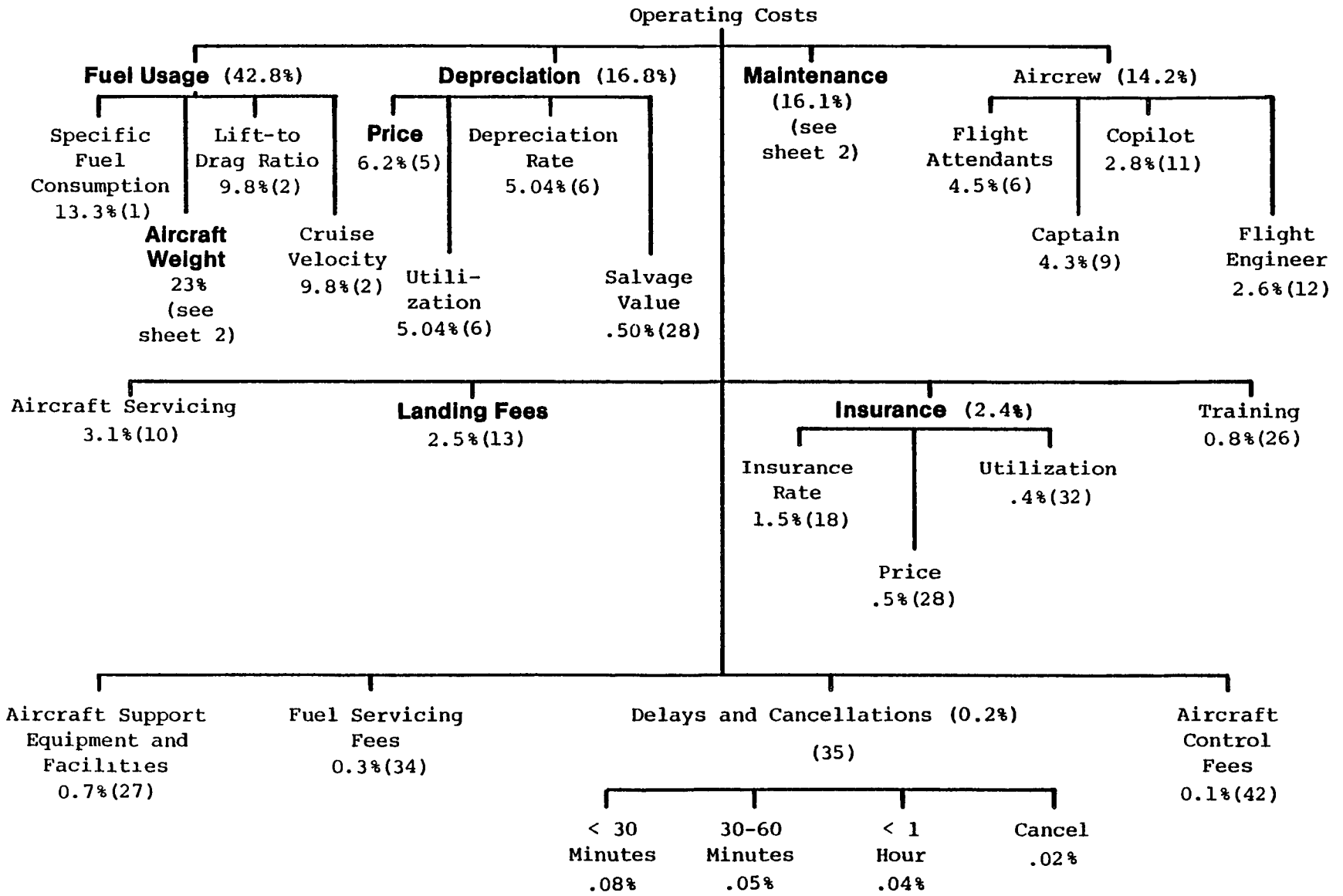


Figure 5-4. OPERATING COSTS PERCENTAGE TREE

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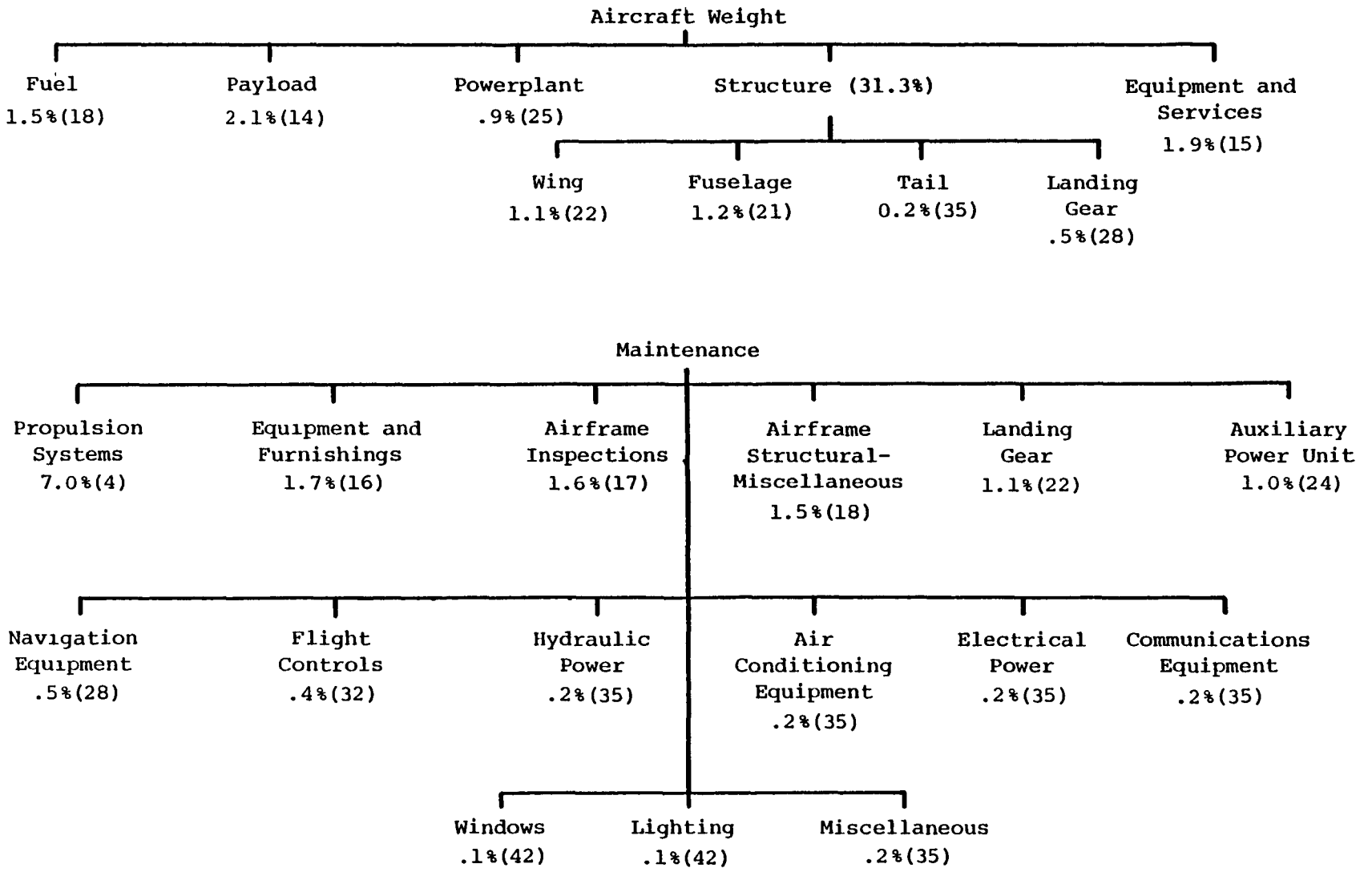

Figure 5-4. (continued)

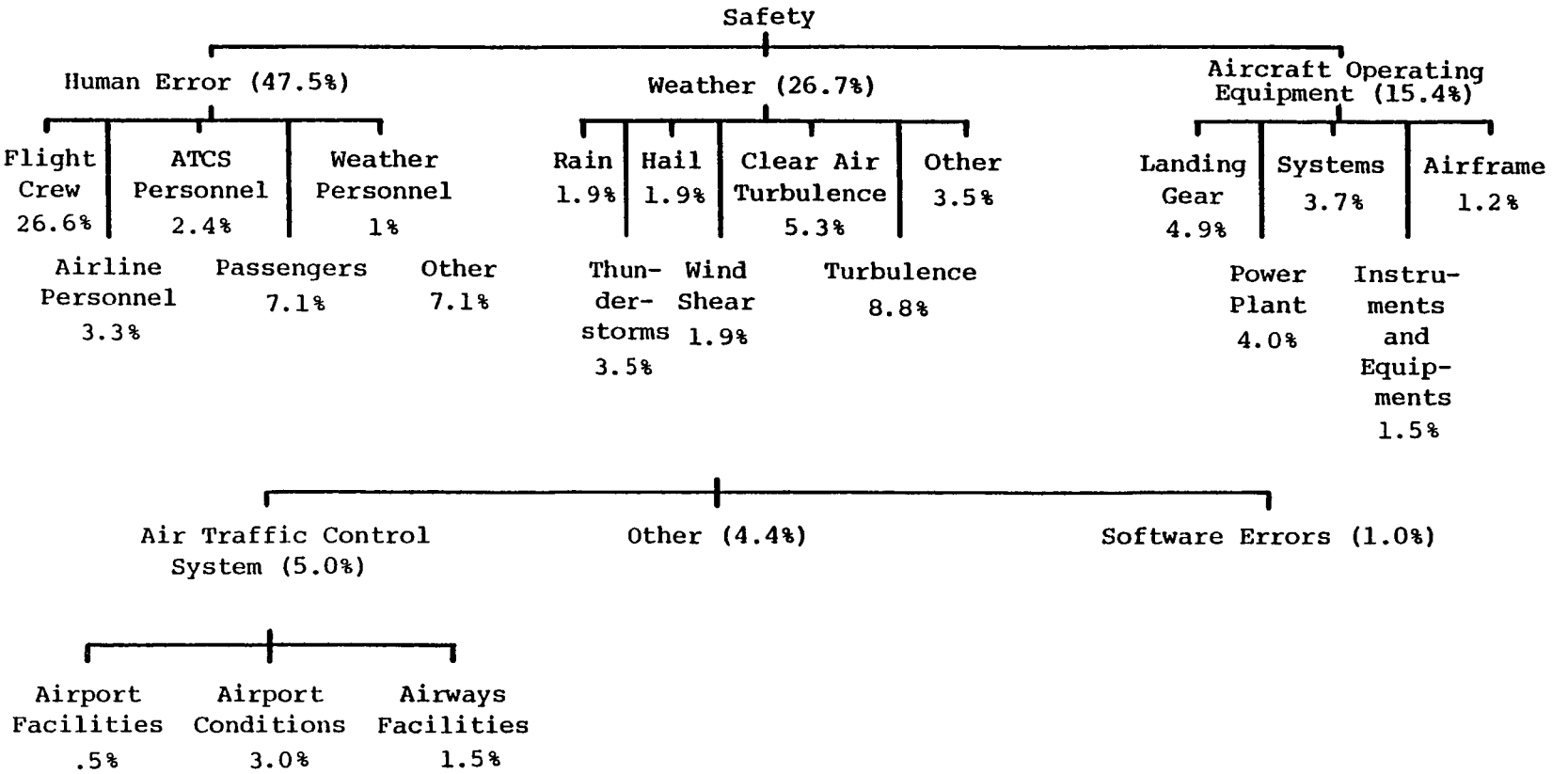

Figure 5-5. SAFETY PERCENTAGE TREE

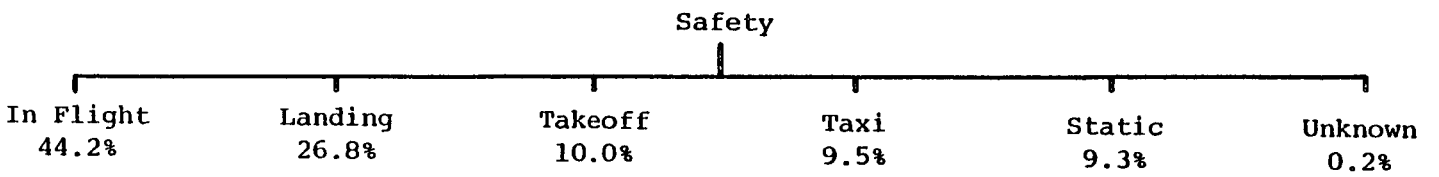

Figure 5-6. SAFETY PERCENTAGE TREE BY PHASE OF OPERATION

1 (MR1), and long-range 1 (LR1) aircraft. (A complex system such as the active landing gear is not considered a candidate for use aboard the current generation of short-range aircraft.) These aircraft are follow-on designs to the 737, A-310, DC-9; 757, 767; and 747 DC-10 classes of aircraft, respectively. Figure 2-2 in Chapter Two, Projected Aircraft Introduction Dates and Lifetimes, and the fleet mix statistics in Table 2-5, Aviation Scenarios, shows that these aircraft are not expected to be introduced until 2000. For the purpose of this example, then, we will assume that all SR1, SR2, MR1, and LR1 aircraft built in 2000 or later will be equipped with the active landing gear, as will later generations of those aircraft. This means in essence that all aircraft built after 2000 will use the active landing gear, but not those built before, since the concept is far too complex to be retrofit into existing aircraft. Table 2-1, in Chapter Two, Forecast Aircraft Production, provides data on the construction of new aircraft after 2000. These data will be applied to the benefits and costs of the concept to determine total benefits.

In calculating the benefits of the active landing gear concept, we begin assuming that the implementation of this concept will result in a net reduction in airframe weight equal to 15 percent of the landing gear weight. This figure is based on engineering judgment and a review of the structure of current landing gear designs. One of the strengths of the methodology is that the sensitivity of the results to this assumption can be quickly determined. Different estimates, say 10 percent and 20 percent, can also be applied, and the effects on the final rank ordering and benefit/cost figures can be observed.

The assumed weight reduction would appear mostly in the landing gear itself, but also in the rest of the aircraft structure. That portion of the aircraft wing, engines, and body required to provide the lift, thrust, and strength for the removed weight can be eliminated. Thus a weight reduction in one part of the aircraft has a "ripple effect" throughout must of the aircraft design. This effect is taken into account in the formulation of Figure 5-1.

Starting, then, with the assumption of a 15 percent reduction in the weight of the landing gear system, we used Figure 5-1 to determine that this would produce a 1.36 percent reduction in aircraft empty weight, which produced a corresponding reduction in fuel usage of 0.2 percent and a reduction of operating costs of 0.086 percent. The 1.36 percent reduction in empty weight also produces a 1.31 percent reduction in initial aircraft price* (Reference 42), leading to a 0.48 percent reduction in depreciation, and a 0.08 percent reduction in operating costs. These factors produce a reduction in operating costs of 0.17 percent per aircraft for 1980, plus a 1.31 percent reduction in initial aircraft price. Using an average lifespan of twenty years, the annual benefit per aircraft is about $34,000.

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*Here we are referring to the basic aircraft costs. There are of course additional costs associated with the active landing gear itself and these will be addressed in a following paragraph.

If the assumed weight reduction were only 10 percent for the landing gear system, the reduction in aircraft empty weight would be 0.91 percent. Using Figure 3-1 and Reference 42, this weight reduction would directly produce a 0.57 percent reduction in operating costs, a 0.873 percent reduction in initial aircraft price, and a 0.32 percent reduction in depreciation. Using 1980 data from Reference 4, plus a twenty-year aircraft lifespan, the annual benefit per aircraft is about $22,462.

If the assumed weight reduction is increased to 20 percent for the landing gear system, the reduction in aircraft weight would be 1.82 percent. Using Figure 5-2 and Reference 42, this weight reduction would result in an 0.11 percent reduction in operating costs, a 1.75 percent reduction in initial aircraft price, and a 0.67 percent reduction in depreciation. Using 1980 data from Reference 4, plus a twenty-year aircraft lifespan, the annual benefit per aircraft is $44,975.

The cost of an active control landing gear system is estimated to be approximately $75,000 per main landing gear (Reference 13) or $150,000 per aircraft. In this, we assume that the LR1, LR2 and LR3 aircraft will follow the configuration of the DC-10 and L1011, with only two main gears. The primary components of the system would include stress sensors ($5,000), a microprocessor for control of the landing gear ($5,000), accelerometers ($5,000), and electric actuators for moving and controlling the landing gear ($10,000) (costs figures include amortized development costs). This microprocessor would make use of the stress sensors and accelerometers on the landing gear system plus information from the air data computer to determine the aircraft loads on the landing gear during landing, takeoff, and taxi operations.

We can now apply these benefit and cost estimates to the data on aircraft production in Table 2-1 from Chapter Two. That table shows the numbers of aircraft built after the year 2000.

As before, to simplify our calculations, we will assume that the benefit applies to the number of equipped aircraft existing at the beginning of a two-year period, plus half the number of aircraft built in that year. This has the effect of averaging the benefits over the new production of that year, thus taking into account the fact that an aircraft built on the first day of the year will accrue the benefit for the whole year, while an aircraft built on the last day of the year will not accrue any benefit at all in that year. From Table 2-1 we extract the following information:

Period	Total Post-2000	Aircraft Produced in this 2-Year Period
2000 to 2002	0	1,200
2002 to 2004	1,200	1,400
2004 to 2006	2,600	1,400
2006 to 2008	4,000	1,400
2008 to 2010	5,400	1,400

Previously we determined the sensitivity of the benefits to the assumption as to the percent reduction in airframe weight effected by the active landing gear concept. For the purposes of this example, let us select the 20 percent case as being the expected reduction. Referring to our previous discussion, we obtain a per aircraft benefit of $44,975 per year. Since our production figures are in two-year increments, we will state the benefit as $89,950 per aircraft per two-year period. For the 2000 to 2002 period, then, the benefit is applied to only the new-production aircraft, since no post-2000 aircraft will exist in 2000. The benefit is applied to half the new production, as discussed earlier: $89,950 × (1,200/2) = $53.9 million. In the 2002 to 2004 period, the benefit is applied to the 1,200 existing aircraft, plus half of the new production: ($89,950 × 1,200) + ($89,950 × 1,400/2) = $170.9 million. Similarly, the remaining periods are calculated to yield benefits of $296.8 million, $422.8 million, and $548.7 million. We can now apply the efficiency weighting factors as discussed earlier. The resulting benefit values are $40.4 million, $128.2 million, $222.6 million, $317.1 million, and $411.5 million for the five successive two-year periods between 2000 and 2010. As before, it is necessary to calculate the present value of these benefits in the base year of 1980. Using the net present value utility program as before, we calculate the 1980 net present value (at 10 percent) to be $91.0 million. Because we have calculated these values based on two-year intervals, we must enter Ø values for the odd numbered years when using the utility program; the utility program is structured to enter annual cash flows in order to be useful in the more general case.

The costs of the system estimated earlier are applied to the new production figures for each two-year period. For the period 2000 to 2002, the cost of $150,000 per aircraft is applied to the 1,200 aircraft produced in that period: $150,000 × 1,200 = $180 million. Similarly, the cost for the subsequent periods are $210 million, $210 million, $210 million, and $210 million. Computing the present value in 1980 yields $96 million.

To summarize, assuming that the active landing gear concept can reduce airframe weight by 20 percent for all aircraft built in 2000 and after, the present value of benefits in the base year of 1980 are $91 million, while the present value of the costs of system implementation is $96 million. Again, we cannot make a final judgment as to the merit of this concept until we have considered the input of the costs of the generic technologies required to make this concept feasible in relation to those of the other concepts under consideration. We will examine those issues at the end of this chapter when we rank the concepts in this example using the ARCEM computer program.

The assumption that benefits and costs apply to the beginning of a period is an approximation we make to simplify our calculations. Added precision could be obtained by integrating over the period under consideration, but at the expense of considerable added computational complexity. The user of this methodology will find that such simplifying approximations greatly facilitate calculations, while introducing only negligible error.

5.1.3 Reduce the Number of Flight Attendants

The third ARINC Research-generated concept deals with one of the four major expense factors associated with aircraft operation: personnel. People costs are almost always a key element of the cost of doing business in any field.

Flight attendant costs are the principal element of aircrew costs. The consideration of flight attendants as a principal cost element is a relatively recent development that has come to light as a result of NASA research into aircraft operating costs. Conventional statistics on direct operating costs excluded flight attendants, grouping their costs with indirect operating costs such adminstrative salaries. The results of the NASA study correctly pointed out that flight attendant costs are in fact directly related to aircraft operation. This is shown clearly by a simple conceptual test: indirect expenses do not disappear if a single aircraft is removed from service, while direct expenses do. Consider the indirect expense of administrative salaries. If a single aircraft is removed from service (i.e., the airlines fleet is reduced by one), the salary of administrators is probably not affected. Direct expenses, such as fuel, do disappear: an aircraft that does not fly uses no fuel. Clearly, in the test case where the fleet shrinks by one aircraft, the flight crews associated with the aircraft (usually 3) will be furloughed: an aircraft that does not fly needs no crew. Thus the costs associated with flight attendants are properly considered as direct operating expenses, along with those associated with the captain, and the first and second officers.

Figures 5-7, 5-8, and 5-9 show that the cost of the aircrew is the fourth largest operating expense for airlines. The expense is divided between the flight crew and flight attendants on about a 2:1 basis with the captain getting 30 percent, the first and second officers sharing 38 percent, and the flight attendants getting 32 percent. Flight crews will probably not be reduced below the two currently being authorized for new generation aircraft. Therefore, the most logical place to reduce flying labor cost is by reducing the number of flight attendants. An examination of their functions revealed that the primary reasons for having flight attendants aboard the aircraft are for reasons of safety in case of an emergency, and to provide an interface between flight crew and passengers. Any concept that would degrade these functions would have to be rejected. The other functions of flight attendants, such as providing service to passengers, are entirely secondary to the safety function.

The two primary functions of flight attendants in an emergency are to open the cabin doors and deploy the escape chutes and to tell passengers what to do. If electronic devices could perform those functions, the number of flight attendants could be reduced. The concept we evaluated is designed to use electronic devices for self-deploying doors and escape chutes and voice-synthesized instructions for emergencies.

The concept of reducing the number of flight attendants has the goals of reducing operating costs and improving safety. Those goals would be

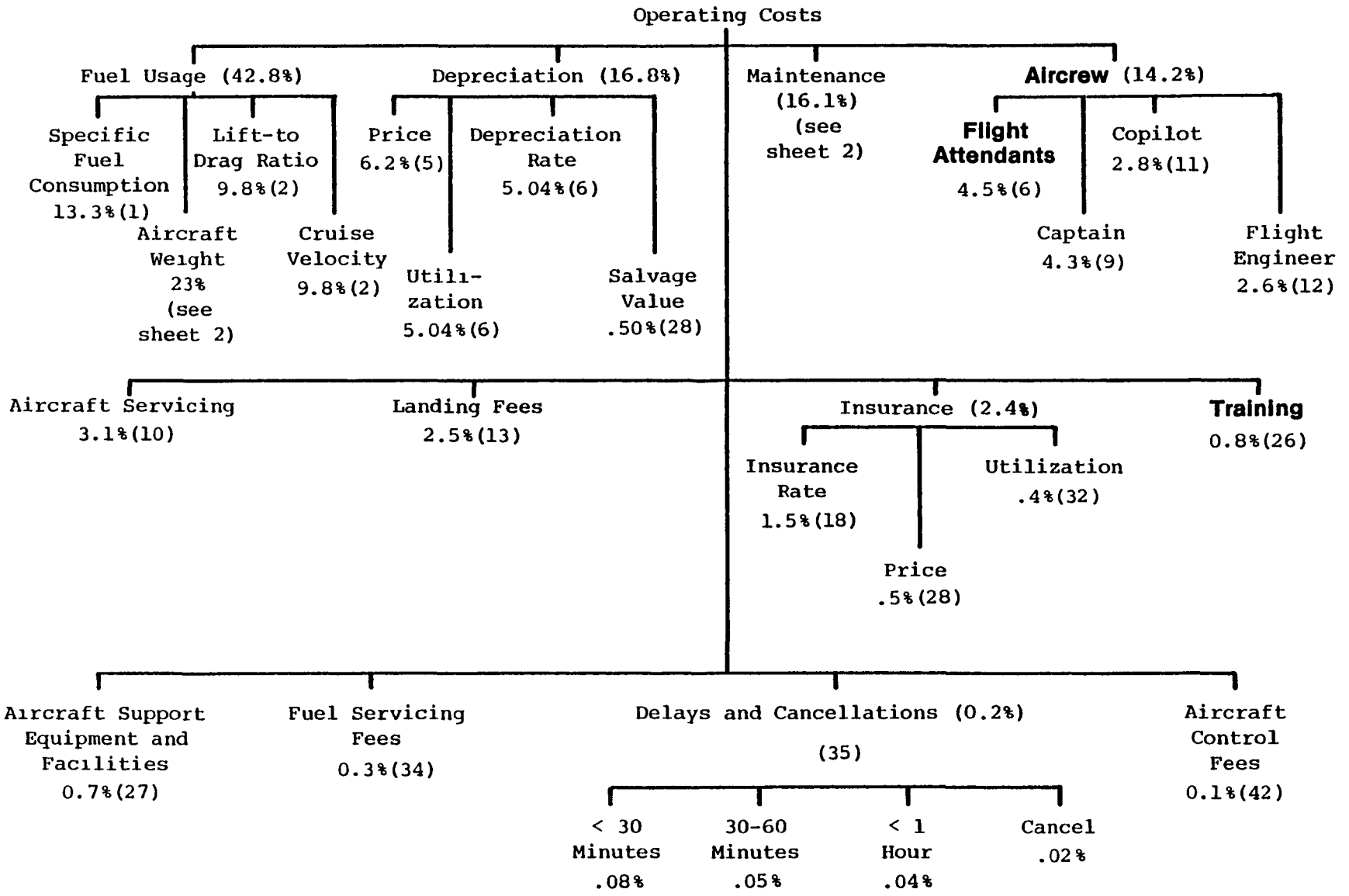

Figure 5-7. OPERATING COSTS PERCENTAGE TREE

(continued)

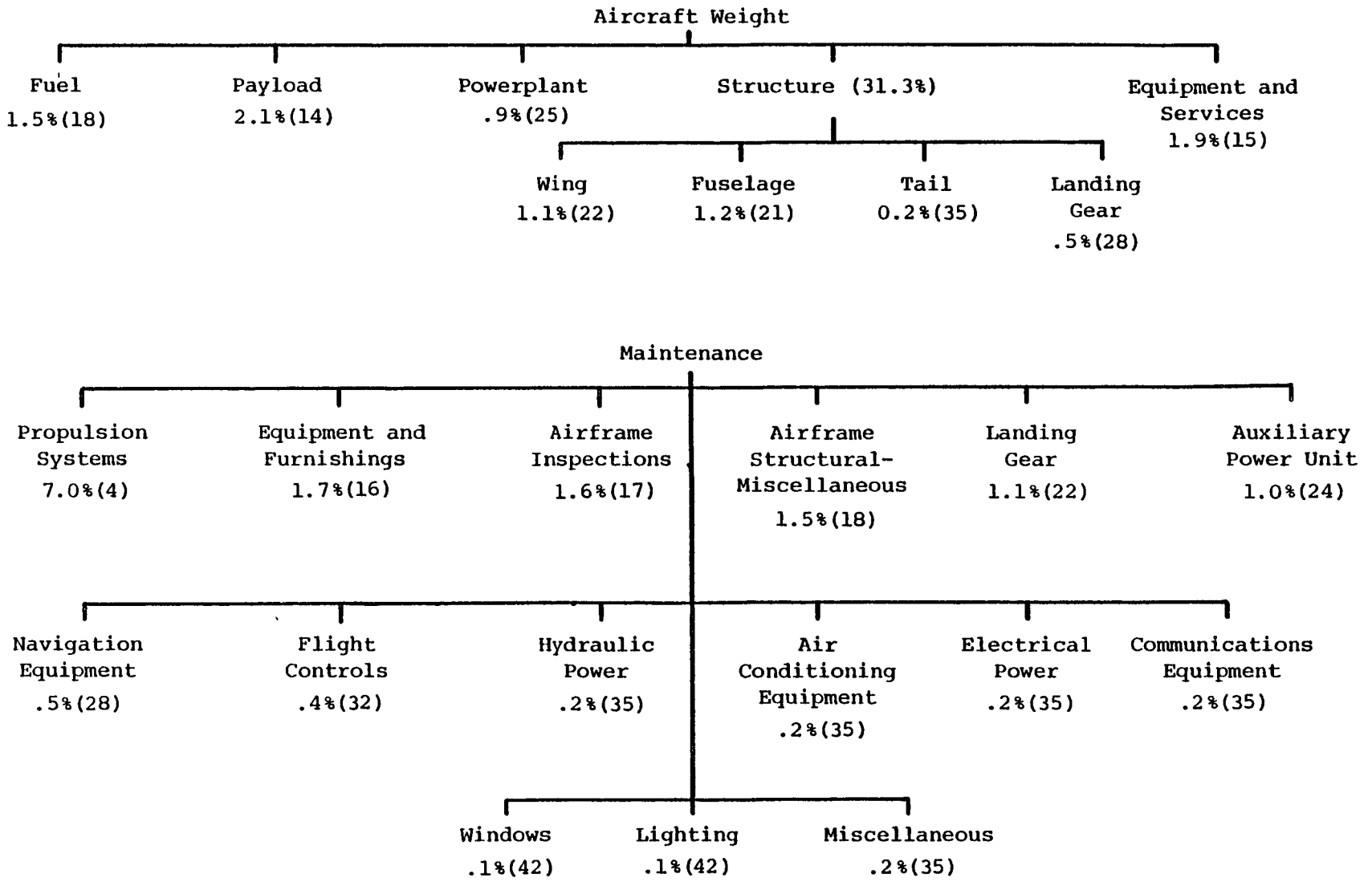

Figure 5-7. (continued)

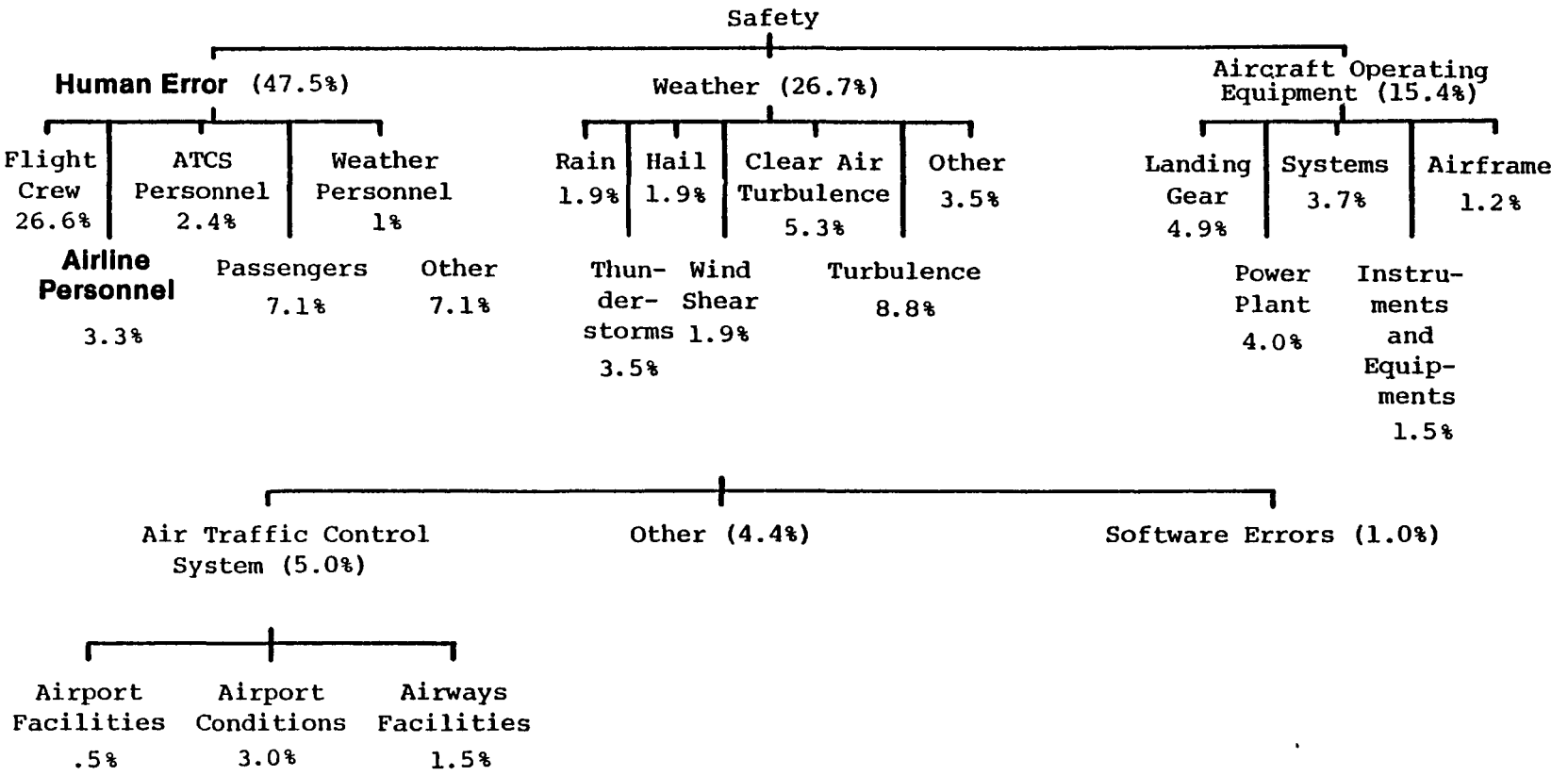

Figure 5-8. SAFETY PERCENTAGE TREE

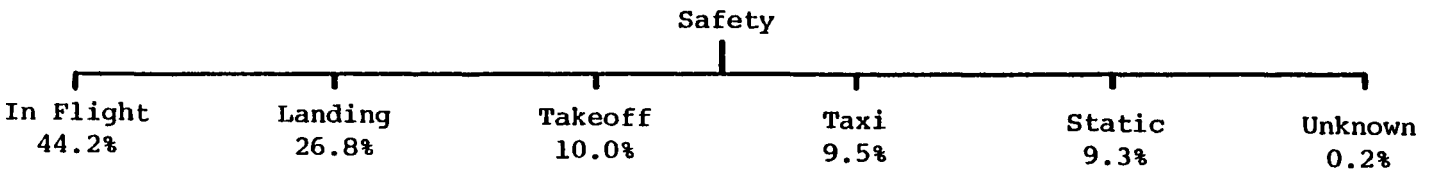

Figure 5-9. SAFETY PERCENTAGE TREE BY PHASE OF OPERATION

achieved by decreasing aircrew costs, training costs, and the number of accidents due to human errors. To achieve those goals, the concept must have these desired capabilities: reduce aircrew size, reduce initial training costs, reduce recurring training costs, and reduce accidents due to judgment errors. These conditions can all be met by the concept of using electronics for door and escape chute deployment and issuance of emergency instructions. This concept, which would be applicable to all aircraft, would affect three different performance factors: flight attendant costs, training costs, and accidents caused by airline personnel.

Current Federal Aviation Administration (FAA) regulations require one flight attendant for every fifty passenger seats on an aircraft. Changing the ratio from 1:50 to 1:75, would result in a 33 percent reduction in the number of flight attendants required. Figure 5-3 shows that this reduction in the number of personnel would produce a 10.56 percent reduction in aircrew costs, which would result in a 1.5 percent reduction in aircraft operating costs. Similarly, the reduced number of flight attendants would reduce training costs by 1.07 percent (from CAB Form 41 data), which would reduce operating costs by about 0.01 percent.

Additionally, the 33 percent reduction in number of flight attendants would reduce the number of accidents attributable to airline personnel by 2.3 percent (Figure 5-3), which would improve overall safety by 1.1 percent. Combining these benefits would produce a net benefit of 1.51 percent reduction in aircraft operating costs plus a 1.1 percent improvement in safety. Using 1980 data from Reference 4, the net benefit per aircraft would be $157,500 per baseline aircraft per year.

The development of such devices as this concept proposes is dependent upon two considerations. Crash environment sensors play a key part in the development because they must detect when a crash has occurred so that the necessary equipment can be used. The second necessary development is the perfection of the self-deploying emergency escape slide. Although current escape slides are self-inflating once the deployment sequence has been initiated by a flight attendant, the escape slides used for this concept must be capable of detecting a crash and deploying without any human assistance. The mechanism for accomplishing and controlling the self-deployment must be developed for this concept to be achievable. The projected state of the art as shown in Table 2-2 of Chapter Two suggests that it would be 1990 before such a system could be operational, perhaps even longer due to the extensive testing necessary for determining its reliability.

The cost of developing such systems as this concept calls for are relatively modest compared to the possible benefits. The development cost for the self-deployment mechanism, sensors, and actuators for the self-deploying emergency escape slides could amount to about $10 million, much of it for reliability testing. The production costs for such a system could be about $20,000 per aircraft, primarily for the self-deployment mechanism, sensors, and the modification of existing escape slides.

The development of a system to deliver voice-synthesized emergency instructions would be more extensive than the escape slides, but the system

would be cheaper to produce. Voice-synthesized speech modules would deliver instructions to passengers before takeoff and landing and in any emergency situation. Sensors and cockpit interfaces and switches would permit detection of the mode of operation and deliver the appropriate messages. Multiple units mounted in the aircraft ceiling could use existing speakers, independently powered and self-contained. Additional messages could be triggered from the cockpit to fit the situation. Development costs for the voice-synthesized aircrew instructions, including extensive reliability testing, could amount to approximately $20 million. Production costs for the voice-synthesizer modules and installation and modification of aircraft for an average of 4 to 6 units could be $10,000 per aircraft (based on discussions with Texas Instruments).

The overall cost would be approximately $43,500 per baseline aircraft.

These system concepts are applicable to all aircraft, both existing and newly built. Let us assume that the technology to implement the concept becomes available in 1990. Table 2-1 again provides information on the numbers of aircraft produced and in service:

Period	Number of Aircraft	Number of Aircraft Built in Each 2-Year Period
1990 to 1992	7,750	1,100
1992 to 1994	8,100	1,100
1994 to 1996	8,450	1,100
1996 to 1998	8,800	1,200
1998 to 2000	9,250	1,200
2000 to 2002	9,600	1,200
2002 to 2004	9,900	1,400
2004 to 2006	10,300	1,400
2006 to 2008	10,700	1,400
2008 to 2010	11,100	1,400

Again, for simplicity, we will assume that the benefits and costs apply to the beginning of each time period, and we will calculate benefits based on existing aircraft plus half of the number of newly produced aircraft, as explained earlier.

Thus, in the 1990 to 1992 period the benefit of $315,000 per baseline aircraft (the annual benefit over the 2-year period) applies to the 7,750 existing aircraft, plus half of the 1,100 new aircraft produced in that period. The benefit for this period is then computed as (7,750 × $315,000) + (1,100/2 × $315,000) = $2,614 million. Applying the efficiency factor

yields a net benefit of $2,352.6 million. Repeating this calculation for the remaining periods yields the following results:

Period	Benefit (In Millions of Dollars)	Net Benefit (Including Performance Factor) (In Millions of Dollars)
1992 to 1994	2,724	2,451
1994 to 1996	2,835	2,551
1996 to 1998	2,961	2,665
1998 to 2000	3,103	2,793
2000 to 2002	3,213	2,410
2002 to 2004	3,339	2,504
2004 to 2006	3,465	2,599
2006 to 2008	3,591	2,693
2008 to 2010	3,717	2,788

Calculating the 1980 net present worth as before yields a present value of $4,355 million.

The costs associated with the implementation of this concept are computed by applying the baseline per aircraft costs to the initial equipage of the existing 1990 fleet, plus the new production aircraft through 2010:

Period	Number of Aircraft	Cost (In Millions of Dollars)
1990 to 1992	8,850	385.0
1992 to 1994	1,100	47.9
1994 to 1996	1,100	47.9
1996 to 1998	1,200	52.2
1998 to 2000	1,200	52.2
2000 to 2002	1,200	52.2
2002 to 2004	1,400	60.9
2004 to 2006	1,400	60.9
2006 to 2008	1,400	60.9
2008 to 2010	1,400	60.9

The 1980 present value of these costs is $207 million.

The very large benefit associated with this concept is a reflection of the major part that personnel costs play in airline operating expenses. However, as before, we must consider the costs of generic technologies required to support the implementation of this concept. These costs can add dramatically to the costs of a concept and must be considered in relation to the technologies required by other concepts under consideration.

5.1.4 Lockheed Concepts

As discussed previously, the NASA-sponsored Electronic/Electric Technology Study, performed by the Lockheed-California Company, identified eight concepts related to future aviation needs. Of these eight, five were independent; two of the eight were subsets of other concepts; while a third included all of the other concepts. The five independent concepts were selected for inclusion in this example use of the ARINC Research methodology. The costs and benefits used in the analysis that follows were taken directly from the Lockheed study. As in our analyses, Lockheed used 1980 as the base year for calculation of benefits and costs. Each of the five concepts is outlined in the sections that follow. The reader is referred to Reference 46 for complete details.

5.1.4.1 Advanced Flight Controls (AFC)

The Lockheed advanced flight systems concept encompasses a number of advanced technologies to implement a complete fly-by-wire capability in a relaxed static stability mode. A four-channel redundant system completely eliminates the heavy and bulky hydraulic system used in current-generation aircraft. Four independent computer systems operate in parallel, calculating and comparing control surface commands and voting on the result. Out-of-tolerance signals are rejected, and the median value of the remainder is selected for control actuation. Three of the four computers can fail without loss of control. The total system exhibits a probability of failure of less than 10^{-9} per ten flight hours. Some of the key features of this concept are automatic check-out of systems, software reliability analysis, relaxed static stability, center-of-gravity management, and direct life control.

5.1.4.2 Advanced Secondary Power Systems (ASP)

In this concept, advanced power generation and distribution systems are employed to enhance reliability and efficiency and reduce weight and bulk. Advanced generators using rare-earth magnets and constant frequency drives are used in pylon-mounted and integrally mounted configurations. High efficiency starters and advanced auxiliary power units are included.

5.1.4.3 Advanced Avionics Components (AA)

The advanced avionics concept includes specific systems that support such functions as flight control, navigation, and communications. The concept comprises digital data transfer, large scale integrated circuits, standard module (card), integrated avionics racking, multiplexed interconnection, and advanced sensors such as laser gyros.

The standard module is an approach to an integrated avionics structure that replaces individual avionics boxes with circuit cards housed in standard enclosures. Additions, deletions, and modifications can be made by manipulating individual cards, which can be easily removed and replaced without the installation activities associated with conventional boxes.

5.1.4.4 Advanced Cockpit (AC)

Lockheed has postulated an advanced cockpit configuration containing multipurpose flat panel color displays, multifunction controls, and side arm controllers.

The displays will use liquid crystal or electro-luminescent technology, with keyboards integrated with the displays. The display will provide key legends, corresponding to the software-controlled function presently assigned to that key. Advanced alerting and warning systems are provided, using synthesized voices, flashing information displays, and tones. Head-up displays employ holographic lenses to display a variety of information in the pilot's field of view, including auto-land back-up symbology. Voice control of systems such as flaps, landing gear, and spoilers is also included.

5.1.4.5 Air Traffic Control (ATC)

In this concept, advanced flight management computers are integrated with cockpit systems including CDTI and DABS. The system will work cooperatively with ground systems such as MLS, DABS, AERA, and ETABS. The benefits of this concept include more conservative land use at airports, energy savings and noise abatement in addition to money savings.

5.1.4.6 Analysis of Concepts

These five concepts were analyzed by Lockheed by means of its ASSET computer program. Lockheed's conclusions are summarized below for the aircraft referred to in the study as the ATX-350. (This aircraft configuration is similar to the LR1 aircraft identified in our study and will be used for comparison.) The percentage reduction in DOC calculated by Lockheed was applied to the average base year DOC of approximately $10,000,000 per aircraft.

Concept	Benefit* (In Thousands of Dollars per Aircraft) Per Year	Gross Cost (In Thousands of Dollars)
Advanced Flight Control	400	5,653
Advanced Secondary Power Systems	600	5,322
Advanced Avionics	50	6,113
Advanced Cockpit	300	6,043
ATC Systems	600	6,146

Lockheed bases its estimates on a predicted production run of 300 aircraft with a lifetime of 16 years. For the purposes of this example, we will assume that these aircraft will enter service at the beginning of 1990 and will continue in service for 16 years. The total cost of each concept is obtained by multiplying its cost by 300, the number of aircraft. The benefits accrue over the 16-year life of the aircraft. As before, the 1980 present value of the benefits and costs is calculated. The dollar benefit of concepts is calculated by applying the Lockheed estimates of percent DOC savings to the 1990 DOC of about $10,000,000 (taking into account the efficiency factor). We will assume that the efficiency factor does not change in this case, since all the aircraft are assumed to enter service at the beginning of the period.

Calculating the benefits and costs for the various system concepts yields:

Concept	Benefit (In Millions of Dollars)	Net Cost (In Thousands of Dollars)
Advanced Flight Control	361.9	-150.6
Advanced Secondary Power Systems	542.9	-249.9
Advanced Avionics	45.3	-12,600
Advanced Cockpit	271.5	-33.6
ATC Systems	542.9	-2.7

The negative cost figures indicate a savings over the cost of similar systems on the baseline aircraft. As before, however, we must consider the effect of generic technology costs before drawing conclusions as to the overall merit of each concept.

*Based on Lockheed results of reduction in DOC applied to base year DOC values.

5.2 GENERIC TECHNOLOGIES

To conclude this example use of the methodology, we will estimate the types and costs of generic technologies needed to implement the concepts we have examined and rank-order the concepts using ARCEM. We have selected the following generic technologies for inclusion in this example.

1. High-Reliability Systems
2. Fault-Tolerant Computers
3. Electromechanical Actuators
4. Digital Avionics
5. Software Verification
6. Airborne Laser Systems
7. Advanced Attitude Sensors

The costs associated with these technologies will be treated in the way they would be in a sensitivity analysis. The initial estimate will be adjusted, and the change in results observed. The concept data and generic technology initial cost estimates are summarized in Figure 5-10. These data were entered into the ARCEM Program as described previously, and the program was used to rank-order the concepts and to compute cumulative benefit-cost ratios. The results are reproduced in Appendix F. Figure F-1 shows the listing of the concepts as entered from the work form. The program was used to sort the concepts and compute the cumulative benefit-cost ratios, with the results shown in Figures F-2 and F-3. Figure F-2 shows the concepts in their sorted order, with the cumulative ratio shown for each. The ratio shown for the fifth concept, for instance, is the cumulative ratio for doing the first five concepts in order. Figure F-3 shows these results in graphic form. As that figure shows, the cumulative benefit-to-cost ratio reaches a maximum upon performing the sixth concept and thereafter declines. As a result, the planner knows that if he wishes to maximize the benefit-to-cost ratio of his program, he should implement the first six concepts and then stop. Although the absolute ratios are high enough for the last two concepts, their performance will degrade the cumulative ratio from its peak value.

The negative cost values for the Lockheed concepts are ordered by their benefit-to-cost ratio. Since negative ratios have no meaning, it was necessary to adjust the cost values for the purposes of computation. In this example, we simply assigned a very small positive cost value to each concept that had a negative cost value. This produces negligible error since the negative cost values were very small compared to the benefit. Another approach would be to add the difference between the actual and adjusted cost to the benefit. This approach should be used when negative costs are encountered that are large relative to the benefits. The adjustment in the costs will be reflected in subsequent listings of the concepts.

The ARCEM Program can be used to reveal the sensitivity of the results to changes in our input assumptions. We will suppose that our estimate of the cost of the first generic technology was in error by 100 percent; that it is $1,000 million instead of $500 million. Using the editing capability

Concept Number	Concept Name	Benefit	Cost	Generic Technologies																		
				1. High Reliability Systems	2. Fault Tolerant Computers	3. Electromechanical Actuators	4. Digital Avionics	5. Software Verification	6. Airborne LASER Systems	7. Advanced Sensors	8. Advanced Displays	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
1	Wind-Shear Detector	$ 304M	$203M	1	1	0	0	0	1	1	0											
2	Active Control Landing Gear	$ 91M	$ 96M	1	1	1	0	0	0	1	0											
3	Reduced Number of Flight Attendants	$4,355M	$207M	1	1	1	0	1	0	1	0											
4	Advanced Flight Control System	$ 361.9M	-$.15M	1	1	1	1	1	0	1	0											
5	Advanced Secondary Power Systems	$ 542.9M	-$.249M	1	1	0	0	0	0	0	0											
6	Advanced Avionics	$ 45.3M	-$.012M	0	0	0	1	1	0	0	0											
7	Advanced Cockpit	$ 271.5M	-$.033M	1	1	0	1	1	0	0	1											
8	Advanced ATC	$ 542.9M	-$.002M	1	1	0	1	1	0	0	1											
			Costs:	$500M	$500M	$100M	$100M	$ 50M	$150M	$ 50M	$ 50M											

Figure 5-10. EXAMPLE WORK SHEET

of ARCEM, we make this change as shown in the listing in Figure F-4. We then recompute the results, shown in Figures F-5 and F-6. Comparing these results with the previous run shows that the increase in the cost estimate did not result in a change in the ordering, although it did reduce the ratio values. The peak value of benefit-cost is reduced from 3.93 to 2.97. The overall shape of the output, however, is relatively unchanged. Note that the scale of the y-axis changed as the numerical values were reduced.

As a second sensitivity test, we will observe the effect of increasing the benefit of the advanced avionics concept to $100 million. This change is reflected in the listing in Figure F-7. The results, shown in Figures F-8 and F-9, indicate that no change in rank-ordering results and only small changes in cumulative ratios occur.

As a final sensitivity test, we will observe the effect of reducing by about 50 percent the benefit associated with the wind-shear detector concept. This change, shown in Figure F-10, results in a significant reduction in the cumulative benefit-to-cost ratio. These results are shown in Figures F-11 and F-12. Thus the results are shown to be quite sensitive to this change.

5.3 SUMMARY

This chapter has presented examples of the use of the project methodology in analyzing concepts created by the methodology, as well as concepts obtained from outside sources. In exemplifying the methodology, we have to use benefit and cost estimates that are as meaningful and realistic as possible. Readers may have differing opinions as to the values used, especially in the estimates of generic technology costs. These readers are invited to substitute their estimates for ours, and using the project methodology, determine the results of their assumptions.

CHAPTER SIX

CONCLUSIONS

In this project, we have developed a structured methodology for the generation and analysis of controls and guidance concepts aimed at improving the performance of various types of aircraft. This methodology is supported by a base of information on the relationships between the various elements of the aircraft and its overall performance.

The information collected on aircraft performance indicates clearly that future development of aircraft will be evolutionary, rather than revolutionary. No dramatic departures from conventional engineering practices are expected. Exotic fuels such as liquid hydrogen are not expected to be used to any significant extent through the year 2010.

The operators of transport aircraft in the coming three decades are expected to face many of the same problems faced by operators today. The cost of fuel will continue to be the dominant factor in operating costs. Maintenance, depreciation (including purchase price of the aircraft), and crew costs are also expected to remain as major cost elements. The safety of the passengers, crew, and aircraft are expected to remain key considerations, as is the level of noise and air pollution produced by aircraft.

Controls and guidance concepts can materially aid in alleviating these and related problems. The structured methodology developed in this study can serve as a framework for planners to use in identifying the most promising areas for the application of concepts. It can also serve as a tool for analyzing the concepts and structuring the research and development program to obtain the maximum benefit by taking advantage of high pay-off concepts and technologies already acquired in the development of related concepts.

This general, open-ended methodology is applicable to a wide range of concepts. It is not specific to controls and guidance concepts, or even to aviation. Supported by an appropriate base of performance data similar to that created in this study for civil transport aircraft, the methodology can be used in many other fields. It is applicable to any planning task in which independent alternatives with quantifiable benefits and costs are being considered. The speed and ease of computation provided by the automated portion of the methodology, the ARCEM Program, makes the methodology applicable to planning tasks requiring parametric, iterative, or sensitivity

analyses. These techniques are extremely useful in performing planning activities when only poor or incomplete information is available. The ARCEM Program provides a powerful tool for the analysis of such cases.

We at ARINC Research believe that the approach to program planning described in this report, consisting of both a conceptual framework and a set of useful analysis tools, is a meaningful response to requirements placed on planners in today's environment. The structuring of a research and development program using this methodology will help to ensure the maximum return for the money and effort expended on research.

APPENDIX A

ANALYTICAL RELATIONSHIPS

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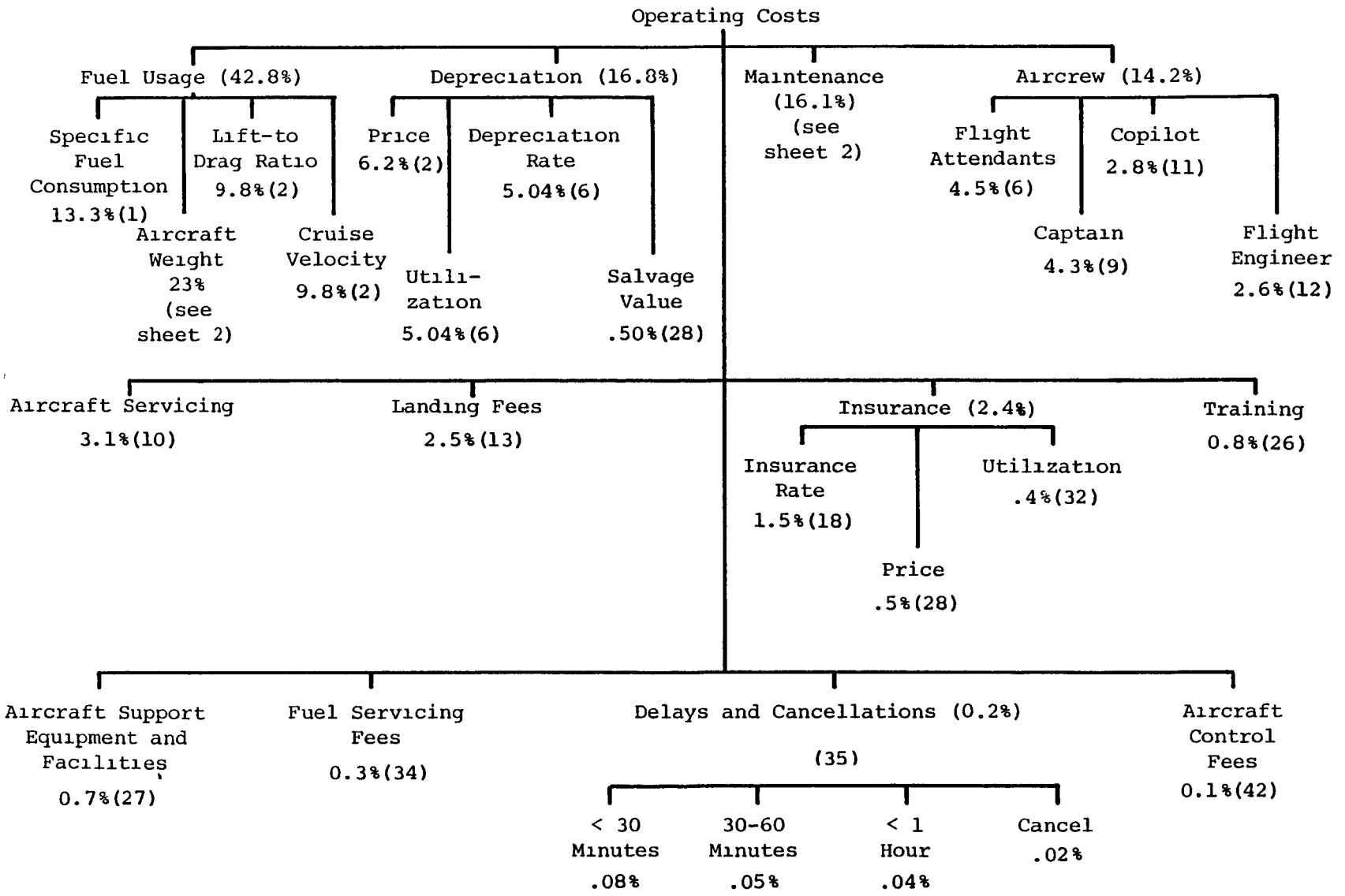

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Figure A-1. OPERATING COSTS PERCENTAGE TREE

(sheet 1 of 2)

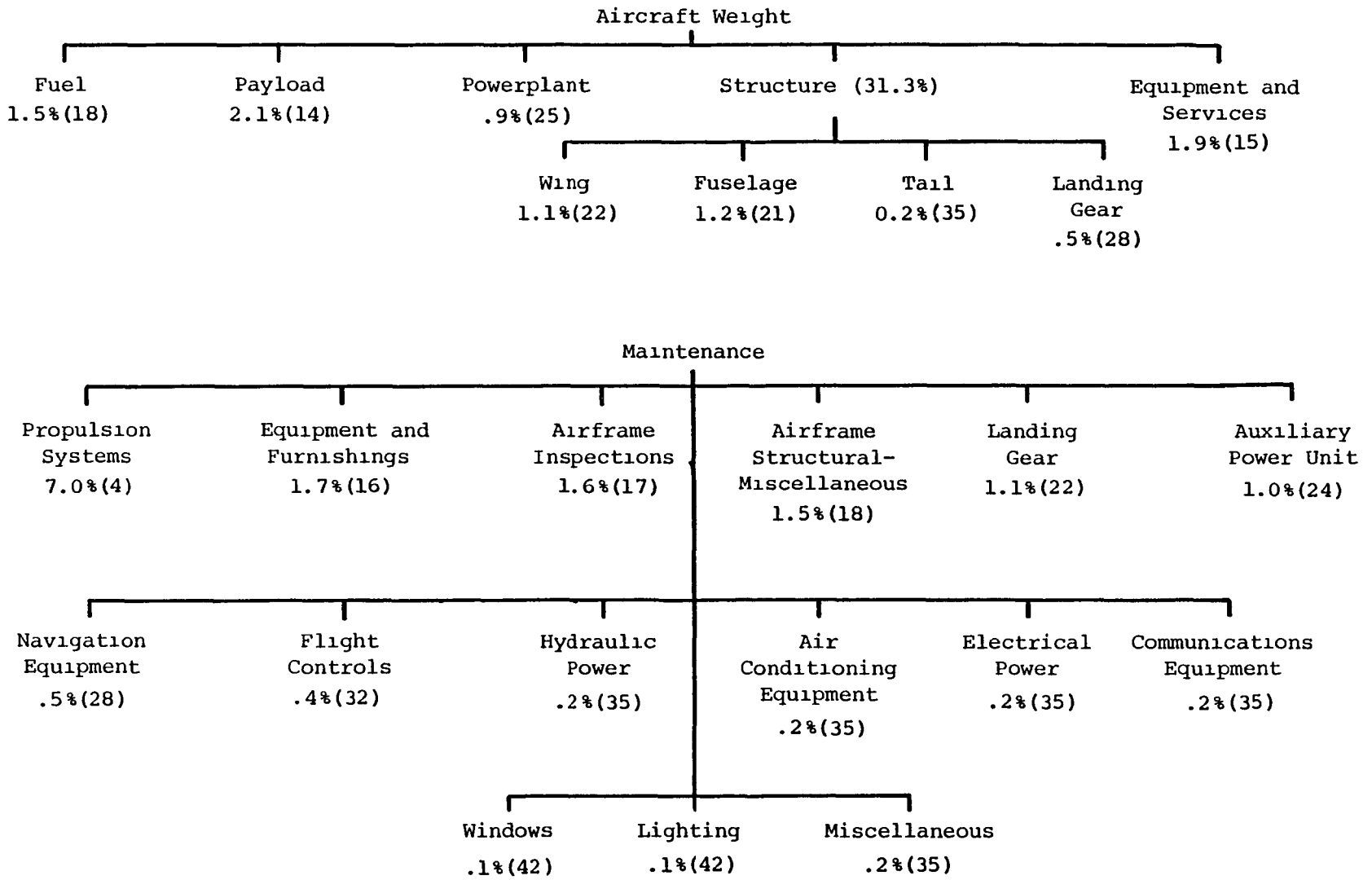

Figure A-1. (continued)

(sheet 2 of 2)

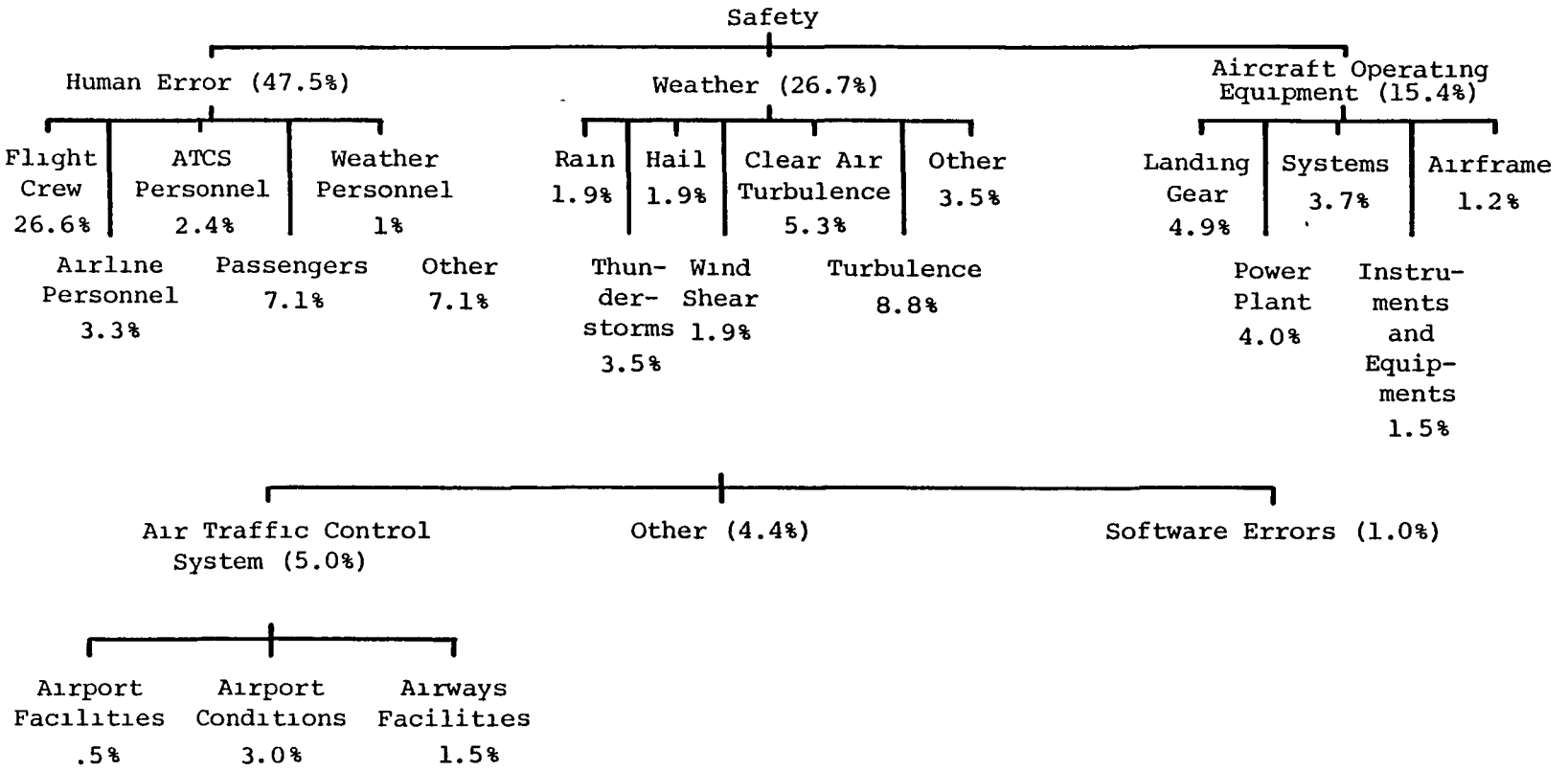

Figure A-2. SAFETY PERCENTAGE TREE

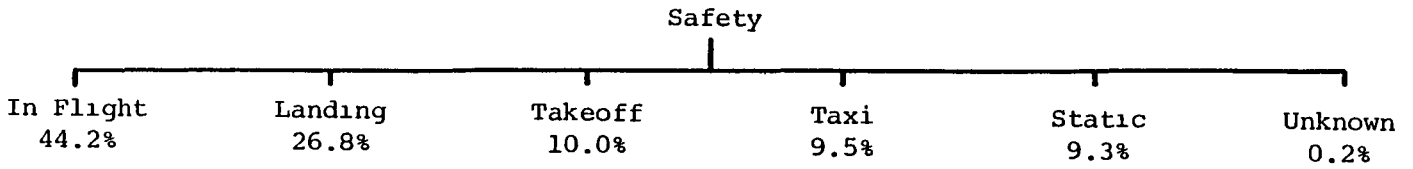

Figure A-3. SAFETY PERCENTAGE TREE BY PHASE OF OPERATION

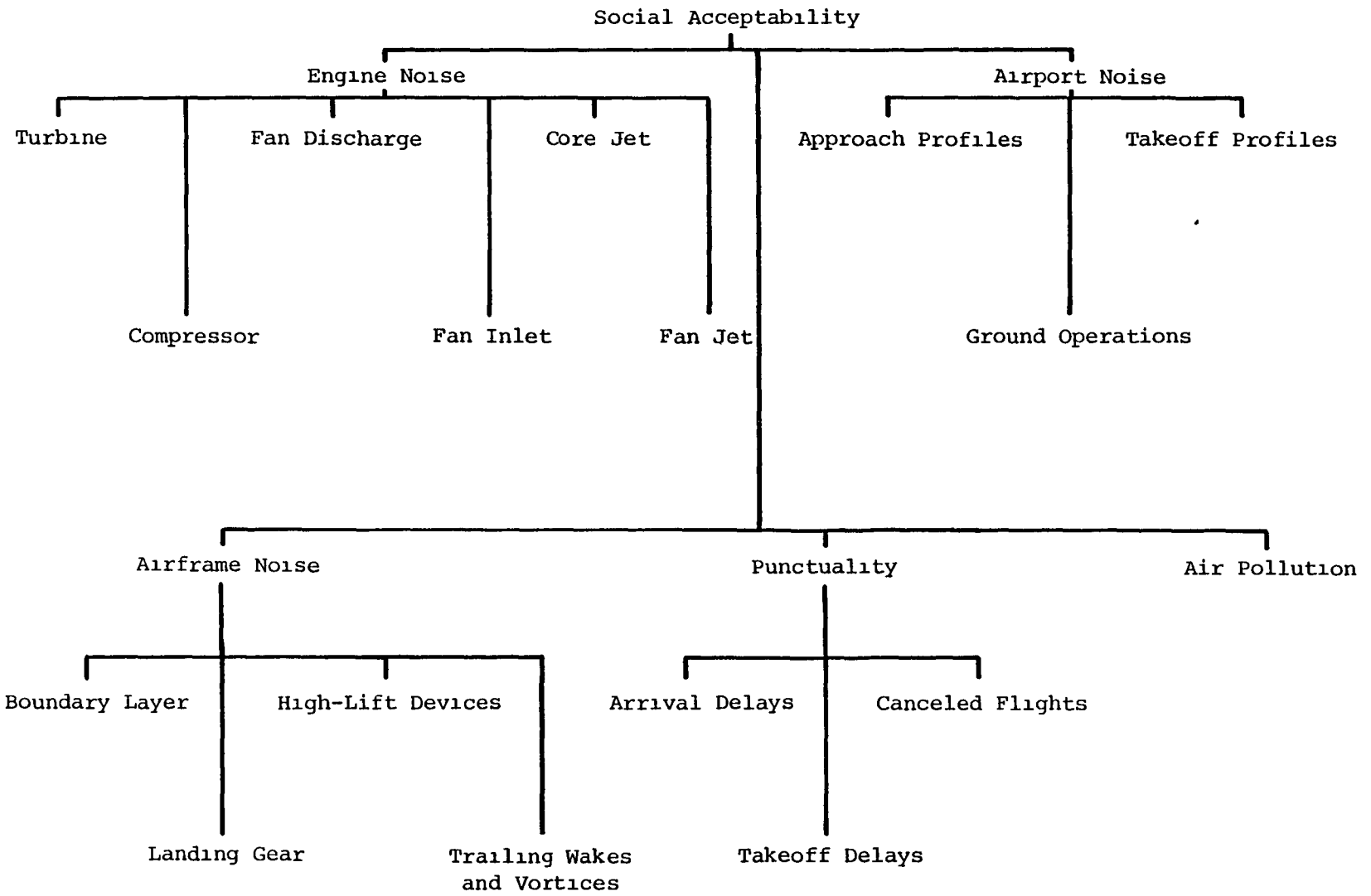

Figure A-4. SOCIAL ACCEPTABILITY FACTORS

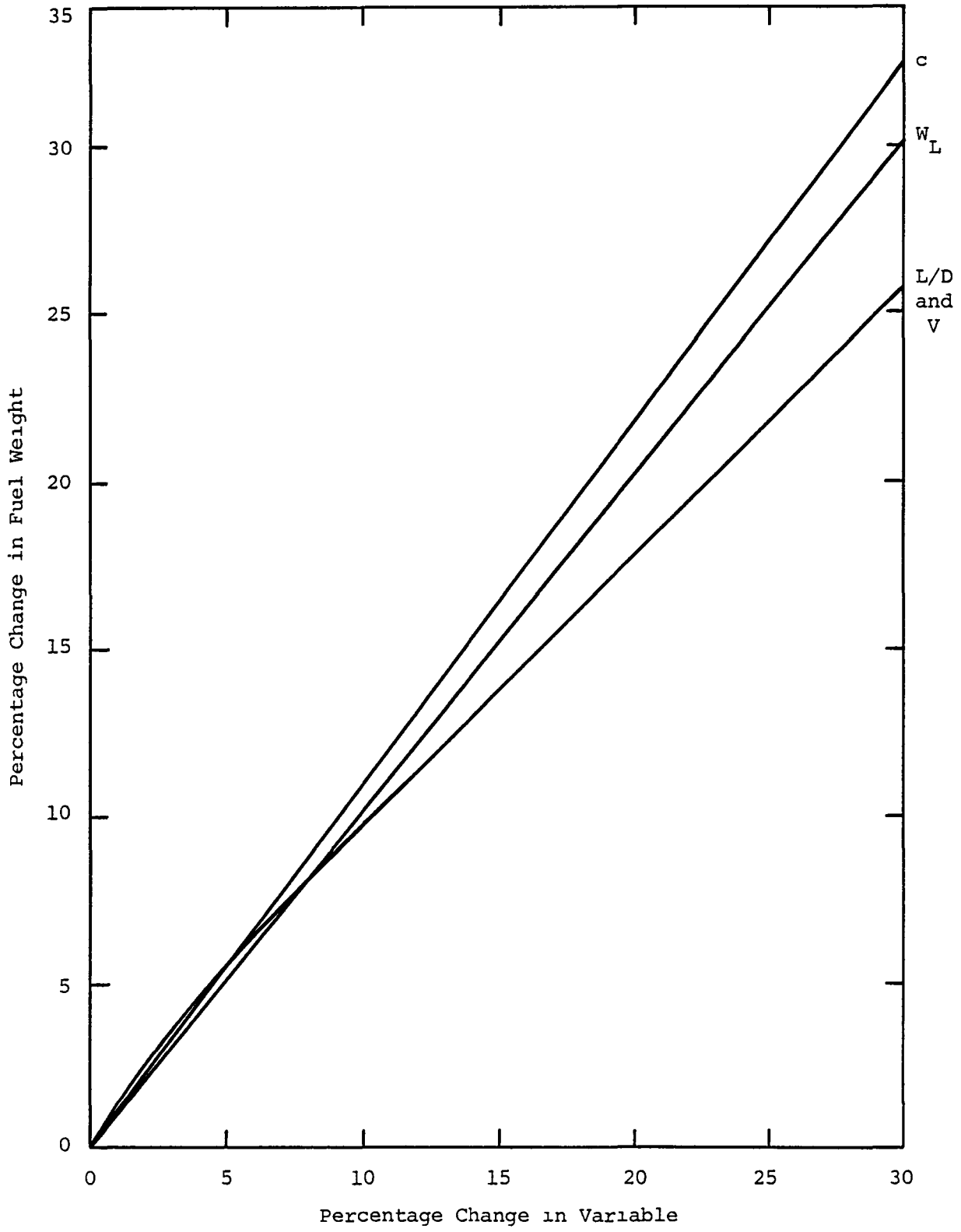

Figure A-5. FUEL USAGE: SHORT- AND MEDIUM-RANGE AIRCRAFT

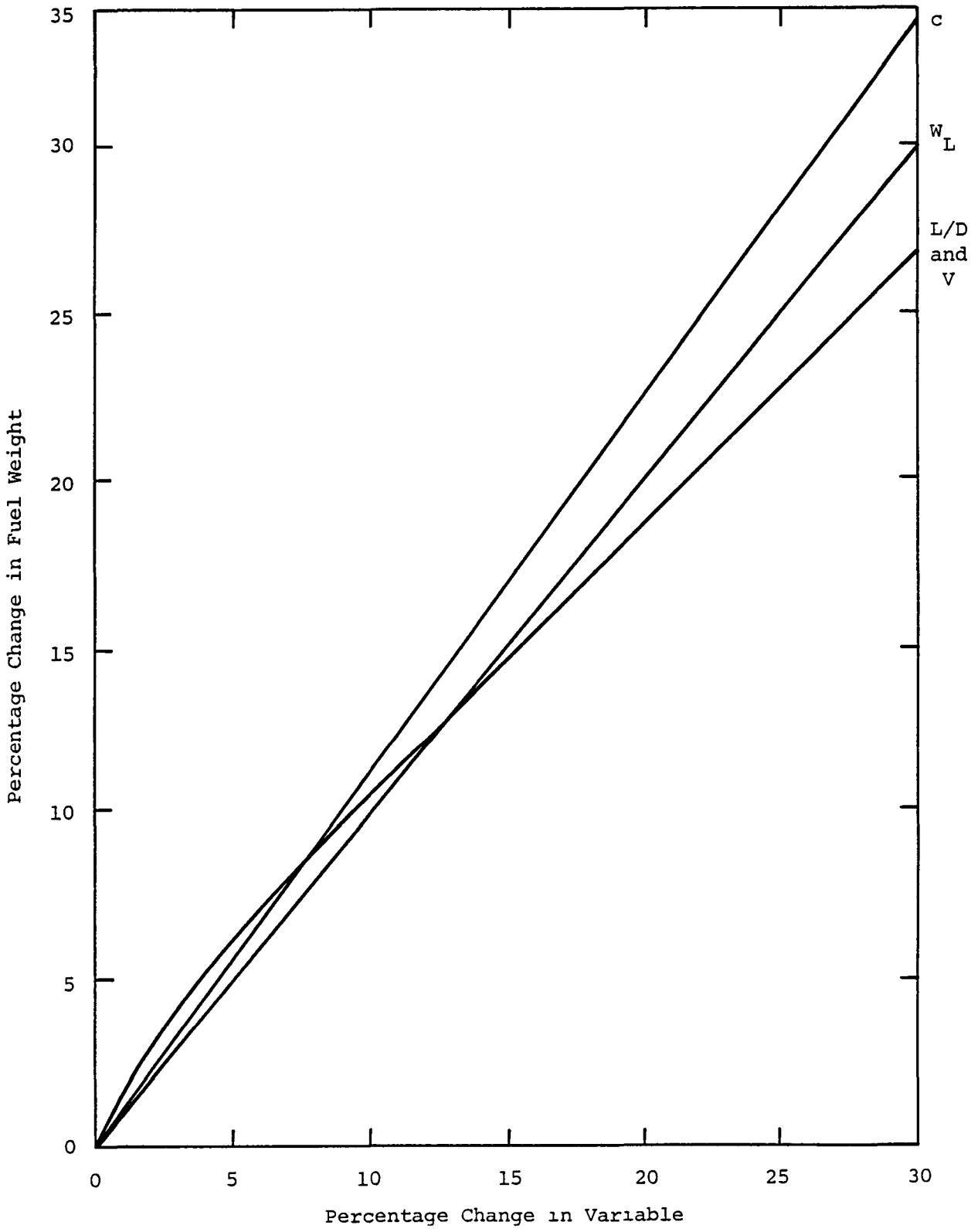

Figure A-6. LONG-RANGE AIRCRAFT FUEL USAGE

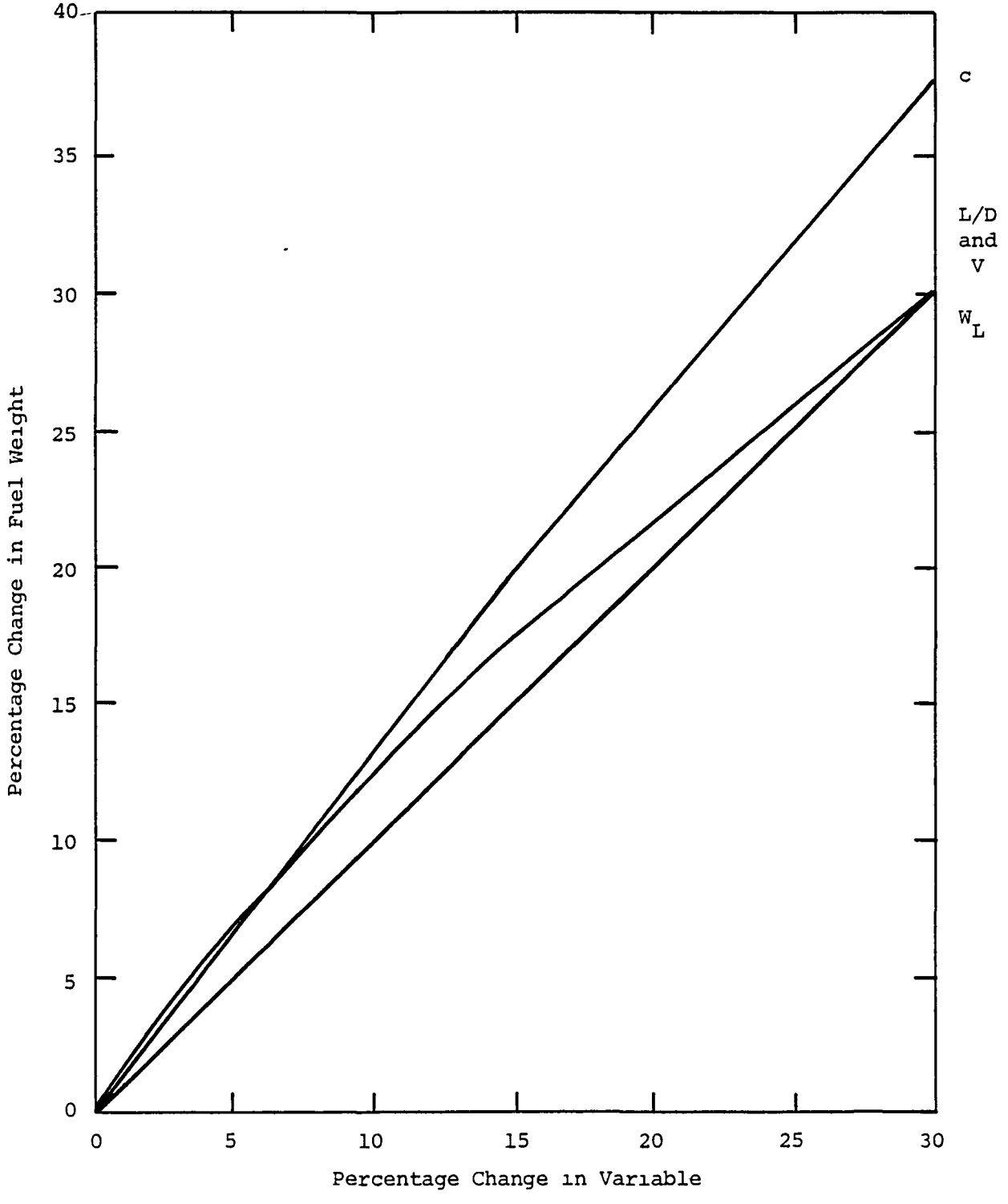

Figure A-7. FUEL USAGE: SUPERSONIC TRANSPORT AIRCRAFT

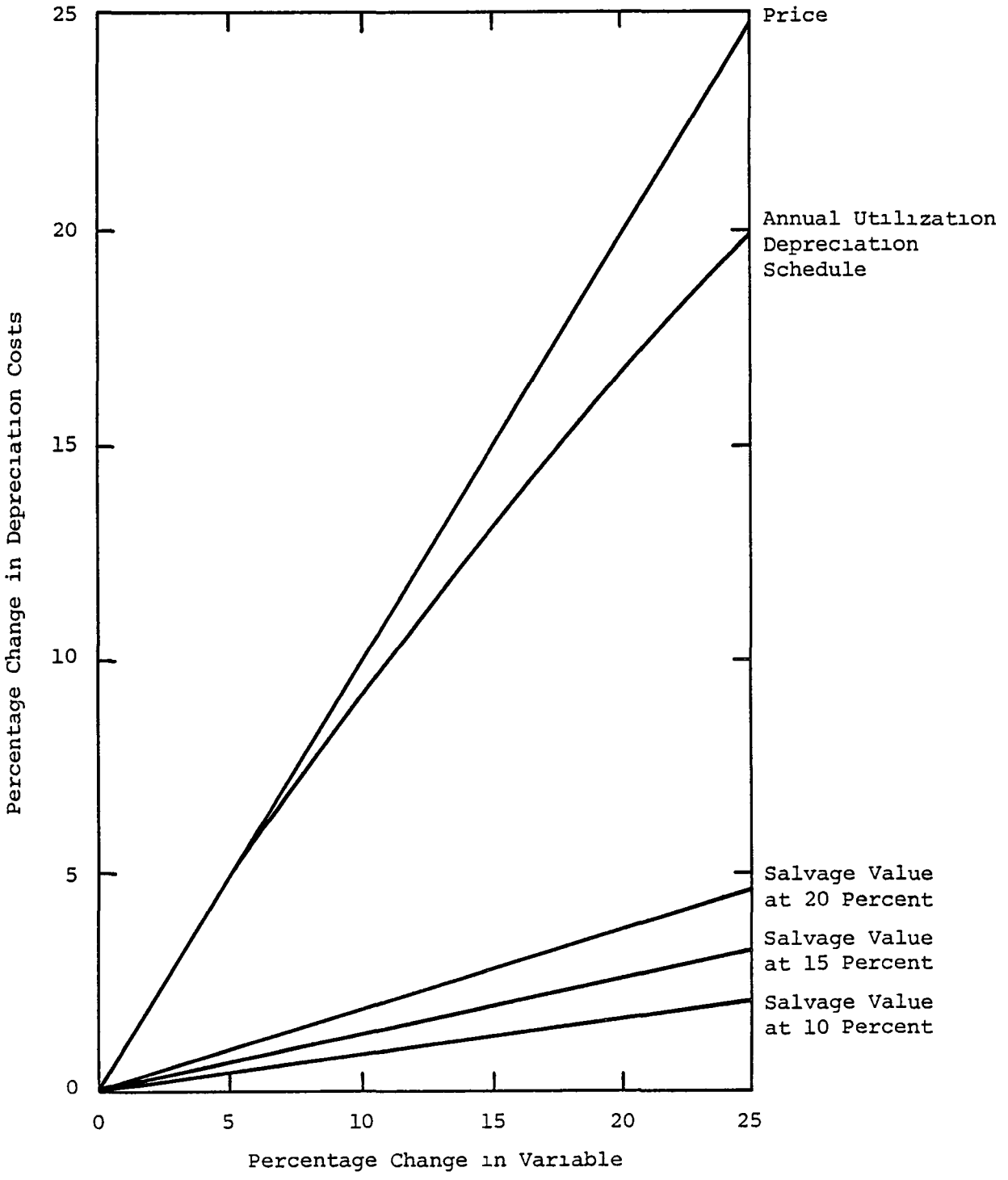

Figure A-8. DEPRECIATION FACTORS

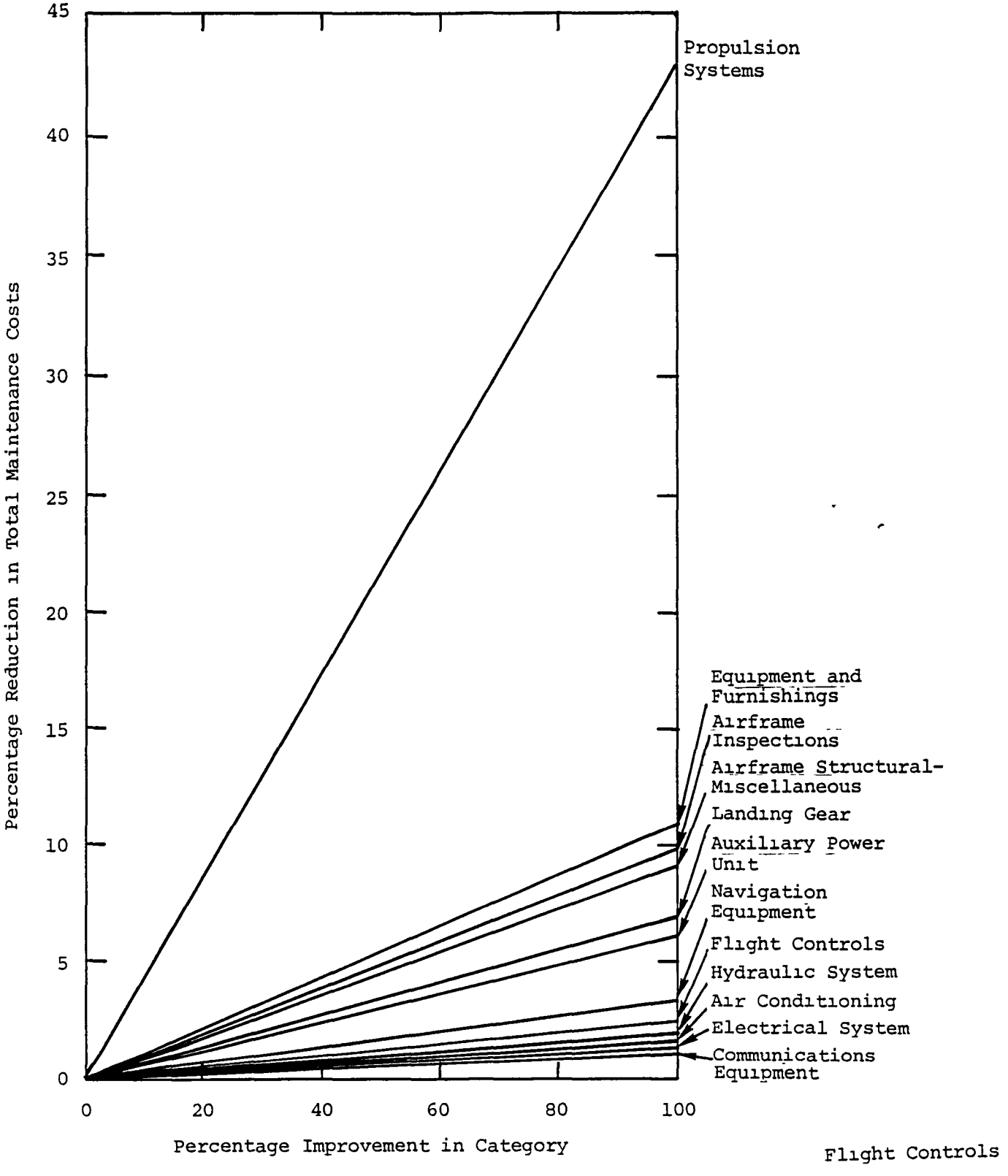

Figure A-9. AIRCRAFT MAINTENANCE FACTORS

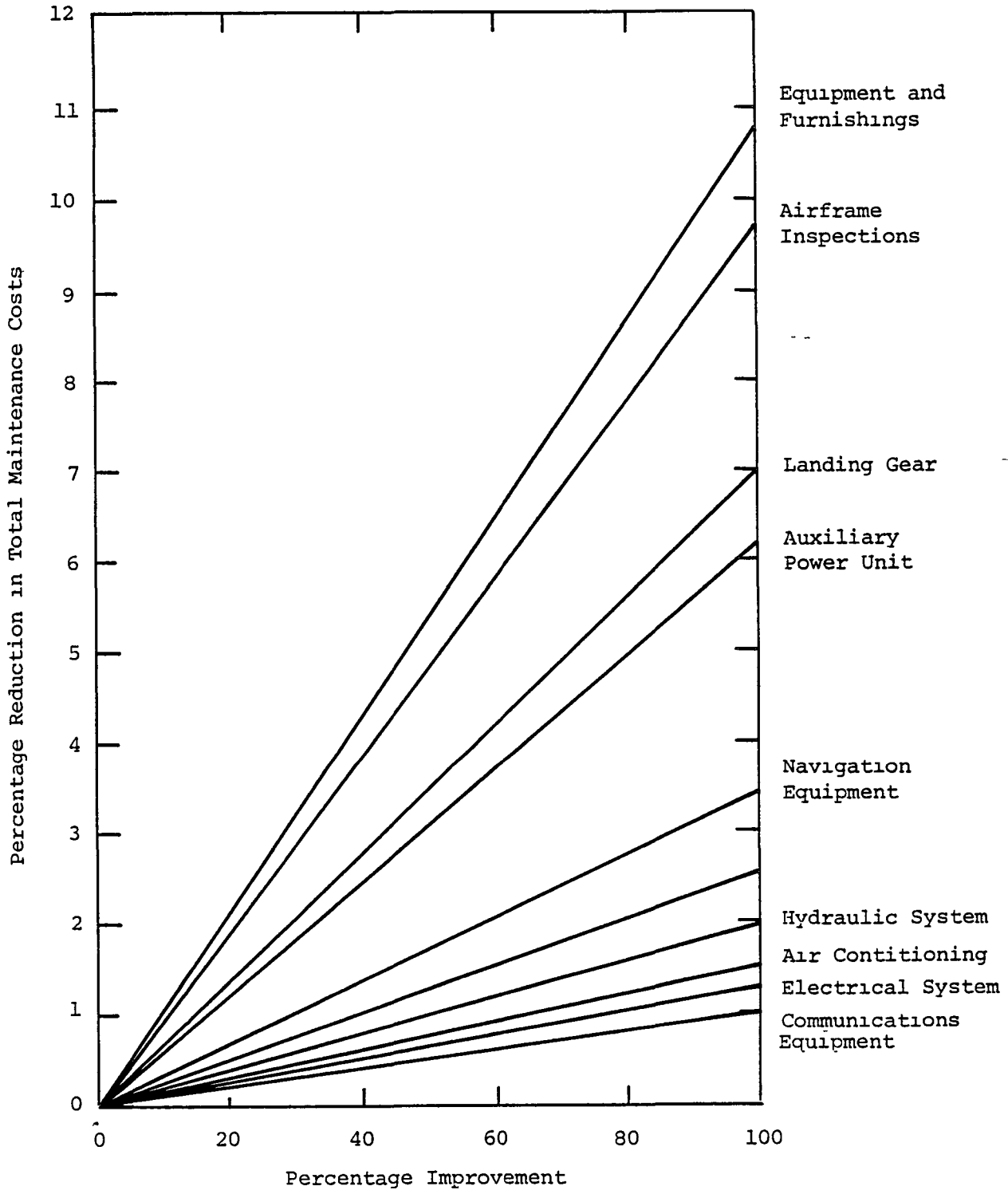

Figure A-10. AIRFRAME MAINTENANCE FACTORS

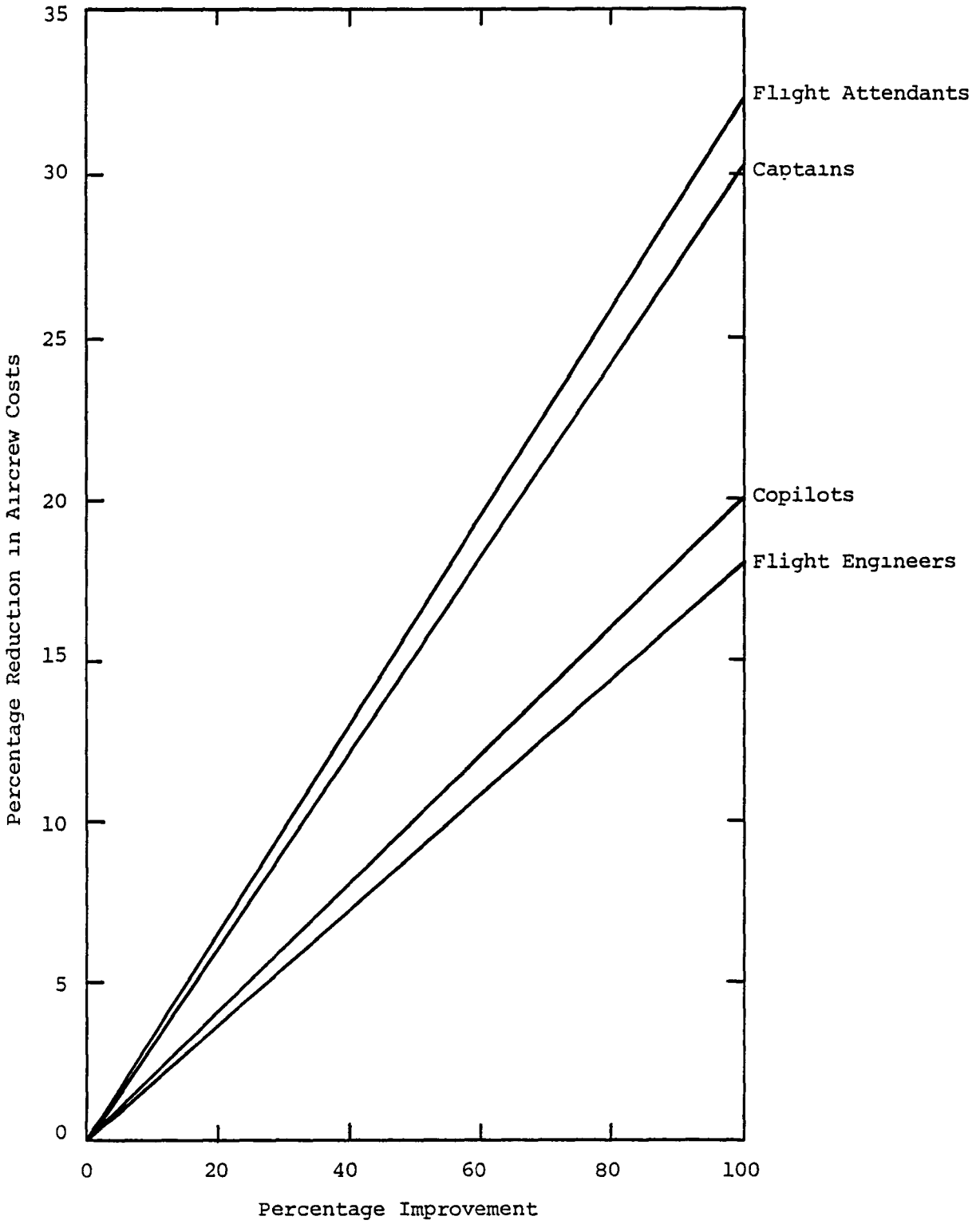

Figure A-11. AIRCREW COST FACTORS

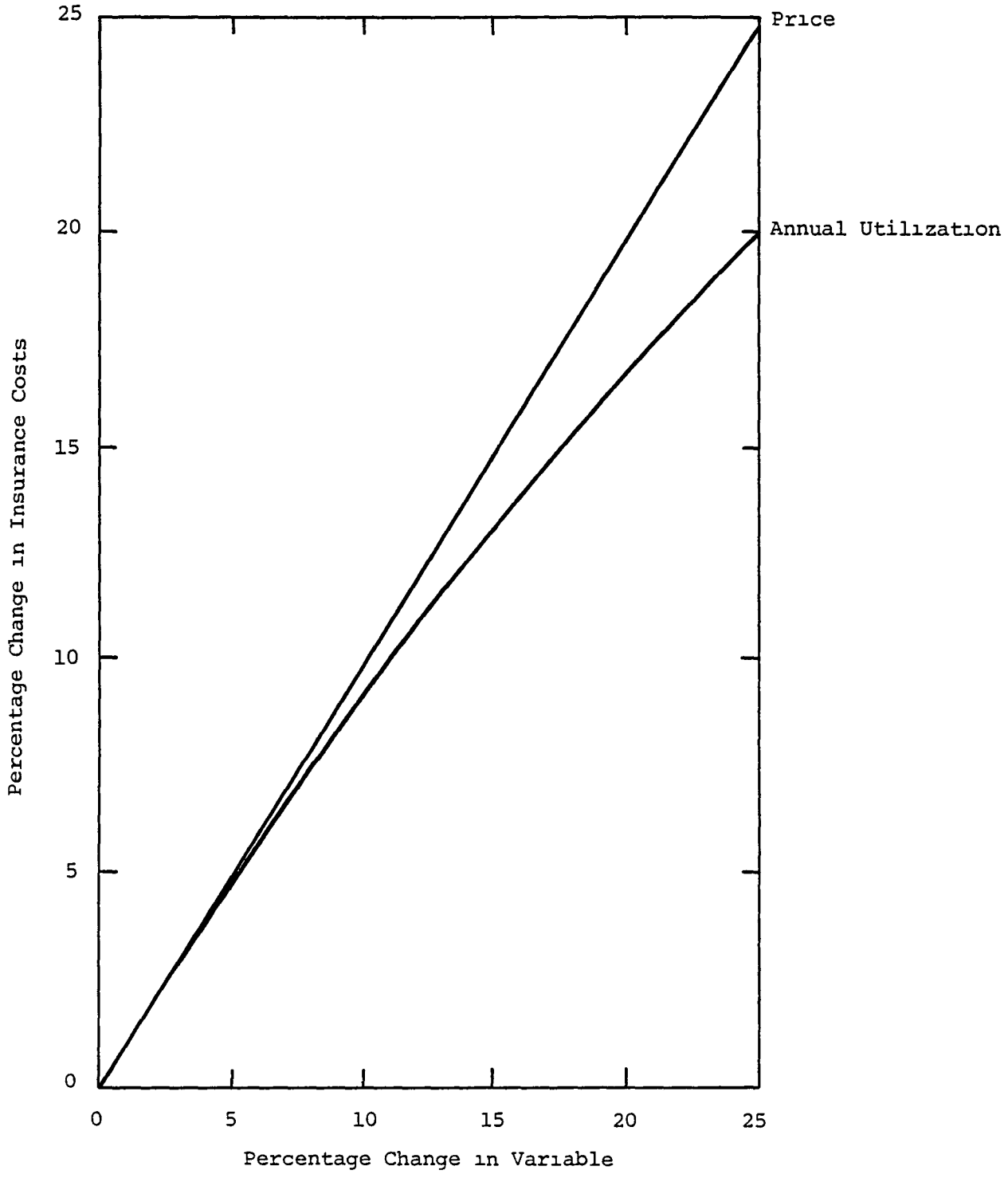

Figure A-12. INSURANCE FACTORS

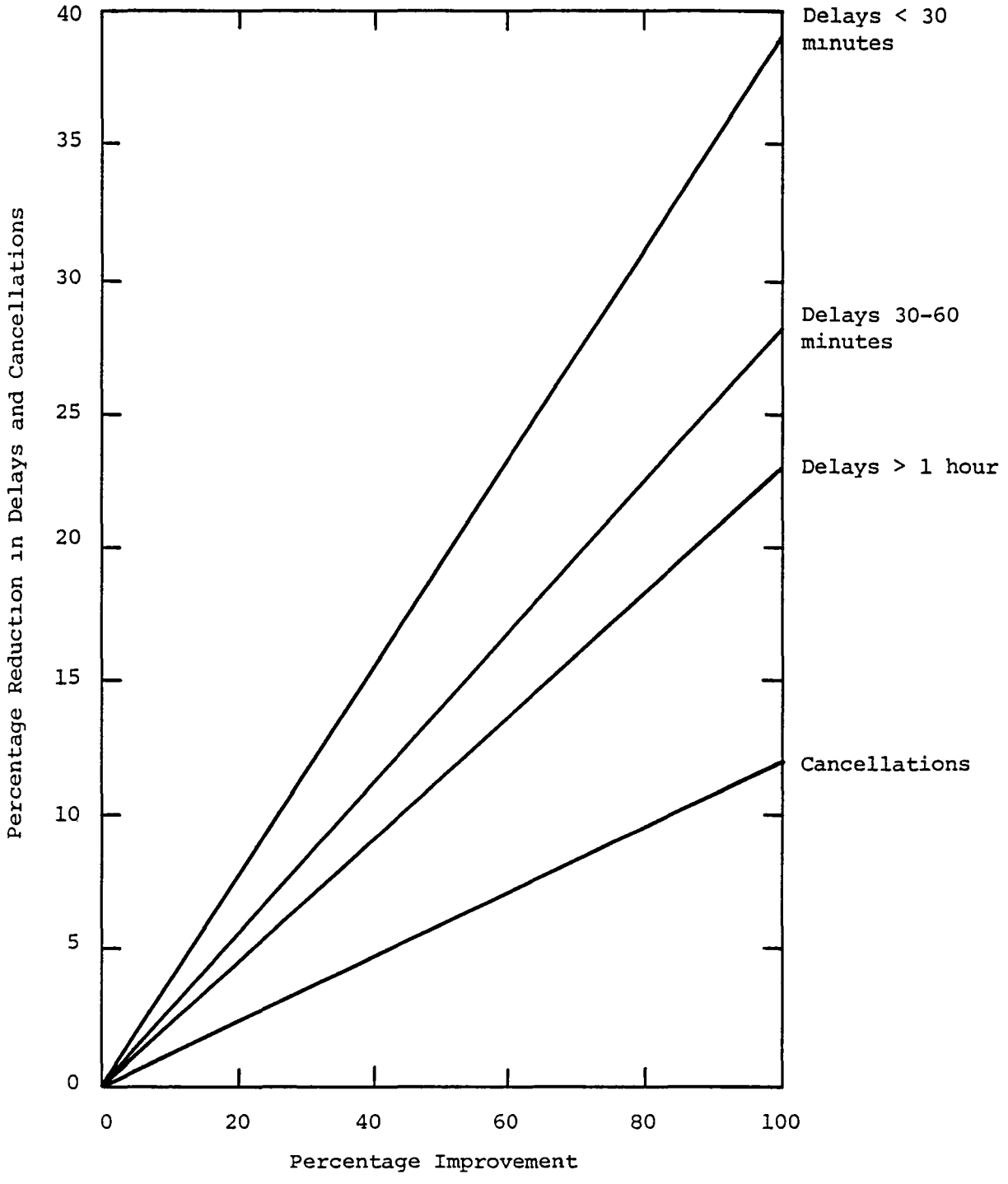

Figure A-13. DELAY AND CANCELLATION FACTORS

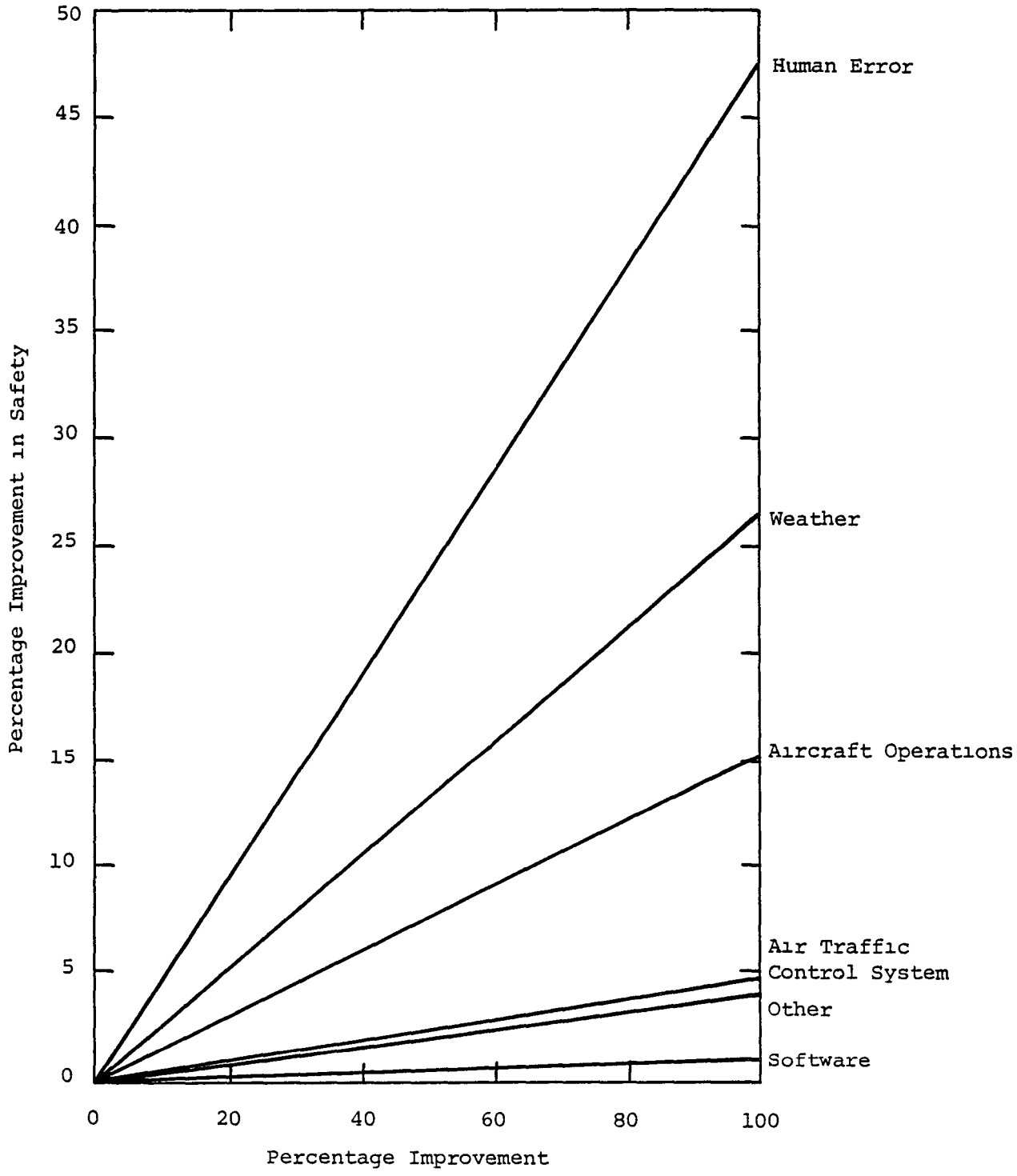

Figure A-14. SAFETY FACTORS

APPENDIX B

MILITARY AIRCRAFT PERFORMANCE CHARACTERISTICS

The primary goal for a high-performance attack or fighter aircraft, or any military aircraft, is successful completion of its mission to deliver ordnance. For a high-performance aircraft, that usually involves climb and cruise to a distant target area, descent into the vicinity of the target, a brief period of combat, and climb and cruise back to home base. The aircraft must have a capability of delivering ordnance on target.

The primary goal of mission completion can be divided into several subcategories. Figure B-1 shows the performance tree developed for attack and fighter aircraft. This appendix describes the key elements of the tree in detail.

1. COST

Cost is a very important consideration in the design and planning stages of a new aircraft. Cost factors must be traded off against all other performance factors. It is true that in an actual combat situation, cost and efficiency are not particularly important, but they must be considered for the purpose of planning an effective military force that can be called into service at any time. Reducing overall costs will make the force more effective for the budget constraint it must meet.

The breakdown of cost elements presented here includes both acquisition and operating costs. The structure is not dissimilar to that of civil aircraft; there are costs associated with the crews, airframe, and maintenance and support. Reductions in any aspect of cost without decreasing performance increases the productivity of the force and frees resources for other purposes.

2. CREW COSTS

Crew costs are those associated with the pilot or the crew members of the airplane. It includes not only crew members' pay and benefits but also expenses for support staff and equipment. In general, however, crew costs

are people costs, and since salaries and benefits are largely fixed, the only way to reduce these costs is to find a way to get the job done in fewer man-hours.

3. TRAINING

Costs involved in training crews to an acceptable level of proficiency and then maintaining that level are a significant fraction of the total life-cycle costs of a particular aircraft. The more complex aircraft require a correspondingly higher training cost. For many aircraft types, a decision was made to design the aircraft for a one-man crew partly because of the increased training costs that would result from a two-man crew. Productivity increases (in terms of the amount of instruction time necessary to bring a new crew member up to an acceptable level of proficiency) are difficult to achieve; however, some auxiliary training equipment can reduce costs in other ways.

4. INSTRUCTORS

Instructor time refers to expenses for personnel directly involved in pilot training. This includes both airborne and ground instruction. Instructor costs, like other personnel costs, are relatively fixed.

5. EQUIPMENT TIME

Various auxiliary equipments are needed to facilitate the training process. Special trainer aircraft and simulators are often used instead of the more costly option of running extra flight operations. Simulators allow training in various unusual situations that might not be expected to come up for hundreds or even thousands of actual flight hours, or would be too dangerous to practice in actual flight (e.g., emergency procedures). As computer technology improves through the rest of this century, simulators may be expected to be used for increasingly higher percentages of total flight training.

6. CREW MEMBER PAY AND BENEFITS

Crew member salary and standard military benefits are an obvious component in the operating costs for the aircraft. Since personnel costs per flight officer are fairly fixed, there are powerful incentives favoring a single man crew, in spite of the higher effectiveness and lower average workload present in a two-man aircraft.

7. PENSION AND SURVIVORS BENEFITS

The allocation for pension costs is a significant percentage of total crew salaries. Even though this expense is not realized for many years,

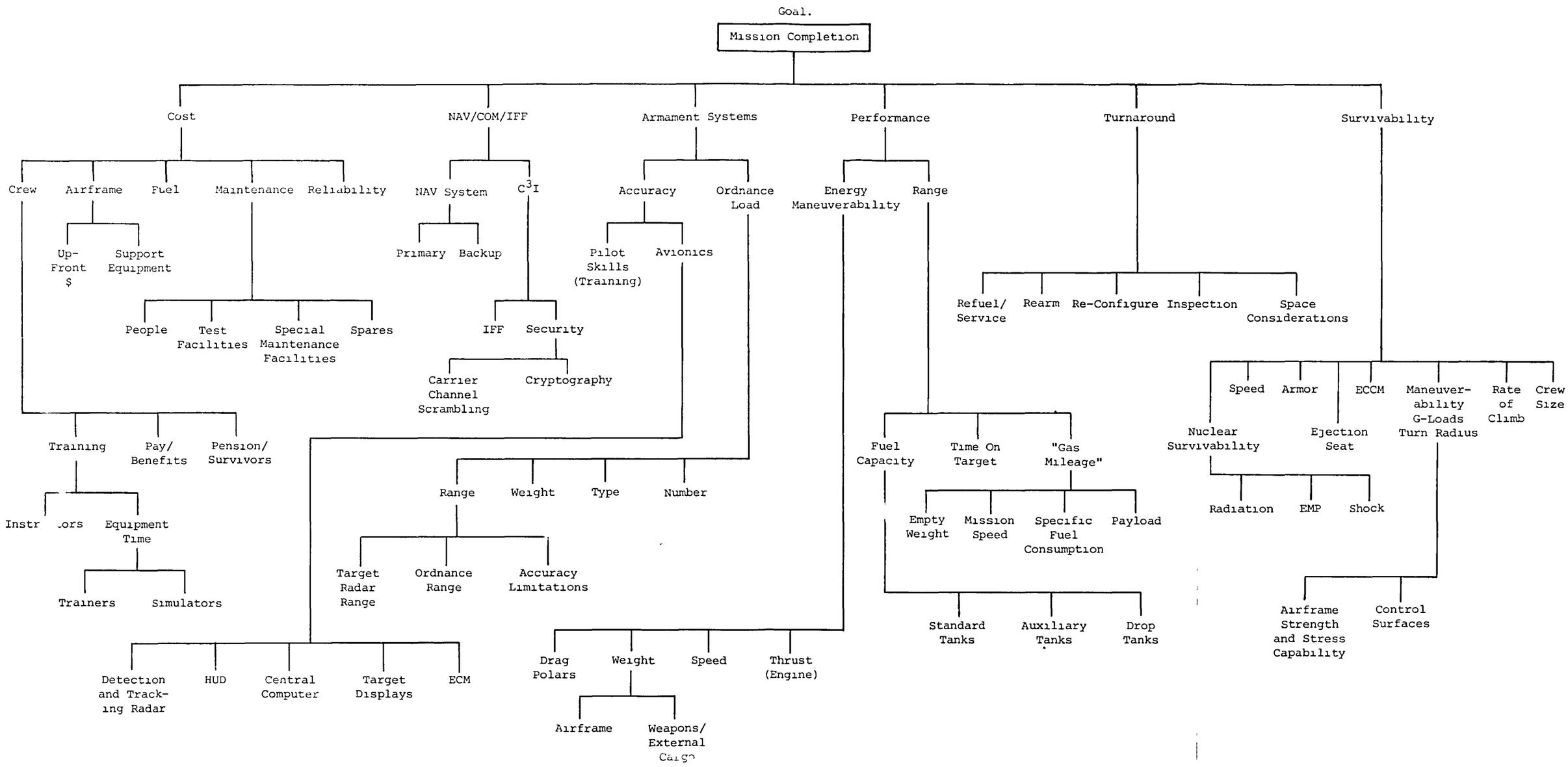

Figure B-1. MILITARY AIRCRAFT PERFORMANCE TREES -- HIGH PERFORMANCE ATTACK AND FIGHTER

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it requires a continuous allocation of funds. In view of the high personal risk taken by the crew of a high-performance military aircraft, survivors' benefits in the form of life and disability insurance payments must be accounted for as well.

8. AIRCRAFT-RELATED COSTS

Costs related to the acquisition of the aircraft are included by this category. They include costs for the airframe, propulsion system, avionics, armaments, and support equipment. Innovations that make some part of the aircraft less expensive or unnecessary can reduce the cost of the aircraft.

9. AIRFRAME COSTS

This category encompasses the initial cost of the airframe, including fuselage, wings and supports, slats and flaps (if applicable), control surfaces, and cockpit accommodations. This is the basic structural frame of the aircraft.

10. PROPULSION SYSTEM

This category covers costs of aircraft engines, fuel storage and delivery systems, and controls for those systems. Costs of these systems depend heavily on the design selected. Designs with lower initial purchase prices might have to pay a penalty in fuel consumption, maintenance costs, performance, or reliability.

11. AVIONICS

All cockpit instrumentation is included in this category. It covers electronic and electromechanical instruments for monitoring flight attitude, engine performance, and support system performance. It also includes armament systems electronics for identifying and locking on to specific targets, navigation and communications functions, and all cockpit displays. Generally speaking, any system that provides the pilot with information on the progress of his flight or on activity in nearby airspace would be in this category. Costs for this equipment should decrease as electronic and computer technology make possible more capability for less cost and less onboard weight and space.

12. ARMAMENTS

Airframe structures and controls associated with the firing of weapons fit into this category, but for the purposes of this study not the weapons themselves. It includes missile mounting hardware and firing mechanisms.

13. SUPPORT EQUIPMENT

Ground-based or ship-based support equipment may be considered an aircraft-related cost even though the equipment is not part of the aircraft itself. This includes takeoff and landing equipment, navigational aids, and towing vehicles. To some extent those functions can be transferred into the cockpit, but to do so usually requires lower performance or higher costs.

14. FUEL COSTS

Fuel is a major operating cost. Fuel consumption can be decreased by decreasing weight or increasing the fuel efficiency of the aircraft. Methods for doing so are discussed in the text of the report.

15. MAINTENANCE

Maintenance costs can be divided into several subcategories. Whether the maintenance is scheduled or the result of a failure, personnel are required to analyze and isolate the problem and replace the proper parts. This requires test facilities, possibly special stations set up strictly for maintenance purposes, and an inventory of spare parts.

The primary way to reduce maintenance costs lies in the design of the aircraft. Use of modular designs permits rapid repair of faulty subsystems. The design can be structured to accommodate specialized troubleshooting procedures that can quickly isolate a bad component. Conversely, a poor design can result in costly difficulties in repairing a failed component because of interdependencies or access problems.

16. RELIABILITY ISSUES

System reliability determines the overall level of unscheduled maintenance. Reliability can be increased by using higher quality components or by performing more extensive, more frequent scheduled maintenance. Either of these solutions could have an adverse effect on costs.

Analyzing system reliability is a very complex undertaking, and is far beyond the scope of this project. For the purpose of this analysis, it is only necessary to note that component and system reliability affect both scheduled and unscheduled maintenance. Any innovation that improves system reliability will decrease maintenance costs.

17. PERSONNEL COSTS

Technicians are needed to perform any maintenance procedure. Their productivity can be increased by providing special equipment or procedures that help the technician do the job better. Like other people-related costs,

costs for maintenance specialists are fairly inflexible and high compared to other non-personnel categories. Efficient maintenance operations require backlogging the work so that the technician's time is fully utilized; however, that can lead to unacceptably long shop times.

18. TEST EQUIPMENT AND FACILITIES

Special tools and test equipment are usually required to perform the maintenance function. Space for maintenance purposes must be allocated near the storage area of the aircraft. The magnitude of the resources required depends on the complexity of the aircraft being maintained, the number that must be maintained, and the reliability of those aircraft.

19. SPECIAL MAINTENANCE FACILITIES

For unusual or complex repairs, separate facilities may have to be established. For example, a particular component may be so reliable that a local repair facility for that component will seldom be used. However, there may be enough failures throughout the entire service to justify such a facility. In such a case, the maintenance crew will replace the bad module from its stock of spares and send the defective unit to the central facility for repair. The cost of staffing and equipping such facilities must be allocated over all hardware in the field that would be maintained by those facilities.

20. SPARES

Spare parts inventory is a major maintenance cost. As the maintenance structure becomes more centralized, the failure rate becomes more predictable and the number of spares required in the system goes down. However, that can lead to longer delays in repairs. Determining the number and location of maintenance centers and the level of spares inventory required at each is a common problem. Various stochastic analysis techniques are available to aid in designing an optimal maintenance structure.

21. NAV/COM/IFF

Navigation and communications functions are a vital factor in mission accomplishment. Armament accuracy depends in part on the accuracy of the navigation system. Backup navigation systems provide the capability to cross check primary system data. Communications with the mission command center will help ensure a coordinated, effective effort. Navigation and communications avionics represent a significant fraction of the total investment in the aircraft and the available space in the cockpit.

21.1 Navigation Systems

The onboard navigation systems are used for a variety of functions. Primary and backup systems, such as INS, Omega, or GPS, are used to pinpoint the absolute and/or relative position of the aircraft. Other systems give position relative to fixed navigational aids.

21.1.1 Primary Navigation Systems

Most military aircraft use an inertial navigation system (INS) as their primary system. Though expensive, INS is self-contained, very accurate, and functional at any aircraft altitude. Its principal drawback is that its accuracy decreases over time; therefore, it must be periodically updated through readings from a different system. The accuracy of an INS is highly dependent on the characteristics of the gyros that measure deviations of the platform orientation. A rate of accuracy degradation of one to two nautical miles per hour of use is typical; however, some INSs being developed for use in military applications have demonstrated rates of accuracy degradation as low as 0.08 nautical miles per hour, using electrostatically suspended gyros.

Omega is a hyperbolic radio navigation system that utilizes sky waves transmitted from eight ground stations scattered around the world. Since each station has an operating range of about 500 nautical miles, coverage is nearly worldwide. Statistical studies conducted in the North Atlantic show that rms positional accuracies of one to two nautical miles are possible. However, military applications generally require greater accuracies; therefore, Omega is best suited as a backup system and as an updating system for INS.

The NAVSTAR Global Positioning System (GPS) is a proposed space-based radionavigation system that is intended to provide accurate navigation and position information to all properly equipped users. The fully operational system will enable continuous worldwide navigation, regardless of weather conditions. Current concepts are based on an 18-satellite constellation -- a reduction from the 24 in the original specification. Using signals from four satellites a user can obtain three-dimension positions (latitude, longitude, and altitude), determine time, and derive velocity. Current plans call for exclusive military use of the precision code which, in the context of an 18-satellite constellation, enables predictable positioning accuracy of 25 meters (0.013 nautical miles) horizontally and 30 meters vertically (95 percent probability). The high degree of accuracy makes GPS suitable as either a primary or backup system.

21.1.2 Secondary Navigation Systems

Tactial air navigation (TACAN) is the military version of VOR/DME. It provides the pilot with bearing and range information with reference to another station within line-of-sight. The station may be on the ground, on a ship, or even on another aircraft. Its performance characteristics make it suitable as a backup system for INS updates or as a tracking system.

The automatic direction finder (ADF) provides bearing information with respect to a fixed ground station. Readings are subject to distortion from the airframe itself and from magnetic disturbances. Consequently, ADF is suitable only for homing to a station. Its poor absolute accuracy makes it a poor choice even for backup operations.

The instrument landing system (ILS) is used for precision landings at airports or on ships. It becomes a necessity in poor weather, when ceiling and visibility are low. ILS provides bearing and range information like VOR/DME or TACAN. It also provides glideslope information for precision approaches.

In addition to their navigation uses, avionics must provide the capability for command, control, communications, and identification functions. Secure voice and data communications are required with other aircraft and with the tactical command center. Reliable identification of radar targets as friend, foe, or neutral is also vital.

21.2 Message Security

Voice and data messages to and from an attack aircraft must be sent in such a way as to assure their reception by the intended receiver and prevent their interception by the enemy. Achieving those goals can involve elaborate channel security and cryptographic techniques.

21.2.1 Channel Scrambling

One way of increasing security of the carrier channels is to scramble the signal. This requires additional equipment to electronically encode and decode the signal at both ends of the communication circuit. Furthermore, scrambling alone does not prevent jamming of the frequency. It is often desirable to broadcast the signal over a wide spectrum or over multiple frequencies to minimize that problem.

21.2.2 Cryptography

Message security can be improved still further through the use of cryptographic techniques. Unlike electronic scrambling, cryptography involves using a code to substitute an apparently meaningless message for a meaningful one. Coders and decoders would still be required. Any innovations in the security or complexity of the code that could be achieved without a corresponding increase in the cost of coding and decoding equipment would enhance communications security.

21.3 Identification, Friend, Foe, or Neutral

Identification of friendly, enemy, and neutral aircraft is accomplished through equipment that sends a coded signal to a target. The nature or absence of a reply is interpreted as an identification of a friend, a foe, or a neutral. IFFN equipment is subject to being exploited if captured by the enemy; for this reason, the counter-signal codes are changed frequently.

22. PERFORMANCE AND ENERGY MANEUVERABILITY

The performance area typically receives the most attention during the design phase of the aircraft. In order to be an effective aircraft in a combat environment, the aircraft must have the capability to maneuver under high g-loads. A powerful engine is necessary to allow the aircraft to climb or to accelerate away quickly if necessary. Another important aspect of the performance category is range. In a situation where the aircraft must fly from an aircraft carrier to the battle area, engage in combat, and return, range is an important consideration. For most of the trip, the aircraft will be flying in a normal cruise configuration. The less fuel spent in getting to and from the battlefield, the more will be available for combat operations.

Energy maneuverability includes factors that enhance or limit the speed and maneuverability of the aircraft. Fuel efficiency is not an important consideration in designing for maneuverability.

22.1 Drag Polars

The inherent efficiency of the airframe can be characterized by a series of constants known as the drag polars. These constants specify lift and drag parameters from which various performance parameters can be calculated. Reduction of drag enhances aircraft performance.

22.2 Weight

Weight has an obvious effect on the maneuverability of the aircraft. A heavier aircraft requires more power to propel it through the air, cannot climb as quickly, and is less responsive in any kind of maneuver. The weight includes not only the airframe weight but also the weight of any externally mounted weapons or cargo. Externally mounted hardware also adds an additional moment of inertia that amplifies the G-loads on the wings in a turning maneuver.

22.3 Speed

Aircraft speed is a tradeoff for maneuverability. The energy produced by the engines can be used to accelerate the aircraft or to turn it. In either case, drag must be overcome. The price paid for a high G-load turn capability will be a reduction in the maximum attainable speed.

22.4 Engine Thrust

The engines produce energy needed to provide thrust force. All other things being equal, a higher thrust engine is desirable because it permits higher cruise speeds, more maneuverability, or both. However, a more powerful engine generally implies more weight and drag and consequently less range for the equivalent amount of fuel.

22.5 Range

Range and maneuverability are, to some extent, conflicting goals. A design that optimizes one of these two goals would not be very effective with respect to the other. For a high-performance military aircraft, combat maneuverability is probably the more critical goal for mission accomplishment. A shortcoming in the range capability can be addressed by means of auxiliary fuel tanks, mid-air refueling, or other means.

22.6 Fuel Capacity

Standard fuel tanks are usually located in the wings and on the exterior of the fuselage. Typically, they are modular, self-contained units with all the internal plumbing necessary to deliver fuel to the engines at the proper rate. Most aircraft also have an interface provided for mid-air refueling. In addition, all aircraft have the capability to carry auxiliary fuel in tanks mounted either on the fuselage or, more typically, under the wings in place of ordnance. Some auxiliary tanks may be jettisoned when their fuel has been exhausted; this results in a considerable decrease in drag and thereby increases range still further.

22.7 Time-on-Target

Time-on-target refers to that phase of the mission during which the aircraft is actively engaging in combat. A typical mission might involve a long cruise to the combat area, a rapid dive to a lower altitude, 15 to 30 minutes of combat activity, climb back to altitude, and a cruise back to base. A disproportionately large percentage of total trip fuel is spent during the brief combat period, because of the fuel-inefficient rapid climbs and descents and to the high-speed, high-performance maneuvers. By the end of the time-on-target phase, the ordnance load and presumably the auxiliary fuel load would have been spent, and the aircraft would then be able to return to its base in a relatively clean configuration.

22.8 Fuel Efficiency

The final factor affecting aircraft range is the fuel efficiency of the aircraft itself. This is affected by the aerodynamic design, the gross weight, and the typical flight speed. Unlike modern civil transports, most military high-performance aircraft were not designed to optimize fuel efficiency.

Reducing aircraft weight is one way to improve fuel efficiency, but if such a weight reduction is achieved by compromising the structural strength of the airframe so that less load can be withstood, the reduction may be counterproductive. Similarly, reducing engine size or weight may improve fuel efficiency but sacrifice performance. The weight of the payload (ordnance, fuel, and crew) is also an important factor since it typically amounts to about 50 percent of the maximum gross weight of the aircraft. External ordnance must be shaped so as not to cause an inordinate amount of extra drag. Innovations that make lighter payloads possible would increase range. Weight considerations are a major factor in the design decision

for a one-man versus two-man crew. Providing space for the extra crew member requires extra weight in the airframe and extra fuel to carry that weight. Even though the fuel capacity may be larger in order to accommodate the same range, the combat efficiency of the aircraft could suffer.

Mission speed also affects fuel efficiency. The airframe is designed to handle the maximum stresses likely in a combat situation, but for most of the trip the aircraft will be in a relatively low-speed cruise. Flying at supersonic speeds or using afterburners results in high fuel penalties that cut down on range. Unless time is critical, it is best to conserve the performance capabilities.

23. ARMAMENT SYSTEMS

Weapons delivery is the most important capability in a high-performance military aircraft. Without the credible threat of firing ordnance at an enemy target, the aircraft is a negligible threat. Therefore, a great deal of development effort goes to support the armament systems on the aircraft.

Once the aircraft has fired all its ordnance, there is little more it can do other than fly back to its base and re-arm. Therefore, it is desirable to load the aircraft with as much ordnance as possible. However, as the load increases, more fuel is required to transport it to the combat area, and the aircraft becomes less maneuverable so there is a practical limit to the amount of ordnance that can be loaded onto the aircraft.

In addition, firepower is useless if the armaments cannot be accurately directed at the proper targets. Armament accuracy is a function of the pilot's skills and training and the avionics he has to work with.

23.1 Ordnance Load

The number and type of armaments that can be carried by an aircraft determine its combat effectiveness to a large extent. Any weight that can be saved in the airframe, crew, or fuel can be used to support additional armaments.

23.1.1 Number

For most aircraft the number of armaments that can be carried is limited by the number of available stations on the fuselage and wings, typically six to ten. There is generally room for one large missile at each wingtip and four smaller missiles under the wings. Up to four additional stations may be found on the fuselage as well; usually these are located on the underside (ventral) of the aircraft aft of the engine intakes.

23.1.2 Type

The type of weapon carried, such as missiles, must be optimized for their targets. Air-to-air operation imposes different requirements than air-to-ground.

In addition to the missiles, most aircraft are equipped with large guns for which they can carry about 1,000 rounds of ammunition. Internal weapons stations are also provided for carrying bombs.

23.1.3 Weight

Maximum ordnance load for high-performance attack and fighter aircraft varies from about 7,000 pounds for the smaller, single-seat aircraft to about 16,000 pounds for the larger, often two-seat aircraft. Any airplane carrying a full or nearly full ordnance load may be unable to carry a full fuel load.

Most air-to-air missiles commonly used (Falcon, Sidewinder, Sparrow) have a launch weight or 200 to 500 pounds each. The Phoenix missile, used on the F-14A, has a launch weight of about 1,000 pounds. Most aircraft in the high-performance class will run out of ordnance station space before they exceed their maximum ordnance load. If any of the stations are used for additional fuel tanks, however, the maximum external load can be reached.

23.2 Range

On-board missiles described in the preceding section generally have a range of 15 to 25 miles. Less sophisticated bombs and ammunition have an effective range of only a few miles. Range is limited not only by the physical limits of the ordnance but also by the range of the instrumentation used in homing and tracking the intended target. The more advanced aircraft have sophisticated radars capable of tracking small, high-speed targets very near ground level. Once fired, the missiles lock onto their targets and are capable of following most evasive maneuvers of target aircraft. A more detailed description of avionics used in the firing of ordnance may be found in the next section.

23.3 Weapon Effectiveness and Accuracy

Every high-performance military aircraft is equipped with a large complement of avionics designed to help identify enemy targets, track them, and accurately launch ordnance at those targets. The accuracy of the ordnance also depends in part upon the skills of the pilot and his training. Training considerations are covered in a previous section under "cost."

24. DETECTION AND TRACKING RADARS

Both one-man and two-man high-performance aircraft are generally equipped with tracking radars that can lock onto a target and display its progress through the air. The radar has a slightly greater range when scanning open skies (about 40 miles) than when scanning ground clutter (about 30 miles), but in either case it has a greater range than the ordnance. Tracking information is fed to a central computer, which calculates the proper trajectory for the missiles or other ordnance to be used.

Several manufacturers have developed pulse-doppler radar, which now constitute the majority of on-board radars in use. Each is tailored to the operating characteristics of the aircraft on which it is installed. Depending on the extent to which the airplane is to be used in close combat, the radar tracking system might have more elaborate output displays that require less pilot workload to successfully launch the ordnance.

25. HEAD-UP DISPLAYS

Head-up displays are displays of flight attitude and target and weapons status projected into the pilot's field of view as he looks out the front window of the aircraft. Such displays allow the pilot to maintain visual contact with the aircraft's environment, including wing-men and targets, while still being able to monitor the status of critical systems. The removal of the need to look from the outside to the instrument panel and back can give the pilot an "edge" of several seconds in assimilating needed information. In critical situations, this small advantage can to decisive.

26. TURNAROUND

As discussed earlier, a fighter or attack aircraft spends only a short time actually engaged in combat activities. In order to achieve maximum effectiveness, the aircraft must be capable of being refueled and re-armed quickly upon return to its base, so that it can return to combat activities in the target areas.

26.1 Refueling and Maintenance

Obviously, the rate at which the aircraft can reach refueling facilities on the airport, be connected to the fuel supply tank, have fuel pumped into its tank, and disconnect from the supply tank has a direct bearing on turnaround time. This is also true of other aircraft service items such as oil, other fluids and consumables, and any repairs that must be made to return the aircraft to service. The latter point refers to minor repairs that can be effected on the flight line by adjustment or replacement from spares immediately on hand. It is unlikely that any major damage could be repaired in the time-frame of a typical battle.

26.2 Re-Arm/Re-Configure

Upon return to base, the aircraft must be either re-armed with the same type ordnance as was expended, or reconfigured and armed with a different type ordnance. The speed and ease with which this can be done has a major effect on turnaround time.

26.3 Inspection

During turnaround, the aircraft must be inspected for damage and the proper functioning of its systems. Delays in this function add to the time before the aircraft returns to combat.

26.4 Space Considerations

Turnaround facilities tend to be localized, both on carriers and land bases. If insufficient facilities are available for the number of aircraft to be serviced, congestions and delays will result. Space must be available to park extra aircraft until service facilities are available.

27. SURVIVABILITY

In order to complete their missions, the aircraft must survive the flight to the combat area and the attack on its target. It is, of course, very highly desirable for the aircraft to survive the post-attack phase, and the flight back to its base. At least, the pilot should be able to survive, both for humanitarian reasons and to preserve his skills, abilities, and training. There are a number of factors having to do with the aircraft design that materially affect the ability of the aircraft and pilot to survive in a hostile environment.

27.1 Nuclear

In a nuclear battlefield, the aircraft will be subjected to thermal and nuclear radiation, physical shock, and a powerful electromagnetic pulse. The ability of the aircraft to remain functional and to protect the pilot in this environment is a key element of survivability.

27.2 Aircraft Speed, Maneuverability, and Rate of Climb

Combat aircraft must be prepared for attack from the ground or from the air. Maneuverability, speed, and rate of climb are key factors in survivability. Being able to out-turn or out-climb an opponent gives a decisive advantage. It is also desirable to be able to out-run an adversary, if necessary. These aircraft performance factors can prove decisive in a hostile environment.

27.3 Electronic Counter-Counter Measures

On the modern electronic battlefield, much reliance is placed on sensors and electronic systems of all types. Their ability to continue to operate in a hostile electromagnetic environment enhances the survivability of the aircraft.

27.4 Armor

An aircraft that can absorb ordnance strikes without damage to flight- or mission-critical systems or injury to the pilot is inherently more survivable than an aircraft without such protection.

27.5 Crew Size

In aircraft with more than one crew member, there are extra hands, eyes, and minds to watch for threats, monitor and operate systems, and deal with

damage. In extreme cases, a second pilot can complete the mission in the event the first pilot is injured or killed.

27.6 Ejection Seat

The survival of the pilot often can depend on his ability to get out of a damaged aircraft and parachute to the ground. At high speeds, an ejection seat is required for this. The effectiveness, reliability, and survivability of the ejection/parachute system itself are principal factors in pilot survivability.

28. SUMMARY

This section has presented in qualitative performance-tree form the individual elements that make up performance of the goal of mission accomplishment for high-performance military aircraft. The tree structure can be used as described in previous chapters to help create system concepts that will enhance aircraft performance or to analyze the effectiveness of proposed concepts.

APPENDIX C

COST MODELS

1. INTRODUCTION

In Tasks 2 and 3, ARINC used several available parametric cost models to evaluate system concepts and determine potential benefits or to estimate probable development and production costs. The models discussed here are the American Airlines parametric operating cost model (Reference 34), two different RAND Corporation aircraft airframe cost estimating models (References 42 and 43), and the General Dynamics-Convair Vehicle Design Evaluation Program (Reference 41).

2. AMERICAN AIRLINES PARAMETRIC OPERATING COST MODEL

The American Airlines model (Reference 34) consists of a set of parametric equations developed in a study for NASA to determine commercial air transport aircraft operating costs as a function of aircraft design characteristics. It can be used to assess the effect of different designs and the effect of advanced technology on existing and future aircraft. This model includes more cost categories than the standard Air Transport Association (ATA) 1967 model, permitting more accurate descriptions of aircraft-related operating costs. For example, the costs associated with flight attendants and aircraft servicing are included in this model, but are not included in the ATA model. These and other cost categories that are added to the ATA model account for nearly 25 percent of aircraft-related operating costs.

The American Airlines model is particularly useful in determining operating costs and benefits because the extensive data base used in developing the model provides a significant number of data points as references. American Airlines used the operating-cost data base accumulated on jet aircraft since 1958. In addition, the company used the Boeing Service Experience Retention Files, which include data on all Boeing aircraft in airline service. This data base permitted and facilitated an extensive regression analysis.

Input data for the parametric equations consist of aircraft design characteristics and requirements, as well as some design requirements of auxiliary equipment. Data inputs include aircraft purchase price, seating capacity, maximum gross weight, average flight time, airframe weight, number of engines, number of electrical generators and their rating in kilovolt

amperes (kVA), the number of inertial navigation systems, the air-flow capacity of the air conditioning package, and the flow capacity of hydraulic pumps.

The output of the parametric equation model is the aircraft-related operating costs, in 1976 dollars, per trip for the different cost categories. The maintenance costs are further divided into labor costs and material costs for each of the ATA Specification 100 Codes. Dividing by the average flight time will yield the aircraft-related operating costs as cost per flight hour, a more useful form for our purposes.

3. RAND MODEL #1

RAND Model #1 was originally developed by the RAND Corporation in 1966 (Reference 42) and revised in 1971 to provide consistent, accurate cost estimates of airframe costs. The model that was developed considered several variables, such as weight, speed, wing loading, wetted area, and aspect ratio, but found that only weight and speed were significantly correlated to warrant consideration. The revision in 1971 added additional information to the data base and made the model more objective, but the model still used aircraft weight and speed as the controlling factors in producing the cost estimates.

The original model included data from 25 aircraft; several more were added in the 1971 revisions. A variety of aircraft, all military, were included in the model, although the cargo aircraft used are similar to the commercial air transport aircraft being studied in our effort. These aircraft include a variety of problems that are representative of development and production problems encountered in the aircraft industry.

Inputs to the computer model consist of basic aircraft performance and manufacturing parameters. Specific inputs include gross takeoff weight; airspeed; maximum production rate; number of engines; engine thrust; engine and avionics research, development, and test and evaluation (R,D,T&E) costs; avionics costs for first unit; and desired airframe profit.

The model output consists of detailed cost breakdowns based on production run and production rate. Specific outputs are airframe R&D costs, airframe production costs (both unit and cumulative), engine production costs (both unit and cumulative), and total aircraft production costs, with or without R, D, T&E costs.

4. RAND MODEL #2

RAND Model #2 (Reference 43) was developed in 1976 as a result of a Defense Department request to review and update RAND Model #1. The review examined other variables that might better explain airframe development and production costs, or that could be combined with several variables to describe program costs accurately. The impact of advances in manufacturing technologies and materials on cost-estimating methodologies was also examined.

The resulting parametric model concluded that weight and speed are still the two items of major significance, although other variables could produce minor impacts.

The data base developed for this model consisted of development and production data for 31 aircraft produced since 1945. Six of the aircraft with first-flight dates earlier than 1952 were deleted because of data-reliability problems. The remaining aircraft included five attack aircraft, two trainers, three bombers, five cargo aircraft, and ten fighter aircraft. Cost data obtained were categorized according to the design effort and whether they represented engineering, tooling, manufacturing, or quality control.

Inputs to the parametric equations consist of airframe unit weight, maximum speed, and the number of test aircraft. The parametric equations used can be categorized according to aircraft grouping or total sample: Group 1 is small slow aircraft, Group 2 is small fast aircraft, and Group 3 is large slow aircraft.

The output of the parametric equations is the number of hours needed to design and manufacture an airframe, the cost of materials, and the total costs. Specific outputs include engineering hours, tooling hours, manufacturing labor, manufacturing materials, cost, quality-control hours, flight-test costs, and total program costs.

5. GENERAL DYNAMICS VEHICLE DESIGN EVALUATION PROGRAM

The General Dynamics model (Reference 41) is the result of a series of Air Force and NASA contracts to develop a computer model that would perform preliminary design analysis and trade-off studies on commercial transport aircraft. The model we are considering was developed for the NASA Langley Research Center in 1977. It consists of an aircraft vehicle sizing routine and a cost-analysis routine, and it determines first-unit manufacturing costs, total program costs, and return on investment.

The model was developed originally from statistical data on several aircraft, with a statistical basis being used to determine vehicle sizes and weights. Detailed cost data were available to establish the necessary relationships between aircraft design characteristics and development and production costs. In addition, a total program cost model was developed that uses cost-estimating relationships and learning curves as well as internally generated cost elements.

Input data consist primarily of key system design parameters that affect overall mission performance. Depending on the level of detail, specific inputs include gross takeoff weight, payload, speed, range, landing-field length requirements, wing loading, span, sweep, taper, aspect ratio, takeoff-field length requirements, climb requirements, slenderness ratio, and fuel requirements. Where nonmandatory inputs are desired but are not available, they are calculated internally by model subroutines.

The model output consists of aircraft design and performance characteristics and development and production costs. Specific output includes aircraft performance characteristics such as C_L, C_D, wing area, thrust-to-weight ratio, fuel capacity, aircraft geometry, weight and balance data, engineering costs, tooling costs, material costs, manufacturing costs, first-unit production costs, and total program costs.

APPENDIX D

ARCEM RUN INSTRUCTIONS

1. INTRODUCTION

This guide provides all the information needed to use the ARCEM computer program. It is configured to show the first time user step-by-step how to run the program, and to provide a reference for the experienced user to help in resolving problems or questions encountered in running the program.

This computer program is the final step in the overall ARCEM methodology. The earlier parts of the process are manual and conceptual in nature, and are described in detail in the ARINC Research Report titled, "NASA Controls and Guidance Program Planning Support: Final Report." This section of this document will describe the earlier parts of the methodology only as they relate to the inputs required for the use of the ARCEM computer program.

The ARCEM methodology is a structured way of generating and prioritizing technical concepts in such a way as to maximize the degree to which the goals addressed by the concepts are attained. The full methodology contains information on the generation of concept ideas and data to support their analysis in terms of benefits and costs. The key concern in the analysis is the relationship between the specific concept ideas and the generic and enabling technologies that must be available in order for the concept to be possible or practical. The ARCEM computer program portion of the methodology orders the concepts by benefit-to-cost ratio, including the effect of generic technology costs, and computes the cumulative benefit-to-cost ratio of implementing the concepts in varying numbers.

The first step in using the ARCEM Program is to fill out the work form shown in Figure 4-1 in Chapter Four. The form provides spaces for the name of the concept, the benefit of the concept, the unit costs of the concept, the generic technologies required, and the costs of the generic technologies. In filling out the generic technology matrix, the user should write a "0" (zero) to denote the case in which a generic technology is not required, and a "1" (one) to denote the case in which a generic technology is required. Thus, the work form will consist of concept benefits and costs and a matrix of 1's and 0's, annotated with the names of the concepts and generic technologies. The data on the form can be entered directly into

the ARCEM Program with a minimum of keystrokes. Figure 5-10 in Chapter Five shows example data entered on the form.

2. PROGRAM DESCRIPTION

The ARCEM Program is configurated to accept concept benefit and cost data, perform the ratio computation, and to present the results in both tabular and graphic form. The computation can be performed with the data in the order in which they are entered, or with the data sorted into descending benefit-to-cost ratio order. The order of the concepts can also be changed at any time to judge the effect of performing the concepts in a different order. ARCEM is configured to accept up to 100 concepts and 20 generic technologies for analysis. However, a maximum of only 25 concepts can be plotted graphically. When more than 25 concepts are being analyzed, only the first 25 are plotted, while results for all concepts are presented in tabular form.

Data can be entered for analysis in two ways: manually by means of the keyboard, or automatically from a previously created disk file. Data entered by the keyboard can be stored on disk for later retrieval. This allows use of a set of data over several computing sessions without the necessity of manually re-entering the data each time. To aid the user, complete editing capabilities are included in the program. The value of any of the input parameters can be changed, and concepts can be added or deleted. The present ordering of the concepts, along with the present values of the benefit, cost, and generic technology matrix can be displayed, with a hard copy output available allowing later reference to the data. Hard-copy print-out is also available at the end of the sorting routine, showing the sorted order of the concepts, and at the end of the computing routine, showing the results in a table and a bar graph.

3. RUNNING ARCEM

The ARCEM Program is configured to run on a TRS-80 Model III Microcomputer. A minimum of 48K of random access memory and one disk drive are required. Also required is a light-pen input device. The program is configured to use the unit made by the 3-G Company, Inc. If hard copy print-out is desired, a TRS-80 Line Printer VII is required.

Throughout this document, the symbol "<ENTER>" will be used to denote the action of pressing the key on the computer keyboard marked "ENTER." The user will understand that the word "ENTER" is not to be typed in.

With the computer, light-pen, and printer set up according to the manufacturer's instructions, power should be applied first to the printer, then to the computer (the light-pen has no separate on-off switch). There should be no disk in the drive at the time of turn-on; switching transients could overwrite valuable data or even the operating system. After turn-on, the red select light on the disk drive will light for about five seconds.

When this light goes out, open the disk drive door and carefully insert the ARCEM disk, with the label side up and read notch toward the back of the drive. Gently press the disk into place until it seats in the drive, and close the drive door. Press the recessed orange reset key at the upper-right of the keyboard. The computer will read the disk operating system (DOS) from the disk and in about five seconds present initialization data and prompt the user for the correct date. Entry of the date in the specified format (MM/DD/YY) is mandatory. After entering the date, press the <ENTER> key. The system will now prompt for the present time. Since the system clock is not used by ARCEM, this option can be bypassed by pressing <ENTER>. The system will now respond with "TRSDOS READY." This indicates that the DOS is now initialized and is ready for commands.

Enter the following command:

BASIC <ENTER>.

This engages the BASIC interpreter and prepares the computer to run the ARCEM Program. The BASIC interpreter prompts for two pieces of information: number of files and memory. Answer each of these prompts by pressing the <ENTER> key. The BASIC interpreter will now respond with "READY," and a prompt, ">", followed by a flashing cursor. Enter the following command exactly as shown below, including quotes:

RUN "ARCEM" <ENTER>

The computer will then load the ARCEM Program from disk and begin execution.

4. ENTERING DATA

ARCEM will present a title page, followed by the main menu, offering six options. If this is the first time a program has been executed since the computer was turned on, all options except "INPUT" are locked out, since no action can be taken until data have been entered. Select "INPUT" by gently touching the tip of the light pen to the cursor next to the word "INPUT." The light pen works by detecting the light from the cursor with a photo-transistor; no pressure on the pen is required, and may damage the pen or the screen face. A light touch is called for. The program identifies the selected cursor by flashing all the cursors in sequence. When the flashing is detected by the light pen, the program identifies which cursor has been selected, and the program then branches to the desired section.

The input routine presents the user with three options: "KEYBOARD INPUT," "DISK INPUT," and "RETURN TO MENU." Selection of the last option returns the program to the main menu. This feature will be found in all of the sections of the program; the option to return to the menu is always available. This allows the user to escape from an erroneously selected option without altering data already entered. Selection of "KEYBOARD INPUT" allows input of data through the keyboard. The program prompts for

the number of concepts to be entered. Consult your work sheet and enter the number of concepts to be analyzed, followed by <ENTER>. (Remember that concepts can be added or deleted at any time during use of the program.) The program then prompts for the first concept. The concept name, benefit, cost, and technology line can be entered directly from the work form, as in the example below:

NAME 100 50 10110

The concept name can be any seven letters or numbers, and should be chosen to act as a mnemonic for the concept under analysis. The benefit and cost numbers may be in any units, but they must be in the same units, such as thousands of dollars, or hundreds of thousands of dollars.

The technology line is the row of the technology matrix for the concept being entered. The 1's and 0's denote generic technologies that are needed or not needed, respectively. During the entry of the technology line, only the "1" and "0" keys are active; all other keys are locked out to avoid the accidental entry of erroneous data. Follow entry of the line of data by pressing the <ENTER> key. The program will then prompt for the next concept. When all concepts have been entered, the program will prompt for entry of the generic technology costs. After entering each cost from the work form, press the <ENTER> key. It is not necessary to enter the number of generic concepts, since the program computes that quantity from the technology line data previously entered. Following entry of the last technology cost, the program will indicate that the data have been entered and return to the main menu. While entering data manually, if an error is detected before the <ENTER> key has been pressed, it can be corrected by simply backspacing with the back-arrow key, located on the right side of the keyboard, just above the <ENTER> key.

If the disk file input, rather than keyboard input, has been selected, the disk input routine will prompt for the name of the disk file. This is the name that was assigned to the file at the time it was created (see section on saving data to disk). Enter the name, followed by <ENTER>. The program will attempt to read the designated file from the disk. If the file is found, the program will notify the user that the file has been loaded and return to the main menu. If the file is not found, an error message will appear, and the user will be asked to re-enter the file name. If this occurs, check to see that the file name you entered was the correct one and that the correct disk is in the drive. Upon successfully loading the file, the program returns to the main menu.

5. LISTING DATA

After completing the input section of the program, review the data that have been entered by means of the "LIST" routine. From the main menu, select the "LIST" option with the light pen. The concept data will be listed as they were entered. If the listing contains more than 10 lines, the program will pause at every tenth line. To continue listing, touch

the light pen to the continue command. After reviewing the concept listing, use the light pen to select the "NEXT PAGE" option. That causes the program to list the generic technology costs. As you review those data items, note the concept or generic cost number of any erroneous data items. They can be corrected through the use of the edit routine. After reviewing all data items, use the light pen to select either "PRINT-OUT" or "RETURN TO MENU." The print-out option provides a hard copy of the concepts and generic technology costs on the printer before returning to the menu.

6. EDITING DATA

To edit data fields in a concept, to change a generic technology cost, to add, delete, or re-order the concepts, select the "EDIT" option from the main menu with the light pen. Within the edit routine there are four edit options: editing concepts, editing generic technology costs, deleting concepts, and re-ordering concepts. A fifth option is return to menu.

If you wish to change the values of the benefits or costs of a concept, or wish to change the technology line for a concept, then select the "EDIT CONCEPTS" option with the light pen. The program will prompt for the number of the concept you wish to change. Enter the number of the concept to be changed, and press <ENTER>. The program will display the present values of the various parameters and prompt for changes, starting with the concept name. If you wish to change the name of the concept, simply enter the new name, then press <ENTER>. If you do not wish to change the name, press <ENTER> without entering a new name; the name will remain unchanged. The program will prompt for changes to the next field, benefit, and so on. Each time, if you wish to change a field, type in the new value, then press <ENTER>. To bypass a field without changing the value, press <ENTER> alone. If you wish to enter a new technology line, you must enter the entire line, even if only one element is changed; you cannot edit individual elements of a technology line. Following the last change option, the technology line, the corrected concept is displayed. Select "RETURN TO MENU" to continue processing.

To edit a generic technology cost, select that option with the light pen. The program will prompt for the number of the generic technology to be edited. Enter the number and press the <ENTER> key. The program will display the current value, then a prompt for the new value. Enter the new value and press the <ENTER> key. The program will display the corrected value. Enter additional corrections or select "RETURN TO MENU" to continue processing.

If you wish to delete a concept, select "DELETE CONCEPT" with the light pen. The program will prompt for the number of the concept to be deleted. Enter the number and press the <ENTER> key. The program will name the deleted concept to confirm that the proper concept was deleted. Erroneously deleted concepts may be restored by using the "EDIT CONCEPT" option. Select "RETURN TO MENU" to continue processing.

If you wish to change the order of the concepts, select "CHANGE ORDER" with the light pen. The program will prompt for the number of the concept you wish to move and the number of the position you wish it to occupy. Enter the two numbers, separated by a comma, and press the <ENTER> key. The program will list the concepts in the new order. If you wish to have a hard copy print-out of the list, select "PRINT-OUT" with the light pen. Otherwise select "RETURN TO MENU" to continue processing.

Anytime you engage the editor, the concept list automatically reverts to the unsorted ordering prior to accepting the prior edit command; that is, the order in which the concepts were before the last sort. This allows the user to work with the concepts in a known or preferred order, and then observe the effects of his changes as the revised data are sorted.

7. SORTING

The sort routine allows for the optimal ordering of the concepts. It answers the question, "In what order should I implement these concepts?" The sort routine examines the benefits and costs of each concept, including the costs of required generic technologies, and ranks them in order of descending benefit-to-cost ratio.

In order to use the sort routine, simply select the "SORT" option from the main menu with the light pen. No input parameters are required. The program notifies that the sort routine is engaged and displays the number of sort iterations left to be performed. The sort routine is the longest of the ARCEM routines; it can take several minutes to run if a large number of concepts and generic technologies are being sorted. The display of the number of iterations left to go provides an indication of the amount of time required for the sort to be completed.

When the sort is completed, the program will provide a listing of the concepts in their sorted order. If you wish to have a print-out of the list, select the "PRINT-OUT" option with the light pen. Otherwise, select the "RETURN TO MENU" option to continue processing.

8. COMPUTING

The compute routine calculates the cumulative benefit-to-cost ratio of the concepts as they presently exist. If the sort routine has been run since the last input or edit of data, the concepts will be analyzed in their sorted order. Otherwise, they will be analyzed in their order as entered or edited.

To engage the compute routine, select "COMPUTE" from the main menu with the light pen. No input parameters are required. The program displays the message "WORKING" to inform the user that the computations are taking place. When the calculations are completed, the program displays a list of the concepts, along with the cumulative benefit-to-cost ratios associated with doing those concepts. The ratio shown with, say, the fifth concept,

is the cumulative ratio for the first five concepts. It is the benefit-to-cost ratio that would result from implementing the first five concept ideas. If a hard copy print-out of this list is desired, select the "PRINT-OUT" option.

The "GRAPHICAL OUTPUT" option causes the program to draw a bar graph showing the cumulative benefit-to-cost ratio as a function of the number of concepts performed. Benefit-to-cost ratios greater than 12 cannot be displayed graphically; in such cases, a message to that effect is displayed, and the program returns to the main menu. If a hard copy print-out of the bar graph is desired, select the "PRINT-OUT" option with the light pen. Otherwise, select the "RETURN TO MENU" option to continue processing. The print-out of the bar graph can take up to 10 minutes for cases with large numbers of concepts.

9. SAVING CONCEPT DATA

The ARCEM Program provides for the storage of concept data on magnetic disk. If you wish to save the set of concepts and generic technology costs, select the "DATA TO DISK" option from the main menu.

The "DATA TO DISK" routine will prompt for a file name to be used. Enter any combination of letters and numbers up to seven characters, then press the <ENTER> key. The user may wish to choose the file name to act as a mnemonic for the file it identifies. Alternately, the files can be numbered sequentially or identified by the name of the file's originator. The program will store the data and inform the user of completion. Select "RETURN TO MENU" to continue processing.

10. PRESENT VALUE UTILITY

The present value utility program is a stand-alone program designed to aid the user in the preparation of data for computation with the ARCEM Program. It will accept a series of cash flows and a discount rate and return the present value of the series. Both uniform and non-uniform series can be accommodated.

To use the utility program, execute the following command after engaging the basic interpreter as described above:

RUN "UTILITY" <ENTER>

The present value utility program will present a menu with three options: uniform value, non-uniform value, and end utility. Select uniform value if the series of values is uniform from year to year; for instance, a benefit of $100,000 a year for 10 years is a uniform benefit. The program will prompt for the number of years over which the value applies. Enter the number of years and press <ENTER>. The program will then prompt for the discount rate to be used in computing the present value. Enter the

discount rate desired, in whole numbers (e.g., 12 percent) and press <ENTER>. Pressing <ENTER> without first entering a value will result in the use of the default value of 10 percent. The program will compute the present value, present the result, and then prompt for the next value. Enter the next values to be computed and continue as before. When you have completed calculation of all uniform cases, enter 0 to return to the menu.

A non-uniform series of values is one in which the values vary from year to year. For instance, a benefit of $50,000 the first year, $75,000 the second year, and $100,000 the third year is an example of a non-uniform series. For such cases, select the non-uniform option from the menu. The program will prompt for the number of years to be considered, and the discount rate to be used. Enter these as described above. The program will then prompt for the various values year by year. Enter each of these, then press <ENTER>. When all the values have been entered, the program will compute the present value and present the results. Select "RETURN TO MENU" to continue processing.

When you have completed all present value calculations, select "END SESSION" from the menu and the utility program will terminate. At that time, you may execute the ARCEM Program as described above or terminate the computing session as described below.

11. ENDING THE COMPUTING SESSION

When you have completed all computations and wish to terminate the computer session, first be sure that you have obtained all print-outs that you require. Also be sure that you have saved to disk any concept data you wish to retain. (When the computer is turned off, all data in the computer's memory are lost.)

Having verified the above, open the disk drive door and carefully remove the disk. Do not turn the computer off while a disk is in the disk drive; switching transients could cause valuable data to be erased. Store the disk in its protective sleeve, away from sources of heat or magnetic fields. Close the disk drive door, and turn off the computer. Finally, turn the printer off.

APPENDIX E

PROGRAM LISTING

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10 'DRIVER ROUTINE
20 CLEAR 10000:DIM N$(100),BEN(100),CST(100),CGT(100),N1$(100),B1(100),C1(100),S
1$(100),Q(100),CR(100),GC(20),S$(100),B(100)
30 CLS:PRINT@154,"ARINC RESEARCH" PRINT@216,"CONCEPT EVALUATION" PRINT@285,"PROG
RAM" PRINT@478,"ARCEM":PRINT@725,"(C) ARINC RESEARCH CORP" PRINT@794,"2551 RIVA
RD" PRINT@855,"ANNAPOLIS, MD, 21401"
40 FOR J= 1 TO 1200:NEXT J
50 F2=0:F3=0
60 POKE 16916,0:CLS PRINT@26,"***MENU***":PRINT TAB(12),"THE FOLLOWING FUNCTIONS
 ARE AVAILABLE ";
70 POKE 16916,0
80 ON ERROR GOTO 3480
90 GOSUB 2800
100 PRINT@ 276,"INPUT"
110 PRINT@ 404,"EDIT"
120 PRINT@ 532,"LIST"
130 PRINT@ 296,"SORT"
140 PRINT@ 424,"COMPUTE"
150 PRINT@ 552,"DATA TO DISC"
160 PRINT@788,"SELECT DESIRED FUNCTION"
170 C(1)=272:C(2)=400:C(3)=528:C(4)=292:C(5)=420:C(6)=548
180 NN=6:GOSUB 2880  V=P IF V<>1 AND F3=0 THEN CLS PRINT@26,"***ERROR***":PRINT
CHR$(204),"NO DATA HAS BEEN ENTERED:GO TO ",CHR$(34),"INPUT",CHR$(34):FOR J=1 TO
 1000:NEXT J:GOTO 60
190 ON V GOSUB 210  ,560  ,1100 ,1360 ,1700 ,2420
200 GOTO 60
210 'INPUT ROUTINE
220 CLS PRINT@22,"***INPUT ROUTINE***" PRINT@286,"INPUT FROM KEYBOARD" PRINT@414
,"INPUT FROM DISC":PRINT@542,"RETURN TO MENU"
230 NN=3:C(1)=282 C(2)=410 C(3)=538:GOSUB2800 :GOSUB2880 :ON P GOTO 240  ,2560 ,
60
240 CLS:FOR J=1 TO 20:GC(J)=0:NEXT J:F2=0
250 PRINT@20,"***KEYBOARD INPUT***" PRINT
260 PRINT"ENTER NUMBER OF CONCEPTS":PRINT"(0=RETURN TO MENU)":INPUT "NUMBER=",N:
IF N=0 THEN 60
270 IF N>100 OR N<2 THEN 260
280 CLS LMX=0:F3=1 POKE 16916,2 'SCROLL PROTECT TOP 2 LINES
290 PRINT"ENTER                    CONCEPT#"
300 PRINT"  NAME     BENEFIT  COST     TECHNOLOGY LINE"
310 FOR X=1 TO N
320 PRINT@31,X,
330 IF X<=14 THEN SC=X+1 ELSE SC=15
340 FOR G=1 TO SC PRINTCHR$(26),:NEXT G:PRINTCHR$(29);
350 INPUT N$(X)
360 PRINT TAB(10) CHR$(27);
370 INPUT BEN(X)
380 PRINT TAB(18) CHR$(27);
390 INPUT CST(X)
400 PRINT TAB(27) CHR$(27),"? ",
410 GOSUB 3520  'BRANCH TO TECH LINE INPUT ROUTINE
420 IF LEN(S$(X))>LMX THEN LMX=LEN(S$(X))
430 PRINT CHR$(13);
440 NEXT X
450 PRINT PRINT"DATA ENTERED" FOR J=1 TO 200 NEXT J:POKE 16916,1
460 CLS PRINT"ENTER COSTS OF GENERIC TECHNOLOGIES"
470 PRINT
480 FOR X=1 TO LMX
490 PRINT"COST OF GENERIC TECHNOLOGY #",X;" "
500 INPUT CGT(X):GC(X)=CGT(X)'LOAD SHADOW COST VALUES
510 NEXT X
520 FOR J=1 TO N
530 N1$(J)=N$(J):B1(J)=BEN(J):C1(J)=CST(J) S1$(J)=S$(J)
540 NEXT J
550 PRINT:PRINT "DATA ENTERED" FOR J= 1 TO 200:NEXT J:RETURN
```

```
560 CLS: PRINT@22,"***EDIT ROUTINE***" PRINT'EDIT CONCEPTS ROUTINE
570 PRINT"                    WHICH DO YOU WISH TO DO?"
580 GOSUB 2800
590 PRINT@286,"EDIT CONCEPT", PRINT@414,"DELETE CONCEPT",:PRINT@542,"EDIT GENERI
C TECH COSTS";:PRINT@670,"CHANGE ORDER OF CONCEPTS" PRINT@798,"RETURN TO MENU"
600 NN=5:C(1)=282:C(2)=410 C(3)=538:C(4)=666 C(5)=794 GOSUB 2880
610 ON P GOTO 620  ,910  ,800  ,3600 ,60
620 CLS F1=0:F2=0
630 PRINT@23,"***CONCEPT EDIT***" PRINT
640 INPUT"WHICH CONCEPT NUMBER DO YOU WANT TO EDIT",NE
650 PRINT " #  NAME   BENEFIT   COST   TECHNOLOGY LINE"
660 IF NE>N THEN N=N+1 NE=N
670 PRINT NE;TAB(4),N$(NE),TAB(10),BEN(NE);TAB(20);CST(NE),TAB(28),S$(NE)
680 PRINT
690 IF F1=1 THEN RETURN
700 PRINT"ENTER NEW CONCEPT #",NE
710 PRINT
720 INPUT"NEW NAME=",N$(NE)
730 INPUT"NEW BENEFIT=",BEN(NE)
740 INPUT"NEW COST=",CST(NE)
750 INPUT"NEW TECH. LINE=",S$(NE)
760 PRINT:PRINT"CORRECTED CONCEPT #",NE,":"
770 F1=1:GOSUB 650   F1=0
780 GOSUB 1060
790 PRINT@558,"RETURN TO MENU", NN=1:C(1)=555 GOSUB 2800  GOSUB 2880  RETURN
800 CLS:PRINT"                    ***GENERIC TECHNOLOGY COST EDIT***" PRINT
810 F2=0
820 PRINT"WHICH COST DO YOU WISH TO EDIT" PRINT"(0=RETURN TO MENU)":INPUT"COST N
UMBER=",X
830 CLS:IF X>LMX THEN PRINT"***THERE ARE ONLY ",LMX;" GENERIC TECHNOLOGIES***":P
RINT:GOTO 820
840 IF X=0 THEN GOSUB 1060  RETURN
850 PRINT"GENERIC TECHNOLOGY COST #",X,"=",CGT(X)
860 INPUT"ENTER NEW COST ",Y
870 CGT(X)=Y
880 PRINT
890 PRINT"NEW GENERIC TECHNOLOGY COST #",X;"=",CGT(X)
900 PRINT:GOTO 820
910 CLS:PRINT@22,"***DELETE CONCEPT***":PRINT:PRINT"WHICH CONCEPT DO YOU WISH TO
 DELETE":F2=0
920 PRINT"(0=RETURN TO MENU)";
930 INPUT D:DN$=N$(D) 'SAVE NAME OF DELETED CONCEPT
940 IF D=0 THEN 60
950 IF D=N THEN N$(D)="" BEN(D)=0:CST(D)=0:S$(D)="":N=N-1:GOTO 1030
960 N=N-1
970 FOR J=D TO N
980 N$(J)=N$(J+1)
990 BEN(J)=BEN(J+1)
1000 CST(J)=CST(J+1)
1010 S$(J)=S$(J+1)
1020 NEXT J
1030 PRINT PRINT"CONCEPT #",D;" NAMED ";CHR$(34),DN$,CHR$(34);" HAS BEEN DELETED
"
1040 GOSUB 1060
1050 GOSUB 3120  GOSUB 2880  GOTO 60
1060 FOR J=1 TO N
1070 N1$(J)=N$(J) B1(J)=BEN(J):C1(J)=CST(J):S1$(J)=S$(J)
1080 NEXT J
1090 RETURN
1100 CLS:POKE 16916,1 'SCROLL PROTECT TOP LINE
1110 'MATRIX PRINTOUT ROUTINE
1120  PRINT" #  NAME   BENEFIT  COST   TECHNOLOGY LINE"
1130 FOR J=1 TO N
1140 PRINT J,TAB(4),N$(J),TAB(10),BEN(J);TAB(19);CST(J);TAB(27),S$(J):IF (J/10)-
INT(J/10)=0 THEN GOSUB 1230
```

```
1150 NEXT J:PRINT@951,"NEXT PAGE", NN=1:C(1)=947 GOSUB2800 :GOSUB2880 :POKE 1691
6,0:CLS:POKE 16916,2
1160 PRINT"GENERIC TECHNOLOGY COSTS "
1170 PRINT"#          COST"
1180 FOR J=1 TO LMX
1190 PRINT J;TAB(9);CGT(J)
1200 IF(J/10)-INT(J/10)=0 THEN GOSUB 1230
1210 NEXT J
1220 GOSUB 2800  PRINT@816,"PRINT TABLES"; PRINT@944,"RETURN TO MENU", NN=2:C(1)
=812:C(2)=940:GOSUB 2880  ON P GOTO 1240 ,60
1230 GOSUB2800 :PRINT@936,"CONTINUE", NN=1 C(1)=932 GOSUB 2880 :PRINT@932,"
       ", PRINT CHR$(13), RETURN
1240 LPRINT CHR$(30):LPRINT " #  NAME   BENEFIT  COST    TECHNOLOGY LINE"
1250 LPRINT
1260 FOR J=1 TO N
1270 LPRINT J;TAB(4);N$(J);TAB(10);BEN(J),TAB(19);CST(J);TAB(28);S$(J)
1280 NEXT J
1290 LPRINT:LPRINT
1300 LPRINT"GENERIC TECHNOLOGY COSTS" LPRINT
1310 LPRINT " #   COST":LPRINT
1320 FOR J=1 TO LMX
1330 LPRINT J;TAB(4);CGT(J)
1340 NEXT J
1350 GOTO 60
1360 F2=1 'SET FLAG TO INDICATE SORTED DATA
1370 'SORT ROUTINE
1380 MX=0:BMX=0:CT=0 FOR J=1 TO LMX GC(J)=CGT(J):NEXT J
1390 FOR J=1 TO N Q(J)=0:NEXTJ PRINT CLS PRINT@407,"***SORTING***" PRINT@471,"IT
ERATION",
1400 FOR H=1 TO N
1410 PRINT@481,(N-H);
1420 FOR J=1 TO N
1430 IF Q(J) = 1 THEN 1530
1435 IF CST(J)<=0 THEN CST(J)=.001
1440 CT=CT+CST(J)
1450 FOR K=1 TO LMX
1460 CT=CT+(VAL(MID$(S$(J),K,1)))*GC(K)
1470 NEXT K
1480 BC=BEN(J)/CT
1490 IF BC<BMX THEN 1510
1500 T=J:BMX=BC
1510 CT=0
1530 NEXT J
1535 FOR K=1 TO LMX IF(VAL(MID$(S$(T),K,1)))=1 THEN GC(K)=0:NEXT K   'REM ZERO O
UT GEN.TECH. COSTS THAT HAVE ALREADY BEEN ADDED
1540 N1$(H)=N$(T)
1550 B1(H)=BEN(T)
1560 C1(H)=CST(T)
1570 S1$(H)=S$(T)
1580 Q(T)=1 B(H)=BMX
1590 BMX=0:T=0 NEXT H:CLS:PRINT"SORTED ORDER":PRINT PRINT" #     CONCEPT":PRINT
1600 FOR X=1 TO N
1610 PRINT X;"    ";N1$(X)
1620 IF (X/10)-INT(X/10)=0 THEN GOSUB 1230
1630 NEXT X
1640 GOSUB 2800 :PRINT@804,"PRINT TABLE",:PRINT@932,"RETURN TO MENU";:NN=2:C(1)=
800:C(2)=928 GOSUB 2880   ON P GOTO 1650 ,60
1650 LPRINT CHR$(31):LPRINT"SORTED ORDER:":LPRINT:LPRINT" #   CONCEPT":LPRINT
1660 FOR X=1 TO N
1670 LPRINT X,TAB(5),N1$(X)
1680 NEXT X:LPRINT
1690 GOTO 60
1700 'CUMULATIVE BENEFIT/COST ROUTINE
1710 'COMPUTE ROUTINE
1720 CLS:PRINT@407,"***WORKING***"
1730 MX=0:FOR J=1 TO LMX:GC(J)=CGT(J) NEXT J CB=0 CC=0
```

```
1740 FOR H=1 TO N
1750 CB=CB+B1(H)
1760 CC=CC+C1(H)
1770 FOR J=1 TO LMX
1780 CC=CC+(VAL(MID$(S1$(H),J,1)))*GC(J)
1790 IF (VAL(MID$(S1$(H),J,1)))=1 THEN GC(J)=0
1800 NEXT J
1810 'COMPUTE CUMULATIVE RATIO
1820 CR(H)=CB/CC:IF INT(CR(H))>MX THEN MX=INT(CR(H))
1830 NEXT H
1840 CLS:PRINT"RESULTS:CUMULATIVE B/C" IF F2=1 THEN PRINT"NOTE: CONCEPTS HAVE BE
EN SORTED" ELSE PRINT"NOTE: CONCEPTS HAVE *NOT* BEEN SORTED" PRINT
1850 PRINT:PRINT"# CONCEPTS     NAME        CUMULATIVE B/C"
1860 FOR J=1 TO N PRINT J;TAB(14);N1$(J);TAB(24),CR(J)
1870 IF (J/10)-INT(J/10)=0 THEN GOSUB 1230
1880 NEXT J:GOSUB 2800  PRINT@816,"PRINT TABLE",  PRINT@944,"GRAPHICAL OUTPUT";;
 NN=2 C(1)=812:C(2)=940 GOSUB 2880 :ON P GOTO 2340 ,1890
1890 CLS IF MX>12 THEN PRINT"THE MAXIMUM B/C IS GREATER THAN 12 AND CANNOT BE PL
OTTED GRAPHICALLY" FOR J=1 TO 900 NEXT J RETURN
1900 TEMP=0:IF N>25 THEN TEMP=N:N=25
1910 'PRINT VERTICAL AXIS
1920 FOR I=10 TO 778 STEP 64
1930 PRINT @ I,CHR$(191)
1940 NEXT I
1950 'PRINT HORIZONTAL AXIS
1960 PRINT@779,STRING$(53,176);
1970 'PRINT X-AXIS SCALE
1980 FOR I=1 TO N
1990 M=I
2000 IF I>9 THEN M=(INT(I/10))
2010 S=INT(49/(N-1))
2020 PRINT @(843+((I-1)*S)),M;
2030 AR=((I/10)-INT(I/10))*10:IF AR<1 AND AR<>0THEN AR=1
2040 IF I>9 THEN PRINT @ (907+((I-1)*S)),AR
2050 NEXT I
2060 MX=MX+1'SCALE Y-AXIS
2070 IF MX=1 THEN I=12
2080 IF MX=2 THEN I=6
2090 IF MX=3 THEN I=4
2100 IF MX=4 THEN I=3
2110 IF MX=5 THEN I=4
2120 IF MX=6 THEN I=4
2130 IF MX=7 THEN I=3
2140 IF MX=8 THEN I=3
2150 IF MX>8 THEN I=2
2160 IF MX>4 THEN L=2 ELSE L=1
2170 'PRINT Y-AXIS VALUES
2180 FOR J=0 TO 12 STEP I
2190 PRINT @ (6+(12-J)*64),((J/I)*L);
2200 NEXT J
2210 PRINT @ 384,"B/C",
2220 PRINT @ 906,"# OF CONCEPTS",
2230 'DRAW BARS
2240 FOR J=1 TO N
2250 LI=INT((CR(J)*I)/L):IF LI>12 THEN LI=12
2260 FOR K=0 TO LI
2270 PRINT @ (780+((J-1)*S))-(64*K),CHR$(191);
2280 NEXT K
2290 NEXT J
2300 IF TEMP <> 0 THEN N=TEMP
2310 GOSUB 2800
2320 PRINT@973,"PRINTOUT";
2330 PRINT@1000,"RETURN TO MENU",:NN=2:C(1)=970:C(2)=997 GOSUB 2880 :V=P:ON V GO
TO 3130 ,60
2340 CLS LPRINT CHR$(31)
2350 IF F2=1 THEN LPRINT"NOTE: CONCEPTS HAVE BEEN SORTED" ELSE LPRINT"NOTE: CONC
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```
ERTS-HAVE-*NOT* BEEN SORTED"
2360 LPRINT
2370 LPRINT " #  NAME      CUMULATIVE B/C" LPRINT
2380 FOR J=1 TO N
2390 LPRINT J;TAB(4);N1$(J),TAB(12),CR(J)
2400 NEXT J
2410 GOSUB 2800  PRINT@286,"GRAPHICAL OUTPUT" PPINT@414,"RETURN TO MENU" C(1)=28
2 C(2)=410 NN=2 GOSUB 2880  ON P GOTO 1890 ,60
2420 'FILE OUTPUT ROUTINE
2430 ON ERROR GOTO 0
2440 CLS
2450 CLS  PRINT@24,"***DISK OUTPUT***" PRINT PRINT PRINT"WHAT DO YOU WISH TO NAM
E THE OUTPUT FILE?"
2460 PRINT "(ENTER 0 TO RETURN TO MENU)" PRINT
2470 INPUT "NAME=",A$
2480 IF A$="0" THEN 60
2490 OPEN "O",1,A$
2500 FOR J= 1 TO N
2510 PRINT#1, N$(J),",",BEN(J),",",CST(J),",",S$(J);",",CGT(J)
2520 NEXT J
2530 CLOSE
2540 PRINT PRINT"THE CONCEPT FILE NAMED ",CHR$(34);A$;CHR$(34)," HAS BEEN SAVED
TO DISK"
2550 GOSUB 3120  GOSUB 2880  RETURN
2560 'FILE INPUT ROUTINE
2570 CLS ON ERROR GOTO 2770
2580 J=0:F2=1
2590 PRINT@24,"***DISK INPUT***" PRINT PRINT PRINT"WHICH FILE DO YOU WISH TO INP
UT?":PRINT"(ENTER 0 TO RETURN TO MENU)" PRINT INPUT"FILE NAME=";A$
2600 IF A$="0" THEN 60
2610 F2=0
2620 OPEN "I",1,A$
2630 J=J+1
2640 IF EOF(1) THEN 2670
2650 INPUT#1,N$(J),BEN(J),CST(J),S$(J),CGT(J)
2660 GOTO 2630
2670 N=J-1:CLOSE:LMX=0
2680 FOR J=1 TO N
2690 X=LEN(S$(J))
2700 IF X>LMX THEN LMX=X
2710 NEXT J
2720 PRINT:PRINT"THE CONCEPT FILE NAMED ",CHR$(34),A$,CHR$(34)," HAS BEEN ENTERE
D"
2730 FOR J=1 TO N
2740 N1$(J)=N$(J):B1(J)=BEN(J):C1(J)=CST(J):S1$(J)=S$(J)
2750 NEXT J
2760 GOSUB 3120 :GOSUB 2880  RETURN
2770 CLOSE CLS PRINT@27,"***ERROR***" PRINT PRINT:PRINT"THE CONCEPT FILE NAMED "
,CHR$(34);A$,CHR$(34);" IS NOT ON THIS DISK"
2780 PRINT PRINT"CHECK THE FILE NAME AND TRY AGAIN"
2790 PRINT PRINT FOR J=1 TO 1200 NCXT J RESUME 2580
2800 'DEFINE CURSOR CHARACTER
2810 C$=CHR$(131)
2820 'DEFINE BLANK CHARACTER
2830 B$="  "
2840 'ACTIVATE LIGHT PEN
2850 OUT 255,4:REM MODEL 1 ACTIVATED
2860 OUT 206,2 REM MODEL 3 ACTIVATED
2870 RETURN
2880 'LIGHT PEN SCAN ROUTINE
2890 'TURN ON THE CURSORS
2900 FOR JA=1 TO NN PRINT@C(JA),C$, NEXT JA
2910 'RESET FLIP FLOP
2920 OUT 255,4
2930 'SEE IF THERE IS ANY LIGHT DETECTED
2940 IF INP(255)<128 THEN 2940
2950 'SEE WHICH CURSOR IS SELECTED
2960 FOR P=1 TO NN
```

```
2970 FOR JB=1 TO 2
2980 'TURN OFF THE CURSOR AND CHECK
2990 PRINT@C(P),B$;
3000 FOR JA=1 TO 2 NEXT JA
3010 OUT 255,4
3020 FOR JA=1 TO 2 NEXT JA
3030 IF INP(255)>128 THEN 3100
3040 'TURN ON CURSOR AND CHECK
3050 PRINT@C(P),C$,
3060 FOR JA=1 TO 2:NEXT JA
3070 IF INP(255)<128 THEN 3100
3080 NEXT JB
3090 RETURN
3100 NEXT P
3110 GOTO 2880
3120 PRINT@926,"RETURN TO MENU" NN=1 C(1)=923 GOSUB2900  RETURN
3130 CLS PRINT@407,"***PRINTING***"
3140 PRINT@471,"(0-10 MINUTES)"
3150 TEMP=0:IF N>25 THEN TEMP=N:N=25
3160 LC=1:LL=0:LN=MX F1=0
3161 IF MX=5 OR MX=6 THEN LN=6
3162 IF MX=7 OR MX=8 THEN LN=8
3163 IF MX=9 OR MX=10 THEN LN=10
3164 IF MX=11 OR MX=>12 THEN LN=12
3170 SP=INT((467-(6*N))/N) IF SP=12 THEN SP=11
3180 VS=3*I VT=VS+1 LPRINT LPRINT
3190 LPRINT CHR$(30);"B/C"
3200 LPRINT
3210 FOR K=1 TO 36
3220 IF LC=VT THEN LC=1
3230 IF LC=1 THEN GOSUB 3440  GOTO 3240 ELSE LA=32 LB=32
3240 LC=LC+1
3250 LPRINT CHR$(30),CHR$(LA),CHR$(LB),CHR$(18),CHR$(28),CHR$(2);CHR$(255);
3260 FOR J=1 TO N
3270 IF K>(36-(INT(CR(J)*VS)/L)) THEN BAR=255 ELSE BAR=128
3280 LPRINT CHR$(18);CHR$(28),CHR$(SP),CHR$(128),CHR$(18);CHR$(28):CHR$(6),CHR$(
BAR);
3290 NEXT J
3300 LPRINT CHR$(26)
3310 NEXT K
3320 LPRINT CHR$(30);"00",CHR$(18);CHR$(28),CHR$(230);CHR$(131);CHR$(28);CHR$(23
9),CHR$(131)
3330 LPRINT CHR$(18),CHR$(28),CHR$(19),CHR$(128),
3340 SP=SP-5
3350 FOR J=1 TO N
3360 TN=(INT(J/10)) UN=J-(TN*10) 'TENS AND UNITS PLACES
3370 IF TN=0 THEN D1=UN+48:D2=32 ELSE D1=TN+48 D2=UN+48
3380 LPRINT CHR$(18),CHR$(28);CHR$(SP),CHR$(128),CHR$(30),CHR$(D1),CHR$(D2);
3390 NEXT J
3400 LPRINT CHR$(26) LPRINT
3410 LPRINTCHR$(31), CHR$(16);"21","NUMBER OF CONCEPTS"
3420 IF TEMP <> 0 THEN N=TEMP
3430 GOTO 60
3440 LA=INT(LN/10)+48
3450 LB=INT ((LN)-(INT(LN/10))*10)+48
3460 LN=LN-L
3470 RETURN
3480 'ERROR TRAP
3490 CLS:PRINT@26,"***ERROR***"
3500 PRINT@192,"AN ERROR CONDITION HAS OCCURRED. VERIFY INPUT DATA TO INSURE
THAT ALL BENEFIT, COST, AND TECHNOLOGY LINE ARGUMENTS ARE       CORRECT AND MEAN
INGFUL (NOTE ALL COST VALUES MUST BE GREATER     THAN ZERO)"
3510 GOSUB 3120  GOSUB 2880  RESUME 60
3520 S$(X)="" 'TECH LINE INPUT ROUTINE
3530 AA$=INKEY$
3540 IF AA$=CHR$(13) THEN 3590
```

```
3550 IF AA$<>"1" AND AA$<>"0" THEN 3530
3560 PRINT AA$,
3570 S$(X)=S$(X)+AA$
3580 GOTO 3530
3590 RETURN
3600 'EXCHANGE ROUTINE
3610 F2=0
3620 CLS:PRINT@22,"***CHANGE ORDER***" PRINT PRINT PRINT"ENTER THE NUMBER OF THE
 CONCEPT WHICH YOU WISH TO MOVE (FROM),   AND THE POSITION TO WHICH YOU WISH TO
MOVE IT." PRINT
3630 INPUT "FROM,TO=",F,T IF F>N OR T>N THEN 3630
3640 NT$=N$(F) BT=BEN(F) CT=CST(F):ST$=S$(F)
3650 IF F>T THEN 3680
3660 IF F<T THEN 3720
3670 IF F=T THEN PRINT"FROM AND TO CANNOT BE THE SAME" GOTO 3630
3680 FOR J=(F) TO (T+1) STEP -1
3690 N$(J)=N$(J-1):BEN(J)=BEN(J-1) CST(J)=CST(J-1) S$(J)=S$(J-1)
3700 NEXT J
3710 GOTO 3750
3720 FOR J=F TO T-1
3730 N$(J)=N$(J+1):BEN(J)=BEN(J+1):CST(J)=CST(J+1):S$(J)=S$(J+1)
3740 NEXT J
3750 N$(T)=NT$:BEN(T)=BT CST(T)=CT S$(T)=ST$
3760 CLS:PRINT"THE CONCEPTS ARE NOW ORDERED AS FOLLOWS ":PRINT:PRINT " #   CONCE
PT NAME"
3770 FOR J=1 TO N
3780 PRINT J,N$(J)
3790 IF (J/10)-INT(J/10)=0 THEN GOSUB 1230
3800 NEXT J
3810 GOSUB 1060 'STORE VALUES FOR COMPUTATION
3820 GOSUB 3120 :GOSUB 2880 : GOTO 60
```

```
10 CLS:CLEAR
20 PRINT@18,"***PRESENT WORTH UTILITY***"
30 PRINT:PRINT"SELECT THE DESIRED FUNCTION "
40 PRINT@350,"UNIFORM BENEFITS OR COSTS"
50 PRINT@478,"NON-UNIFORM BENEFITS OR COSTS"
60 PRINT@606,"END UTILITY RUN"
70 C(1)=346 C(2)=474:C(3)=602 N=3
80 GOSUB 470
90 GOSUB 550
100 ON P GOTO 110  ,280  ,460
110 'UNIFORM SERIES ROUTINE
120 CLS
130 PRINT@21,"***UNIFORM SERIES***"
140 PRINT PRINT"ENTER DISCOUNT RATE TO BE USED (DEFAULT=10%)"
145 I=10
150 INPUT"DISCOUNT RATE= ",I
160 I=I/100
170 PRINT"ENTER THE NUMBER OF YEARS OVER WHICH THE BENEFIT OR COST WILL   APPLY"
180 INPUT"NUMBER OF YEARS= ",N
190 F=(((1+I)[N)-1)/(I*(1+I)[N)
200 PRINT"ENTER THE AMOUNT OF THE BENEFIT OR COST (0=RETURN TO MENU)"
210 INPUT"AMOUNT= ",A
220 IF A=0 THEN 10
230 PW=A*F
240 PRINT PRINT"THE PRESENT WORTH IS·"; PRINT USING"$$########";PW
250 PRINT
260 GOTO 200
270 F=1/((1+I)[N) RETURN
280 'NON-UNIFORM SERIES ROUTINE
290 CLS CLEAR
300 PRINT"ENTER THE NUMBER OF YEARS OVER WHICH THE BENEFIT OR COST WILL   APPLY"
310 INPUT "NUMBER OF YEARS= ",N1
320 PRINT"ENTER DISCOUNT RATE (DEFAULT=10%)"
330 I=10
340 INPUT"DISCOUNT RATE= ",I
350 I=I/100
360 FOR N=1 TO N1
370 PRINT "ENTER THE AMOUNT FOR YEAR #",N
380 INPUT "AMOUNT= ",A
390 GOSUB 270
400 PW=A*F
410 NPW=NPW+PW
420 NEXT N
430 CLS
440 PRINT"THE NET PRESENT WORTH IS ", PRINT USING"$$########",NPW
450 PRINT@926,"RETURN TO MENU" C(1)=922:N=1 GOSUB 470   GOSUB 550   GOTO 10
460 CLS PRINT@473,"UTILITY ENDED" FOR J=1 TO 200:NEXT J CLS END
470 'DEFINE CURSOR CHARACTER
480 C$=CHR$(131)
490 'DEFINE BLANK CHARACTER
500 B$="  "
510 'ACTIVATE LIGHT PEN
520 OUT 255,4:REM MODEL 1 ACTIVATED
530 OUT 236,2 REM MODEL 3 ACTIVATED
540 RETURN
550 'LIGHT PEN SCAN ROUTINE
560 'TURN ON THE CURSORS
570 FOR I=1 TO N:PRINT@C(I),C$ NEXT I
580 'RESET FLIP FLOP
590 OUT 255,4
600 'SEE IF THERE IS ANY LIGHT DETECTED
610 IF INP(255)<128 THEN 610
620 'SEE WHICH CURSOR IS SELECTED
630 FOR P=1 TO N
```

```
640 FOR I=1 TO 2
650 'TURN OFF THE CURSOR AND CHECK
660 PRINT@C(P),B$
670 FOR J=1 TO 2:NEXT J
680 OUT 255,4
690 FOR J=1 TO 2:NEXT J
700 IF INP(255)>128 THEN 770
710 'TURN ON CURSOR AND CHECK
720 PRINT@C(P),C$
730 FOR J=1 TO 2 NEXT J
740 IF INP(255)<128 THEN 770
750 NEXT I
760 RETURN
770 NEXT P
780 GOTO 550
```

APPENDIX F

EXAMPLE COMPUTER RUNS

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#	NAME	BENEFIT	COST	TECHNOLOGY LINE
1	SHEAR	304	213	11000110
2	ACT LG	91	26	11100010
3	RED. FA	4355	207	11101010
4	AFC	361.9	1E-03	11111010
5	ASR	542.9	1E-03	11001000
6	MA	45.3	1E-03	00011000
7	AC	271.5	1E-03	11011001
8	ATC	542.9	1E-03	11011001

GENERIC TECHNOLOGY COSTS

#	COST
1	500
2	500
3	100
4	100
5	50
6	150
7	50
8	50

Figure F-1. DATA AS ORIGINALLY ENTERED

NOTE: CONCEPTS HAVE BEEN SORTED

#	NAME	CUMULATIVE B/C
1	RED. FA	3.00524
2	ASR	3.48109
3	ATC	3.49441
4	AFC	3.72604
5	MA	3.75593
6	AC	3.9383
7	SHEAR	3.94556
8	ACT LG	3.20139

Figure F-2. FIRST SORT

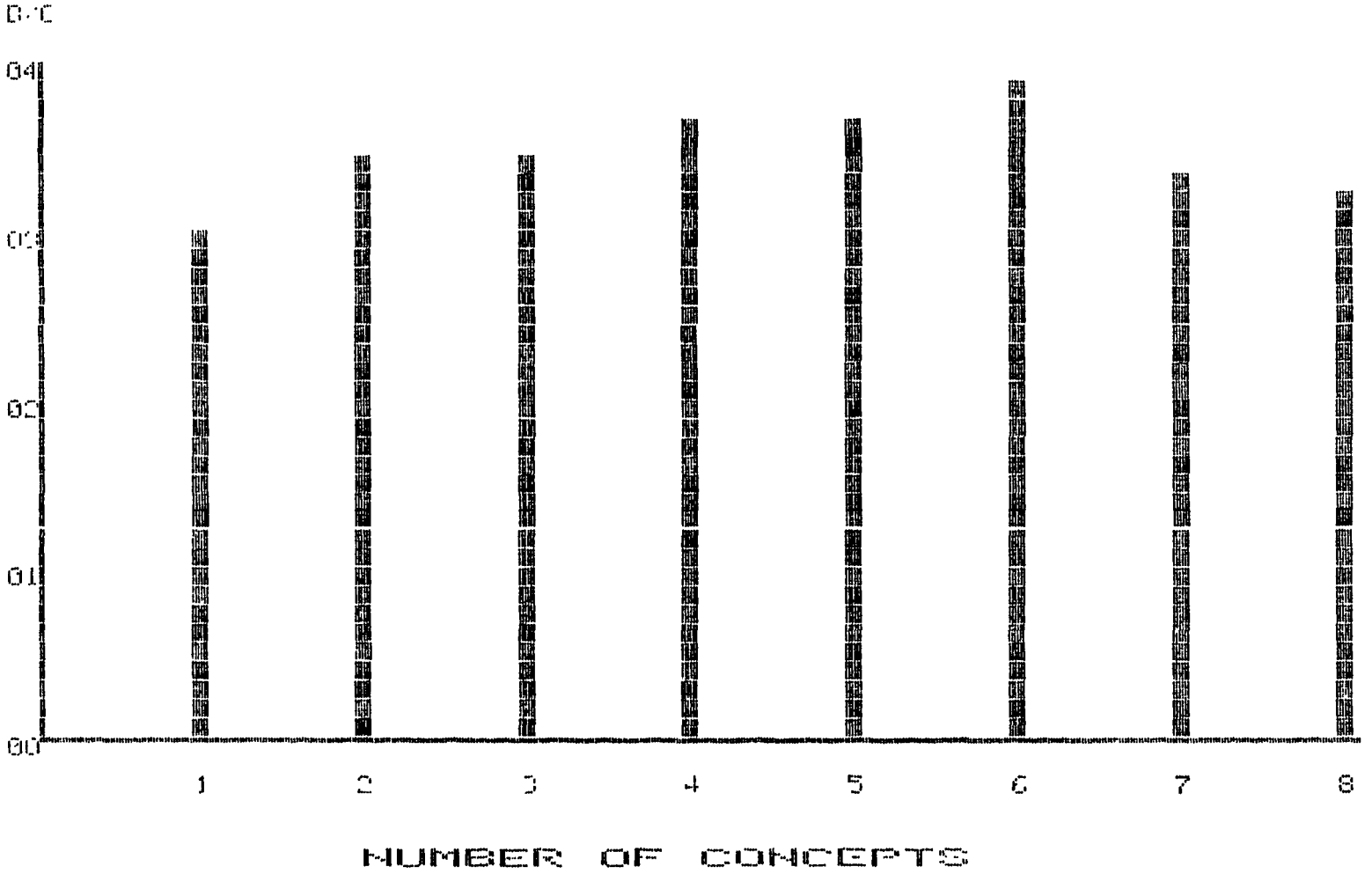

Figure F-3. GRAPHIC DISPLAY OF FIRST SORT

#	NAME	BENEFIT	COST	TECHNOLOGY LINE
1	SHEAR	304	213	11000110
2	ACT LG	91	96	11100010
3	RED. FA	4055	207	11101010
4	AFC	361.9	1E-03	11111010
5	ASP	542.9	1E-03	11001000
6	AA	45.3	1E-03	00011000
7	AC	271.5	1E-03	11011001
8	ATC	542.9	1E-03	11011001

GENERIC TECHNOLOGY COSTS

#	COST
1	1000
2	500
3	100
4	100
5	50
6	150
7	50
8	50

Figure F-4. DATA WITH FIRST GENERIC TECHNOLOGY COSTS DOUBLED

NOTE: CONCEPTS HAVE BEEN SORTED

#	NAME	CUMULATIVE B/C
1	RED. FA	2.28369
2	ASP	2.56033
3	ATC	2.64501
4	AFC	2.82095
5	AA	2.84297
6	AC	2.97496
7	SHEAR	2.65430
8	ACT LG	2.50922

Figure F-5. SECOND SORT

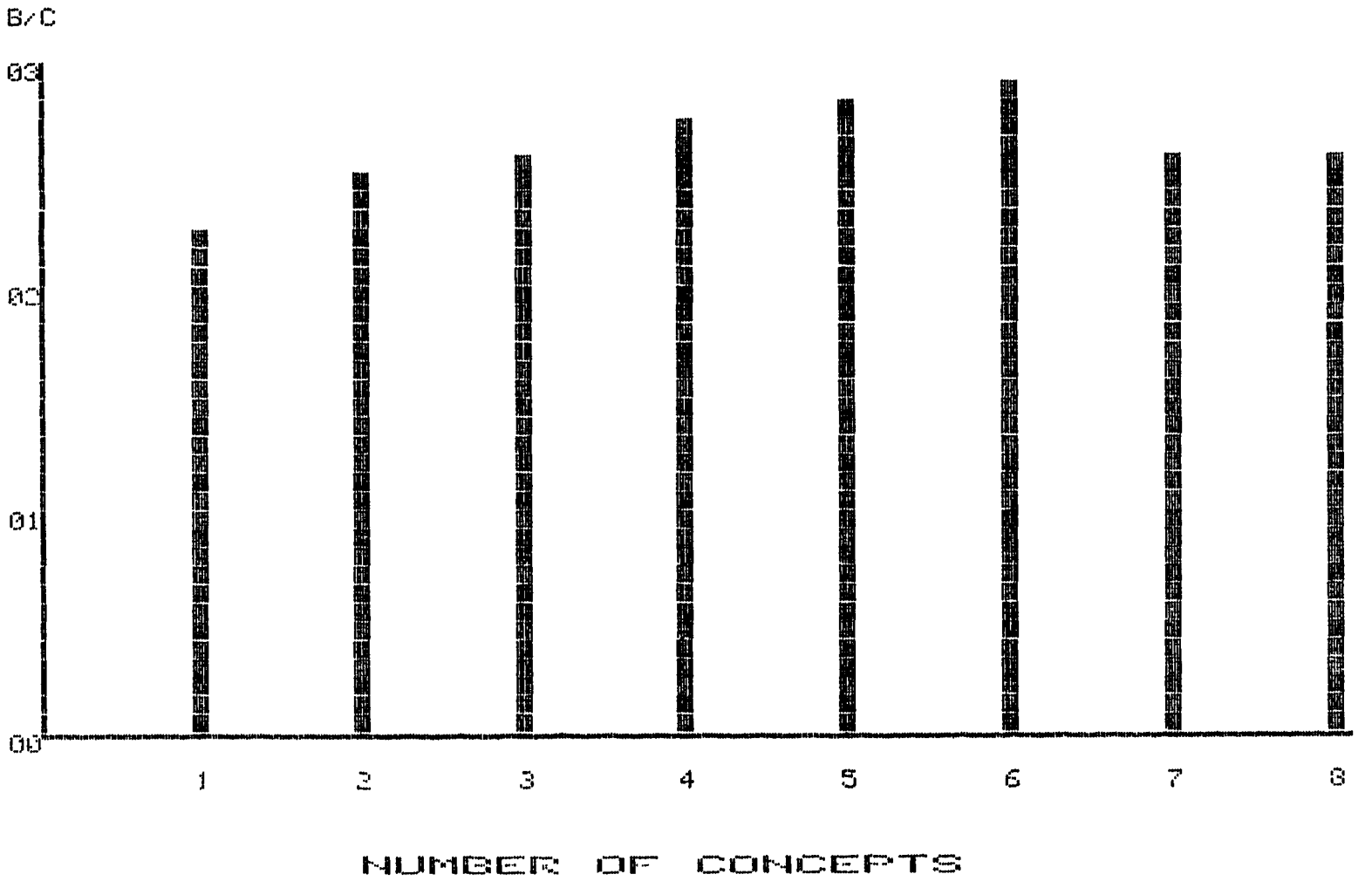

Figure F-6. GRAPHIC DISPLAY OF SECOND SORT

#	NAME	BENEFIT	COST	TECHNOLOGY LINE
1	SHEAR	304	213	11000110
2	ACT LG	91	96	11100010
3	RED. FA	4355	207	11101010
4	AFC	361.9	1E-03	11111010
5	ASP	542.9	1E-03	11001000
6	AA	100	1E-03	00011000
7	AC	271.5	1E-03	11011001
8	ATC	542.9	1E-03	11011001

GENERIC TECHNOLOGY COSTS

#	COST
1	1000
2	500
3	100
4	100
5	50
6	150
7	50
8	50

Figure F-7. DATA WITH ADVANCED AVIONICS BENEFITS DOUBLED

NOTE: CONCEPTS HAVE BEEN SORTED

#	NAME	CUMULATIVE B/C
1	RED. FA	2.28369
2	ASP	2.56838
3	ATC	2.64501
4	AFC	2.82095
5	AA	2.96956
6	AC	3.00155
7	SHEAR	2.67694
8	ACT LG	2.61896

Figure F-8. THIRD SORT

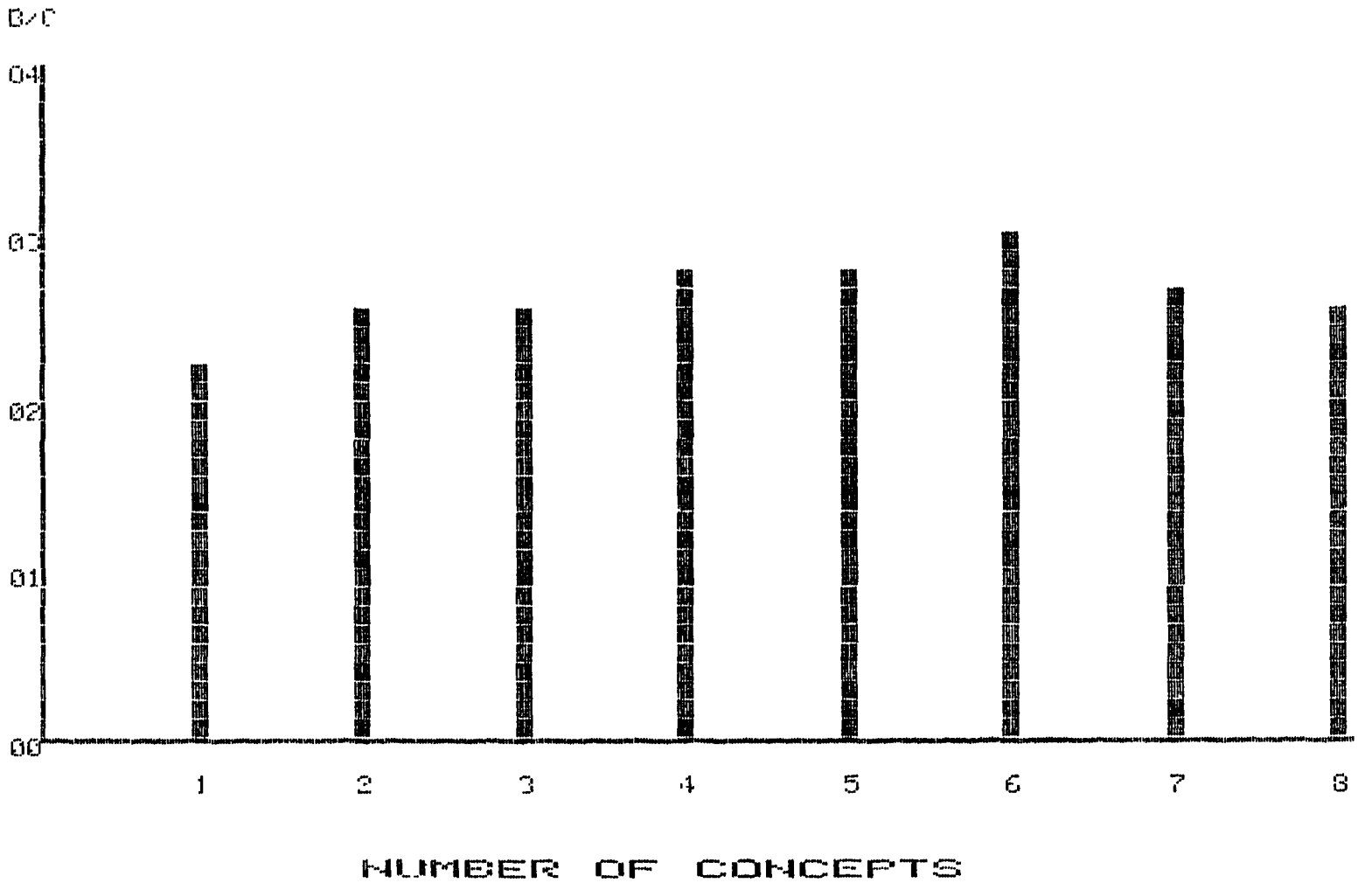

Figure F-9. GRAPHIC DISPLAY OF THIRD SORT

#	NAME	BENEFIT	COST	TECHNOLOGY LINE
1	SHEAR	304	213	11000110
2	ACT LG	91	96	11100010
3	RED. FA	2000	207	11101010
4	AFC	361.9	1E-03	11111010
5	ASP	542.9	1E-03	11001000
6	AA	100	1E-03	00011000
7	AC	271.5	1E-03	11011001
8	ATC	542.9	1E-03	11011001

GENERIC TECHNOLOGY COSTS

#	COST
1	1000
2	500
3	100
4	100
5	50
6	150
7	50
8	50

Figure F-10. DATA WITH BENEFITS FROM FEWER FLIGHT ATTENDANTS REDUCED

NOTE: CONCEPTS HAVE BEEN SORTED

#	NAME	CUMULATIVE B/C
1	RED. FA	1.04877
2	ASP	1.33346
3	ATC	1.50014
4	AFC	1.67608
5	AA	1.72469
6	AC	1.85668
7	SHEAR	1.7008
8	ACT LG	1.67496

Figure F-11. FOURTH SORT

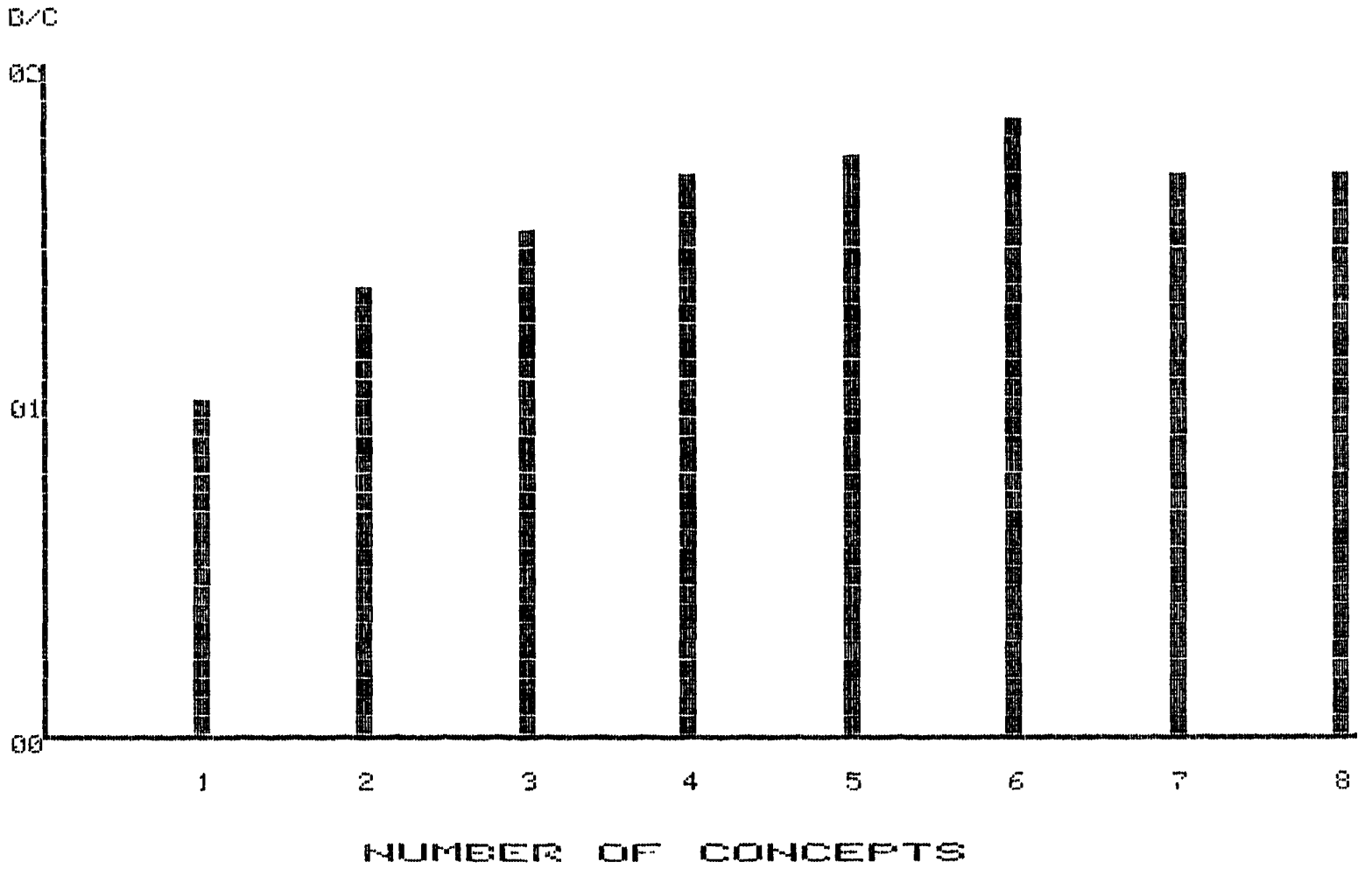

Figure F-12. GRAPHIC DISPLAY OF FOURTH SORT

APPENDIX G

GLOSSARY

Air Traffic Control System. The facilities and equipment that constitute the system established and operated by the Federal Aviation Administration (FAA). This system is designed to permit the safe and orderly flow of aviation traffic between points within the system. The air traffic control system also includes those private and publicly operated facilities which are regulated by the FAA.

Aviation Goal. An objective that the aviation industry, users, and associated government agencies should strive for.

Avionics. The electronic equipment used in aviation that is installed and operated on aircraft. This equipment includes devices that guide, control, display, and communicate with an aircraft and its flight crew.

Civil Aviation. Those aircraft which are not used for military purposes. They include general aviation aircraft, air transports, cargo aircraft, helicopters, business aircraft, agriculture aircraft, and utility aircraft. For the purposes of this study, civil aviation will be limited to large commercial transport aircraft used by the U.S. and major foreign airlines in scheduled service.

Concepts. The technological approach that can be used to achieve a desired capability.

Controls. The ability to steer an aircraft on an arbitrary flight path. In this study, controls are the surfaces and actuating and interconnecting devices that react with an aircraft and its environment. These surfaces and devices include flaps, ailerons, elerons, flaperons, rudders, elevators, horizontal stabilizers, vertical stabilizers, canards, slats, and landing equipment.

Desired Capability. A specific aircraft characteristic that can be altered to achieve a desired improvement.

Flight Electronics. The electronic equipment used in aircraft that is associated with the operation and control of the aircraft. Flight electronics is a subset of avionics.

Human Factors. The techniques and technologies that address the human interactions with an aircraft and the operating environment.

Improvement Area. A specific area of aviation performance in which improvement will contribute to achievement of an aviation goal. For example, for the goal of reduced operating costs, an improvement area is fuel usage costs.

Problem Areas. Groupings of specific problems in the aviation environment that are encountered by aircraft and aircrews. The three problem areas addressed in this study are operations, safety, and social interaction.

APPENDIX H

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