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SST

AN ECONOMIC ANALYSIS

Part III. Contractor's Reports

B. Cost Performance

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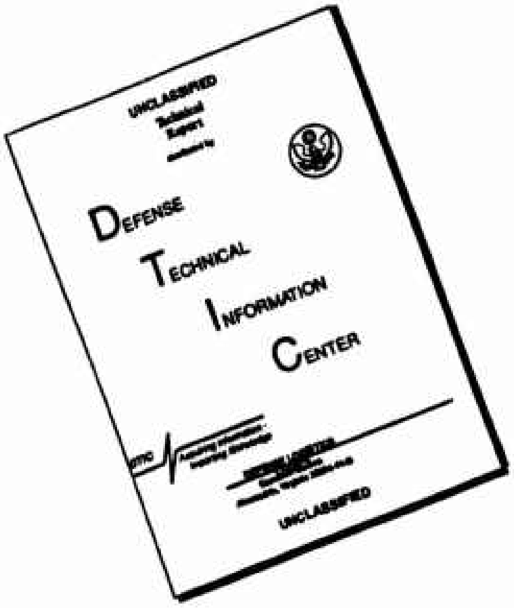

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Technical Report

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EXPLANATION OF RELEVANCY OF CONCLUSIONS AND DATA CONTAINED IN THE SST ECONOMIC ANALYSIS REPORTS PREPARED BY THE DEPARTMENT OF COMMERCE

In an effort to provide as complete a history as possible of the course of the SST program, materials consisting of Part I, Executive Summary and Supplements, and Part III, Contractor's Reports*, have been made publicly available. However, all persons using these materials should be advised that the data and conclusions pertaining to the SST designs contained therein are not current and have been superseded by the SST designs submitted to the FAA September 6, 1966, which were the basis for the Economic Feasibility Report prepared by the FAA in April 1967 and for the reports of the Economic Research Contractors submitted December 31, 1966. Using the superseded designs and the related economic data for comparisons with economic characteristics of other aircraft, both American and European, could be misleading and not representative of what was achieved with the more recent SST designs.

Because of the changes in development costs and total program costs and because of the provisions of the Phase III contracts with the airframe and engine manufacturers, the financial data and conclusions contained in the Executive Summary relating to the financial capability of the manufacturers do not reflect their financial capability in the context of the current program or their general financial position.

Accordingly, the materials attached hereto should be viewed as predominately historical in character.

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* Part II of the SST Economic Analysis was never issued.

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Technical Report 295

OPERATIONS RESEARCH *Incorporated*

SILVER SPRING, MARYLAND

COST-ESTIMATING RELATIONS FOR AIRCRAFT

VOLUME I. DEVELOPMENT OF EQUATIONS

by

F. B. Brown, D. S. Orkand, J. P. Bowling,
R. J. Byer, and N. Simat

15 December 1964

Prepared under Contract OSD-275
for the Office of Secretary of Defense
Assistant Secretary of Defense (Comptroller)
for the Department of Commerce

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FOREWORD

Two parallel and independent studies of cost-performance relationships applicable to present and future commercial transport aircraft are contained in this volume. Parallel efforts were considered essential because of the great uncertainties in estimating future development, production, and operating costs for technically advanced aircraft.

The first study presented was conducted by Operations Research, Incorporated.

The second study was made by Planning Research Corporation.

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ACKNOWLEDGMENTS

ORI wishes to acknowledge the cooperation of those organizations and individuals who provided exceptional support to this study in making available certain of the cost data and other information upon which the analysis is based.

Mr. Wallace West	Boeing Airplane Co.
Mr. R.A. Barnard	Lockheed Corporation
Mr. Frank Ruelke	Douglas Aircraft Co.
Mr. Tom Fowlkes	General Dynamics/Fort Worth
Mr. John Melzer	General Electric Co.
Mr. Richard Hoff	Pratt and Whitney

Mr. Richard J. Maurer, Power Plant Division of BuWeps of the Navy, was especially helpful in providing data and cost approaches on jet engines. Mr. Tom Dehaven of WPAFB cooperated in supplying valuable information on one of the Air Force's current cost analysis approaches.

The cooperation of Mr. William Neely of American Airline's power-plant maintenance activity is also acknowledged.

ORI wishes to express appreciation to Mr. Harry P. Hatry of the Directorate for Cost and Economic Analysis of OSD for his assistance in arranging contracts with government and industry personnel, and for his technical discussions, suggestions, support, and direction.

The assistance of both DOD and the Department of Commerce in reviewing preliminary ORI reports and providing helpful criticisms and suggestions is also appreciated.

An alphabetical list of individuals contacted is shown on the following page.

A listing of companies and organizations with personnel contacted is in Section VIII of this Volume.

[redacted]

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ABSTRACT

This study was directed to the development of cost estimating relations (CERs) to predict the costs of the Supersonic Transport (SST) and competing current and advanced subsonic transports. The CERs developed relate cost to physical, performance, and operational characteristics of the aircraft system and cover research and development (R&D) costs, investment costs, and both direct and indirect operating costs. The basic method used to develop the CERs consisted of multivariate regression analysis of historical data on similar systems. The equations so developed were modified to extend their applicability to SST physical characteristics and operating points. The data used in this analysis were collected through direct contact with airplane and engine manufacturers, airlines, government agencies, and trade associations.

The results of the study are presented in three volumes.

VOLUME I. DEVELOPMENT OF EQUATIONS, provide the major results and describes their development.

VOLUME II. SUMMARY OF COST-ESTIMATING RELATIONS(CER), contains a summary of the estimating equations.

VOLUME III. APPLICATION TO THE SUPERSONIC TRANSPORT(SST), presents the results of applying the estimating equations to the competing SST designs.

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I. INTRODUCTION

PURPOSE OF THE STUDY

1.1 This report presents the results of a 4-1/2-month study conducted under contract SD-275 for the Office of the Secretary of Defense, Assistant Secretary of Defense (Comptroller). The study was initiated on 31 July 1964 and completed on 15 December 1964.

1.2 The primary purpose of this study was the derivation of cost-estimating relationships (CERs) that relate the expected costs of the supersonic transport (SST) to physical and performance characteristics of the system and the development of independent cost estimates for the specific designs proposed by airframe and engine manufacturers. In order to provide a basis for comparison, it was also necessary to derive equations and coefficients applicable to current and advanced subsonic aircraft.

RELATIONSHIP TO OVERALL SST ECONOMIC ANALYSIS

1.3 This study is one of eight basic elements of the overall economic analysis of SST conducted by the Department of Commerce at the direction of the President. The objective of the Department of Commerce study is to assess the economic impact of the SST program on the air transport industry and aircraft manufacturers and to determine the effect of such a program on the U.S. balance of trade.

1.4 The CERs presented in this report will contribute to the overall objective in two ways: First, the operating cost CERs will serve as inputs, along with data on demand, routes, rates, and sonic boom effects, to the world route simulation model being developed by ORI under a separate contract with the Department of Commerce. Second, the CERs for R&D and investment costs will be used directly in the cost-benefit analysis task and will also be reflected in the analyses of the financial capability of industry and the balance-of-payments effects.

SCOPE OF COVERAGE

1.5 The CERs developed during the course of this study provide a mechanism for the estimation of three categories of cost elements, R&D costs, investment costs, and operating costs, for subsonic and supersonic aircraft. Operating costs, both direct and indirect, are treated through the derivation of separate sets of CERs for U.S. domestic, U.S. international, and foreign air carriers. (Sonic boom costs, however, are not included in the scope of this effort but are being assessed by a separate study group.) Investment costs are first treated through the derivation of CERs for each major element of production cost (labor, material, overhead, etc.) by subsystem (airframe, engines, and avionics).

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The procurement costs of initial spare parts stocks, which are related to the cumulative average production costs,are also included. The coverage of the R&D CERs is similar to that of the investment CERs in terms of cost elements and subsystems, but the treatment is considerably more gross.

1.6 By means of these CERs independent cost estimates were derived for the SST aircraft and engine designs that are currently prepared. Estimates were developed for the Boeing and Lockheed airframe designs and the General Electric and Pratt & Whitney engine designs. In all cases, the designs considered were those submitted to the Federal Aviation Agency as of 1 November 1964.

LIMITATIONS IN SCOPE

1.7 In order to complete this study within the time constraints imposed by the schedule for the total Department of Commerce study, it was necessary to accept certain limitations in the scope and depth of analyses. These limitations pertain to the acquisition of data, the selection and testing of appropriate CERs, and the application of the CERs to the designs proposed for airframe and engine. They are stated here in general form; the detailed implications are discussed in the sections of this report devoted to the derivation of the particular equations.

1.8 A basic limitation on the completeness of this analysis (and most similar analyses) was the unavailability of relevant data and the ambiquity of much of the data that could be obtained. Security considerations made it impossible to obtain certain data pertaining to military aircraft; data pertaining to commercial aircraft were limited by proprietary considerations. Further, the definitions and completeness of cost aggregations, particularly R&D costs, varied sharply from company to company and program to program. It was not possible within the scope of this study to undertake the detailed analyses needed to distinguish actual cost variations from the variations attributable to differences in definition or accounting practices.

1.9 In formulating and selecting appropriate CERs, a basic aspect of the technical approach was to supplement the statistical analyses with engineering evaluations. However, this could not be done in detail in every instance where it appeared desirable. In addition, more extensive testing of the CERs, through their application to programs for which actual data are available, would be extremely useful.

1.10 It should also be noted that the application of the CERs to the proposed SST designs was undertaken at a relatively gross level, without detailed analysis of particular design features and the associated effect on costs. No effort was made to analyze, in detail, the differences between the manufacturer's cost estimates and those derived from the CERs.

ORGANIZATION OF STUDY DOCUMENTATION

1.11 The study documentation is organized into three volumes. Volume I describes the research activity, presents and discusses the CERs that were derived, and provides methods for estimating the uncertainity in

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cost predictions made from the CERs.

1.12 Volume II summarizes the pertinent results of the study, including the CERs for operating cost, investment cost, and development cost, as well as the resultant summary cost estimates obtained by applying these CERs to the Lockheed and Boeing SST proposals.

1.13 Volume III presents the details of the SST cost analysis. This volume is classified CONFIDENTIAL because of certain sensitive performance data contained therein.

CONTENTS OF VOLUME I: DEVELOPMENT OF CERs

1.14 This volume is divided into eight sections. Section II describes the research approach, with certain technical details of that approach being placed in the appendixes. Sections III, IV and V discuss the development of specific CERs for operating cost, investment cost, and development cost, respectively. Section VI discusses the treatment of special cost items not covered explicitly by the CERs.

1.15 Section VII summarizes the recommendations for further research that ORI felt are important to retain. Finally, Section VIII presents a bibliography of material bearing on this study and a list of corporate, governmental, and individual contacts made during the course of the study.

1.16 For convenience, a foldout containing definitions of the nomenclature used in the study is inserted as the final page in this volume and in Volumes II and III.

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II. TECHNICAL APPROACH

DISCUSSION OF THE PROBLEM

2.1 As previously indicated, the basic objective of the study undertaken by ORI has been to develop equations for calculating the cost of aircraft, both subsonic and supersonic, and to apply those equations to obtain an independent estimate of the cost of the SST aircraft programs proposed by Lockheed and Boeing. It is important that the equations developed provide reasonably accurate predictions for aircraft that will be operating beyond the region of present experience and, further, that they be based on parameters that can be estimated at the earliest stages of design concept.

2.2 There are a number of possible approaches to the problem of estimating aircraft cost. Probably the most obvious of these is the preparation of a direct estimate based on the specific engineering configuration and on the details of production technology. However, this involves considering each aircraft in complete detail; the resultant cost estimate would be cumbersome to use and would be inflexible in the sense that it could not be used as a general equation applicable to other aircraft or to a range of possible design and performance characteristics. Furthermore, such an estimate could not be developed until the design is fully configured, so that the basic purpose of the cost equation, that of providing an <u>advance indication</u> of <u>approximate cost</u>, would not be realized.

2.3 A second approach to the problem calls for developing an estimate based on the cost of "similar" aircraft. This has the obvious disadvantage that, for a new SST that is pushing the state-of-the-art on a number of fronts, there are no really similar aircraft. In addition, other aircraft, even when grouped into as technologically homogeneous categories as possible, still display wide variations in cost which prevent the use of such categories as standards of comparison. Further, it is impossible through this approach to provide objective assessments of the uncertainty of the estimates.

2.4 A third approach, that of developing CERs through multiple regression analysis of empirical data, has been employed by RAND 1/ and others for the estimation of aircraft costs and is now well known.2/ Despite the existence of a number of previous studies, however, there are significant technical difficulties in actually applying these techniques to the SST program.

2.5 A CER that is applicable to the new SST design must deal with major technological innovations and new system elements constituting a giant extrapolation from existing experience. The data that bear on experience closest to the present state-of-the-art are limited in availability and validity. Nevertheless it was the judgment of ORI that the CER would serve as a useful formalism for organizing, reconciling, and making the maximum use of available information by directing it objectively to the problem of cost estimation. Although

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1/ G.H. Fisher, <u>Derivation of Cost Estimating Relationships: An Illustrative Example</u>, RAND Memorandum M-3366, November 1962.

2/ See the bibliography contained in Section VIII.

[redacted]

the accuracy of such estimates will be limited in the absolute sense, the appraisal of the <u>relative cost</u> of competing designs and of the sensitivity of cost to design modification should be useful for planning purposes. Furthermore, ORI anticipated that the experience gained from the current study effort would lead to recommendations for standardization of accounting and data reporting, which would add rigor to future studies of a similar nature.

THE CONCEPT OF THE CER

2.6 It is the purpose of the CERs to relate the R&D, investment, and operating costs of an aircraft to its design and performance characteristics. In very general terms this is accomplished in the following manner:

a. Relevant cost categories (dependent variables) and physical and performance characteristics (independent variables) are selected on the basis of previous studies, experience, and engineering considerations.

b. Alternative forms of CERs are hypothesized for each cost category.

c. Historical cost, performance, and design data are acquired, screened, and stratified and relevant data points are identified.

d. The CER coefficients are computed for each functional form from the empirical data through regression analysis and correlation coefficients are evaluated.

e. Preferred CERs are selected for each cost category and tested against actual program data.

2.7 Stated in conceptual terms the problem is straightforward and the approach intuitively appealing. However, the implementation of this concept involves four major problem areas:

a. Determination of data requirements and acquisition of data

b. Assessment of data accuracy

c. Formulation and selection of preferred CER

d. Testing and analysis of results.

2.8 The remainder of this section will discuss the approach that ORI has taken to these problems.

DATA ACQUISITION

2.9 ORI experience has indicated that the advance preparation of a carefully designed data format materially assists in the acquisition of data by establishing for the information suppliers a mechanical, standardized questionnaire which, since it has been tailored specifically for the demands of the study, will serve to reduce the total data demand. The net result is to materially lessen the need for costly research on the part of data suppliers and to reduce the collection of artificial, superficial or useless data.

2.10 It was necessary to this study that two types of information be obtained: one bearing on the performance and physical characteristics of the aircraft and the other bearing on cost and associated production of data.

<u>Aircraft and Engine Characteristics</u>

2.11 In general, information bearing on performance and physical characteristics of aircraft, engines, and

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other accessories was readily available from the Civil Aeronautics Board (CAB) or Federal Aviation Agency (FAA) records, and from the manufacturer, or from the user. The exceptions to this statement are the military classified aircraft, such as the F-111, the A-11, and the RS 70, and such engines as the J-58. Here delays were encountered that, at least in the case of the A-11, prevented its incorporation in the study. Such gaps in the data did not permit an analysis of the most technologically advanced aircraft that are generically closest to the proposed SSTs. However, ORI was able to obtain data on the J-93 engine and on the RS 70, as well as the B-58 and B-52 and the Century series, which partially offset this disadvantage. Data were not consistently defined or organized and the same statistics differed by source, consequently screening and reconciliation of these data were required.

2.12 In general, information was obtained for each of the characteristics shown in Table 2.1. The portions that were used in the analysis are indicated in Sections III to VI of this volume.

2.13 It is felt that the efforts to obtain similar data on state-of-the-art aircraft should be continued; the analysis provided herein can be readily updated to accommodate such information as it becomes available.

Cost and Production Information

2.14 Cost data and production information, such as rates and quantities produced and special technology, were more difficult to obtain. This difficulty stemmed partly from reluctance of the manufacturer to divulge information felt to be proprietary and partly from differences in or lack of precision in accounting practices. ORI found that the

TABLE 2.1
RECOMMENDED DATA BASE FOR PHYSICAL SYSTEM CHARACTERISTICS
(Partial)

Aircraft Characteristic	Engine Characteristic
Speeds (knots) - max. at sea level	Dimensions - inlet diameter max.
Range (nmi) - with max. load	Weights (lb) - total dry
Ceiling (ft) max. with max. load	Thrust (lb) - at sea level
Ground runs (ft) - takeoff and landing	Specific fuel consumption (SFC) - at sea level
Capacity - payload	Operating temperatures - turbine
Propulsion - L/D - total thrust	Configuration - number of stages
Weights (lb) - AMPR-gross takeoff	Mass flow
Dimensions - wing span	Pressure ratio
	By-pass ratio

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"top-level" information, such as total cost of a program or the total number of B-52s produced to date, was either available in open literature or was readily provided on all except the militarily classified programs by the manufacturer and from data developed in previous studies. More detailed cost data that required an analysis of internal company records were progressively more difficult to define and to obtain.

2.15 It was the intention of ORI to obtain cost data applicable to the various phases of the development program and to various aircraft subsystems in order to permit later stratification in the analysis. However, because of the pressure of time, it was felt that effort should be concentrated on developing as accurate an accounting as possible of the information in Table 2.2. The portions that were used in the analysis are indicated in Sections III to VI of this volume as appropriate.

2.16 To obtain the information outlined above, ORI personnel made use of CAB, FAA, Department of Commerce, and the Department of Defense records locally available, and carried out field trips to confer with engineering, management, and accounting personnel. The following visits were made to the manufacturers, the using airlines and other organizations and are further documented in Section VIII of this volume:

Company	Location
American Airlines	Tulsa, Oklahoma
Boeing Airplane Co.	Renton, Washington
Douglas Aircraft Co.	Long Beach, California
General Dynamics/Convair	San Diego, California
General Dynamics/Fort Worth	Fort Worth, Texas
General Electric Company	Evendale, Ohio

TABLE 2.2

DATA BASE FOR COSTS AND PRODUCTION INFORMATION
(Partial)

Development Phases for Costing	Subelements for Costing
Sustaining engineering	Titanium experience
Manufacturing labor	Avionics
Tooling	Overhead structures
Materials	Raw materials
Monthly production rates	Subcontracts
Research	Testing requirements
Product development	

Note: Information was not complete in all categories.

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Lockheed Aircraft Co.	Burbank, California
North American Aviation	El Segundo, California
Planning Research Corp.	Washington, D. C.
Pratt & Whitney	Hartford, Connecticut
Republic Aviation	Long Island, New York
Rand Corporation	Santa Monica, California
Rand Corporation	Washington, D. C.
Wright Patterson Air Force Base	Dayton, Ohio
U. S. Government	Washington, D. C.
Dept. of Defense	
BuWeps, Dept. of the Navy	
Center for Naval Analysis	
Civil Aeronautics Board	
Dept. of Commerce	
Federal Aviation Agency	

2.17 The overall cooperation of industry was excellent. It is felt that the resulting data compilation, although not complete, is acceptable for the purpose of this analysis. Certain important data elements have, in fact, been included for the first time in a cost study of this nature.

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DATA VALIDITY

2.18 The usefulness of a CER is limited by the validity of the underlying data from which it is derived. It is important that these data be accurate, and that they be organized, and interpreted in such a way that a given cost element can be defined clearly and associated with appropriate design and performance characteristics. For example, top-level information regarding the total cost of the CV-880 program may be accurate, but the lack of structure to such an aggregate number does not permit the analyst to make the necessary association with the underlying causative factors that produced the cost. Without such an association, a CER cannot be developed that would be useful for prediction.

2.19 As a step toward standardization of input data, all costs in this analysis have been converted to 1963 dollars. Some labor costs when secured were already expressed in terms of 1963 dollars. Other labor data, e.g., manufacturing labor, were obtained in terms of man-hours and costed using rates obtained from the Bureau of Labor Statistics, in this case $2.95.

2.20 Conversion to 1963 dollars was accomplished for material and product prices by reference to data prepared by the Bureau of Labor Statistics, Department of Labor, in their Code 11 indices on Machinery and Motive Products. The conversion factors derived from the source data are shown in Table 2.3

2.21 Engine R&D costs were converted to 1963 dollars by adding 6 percent per year as a result of discussions held with GE and Pratt & Whitney. This compares well with the $5\frac{1}{4}$ percent compounded in the Bureau of Naval Weapons study referred to in the bibliography, Section VIII.

TABLE 2.3

FACTORS FOR CONVERTING TO 1963 DOLLARS

Year	Factor	Year	Factor
1939	2.33	1952	1.25
1940	2.31	1953	1.24
1941	2.23	1954	1.22
1942	2.14	1955	1.19
1943	2.15	1956	1.10
1944	2.15	1957	1.04
1945	2.13	1958	1.02
1946	1.90	1959	1.000
1947	1.65	1960	.998
1948	1.51	1961	.999
1949	1.43	1962	.999
1950	1.40	1963	1.00
1951	1.28		

2.22 In order to achieve the necessary data validity, stratification of the sample is necessary, accompanied by careful refinement and definition of the data base. Figure 2.1 illustrates the approach taken by ORI toward stratifying the data. The total program cost was broken down by system, subsystem, assembly, black-box, and lower indenture levels of equipment; it was also broken down by design detail and by phase of development. At each stage of stratification the variance decreases.

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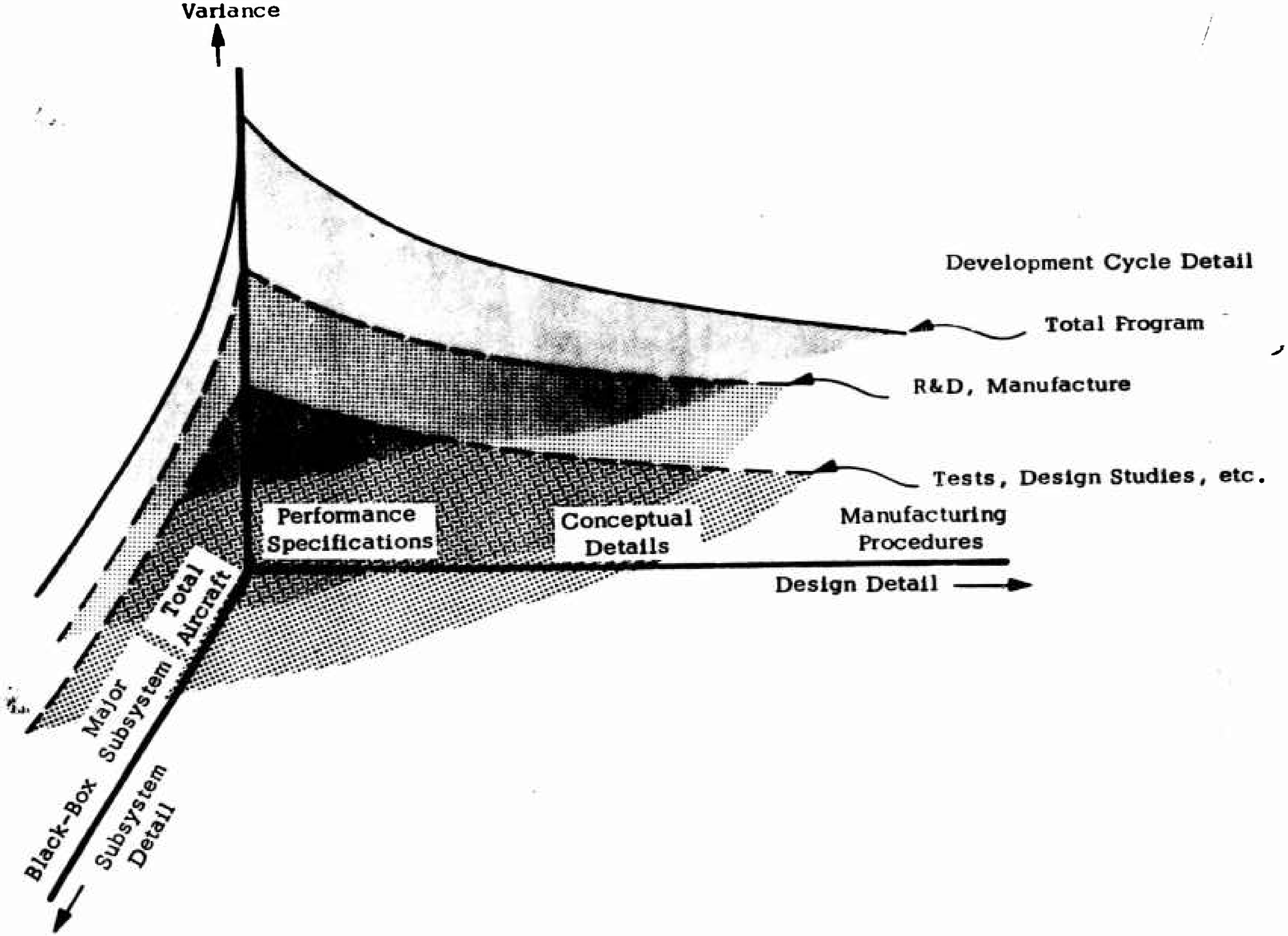

FIGURE 2.1. CONTROL OF VARIANCE THROUGH STRATIFICATION

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Thus, the total program cost could be thought of as being composed of a number of subcost elements, such as the cost of manufacture of the airframe and the cost of R&D on the engine. These subcost elements can be further stratified along the same dimensions into such components as the cost of hard tooling for titanium portions of the leading edge of the wing or the cost of testing the creep characteristics of the engine material under operating temperatures. Pushed to its conceptual limits, stratification would lead progressively to more and more sharply defined operations, until the analyst is dealing with a single specific step on a single specific subassembly, e.g., the wiring of the instrument panel or the design of a wind-tunnel test. At each step the factors bearing on cost are reduced and at the same time become more obvious to the analyst.

2.23 There are, of course, counterbalancing factors that limit the extent of stratification that is practical. One such factor is the availability of data referred to in the preceding paragraphs. In most cases accounting practices do not carry forward or retain data on the cost of microscopic program elements. For such cases stratification serves to reduce the sample size even further. Even if it were possible to obtain the necessary information, the synthesis of a CER and its application to a new aircraft development program for cost prediction would be extremely cumbersome and would require a level of design detail about the new aircraft that is neither available nor desirable at the early stages of the program. A further limitation is, of course, the amount of time and effort available for the development of the CER.

2.24 Within the available time, ORI found it practicable to go to the level of stratification indicated in Table 2.2. Even at this level it was often extremely difficult to draw cost data from different companies, using different definitions and different accounting practices, into a meaningful composite picture. The point at which R&D ended and production began was particularly difficult to identify; production learning curves needed to be reconciled; special factors creating "unusual" cost situations had to be examined. In most cases, these unusual programs were retained in this analysis in order to reflect a realistic uncertainty in the resultant CERs.

2.25 In the case of operating costs, experience on commercial jets is of course limited both in time and in sample size, and virtually every year was considered a special or unusual case by one or more operating airlines.

2.26 A detailed discussion of the data base that was used in the ORI study and its limitations is presented in Sections III to VI of this volume.

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SELECTION OF CER

2.27 The development of a CER consisted of four steps:

- a. Selection of sensitive independent variables
- b. Preliminary determination of equation form
- c. Development of alternative CERs
- d. Selection and refinement of the CER.

2.28 It is important throughout this process to remember that to be useful a CER must not only track history well but must also be dependable for prediction in new technological areas, i.e., one must be able to extrapolate with reasonable assurance that the equation and its derivatives exhibit no major discontinuity. Consequently, the selection of "probably significant" independent variables and the preliminary determination of the equation form must be based not only on a review of the empirical data but also on engineering and physical judgment of how the cost equations should behave.

2.29 The development of the alternative CERs was carried out using an IBM 1620 computer. The computer program made a multidimensional least-squares fit to the empirical data, using either linear or log-linear equation forms, i.e.

$$y = a + bx_1 + cx_2 \; \ldots . \text{ or}$$

$$\ell n\, y = a + b\, \ell n\, x_1 + c\, \ell n\, x_2 + \ldots ..$$

The program was designed to print out the sums of the squares of the residuals, the correlation coefficient, the standard error, the mean derivation, and the fractional standard error and deviation (i.e., their ratio to the mean).

2.30 The alternative CERs developed by the computer were then subjected to a number of screening and evaluation steps:

- a. The equation form and the contribution of its components to total cost had to be physically justifiable; if not the CER was rejected even if there were a good correlation. For example, airframe maintenance labor should be expected to correlate positively with both aircraft weight and maximum cruise speed. However, the correlation between weight and speed led to a physically unrealistic bivariate equation involving negative coefficients. The CERs showing such a negative term were therefore not considered even though a high correlation was exhibited over the available data. In a similar way, an airframe maintenance material CER was rejected because it exhibited a slightly positive second derivative as a function of cost, whereas a zero or negative second derivative seemed more reasonable. It was assumed that such CERs could not be rationally extrapolated.

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b. The equation must lead to "reasonably" high correlation coefficients, a low standard error, and a major reduction in the sums of residuals.

c. The equation was more attractive if its prediction utility for SST was high. This in turn was estimated qualitatively as inversely proportional to the extent of extrapolation required.

d. Final selection of the CER was based on the significance of adding additional variables. As a rough criterion, if the fractional reduction in the sums of squares of residuals was greater than the fractional decrease in degrees of freedom when a new variable was added to the CER, that addition was treated as significant and retained, all other factors being equal.

Refinement of the CER

2.31 The CERs developed in accordance with the described format relate of course to currently existing aircraft. There obviously are physical discontinuities in extrapolating from this region to the SST operating point, some of which can be readily recognized.

2.32 In order to make the CERs useful for predicting in the SST region, it is necessary to modify the CERs so that they are applicable to the use of titanium rather than aluminum and are responsive to other added complexities of design and production that are not explicitly recognized in the CERs. These factors were developed independently of the CERs and, where applicable, were appended to the selected CERs as multiplicative coefficients. Details of the development of these factors are incorporated in Sections IV and VI of the volume.

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ANALYSIS OF RESULTS

2.33 The cost equations and factors resulting from the described process covered the major elements of the cost of developing, producing, and operating an aircraft. As a rough check of their applicability, they were applied to existing aircraft whose costs were known but which, where the quantity of data was great enough, were withheld from the analysis for test purposes. In general, the tests showed that the CERs were acceptable for a rough estimate; the results are included in Volume III.

2.34 It is important that any estimates provided by the CERs be viewed in the light of their reliability. Three factors bear on the reliability of the prediction— the ability of the CER regression to account for variances in the observed data, the extent of extrapolation to the operating point at which the prediction is to be made, and the validity of the assumption that the physical world does not introduce unexpected discontinuities in the CER form over that region.[3] Since the latter factor cannot be adequately treated without extensive engineering research beyond the scope of this study, it introduces a source of uncertainty in the application of the CER that cannot be quantitatively evaluated. Furthermore, it makes superfluous a refined, rigorous treatment of the variance stemming from statistical dispersion and extrapolation.

2.35 Consequently, ORI developed an approximate treatment of variance and applied it illustratively in Volume III to the SST configurations in order in indicate rough lower limits on standard error of the predictions. The development of the equation used to estimate the variance of the predicted value is described in Appendix A of this volume.

2.36 The final CERs were applied using data from the November 1964 SST proposals by Lockheed, Boeing, General Electric, and Pratt & Whitney. Alternative program costs were developed for each possible combination of airframe-manufacturer and engine-manufacturer team. This analysis is presented in Volume III, which is classified because of the restricted nature of certain data.

2.37 During the course of the study a number of observations and recommendations that were essentially corollary to the main thrust of the study were noted. These points are discussed in Section VII of this volume.

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[3] In statistical terms this assumption is equivalent to accepting without test the null hypothesis that the extrapolated characteristics of the advanced aircraft belong to the same population as the cost characteristics of the aircraft in the sample.

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III. OPERATING COST-ESTIMATING RELATIONSHIPS

INTRODUCTION

Form and Content of Estimating Relationships

3.1 This phase of the study determines CERs for estimating costs associated with the operation of subsonic and supersonic aircraft by airlines on route segments through the Free World. The CERs are to be used in the route simulation program to estimate the marginal costs of air services, i.e., the increases or decreases in costs that result when operations over specified routes are altered to increase, decrease, or substitute services. Specifically, the CERs are designed to provide estimates of long-run marginal costs—the changes in operating costs, including those in investment costs that are normally incident to changes in the scale and characteristics of airline operation.[1]

3.2 The CERs have been developed for 20 groupings of airline operating costs. Nineteen of these groupings consist of categories and items of costs recurrently reported by U. S. airlines to CAB, including accruals for depreciation of flight and ground equipment and for armortization of training and other preoperating costs. All appropriate and significant items of operating costs are included in the groupings. The twentieth grouping provides for inclusion of costs associated with sonic boom damage. It was not, however, a function of this study to develop a CER for sonic boom damage. The cost groupings and their content are enumerated in the "Definitions of Terms and Cost Aggregations" on the final pages of this volume.

3.3 In order to reflect unit operating cost differences between subsonic and supersonic aircraft and among U. S. domestic, U. S. international, and foreign air carriers, the CERs deal with nine identifiably different combinations of operating conditions.

3.4 Three sets of CERs are applicable to subsonic aircraft operations for which the unit operating costs of the aircraft are uninfluenced by cost adjustments that are expected to be triggered by the introduction of supersonic aircraft into airline fleets.

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[1] The CERs might have been derived, alternatively, for short-run marginal cost estimation or for estimating so-called "fully distributed" or "fully allocated" costs. Although short-run and fully allocated costs may be relevant for some purposes, such costs are not the germane considerations of airline managements in reaching decisions regarding aircraft acquisitions and capital expenditures. Since an ultimate purpose of the route simulation program is to provide the basis for informed and realistic judgments concerning the potential market for commercial aircraft sales, the use of long-run marginal costs relationships is more appropriate.

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- One set is applicable to operations of U. S. domestic airlines.
- A second set is applicable to U. S. international airline operations.
- The third set is applicable to the operations of foreign carriers.

3.5 Three other sets of CERs have been derived for estimating subsonic aircraft costs where subsonic and supersonic aircraft operations are conducted contemporaneously. Again, the individual sets are applicable to the operations of the three categories of airlines.

3.6 The remaining three sets are applicable to supersonic aircraft operations.

3.7 The proliferation of sets of CERs appears more formidable than is the case. Actually, the differences among the sets for estimating subsonic and supersonic aircraft,operating costs although significant, are not extensive. For instance, CERs for subsonic operations, before and after introduction of supersonic aircraft, differ only in the crew cost categories. Somewhat higher subsonic crew costs are expected to result from wage scale adjustments that will follow the initiation of operations with supersonic aircraft. Similarly, the differences between the subsonic and supersonic CERs are limited to a small number of cost groupings, notably flight insurance costs and the groupings related to depreciation and maintenance of ground equipment. For supersonic aircraft, insurance costs are expected to be relatively higher and ground equipment costs relatively lower in relation to the estimating factors for subsonic aircraft. There are no differences among the sets in the form of the CER for the individual cost groupings.

3.8 On the other hand, differences in the CERs for estimating operating costs of U. S. domestic, U. S. international, and foreign carriers are more general, reflecting observable differences in unit operating costs in most of the cost groupings. Considerably less confidence may be attached to CERs for foreign carriers than to those of U. S. carriers because the cost data for determining them are neither as reliable nor as well detailed as data available for U. S. carrier operations. This raised a material question concerning the value of determining separate sets of CERs for foreign carrier operations, rather than applying CERs for U. S. international carriers. The question was resolved in favor of separate foreign CERs on the basis of two considerations. First, there are significant differences in the unit operating costs of foreign and U. S. carriers engaged in international operations. Unit operating costs of foreign carriers have been higher. Secondly, there are differences between the overall levels of rates charged for transportation services in markets where the services of foreign carriers are predominant and in markets where U. S. carriers participate to a significant extent. Rates in foreign carrier markets are generally higher and, unless the generally higher unit operating costs of foreign carriers are taken into account in the cost estimation, estimates of profit or loss from operations in foreign carrier markets would be biased. Thus, it seemed desirable to trade the possible errors associated with faulty but independent CERs for foreign carriers for the more-or-less certain error that would result from failing to derive independent CERs.

DERIVATION OF THE CER

3.9 A generally consistent procedure was pursued in deriving empirically based CERs, consisting of the following four basic steps.

a. On the basis of an examination of account content, and behavior, the individual items of operating costs were grouped into the 19 basic groupings. The groupings, of course, are largely the outcome of initial judgments, although some testing of alternative groupings was undertaken.

b. Alernative forms of CERs were hypothesized for each cost grouping.

c. Alternative forms of CERs were quantified, generally by means of regression analyses, and then evaluated.

d. Preferred CERs were selected for each cost grouping.

3.10 In formulating cost groupings and in hypothesizing forms of CERs, consideration was given to existing methodology for estimating operating costs. A wide variety of estimating techniques are currently used by industry and government cost analysts ranging from the multielement formulas devised by the Air Transport Association (ATA) for estimating direct aircraft operating costs to the simple ratio of indirect-to-direct costs used by the CAB staff to estimate the indirect operating costs associated with changes in the scheduled air services of domestic trunkline carriers in proceedings involving new and modified air services.

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3.11 It seemed reasonable to expect that the available body of experience in cost estimation would yield guidelines for the development of CERs and, possibly, even techniques that could be adopted "off-the-shelf."

3.12 Unfortunately, the review of available methodology disclosed no generally accepted or wholly satis-factory technique in current use. Although the ATA formulas for estimating direct aircraft operating costs do come closest to general acceptance, their use has not been dictated so much by their performance—the formulas do not estimate several areas of aircraft operating costs well at all—but by the lack of a satis-factory alternative. There is far less agreement on techniques for estimating indirect operating costs; no technique has achieved a degree of acceptance com-parable to that of the ATA formulas for direct costs and no technique is regarded as wholly satisfactory. Thus, formulating cost groupings and hypothesizing the CER forms become largely a pioneering effort into relatively uncharted territory.

3.13 Because of the lack of guidance from extant cost-estimating methods, it was necessary to explore a multitude of alternative cost groupings and CERs. The constraint of time, however, severely limited the amount of exploration that could be attempted. Certain-ly not all reasonable alternatives were examined. The most that can be claimed for the CERs finally adopted is that they are the most reasonable of the alternatives considered.

3.14 As previously mentioned, the objective in deriving CERs was to determine relationships appropriate for estimating long-run marginal costs. This presented no particular problems in the derivation of CERs for direct aircraft operating costs where experienced cost behavior and the opinions of cost analysts are in agreement that costs are wholly variable with flight activity and where the effects of scale of operations on unit costs are not appreciable. In the case of the indirect costs of airline operations, however, it can-not be assumed realistically that costs are wholly variable and free of scale effects. A simple plotting of the indirect costs of U.S. domestic carriers against measures of output (ton-miles produced or sold) shows that costs follow a classical pattern of the type illustrated by the solid line (OA) in Figure 3.1. Where this pattern of cost behavior prevails, the average cost represented by the broken line (OA') is a poor predictor of the cost changes associated with output changes. As may be observed from Figure 3.1, the average cost line tends to overestimate costs when output is in-creased and underpredicts costs when output is de-creased. For this reason, in deriving CERs for indirect costs of airline operations, cost-estimating factors have been determined from lines fitted to the linear por-tion of the cost curve (O'A"), and only the slope values of the fitted lines have been used in the CERs. This procedure involves an underlying assumption with re-spect to the linearity of operating costs with output but the assumption is well-supported by studies of cost behavior among the airlines.

3.15 In using marginal cost functions, as opposed to the average cost experience that is employed in various alternative methodologies for estimating indirect costs, it is believed that the derived CERs are more appropriate

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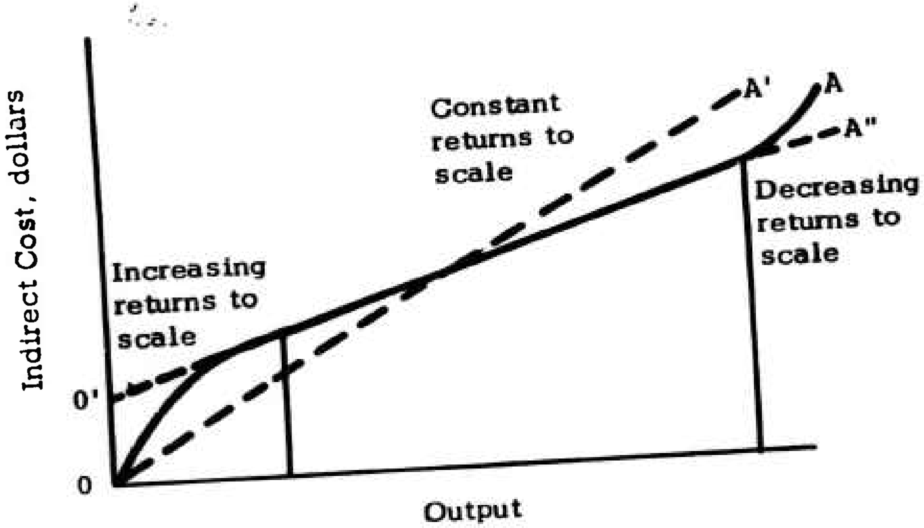

FIGURE 3.1. DEPENDENCE OF INDIRECT COSTS ON PRODUCTIVITY

for their intended use. It is doubtful that the route simulation program will ever be called on to simulate an entire airline system. Only selected route segments and the operations of a portion of the airline fleets will be involved in typical simulation exercises. In these circumstances, average cost functions are not appropriate; they would tend to produce overestimates or underestimates of costs, depending on whether the scale of operations was being expanded or contracted. The use of marginal cost functions avoids such biases.

3.16 In selecting preferred CERs, judgment played a large role. Although correlation coefficients were computed and examined, they were not always controlling in the selection. The inherent logic of the relationships and stability of slope values where variables were introduced or eliminated in some cases was given greater weight than the correlation coefficients. In these cases, however, the correlation coefficients were generally high, as a rule, characterized by small differences. Small sample sizes and the fact that relatively few extreme observations received great weight in the regressions strongly argued against the application of rigorous statistical tests as the criteria of selection.

3.17 In the derivation of CERs for U.S. carriers, parallel analyses were made of the costs of domestic and international carriers to obtain independent CERs for the two groups of carriers. This was not generally possible in the case of foreign air carriers. In most instances, the foreign carrier CERs were determined by adjusting the CERs for U.S. international carriers in line with differences in average costs between the U.S. and foreign carriers. This was not the most desirable approach but was necessitated by the lack of detailed and consistently reported cost data for the foreign carriers. As discussed, the choice essentially lay between assuming that CERs for foreign carriers and U.S. international were the same—involving a certain error—or determining separate CERs for foreign carriers by obviously imprecise techniques. The latter is the lesser of the two evils.

PRINCIPAL FINDINGS

3.18 Several important facets of the CERs derived as a result of the study are described in the following paragraphs as they bear on operating costs.

Types of CERs

3.19 The CERs can be basically divided into three major categories: (a) CERs relating to current outlays for direct aircraft operating expenses, (b) CERs relating to cash outlays for indirect operating costs, and (c) CERs relating to noncash accruals for depreciation and amortization of capitalized costs.

3.20 Direct aircraft operating cost CERs, in turn, fall into the following four principal subcategories:

a. Compensation of flight deck crews (pilots, copilots, flight engineers, and navigators).

b. Costs of fuel and oil consumed in aircraft operations.

c. Costs of maintaining aircraft, engines, and other flight equipment.

d. Insurance costs or incurred losses incident to hull damage and liabilities to third parties.

3.21 Indirect operating costs are similarly grouped into the following four principal subcategories:

a. Costs incident to dispatching, handling, and servicing aircraft at terminals.

b. Costs associated with the promotion, sale, handling, and servicing of all types of air traffic.

c. Costs associated with the maintenance of ground property and equipment.

d. General and administrative costs relating to the overall operations.

3.22 In the major category of accrued, or non-cash, expenses there are three main subcategories of CERs related to:

a. Depreciation of flight equipment investment.

b. Depreciation and amortization of ground property and equipment investment.

c. Amortization of training and preoperating costs associated with the introduction of new equipment. In normal airline accounting practices, such costs are capitalized at the time of expenditure and subsequently amortized through periodic charges to income.

In an economic sense, the accruals for depreciation and amortization represent the reflection in the accounting records of the loss of investment values incurred in the periods charged. In actual practice, however, the rates of depreciation are more-or-less arbitrarily determined; often they do not accurately reflect the changes in the disposition value of the investment assets that occur from period to period.

3.23 Features of direct operating cost equations. A notable feature of the CERs for direct aircraft operating costs is that they differ in various significant respects from the so-called "ATA formulas" that are usually used for estimating the operating costs of alternative types of aircraft.

3.24 In lieu of the complex expression employed in the ATA formulas for estimating flight crew cost—an expression that gives weight to some 10 individual elements of compensation—the derived CER for flight crew costs relates costs per block hour to the single element of aircraft productivity, i.e., available ton-miles produced per block hour.

3.25 The CERs derived for maintenance costs also incorporate several departures from the ATA formulas. As compared with the five factors to which maintenance costs are related in the ATA formulas, i.e., airframe weight, engine thrust, airframe cost, engine cost, and time between overhaul, the derived CERs relate maintenance costs to seven factors, i.e., airframe weight, aircraft cruising speed, aircraft cost, engine maximum inlet temperature, engine thrust, engine weight, and the number of years since introduction. The advantages of the derived CERs over the ATA formulas are several. For one thing, they estimate current maintenance cost experience for subsonic jets more accurately. Secondly, in omitting the time-between-overhaul factor, an element of judgment is eliminated in connection with CER application. And finally, the derived CER is not vulnerable to policy changes regarding frequency and amount of maintenance undertaken in each periodic overhaul. Significantly, it has been reported in the aviation trade press that at least one major airline is contemplating departing from the periodic maintenance system currently followed in connection with engine maintenance.

3.26 The CERs for fuel and insurance costs parallel the ATA formulas with minor modifications. In the case of insurance costs, the separate element contained in the ATA formulas for estimating public liability and property damage has been eliminated because it is minor in relation to the costs for hull insurance and damage.

3.27 Neither the ATA formulas nor the derived CERs undertake to estimate certain miscellaneous costs reported by the airlines in the category of direct aircraft operating expenses. These costs are normally very small in relation to other aircraft operating costs, amounting to less than $1.00 per block hour, on the average, for operations with subsonic jet aircraft.

3.28 Features of indirect operating cost equations. There are no benchmark methodologies, equivalent to the ATA formulas, for the estimation of indirect operating costs. A comparison of the derived CERs and the estimating relationships for indirect costs developed jointly by Boeing and Lockheed is, however, material since the two methodologies are, in a sense, competitive. There are three main points of difference between the derived CERs and the estimating formulas of the manufacturers.

3.29 The derived CERs are designed to estimate marginal costs; the Boeing-Lockheed formulas, on the other hand, more properly can be termed allocation formulas and are not appropriate to estimating marginal costs unless it is assumed that indirect costs are wholly variable.

3.30 The manufacturers' formulas appear to be intuitively premised rather than empirically determined. That is, there appears to have been no attempt made to verify that the hypothesized form of the estimating relationships actually conformed to the behavior of costs among the airlines.

3.31 The third point of difference lies in the level of aggregations of cost groupings employed in the two sets of relationships. The Boeing-Lockheed cost groupings are more numerous and less aggregated than those employed in the derived CERs. This latter difference results from an apparent difference in the conclusions reached regarding the meaningfulness and validity of the finer aggregations for cost estimation in the light of differences among the airlines in cost accounting and reporting practices and in the light of tradeoff relationships among indirect cost centers.

3.32 Structural differences in the forms of the two sets of relationships are of more than academic interest. The relationships produce generally different levels and patterns of cost estimates. In the area of aircraft handling and servicing costs, for instance, the Boeing-Lockheed formulas tend to produce lower estimates of costs for subsonic jets than does the derived CER and still lower estimates of costs for supersonic aircraft in relation to those estimated from the derived CER. This results from two differences in the estimating relationships. Certain segments of costs are assumed in the Boeing-Lockheed formulas to be unrelated to the size of the aircraft operated, and the remaining segment of costs are assumed to vary among aircraft types in relation to landing weight. By contrast, the derived CERs are predicated on what appears to be a more supportable premise in view of actual cost behavior, i.e., that all such costs vary in relation to the maximum gross takeoff weight of aircraft operated.

3.33 In the area of indirect costs associated with the promotion, sale, and handling of traffic, Boeing and Lockheed have evolved a multiplicity of relationships in which separate weight is given to measures of traffic handled (numbers of passengers, tons of mail, express and freight), volume of transportation movement (passenger miles, ton-miles), and other factors (passenger hours). The derived CER employs passenger revenue as a basis of cost estimation. Again the differences are material as to level and pattern. The Boeing-Lockheed relationships tend to produce generally lower levels of cost in the long-haul stages where supersonic aircraft operations are contemplated, and a much greater pattern of taper in unit costs with an increasing stage length of operations. Also, as a result of taper structured into the relationships, the Boeing-Lockheed formulas generally overestimate the costs of carriers engaged in short-haul operations and underestimate the costs of carriers engaged in long-haul operations, signifying that a similar bias occurs when the formulas are applied to estimating the costs of operations for different length segments of the same carrier. Similarly tested, the derived CER gives no indication of a similar bias.

3.34 <u>Features of accrued expense equations</u>. The CERs for depreciation cost accruals generally conform to accounting practices fostered by the CAB. Depreciation accruals are on a straight-line basis, and the CERs

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provide for a residual or salvage value at the termination of the service life of the depreciable asset. Airlines practices vary regarding accruals for amortization of training and other preoperating costs, most airlines amortizing such costs over shorter periods than are used for the depreciation of the flight equipment to which they are related. As a general accounting principle, however, it would appear preferable to conform the armortization period of capitalized preoperating costs to the depreciation period of the equipment so that costs and the revenue benefits derived from the costs will be more nearly matched.

3.35 With this in mind, the CER for the amortization of preoperating costs estimates a rate of amortization that, for subsonic and supersonic aircraft, would write-off preoperating costs over the respective service lives of the two types of aircraft. A second reason for the use of the longer amortization period in the derived CER is to avoid a possible bias in the cost comparisons of subsonic and supersonic aircraft. If a shorter amortization period is implicit in the CER, the costs of supersonic aircraft operations in the early years following introduction would be higher than if a longer period is used. By the same token the costs of subsonic aircraft operations will be largely devoid of amortization accruals at the time when cost comparisons are most critical. The use of the longer period for both subsonic and supersonic accruals will mitigate the differences in costs by avoiding the introduction of an additional difference that is without real distinction.

3.36 In rank order, the derived CERs estimate higher costs for U.S. international carriers, than for like operations of U.S. domestic carriers, and higher costs for foreign carriers than for U.S. international carriers. This relative ranking is borne out by observed data and past studies of cost behavior.

3.37 In the following discussion, the derived CERs and the basis for their derivation are elaborated and documented. The CERs for direct costs relating to aircraft operations are first discussed, followed by discussions of the CER for indirect costs of airline operations. In view of the volume of statistical data and in the interest of preserving continuity of the text, the bulk of the statistical data and computer printouts are presented in Volume IV; data in the text are limited to summary tables and information that could be compactly presented.

Total Operating Cost

3.38 The following pages discuss the development of CERs for each of the 19 cost aggregations described in the preceding pages. A CER for sonic boom cost was not within the scope of this contract, but this cost category is carried for completeness.

3.39 The total operating cost for an aircraft is simply a sum of the costs relegated to each of the 20 cost categories, i.e.,

$$C \text{ (operating)} = \sum_{i=1}^{20} C_i .$$

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FLIGHT CREW COSTS

Composition

3.40 Flight crew costs encompass pay, allowance, insurance, traveling, and related expenses of flight personnel engaged in aircraft operations. Specifically, the items of cost included in the definition of flight crew costs employed in this study are the expenses reported by U.S. airlines in the CAB operating expense accounts enumerated in the table of definitions at the end of this volume.

3.41 The definition of flight crew costs agrees substantially, though not exactly, with that followed by member airlines in the reporting of "flight crew salary and expenses," Account 5.1, to the International Civil Aviation Organization (ICAO). The principal difference is the treatment of training costs which, in prevailing usage in the U.S., are included in flight crew costs. In ICAO reporting, however, training costs are included in the category of "other flight costs."

Sources of Data

3.42 Data for flight crew costs are available from the Form 41 reports of U.S. airlines to CAB. These data are reported separately for domestic and international operations and for each type of aircraft. In lesser detail and with the noted exclusion of training costs, data are also available for foreign air carriers that are members of ICAO. The ICAO Digest of Financial Statistics, published annually, contains aggregate flight crew costs for each reporting entity but no breakdown of these costs by aircraft type. In addition, a separate ICAO annual publication, Fleet-Personnel, provides information on the numbers and average annual renumeration of flight crews for the international operations of reporting airlines. The latter data, however, are not wholly inclusive of all flight crew costs; reimbursements or allowances for travel expenses and carrier contributions to pension and welfare funds, for example, are not included.

3.43 A further source of data with respect to flight crew costs are the agreements between the various airlines and the labor organizations representing flight personnel. Agreements governing the current rates of compensation and work rules for all flight personnel employed by U.S. airlines are on file with ATA and the National Mediation Board (NMB) and are available for inspection.

Considerations in the Estimation of Flight Crew Costs

3.44 The rates of compensation and work rules for flight crews of U.S. airlines are rigidly established by labor agreements. The standard form of agreement contains the following provisions:

a. Longevity pay. This element of compensation is based on the position held by the crew member (pilot, first officer, or flight engineer) and on his years of accredited service. In some agreements the compensation is in the form of a stated monthly amount, without regard to hours flown or the type of equipment flown; in other agreements it is in the form of amount per hour of flight time, without regard to the type of equipment flown.

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b. Hourly pay. Rates per flying hour, based on the speed of the equipment and whether the hours flown are day or night hours, are established for each category of flight personnel. Rates currently in effect generally cover the spectrum of piston and jet aircraft cruising speeds and provide for a ceiling rate per hour for speeds in excess of 450 or 475 miles (statute) per hour. With minor exceptions, the established rates per flying hour are related linearly to speed, increasing at constant rate per unit increment in speed. Illustrative of the form and structure of the relationship are the contract provisions for hourly pay contained in an agreement between Delta Air Lines and the Air Line Pilots Association International (ALPA). Rates per hour of day flying range from $5.65 per hour for speeds of 175 mph or less to $8.65 per hour for speeds of 475 mph and up. The relationship between rates and speed is a straight line, with an intercept value of $3.90 and slope value of 1 cent per unit mile per hour. Lines fitted to rate schedules drawn from a cross-sectional sample of agreements show significant variations among the airlines; intercept values range up to $5.29 (in the case of Flying Tiger) and slope values range down to 0.6 cent per unit mile per hour (also in the case of Flying Tiger). For representative intercept and slope values among the agreements (approximately $4.50 and 0.8 cent per unit mile per hour, respectively), about one half of the hourly pay of a jet pilot is comprised of fixed compensation per hour and the remaining half is comprised of the increment dependent on aircraft speed.

Rates per hour for night flying are from one third to one half higher than the day rates at comparable speeds. A further differential, where applicable, is applied in foreign and international services in the form of an increment of approximately $3.00 per hour to the otherwise established rate. Thus, in foreign and international operations, the fixed component of hourly flight pay is somewhat higher than it is in domestic operations, amounting to about two thirds of the total hourly rate in jet aircraft services.

c. Mileage pay. Crew members are compensated for miles flown at rates varying from 2 to 2.5 cents/mile in the case of a flight captain. Miles credited for pay purposes are not the actual miles flown but a constructed figure that is determined by multiplying the flight hours performed by the pegged speed of the aircraft (generally the cruising speed). Mileage pay in essence is directly related to aircraft speed and serves much the same function in the compensation structure as the speed differential established in the hourly rates of pay.

d. Gross-weight pay. In addition to other

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hourly pay rates, provision is also made for a rate differential based on the maximum certificated gross weight (MCGW) of the aircraft flown. This rate is generally 2 cents per 1000-lb MCGW, or about $6.00 per hour in the case of the captain of a large jet aircraft.

e. <u>Other pay provisions and rules.</u> The compensation provisions of the described flight crew agreements are supplemented by pay allowances for sickness, vacations, training, travel, moving expenses, deadhead time, and operational duty time not directly compensated elsewhere in the agreements. The agreements also contain minimum pay guarantees and certain definitional clauses that condition compensation provisions and have a significant impact on total compensation. For example, the block hour defined for pay purposes is not always the actual block hour flown; it may be the scheduled block hour if the schedule time exceeds the actual block time flown. The attention devoted to these further pay provisions, definitons, and work rules in the negotiation of agreements attests to the importance attached to them, even though their dollar significance is not always readily discernible.

3.45 As a general rule, the flight pay of crew personnel other than the captain or first pilot (the terminology varies among airlines) is established as a percentage of the flight pay of the ranking crew member. The percentage increases with longevity as illustrated by the examples shown in Table 3.1, taken from the Delta Air Lines agreement referred to earlier.

TABLE 3.1

EFFECT OF LONGEVITY ON RELATIVE PAY OF FLIGHT CREW

Years of Service	Percentage of First Pilot Flying Pay	
	Copilot	Second Pilot
Second	52	41
Third	60	52
Fourth	61	53
Fifth	62	54
Sixth	63	55
Seventh	64	56
Eighth	65	57
Ninth and thereafter	66	58

3.46 With minor liberties, the pay structure for flight crews embodied in the standard agreement curently effective can be described as a block-hour compensation scale made up of a fixed element and a variable element, the latter varying partially with the size of the aircraft flown but mainly and linearly with the cruising speed. If there were no reason to expect a change in the compensation structure as SST aircraft are introduced into the airline fleets, flight crew costs could be estimated with reasonable accuracy by extending

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the variable element of the block-hour compensation scale into the region of SST aircraft speeds and gross weights.

3.47 However, the history of changes in agreements dealing with flight crew compensation suggests that it may not be realistic to assume that modifications of the agreements to cover SST operations will simply entail extrapolations of the current pay schedules and will involve no alterations in the compensation structure itself. Comparative analysis of agreements operable at different stages of time indicates that several structural changes have been introduced as the agreements have been modified to cover new aircraft of increased productivity. These changes, in general, have been in the direction of passing on to flight crews operating older and less productive aircraft some of the compensation benefits accruing from the introduction of newer and more productive aircraft. This is done in several ways, the most important of which is the adjustment of the hourly flight pay scale to increase the fixed (intercept) component and to reduce the variable component. The net effect, of course, is to increase the rates per hour for the operation of slower aircraft relative to larger aircraft.

3.48 The changes that have occurred in the rates of compensation for flight personnel other than ranking crew member (captain and first pilot) similarly indicate a structural change in which productivity gains inuring from the introduction of new aircraft result, in part, in higher rates of compensation to flight crews operating older aircraft. Over the years the percentage relationship of copilot compensation, for instance, has been increased as is shown in Table 3.2 by the comparison of sample data taken from the Pan American agreement, effective in 1957, and the Delta agreement (illustrated previously in Table 3.1), which was effective in 1962.

TABLE 3.2

CHANGE IN PAY-SCALE PROPORTIONS OVER TIME

Years of Service	Percentage of Copilot Flying Pay of Equivalent Pilot Flying Pay for Same Length of Service	
	Pan American Agreement, 1957	Delta Air Lines Agreement, 1962
Third	40	60
Fourth	43	61
Fifth	46	62
Sixth	49	63
Seventh	52	64
Eighth	55	65
Ninth and thereafter	55	66

3.49 Since the changes in compensation illustrated in Table 3.2 relate flight crews of newer and of older aircraft, the net effect is to increase the compensation for crews flying the older aircraft concomitant with the increases in flight crew productivity that have followed airline reequipment. A further effect is to narrow the difference in compensation between crews operating the newer and crews operating the older aircraft types, since the longevity spread is considerably narrowed under the post-jet agreements. As may be noted, under the Pan

[redacted]

American 1957 agreement a third-year copilot received 40 percent of the equivalent pilot flying pay for the same length of service and an eighth-year copilot received 55 percent of the equivalent flying pay. Under the later Delta agreement, the respective percentages are 60 and 65—a spread of 5 percentage points as compared with a spread of 15 percentage points in the earlier agreement. Inasmuch as the seniority bidding system among flight crews for route and aircraft assignments generally results in lower seniority personnel being assigned to the older types of aircraft, the narrowing of the differences in the longevity scale connotes a greater increase in the compensation of copilots flying older aircraft than those engaged in flying the newer aircraft. This, of course, reduces the overall difference in unit flight crew compensation between the older and newer aircraft.

3.50 In summary, the history of flight crew agreements suggests that the introduction of SST aircraft will be taken as an occasion to effect further structural changes in the compensation provisions. On the basis of historical patterns, it is a reasonable inference that the changes will be in the direction of spreading among all flight crew personnel a portion of the increases in flight crew compensation resulting from the increased productivity of crews assigned to operations of SST aircraft. This, in turn, suggests that flight crew costs extrapolated within the framework of the structure of current agreements will overstate the costs of SST operations both in absolute terms and relative to the comparative costs of operations with currently existing equipment.

Alternative Methods of Cost Estimation

3.51 The most widely used and generally accepted basis for the estimation of flight crew costs for new aircraft are the ATA formulas. These formulas were initially published by ATA in 1944 and have subsequently been updated in 1949, 1950, and 1960. The current version[2] is under review and will be further updated. At this time, however, revised factors and relationships are not available.

3.52 The CERs for pilots, copilots, and flight engineers contained in the latest published report are

$$C_{bh} = \left(1 + K_V + K_T + K_I + K_P\right)\left[\frac{B.P.}{A.H.} + (DNF)\,(HRF) + (MRF) + (GWF) + (ODP)\right] + E$$

where C_{bh} = cost per block hour (pilot, copilot, and flight engineer, respectively)

K_V = vacation factor (pilot, copilot, and flight engineer, respectively)

K_T = cost of training factor (pilot, copilot, and flight engineer, respectively)

K_I = insurance and payroll tax factor (pilot, copilot, and flight engineer, respectively)

K_P = crew premium pay factor (pilot, copilot, and flight engineer, respectively)

[redacted]

B.P. = annual base pay (pilot, copilot, and flight engineer, respectively)

A.H. = annual flight hours (pilot, copilot, and flight engineer, respectively)

DNF = day-night factor

HRF = hourly rate factor (pilot, copilot, and flight engineer, respectively)

MRF = mileage-rate factor (pilot, copilot, and flight engineer, respectively)

GWF = gross-weight factor (pilot, copilot, and flight engineer, respectively)

ODP = operation duty pay factor (pilot, copilot, and flight engineer respectively)

E = travel expense factor

3.53 The latest publication further estimates values for each of the independent variables up through the range of SST speeds. These values, as they relate to the three categories of crew personnel (pilot, copilot, and flight engineer) and for operations in the subsonic and SST speed ranges and for domestic and international operations, are shown in Table 3.3.

3.54 The ATA formulas for estimating flight crew costs have several important strengths. The formulas contain specific factors for each identifiable and measurable element of the compensation provisions of the agreements. Further, the variable values provided for cost estimation realistically reflect the direction that changes in the agreements have taken in response to the introduction of newer and faster aircraft, hourly rate, mileage rate, and gross-weight factors, as may be noted, are in line with the exponential trend of the development of past experience. In the regions of greater productivity (higher speeds and gross weights) the intercept values of linear functions are larger and the slope values are smaller.

3.55 However, the formulas also have several weaknesses. Perhaps the foremost of these is the difficulty of recalibrating the complex relationships to reflect changes in price levels as opposed to structural changes in compensation. One possible reason that the formulas are updated relatively infrequently is that a vast amount of detailed information, not regularly reported by the airlines, is necessary to reflect in the formula values the most up-to-date data on price level changes that are being constantly made in the agreements. As of now the formula values have been outdated by more than 3 years of subsequent alterations of flight crew agreements. Secondly, the formulas make no provision for what may be termed a "recoil effect," a change in the factors for older equipment that seems to be a related consequence of the introduction of newer equipment. Finally, for the most accurate application of the formulas in connection with a problem such as that contemplated by this study (the estimation of comparative costs of two or more aircraft types operated contemporaneously), it is necessary to develop a highly intricate set of assumptions with respect to crew longevity factors, utilization rates, and the like. For example, it is likely that crews operating

[redacted]

[redacted]

TABLE 3.3

TERMS APPLICABLE TO CURRENT ATA FORMULA FOR ESTIMATING CREW COSTS

Factor	Crew Category	Value for Domestic Operations		Value for International Operations	
		Subsonic	SST	Subsonic	SST
K_V	All	.05	.05	.05	.05
K_T	All	.04	.04	.05	.05
K_I	All	.12	.12	.12	.12
K_P	All	.05	.05	.05	.05
B.P.	Pilot	$3600	$3600	$3600	$3600
B.P.	Copilot	$3200	$3200	$3200	$3200
B.P.	Flight engineer	$3400	$3400	$3400	$3400
A.H.	All	800	NS	750	NS
DNF	All	½-½	½-½	½-½	½-½
HRF	Pilot	$7.69 + .0078 x speed[1]	$11.543 + .002717 x speed[2]	$9.50 + .0125 x speed[1]	$16.35 + .0034 x speed[2]
	Copilot	$4.22 + .00335 x speed[1]	$5.68 + .00145 x speed[2]	$4.90 + .0060 x speed[1]	$8.50 + .0018 x speed[2]
	Flight engineer	$3.71 + .00355 x speed[1]	$5.31 + .00157 x speed[2]	$4.00 + .0060 x speed[1]	$7.85 + .00147 x speed[2]
MRF	Pilot	.025 x speed	6.9 + .0135 x speed	.025 x speed	6.9 + .0135 x speed
	Copilot	.01383 x speed	4.278 + .0067 x speed	.01383 x speed	4.278 + .0067 x speed
	Flight engineer	.01167 x speed	2.982 + .0067 x speed	.01167 x speed	2.982 + .0067 x speed
GWF	Pilot	$3.74 + \frac{.005(GW-150,000)}{1,000}$	Same	Same	Same
	Copilot	$1.79 + \frac{.00249(GW-150,000)}{1,000}$	Same	Same	Same
	Flight engineer	$1.93 + \frac{.00258(GW-150,000)}{1,000}$	Same	Same	Same
ODP	Pilot	.50	.50	.50	.50
	Copilot	.25	.25	.25	.25
	Flight engineer	.25	.25	.25	.25
E	All	1.80	1.80	2.80	2.80

[1] Speeds from 400 to 600 mph.

[2] Speeds from 1000 to 1600 mph.

Note: NS = not specified.

[redacted]

SST aircraft will have greater seniority than crews that are operating subsonic aircraft in the same time periods. There are also likely to be differences in crew utilization rates, in the proportions of day-night flying, and in other factors. Although there is virtue in being able to make alternative assumptions for the variable factors, the technical difficulties in making the necessary assumptions increase apace.

3.56 An alternative and somewhat simplified method of estimating flight crew costs is by employing the experienced relationship between flight crew costs per hour, as reflected in the current financial reports of the airlines, for the various types of aircraft now being operated, and the productivity of the various types of aircraft as reflected by the available ton-miles of capacity produced by each type of aircraft per hour flown.[3]

3.57 Data for aircraft productivity and annual crew costs are shown in Table 3.4 for aircraft in use by U.S. domestic carriers during 1963. A plot of these data on arithmetic scales discloses that the rate of increase in crew costs per hour is not linearly related to the increase in aircraft productivity. The rate of increase in unit crew costs tapers as productivity is increased. However, as is shown in Figure 3.2, a plotting of data on a semilogarithmic scale is reasonably represented by a straight line for the spectrum of aircraft currently in U.S. domestic airline fleets. The relationship, which synthesizes at current price levels all the differences and personnel activity factors associated with variations in the productivity of aircraft currently operated, is

$$Y = -134.9475 + 71.7017 \log_{10} x$$

where $r = .94$

Y = crew cost per revenue airborne hour

x = aircraft productivity

The relationships may be converted to a block-hour basis simply by dividing by the average ratio of block to airborne time. In 1963 the ratio was 1.13 for subsonic jet aircraft.

3.58 As compared with the ATA formulas, this relationship produces higher and more realistic estimates of flight crew costs for subsonic aircraft and a lower estimate of the differential between subsonic and SST flight crew costs. This may be noted from an illustrative and more-or-less hypothetical example devised for purposes of the comparisons. In this example, the assumed characteristics of subsonic and SST aircraft are as stated in Table 3.5.

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[3] Available ton-miles, as defined herein, is the product of available tons per aircraft and the distance flown in airport-to-airport great-circle statute miles. Available ton-miles per aircraft are as defined in CAB Standard Practice Letter No. 4, effective 1 April 1959, a copy of which is reproduced as Appendix B of this volume. In line with the CAB definitions, the available load in tons represents, in essence, the maximum salable load. For purposes of computation of available tons, a cargo density of 10 lb/cu ft and an average passenger weight of 160 lb, without free baggage, are assumed. The assumed factors agree with those typically used by the airlines in reporting available tons.

[redacted]

TABLE 3.4

RELATIONSHIP BETWEEN CREW COSTS PER REVENUE AIRCRAFT HOUR AND AVAILABLE TON-MILES PER REVENUE AIRCRAFT HOUR

(U.S. Domestic Airlines, 1963)

Aircraft Type	Available Ton-Miles, in thousands	Revenue Aircraft Hours	Crew Costs, thousands of dollars	Available Ton-Miles per Revenue Aircraft Hour	Crew Costs per Hour, dollars
B-707	1,807,431	210,167	30,877	8,599.98	146.92
DC-8	1,625,346	220,415	27,888	7,374,03	126.52
B-720	2,025,733	294,455	37,234	6,879,60	126.45
CV-990	241,283	38,968	5,528	6,191.82	141.86
CV-880	623,300	114,293	17,161	5,453.53	150.15
L-1649 1/	35,425	9,954	1,539	3,558.87	154.61
DC-6A	53,587	16,026	1,887	3,343.75	117.48
L-1049C	65,614	21,139	2,203	3,103.93	104.21
DC-7B	437,395	146,112	14,626	2,993.56	100.10
ELECTRA	783,907	277,876	30,020	2,821.07	108.03
SE-210	111,763	40,517	4,871	2,758.42	120.22
DC-7C	43,721	16,748	1,574	2,610.52	93.98
L-1049G 1/	118,400	52,690	6,436	2,247.11	122.21
DC-7	172,590	80,615	8,370	2,140.92	103.83
L-1049	26,374	12,886	1,333	2,046.72	103.45
DC-6B	299,474	168,544	16,034	1,776.83	95.13
DC-6	285,947	175,565	16,674	1,628,72	94.97
L-749 1/	56,318	40,427	4,887	1,393.08	120.88
VISCOUNT	161,932	141,233	11,138	1,146.56	78.86
C-46	11,392	10,070	684	1,131.28	67.92
CV-340	131,630	128,133	8,751	1,027.29	68.30
CV-440	44,996	47,242	3,315	952.46	70.17
CV-240	11,626	17,253	1,310	673.85	75.93
DC-3	8,602	22,803	1,144	377.23	50.17

1/ Excluded from the computation of the formula in Appendix D.

2/ Crew costs include Accounts 23, 24, 28.1, 36, 57, and 68. Source: Form 41 Reports to CAB.

[redacted]

[redacted]

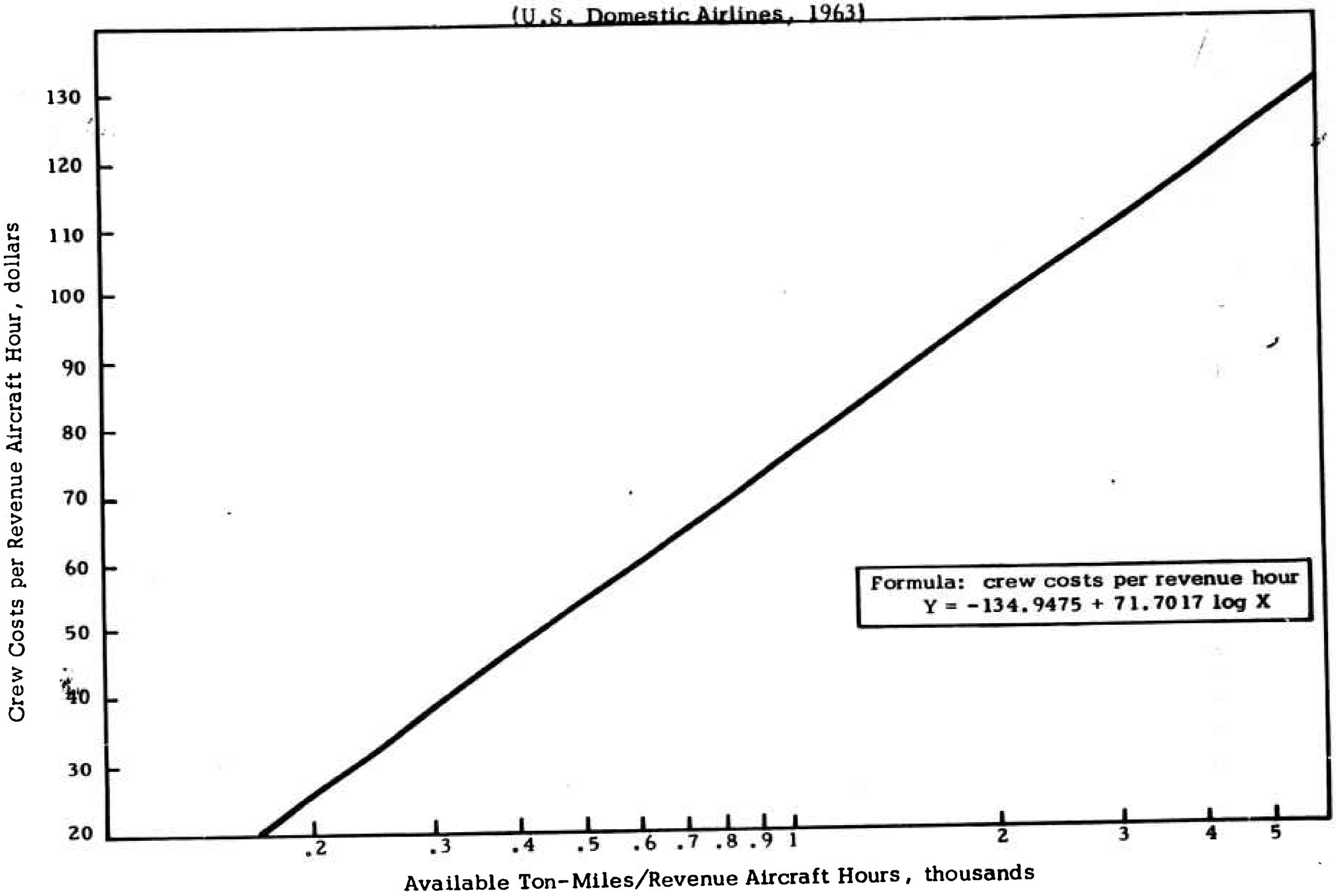

FIGURE 3.2. CREW COST DEPENDENCE ON AIRCRAFT PRODUCTIVITY

[redacted]

[redacted]

TABLE 3.5

ILLUSTRATIVE DATA FOR COSTING FLIGHT CREW DAY

Type of Transport	Block Cruise Speed	Maximum Gross Weight, lb	Available Ton-Miles Per Hour
Subsonic	450	300,000	7,000
SST	2000	400,000	37,000

For the aircraft described, total crew costs determined from ATA and regression formulas compare with each other and with the average reported costs in subsonic air aircraft operations.[4] See Table 3.6.

TABLE 3.6

COMPARISON OF REGRESSION RESULTS WITH ATA FORMULAS

Type of Transport	Flight Crew Costs per Block Hour, dollars	
	ATA Formulas	Regression Formulas
Actual subsonic	122.46	122.46
Computed subsonic	94.06	124.56
Computed SST	170.17	167.29

3.59 It is obvious that the ATA formulas, which in their present published version are derived from experienced conditions no later than 1960, cannot be used fairly to estimate 1963 flight crew costs. At the very least, therefore, an adjustment should be made in the results of the ATA formulas to reflect changes in price levels and average longevity that have occurred since 1960 in order to make the comparisons more meaningful. Such an adjustment, to increase the ATA formula results by 25.7 percent (the increase in the median crew cost per block hour between 1960 and 1963 for subsonic jet operators), shows the comparisons given in Table 3.7.

TABLE 3.7

COMPARISON OF REGRESSION RESULTS WITH ADJUSTED ATA FORMULA

Type of Transport	Flight Crew Costs per Block Hour, dollars	
	ATA Formulas	Regression Formulas
Actual subsonic	122.46	122.46
Computed subsonic	118.24	124.56
Computed SST	213.78	167.29

3.60 The direction of the spread between the crew cost estimates derived from the ATA and regression formulas illustrates two characteristics of the respective formulas. The ATA formulas produce a higher estimate for newer and faster aircraft because they make no allowance for the recoil effect; the regression formulas, whose slopes have already been dampened by reflecting the recoil effect following the introduction of jets, produce a lower estimate because they do not yet reflect the adjustment to the level of the line of relationship that results when a more productive aircraft is introduced into the airline fleets. In short, the probable development of the flight

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[4] Unweighted average of jet crew costs shown in Appendix C, reduced by 13 percent to current airborne time to block time.

[redacted]

crew compensation structure may be expected to result in flight crew cost levels per block hour falling between the estimates of the ATA and regression estimates.

3.61 The adjustment that is necessary to the regression equations to produce estimates that will reflect the upward shift in the compensation structure that may be expected to result from the introduction of SST aircraft can be estimated by referring to the experience following the introduction of jet aircraft. Analysis of the adjustments made in pre-jet versions of the ATA formulas in the most recent post-jet edition of the formulas with respect to cost factors applicable to the estimation of crew costs for speeds in the piston aircraft range indicates that the changes added a flat increment to the hourly rate factors estimated by the earlier formulas. The added amount represented an increase of 8 percent in the total flight crew costs per block hour for the prime piston aircraft equipment, after allowance for cost-of-living wage-level increases at the rate of 2 percent/year. If the increased productivity of the subsonic jet effects an increase in the compensation structure that raises the compensation of piston crews flying the most productive piston aircraft by 8 percent, it is not unreasonable to anticipate that the much greater gain in productivity, in both absolute and percentage terms, associated with SST aircraft will raise the compensation scale for subsonic crews by the amount of 10 percent, or approximately $12.46 per block hour at subsonic jet flight crew compensation levels in 1963. This, of course, represents simply a judgment regarding a development that will be the result of complex negotiations rather than formula.

3.62 It is further expected that the entire scale will be raised by this amount; i.e., that a like amount will be added to flight crew compensation throughout the scale, increasing the formula values for SST flight crew costs as well as subsonic flight crew costs. In short, restating the regression formula to include the increment and also converting to units of block hours, the estimating relationship is

$$y' = -107.01 + 63.453 \log_{10} x'$$

where y' is crew costs per revenue block hour and x' is productivity measured in available ton-miles flown per block hour.

Carrier Cost Differentials

3.63 Experienced data for U.S. domestic and U.S. international airlines, shown in Appendix C of this volume, indicate that flight crew costs per block hour for international air carriers typically run over 50 percent higher than for domestic air carriers for the same types of aircraft. A part of the differential is accounted for by the fact that on many of the international flights a four-man crew is employed whereas flight crews domestically consist of three members. When allowance is made for the additional crew member in international operations, the differential associated purely with differences in compensation levels, travel allowances, and other provisions in current flight crew agreements differing for domestic and international operations is closer to 20 percent/block hour. This compares with the roughly 15 percent premium estimated by the ATA formulas. Since the suggested ATA formula values used in applying the formulas do not reflect differences

[redacted]

in longevity, which normally distinguish domestic and international crews and are reflected in experienced flight crew cost differences, the higher premium appears more realistic and should be applied in estimating flight crew costs associated with the operations of U.S. international carriers.

3.64 Foreign air carrier crew compensation levels, when compared with those of U.S. international airlines, indicate that foreign carrier crew costs are on the order of 60 percent of those of U.S. carriers operating the same equipment (Appendix C). This places the compensation scale for foreign carrier flight crews at about 72 percent of the level for U.S. domestic flight crews. Reported data for pilots and copilots individually indicate that approximately the same differential applies to both categories of personnel in relation to their opposite numbers employed by U.S. international carriers.

Breakdown of Costs by Crew Category

3.65 Unfortunately the reported data for flight crew costs do not permit a ready determination of the individual costs per block hour for pilots, copilots, and other categories of flight personnel. However, it is desirable in the interests of providing CERs in the form for most flexible application to determine separate CERs for pilots, copilots, flight engineers, and navigators. To allow for the greater flexibility, an estimated distribution of flight crew costs by category of personnel has been made, using proportions developed from computed costs for domestic subsonic operations derived from the ATA formulas. The proportions derived in this manner were checked against unpublished data from several domestic air carriers and Pan American. The checks disclosed small differences that could well be accounted for by particular circumstances of the individual carriers. None of the differences were sufficiently large to suggest the proportions were unreasonable as related to average industry experience.

Cost Estimating Relationships

3.66 The CER determined for flight crew costs per flight segment where subsonic and supersonic aircraft are operated contemporaneously are

$$C_1 = n_1 (k_1 + k_1' \log_{10} \frac{pd}{t_b})\, t_b$$

$$C_2 = n_2 (k_2 + k_2' \log_{10} \frac{pd}{t_b})\, t_b$$

$$C_3 = n_3 (k_3 + k_3' \log_{10} \frac{pd}{t_b})\, t_b$$

where

C_1 = pilot costs per flight segment

C_2 = copilot costs per flight segment

C_3 = flight engineer and navigator costs per flight segment

n_1 = number of pilots per aircraft

n_2 = number of copilots per aircraft

n_3 = number of flight engineers and navigators per aircraft

p = aircraft load capacity in short tons, as defined by CAB Standard Practice Letter No. 4 (Appendix B)5/

t_b = block time for flight over the segment

5/ It is assumed that the SST will operate at a maximum seating configuration.

[redacted]

[redacted]

and where the values of the k terms are shown in Table 3.8.

TABLE 3.8

COEFFICIENTS APPLICABLE TO CONTEMPORARY SST AND SUBSONIC AIRCRAFT

Coefficient	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k_1	-50.83	-61.00	-36.60
k_2	-28.79	-34.55	-20.73
k_3	-27.39	-32.87	-19.72
k'_1	30.14	36.17	21.70
k'_2	17.07	20.45	12.29
k'_3	16.24	19.49	11.69

3.67 These coefficients are applicable to both SST and subsonic aircraft during the period when both types are in service.

3.68 Where the CERs are used to estimate subsonic aircraft costs prior to the introduction of SST aircraft, the values of the k terms shown in Table 3.9 apply.

TABLE 3.9

COEFFICIENTS APPLICABLE TO SUBSONIC AIRCRAFT PRIOR TO INTRODUCTION OF SST AIRCRAFT

Coefficient	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k_1A	-56.75	-68.10	-40.86
k_2A	-32.14	-38.57	-23.14
k_3A	-30.58	-36.70	-22.02
k'_1A	30.14	36.17	21.70
k'_2A	17.07	20.48	12.29
k'_3A	16.24	19.49	11.69

3.69 Flight crew costs per block hour estimated from the CER compare with reported unit flight crew costs of U.S. domestic trunk lines as shown in Table 3.10.

[redacted]

TABLE 3.10

COMPARISON OF CER-PREDICTED CREW COSTS WITH REPORTED VALUES

Aircraft Type	Total Flight Crew Costs per Revenue Block Hour		
	Reported* Cost, dollars	Estimated Cost, dollars	Percent Difference
SE-210	102.57	96.66	(5.8)
B-707-100	131.08	128.26	(2.2)
B-707-100B	134.36	131.02	(2.5)
B-707-200/300	122.54	129.12	5.4
B-707-300B	143.10	134.83	(5.8)
B-720	115.14	122.60	6.5
B-720B	108.74	124.13	14.2
DC-8-10	120.50	122.44	1.6
DC-8-20/30	111.98	125.90	12.4
DC-8-60	110.11	127.03	15.4
CV-880	130.68	116.43	(10.9)
CV-990	120.96	119.43	1.3
Unweighted average	120.98	123.15	1.8

Note: ( ) denotes negative.

* From Federal Aviation Agency, Direct Operating Costs and Other Performance Characteristics of Transport Aircraft in Airline Service, 1963. Data on total block-hour basis converted to revenue block-hour basis.

[redacted]

FUEL AND OIL COSTS

Composition

3.70 Fuel costs are comprised of charges incurred by operating airlines for fuel and oil consumed in aircraft operations. These charges include amounts paid to fuel distributors and all nonrefundable taxes and airport charges levied on the basis of fuel usage. The CAB accounts in which the charges are recorded are enumerated in the Table of Definitions at the end of this Volume. Similar costs are reported by foreign air carriers to ICAO in Account 5.2.

Considerations in Developing Fuel and Oil Costs CER

3.71 It is not the function of this study to develop a basis for estimating fuel and oil consumption. Consumption data for individual flight segments and flight profiles will be determined by the U.S. Department of Commerce. This study is only concerned with the problem of deriving factors that will translate consumption data provided by the Department into realistic cost estimates.

3.72 Unit costs of fuel vary throughout the world in relation to supply costs and demand and, further, in relation to local taxes and charges. There is, for example, no U.S. federal tax on kerosene fuel; but at various locations abroad a tax levy is made on fuel consumed or withdrawn from storage. Unquestionably, the most accurate basis for estimating fuel costs would be to apply the particular rates for each location and carrier to estimates of usage by location and carrier. However, apart from the technical difficulties of estimating fuel usage by location, obtaining the necessary information for unit costs is extremely difficult. Prices paid for fuel by the individual carriers at particular locations are not reported in any public source; moreover, the information is closely guarded since it involves matters of competitive advantage and disadvantage. In these circumstances, the best that can be done at this time is to derive general averages for broad geographic areas, to the extent that such averages can be determined from the aggregated reported costs of operating airlines. Because of the importance of fuel costs to supersonic aircraft operating expenses, it would be worthwhile to follow up this phase of the research with more intensive efforts to obtain more precise data for locational and carrier differentials—a difference of even 1 cent in the cost per gallon of kerosene fuel amounts by rough estimate to a difference of $100 per block hour in the cost of supersonic transport operations. By way of comparison, U.S. domestic trunkline carriers reported fuel and oil costs of $191 per total block hour in 1963.

3.73 The fuel cost estimates, submitted to date, of the manufacturers are based on rates per gallon for fuel and oil specified by the FAA. These costs per gallon compare with values recommended for use in the ATA formulas as shown in Table 3.11.

TABLE 3.11. FAA AND ATA ESTIMATES OF FUEL AND OIL COSTS

Cost Items	Cost per U.S. Gallon, dollars	
	FAA	ATA
Kerosene Fuel		
Domestic	0.11	0.11
International	0.12	0.144
International differential	9%	31%
Oil		
Domestic	12.00	6.00
International	12.00	6.00
International differential	-	-

[redacted]

3.74 During the period from 1958 through 1960, U.S. domestic trunkline carriers reported average costs per gallon for kerosene fuel consumed as shown in Table 3.12.

TABLE 3.12. AVERAGE FUEL COSTS REPORTED BY DOMESTIC CARRIERS

Year	Cost per Gallon, cents*
1958	10.17
1959	9.90
1960	9.83
1961	10.83
1962	9.63
1963	9.65

*Data for the period 1958 to 1962 are from the May issues of Airlift for these years. Data for 1963 are from CAB Form 41 reports.

The cost per gallon of oil consumed in U.S. domestic operations has been about $6.

3.75 As may be observed, the reported costs per gallon of U.S. domestic carriers indicate a somewhat lower cost for kerosene fuel than either the FAA and ATA estimates. Specifically, a cost of 9.8 cents per gallon is a representative value for future cost estimation purposes, based on experienced costs and foreseeable future trends. The historical data show no evidence of a pronounced trend—costs per gallon have fluctuated in a comparatively narrow range from 9.63 to 10.83 cents per gallon. Contributing to this stability are the import controls that have been and presumably will continue to be used as a device for stabilizing prices. Barring a drastic change in the demand for kerosene, e.g., that resulting from the widespread use of turbine engines in automobiles, there appears to be no cogent reason for anticipating a significant change in future price levels.

3.76 Reported data also indicate that kerosene fuel costs abroad have been higher than in the U.S. Table 3.13 summarizes cost per gallon data reported by U.S. international carriers for the period from 1960 through 1963. These data have been arranged to compare the costs per gallon for carrier or divisions of carrier operations conducted in the Atlantic, Latin American, and Pacific areas although a precise geographic delineation is not possible since the divisional reporting of carriers is quite broad. For example, for virtually all U.S. international carriers, the reported data include the costs per gallon of fuel consumed in operations within the continental limits of the U.S. and between continental U.S. and off-shore locations where U.S. domestic fuel prices apply. This is the case for Pan American's Latin American operations which include service to Puerto Rico. It is also true of Pan American's and Northwest's Pacific operations, which include services to Hawaii. With adequate allowance for these deficiencies in the report information, the data show a generally consistent differential between U.S. domestic and international kerosene fuel costs per gallon, approximating 20 percent on the average for all areas of the world. The differential appears to be lower in the Atlantic area than in the Latin American and Pacific areas. But the data are not sufficiently clear-cut in their aggregated form to warrant making distinctions between the areas. It is significant, for instance, that operations in the Atlantic area are conducted by Pan American and TWA—the two largest U.S. international operations—whose costs relative to other carriers may reflect scale benefits. For these reasons, it is concluded that an estimated differential of 20 percent is the best judgment that can be made at

[redacted]

TABLE 3.13

COSTS OF KEROSENE FUEL FOR SELECTED U.S. INTERNATIONAL AIRLINES
(1960 and 1963)

Carrier and General Area of Operation	1963		1962		1961		1960	
	Cost per Gallon (Cents)	Percent of Domestic Average	Cost per Gallon (Cents)	Percent of Domestic Average	Cost per Gallon (Cents)	Percent of Domestic Average	Cost per Gallon (Cents)	Percent of Domestic Average
Atlantic								
Pan American			11.0	114	11.6	112	N.R.	
DC-8	10.5	109						
B-707-121	11.0	114						
B-707-321	10.6	110						
B-707-321B	10.7	111						
B-707-321C	10.4	108						
Trans World			9.8	102	11.3	115	9.7	99
B-707-331	10.2	106						
B-707-331B	8.8	91						
Latin America								
Pan American			11.8	123	11.7	113	N.R.	
DC-8	11.1	115						
B-707-121	11.6	120						
B-707-321	12.0	124						
B-707-321B	12.2	126						
Braniff			12.7	132	12.5	121	13,8	140
B-707-200	13.6	141						
B-720	12.3	127						

[redacted]

TABLE 3.13
(Cont)

Carrier and General Area of Operation	1963		1962		1961		1960	
	Cost per Gallon (Cents)	Percent of Domestic Average	Cost per Gallon (Cents)	Percent of Domestic Average	Cost per Gallon (Cents)	Percent of Domestic Average	Cost per Gallon (Cents)	Percent of Domestic Average
Panagra			13.5	140	13.8	134	12.7	129
DC-8	13.5	140						
B-720	12.5	130						
Delta			11.2	116	12.3	119	N.R.	
CV-880	11.8	122						
Western			12.8	133	12.5	121	N.R.	
B-720	12.9	134						
Pacific								
Northwest			12.7	132	13.5	131	13.4	136
B-707-300B	11.1	115						
B-720	12.3	127						
DC-8	12.4	128						
Pan American			11.7	121	13.0	126	N.R.	
B-707-321	11.2	116						
B-707-321B	11.3	117						
B-707-321C	9.4	97						

N.R.--Not reported in source.

Source: 1960-1962 Airlift Magazine, May issues
1963--Form 41 - Reports to CAB

[redacted]

this time with respect to fuel cost differences for U.S. and international operations.

3.77 The cost of oil is minor in relation to kerosene in both subsonic and supersonic operations. As has been pointed out, the FAA has suggested that a cost of $12 per gallon be used for both U.S. domestic and international operations, and the ATA suggested values for oil cost estimation are $6 per gallon for U.S. domestic and international operations. The differences are not material, and the FAA cost values are adopted in this report.

3.78 There remains the question of a differential between U.S. international and foreign carriers in the prices for fuel and oil. Although it begs the question to state that there is no evidence of a differential it is a fact that none can be determined from available data. There are indications of preferential rates to home carriers in some foreign countries, but it is likely that such preferences in prices are offset by scale diseconomies in relation to U.S. international carriers in other countries where operations are conducted. On balance, it is probable that there are no significant differences in average prices for fuel and oil between foreign and U.S. international airlines.

Fuel and Oil Costs CER

3.79 The form of the CER for fuel costs is dictated largely by the form in which input data will be made available. The current understanding is that the Department of Commerce will supply data for pounds of kerosene fuel consumed per flight segment and rates of oil consumption per engine per block hour. The CER set forth following is predicated on this understanding:

$$c_4 = 1.03\left(\frac{k_4 W_f}{D} + N_E k_4{}' G_o t_b\right)$$

where W_f = weight in pounds of kerosene fuel in one flight over the given flight segment

D = kerosene fuel density, 6.7 lb/gal

G_o = gallons of oil consumed per engine per block hour

t_b = flight segment block time per flight, hr

N_E = number of engines per aircraft

1.03 = nonrevenue flight time factor

and where the values in dollars of the k terms are as shown in the following tabulation.

	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k_4	0.098	0.118	0.118
$k_4{}'$	12.00	12.00	12.00

3.80 Fuel and oil costs per revenue block hour determined from the CER compare with reported costs for subsonic jet transports in domestic operations during 1963 as shown in Table 3.14.

[redacted]

[redacted]

TABLE 3.14. COMPARISON OF ESTIMATED AND REPORTED FINAL COSTS IN DOLLARS

Aircraft Types	Fuel and Oil Costs per Revenue Block Hour		
	Reported[1]	Estimated[2]	Percent Difference
SE-210	116.53	113.17	(2.88)[3]
B-707-100	213.32	215.14	.85
B-707-100B	186.56	186.64	.04
B-707-200/300	185.03	223.14	20.60
B-707-300B	186.68	192.38	3.05
B-720	205.62	204.64	(.48)
B-720B	180.83	175.36	(3.03)
DC-8-10	215.73	209.01	(3.12)
DC-8-20/30	221.60	223.29	.76
DC-8-60	187.71	190.33	1.40
CV-880	179.02	182.87	2.15
CV-990	208.12	204.40	(1.79)
Total	2,286.75	2,320.37	
Unweighted Average	190.56	193.36	1.5

[1] FAA, Direct Operating Costs, 1963 costs increased by 3 percent for nonrevenue flying.

[2] At reported consumption of kerosene fuel per total block hour, plus $2 per block hour for cost of fuel.

[3] ( ) Denotes negative.

[redacted]

[redacted]

INSURANCE, INQUIRIES, LOSS AND DAMAGE

Composition

3.81 This expense grouping includes the costs incurred by airlines both in maintaining insurance for protection against loss of income and actual loss of income arising out of damages to flight equipment or damages to third parties in the course of flight operations. Not included are the costs of insurance for or of losses from claims arising in the transportation of passengers and cargo or from claims of employees arising in connection with their employment. Flight equipment damage and insurance for such damage make up the bulk of the reported costs. The CAB accounts comprising the expense grouping are enumerated in the table of definitions at the end of this Volume and comparable data for foreign carriers are reported to ICAO in Account 5.3.

Considerations in the Development of Insurance CER

3.82 Note that insurance and damage costs related to flight operations are complicated by various considerations that make the determination of historical costs—let along future cost estimation—very difficult. For competitive reasons, the terms of insurance contracts, like the terms of fuel contracts, are not generally disclosed by the airlines. A number of carriers self-insure in various degrees in preference to placing all their insurance with commercial companies. The extent to which such carriers reflect the charges to income for self-insurance in their books of record is a matter of accounting policy, and the practices of carriers vary. To be most meaningful for estimation purposes, actual charges for uninsured damages should be averaged over long periods and related to measures of exposure. Because of the various complications that inhibit the determination of true past costs and the degree of uncertainty involved in estimating future costs, any judgments concerning an appropriate CER for insurance and damage costs must necessarily be imprecise and subject to error.

3.83 In Tables 3.15 and 3.16 the reported 1963 annual insurance costs per aircraft are shown for U. S. domestic and international airlines, respectively, and for the individual types of aircraft operated during the year. Based on the insurance costs per aircraft, the imputed value of the equipment insured has been calculated on the alternative assumptions that the reported insurance costs represented 2, 3, and 4 percent, respectively, of the values placed on the equipment in productive use. A comparison of the imputed values with the original cost of aircraft in fly-away condition, without spares, indicates an apparent decline in insurance costs per aircraft unit over the service life of the unit and variations in the levels of unit insurance costs that appear to be related to the replaceability of the aircraft type. Taking into account the original cost of equipment and the years since its first introduction, the following general judgments can be drawn.

a. Subsonic jets have an initial annual insurance cost level of about 4 percent of the original value; thereafter, the cost level declines. It approximates 2.5 percent for aircraft that have been in operation for 5 or more years of the 10- to 12-year service lives currently being estimated for depreciation purposes.

[redacted]

[redacted]

TABLE 3.15. ANNUAL INSURANCE COST PER AIRCRAFT AND IMPUTED VALUE OF EQUIPMENT AT VARIOUS INSURANCE RATE LEVELS

FOR U.S. DOMESTIC TRUNK LINES IN DOLLARS

(1963)

Aircraft Type	Annual Insurance Cost per Aircraft	Imputed Value of Equipment if Insurance Cost is		
		2% of Value	3% of Value	4% of Value
Passenger Aircraft				
DC-3	1,548	77,400	51,600	38,700
CV-340/440	4,519	225,950	150,633	112,975
DC-6/6B	3,811	190,550	127,033	95,275
DC-7/7B/C	6,190	309,500	206,333	154,750
L-749	478	23,900	15,933	11,950
L-1049/1049C/G	1,504	75,200	50,133	37,600
L-1649	2,164	108,200	72,133	54,100
SE-210	38,051	1,902,550	1,268,367	951,275
L-188	29,868	1,493,400	995,600	746,700
V-700	22,239	1,111,800	741,300	555,975
V-800	17,692	884,600	589,733	442,300
DC-8-10	69,554	3,477,700	2,318,467	1,738,850
DC-8-20/30	101,266	5,063,300	3,375,533	2,531,650
DC-8-50	120,779	6,038,950	4,025,967	3,019,475
B-707-100	91,370	4,568,500	3,045,667	2,284,250
B-707-100B	120,200	5,110,000	3,406,667	2,555,000
B-707-200/300	146,365	7,318,250	4,878,833	3,659,125
B-707-300B	195,392	9,769,600	6,513,067	4,884,800
B-720	80,687	4,034,350	2,689,567	2,017,175
B-720-B	167,809	8,390,450	5,593,633	4,195,225
CV-880	84,921	4,246,050	2,830,700	3,123,025
CV-990	126,458	6,322,900	4,215,267	3,161,450

[redacted]

[redacted]

TABLE 3.15 (Cont)

Aircraft	Annual Insurance Cost per Aircraft	Imputed Value of Equipment if Insurance Cost is		
		2% of Value	3% of Value	4% of Value
		Cargo Aircraft		
L-46	2,000	100,000	66,667	50,000
DC-6A	6,501	325,050	216,700	162,525
DC-7B	6,625	331,250	220,833	165,625
L-1049C	2,431	121,550	81,033	60,775
B-707-300P/C	218,051	10,902,550	7,268,367	5,451,275

Source: Direct operating costs and other performance characteristics of transport aircraft in airline service during calendar year 1963 obtained from Office of Policy Development, FAA, July 1964.

[redacted]

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TABLE 3.16. ANNUAL INSURANCE COST PER AIRCRAFT AND IMPUTED VALUE OF EQUIPMENT AT VARIOUS INSURANCE RATE LEVELS

FOR U.S. INTERNATIONAL AIRLINES IN DOLLARS

(1963)

Aircraft	Annual Insurance Cost per Aircraft	Imputed Value of Equipment if Insurance Cost is:		
		2% of Value	3% of Value	4% of Value
	Passenger Aircraft			
DC-3	3,132	156,585	104,400	78,293
CV-340/440	8,526	426,320	284,200	213,160
DC-6/6B	5,333	266,633	177,767	133,316
DC-7/7B/C	12,406	620,318	413,500	310,158
L-749	17,129	856,473	570,967	428,236
DC-8-20/30	85,060	4,252,980	2,835,333	2,126,490
B-707-100	29,587	1,479,345	986,233	739,673
B-707-200/300	56,951	2,847,548	1,898,367	1,423,774
B-707-300B	192,120	5,105,985	3,400,667	2,552,993
B-720	243,335	12,166,728	8,111,167	6,083,364
B-720B	151,676	7,583,788	5,055,867	3,791,894
CV-880	175,758	8,787,923	5,858,600	4,393,961
	Cargo Aircraft			
L-1649A	588	29,383	19,600	14,691
DC-7C	8,245	412,268	274,833	206,134
DC-7F	10,260	513,008	342,000	256,504
B-707-300B/C	63,134	3,156,703	2,104,467	1,578,351

Source:. Direct operating costs and other performance characteristics of transport aircraft in airline service during calendar year 1963 obtained from Office of Policy Development, FAA, July 1964.

[redacted]

b. An insurance cost level of 2.5 percent of the original value appears to be a representative average over the service life of subsonic aircraft; fully depreciated piston and turboprop aircraft are still being insured at rates that, on the average, amount to 1 percent of the original values.

c. Differences in unit insurance costs between U. S. domestic and U. S. international carriers are not sufficiently clear-cut to suggest that a consistent differential exists.

3.84 The rising volume of subsonic aircraft operations and the resulting increase in congestion of the terminal areas suggests an increased exposure of aircraft to damage in the future and the possibility of higher insurance rates. Discussions with aviation underwriters and brokers, however, produced no evidence that this outlook is shared by the insurance industry. Rather the industry is looking forward to a stabilization of rates at the current levels in the belief that improved navigational and communication equipment and improved techniques of air traffic control will offset the adverse effects of increased congestion.

3.85 The outlook is even more speculative regarding insurance costs for supersonic transports. Discussion with knowledgeable insurance brokers and underwriters disclosed that it is generally believed that greater concentrations of exposure represented by high investment values per aircraft for supersonic transports and the uncertainties regarding operating performance will result in initial rates that will possibly be as high as 7 percent of the original values. Thereafter, it is expected that unit insurance rates will be reduced to an average of about 5 percent of the original value of the equipment. These rates are adopted in this report as reasonable, considering both the exposure concentration and the probability that supersonic aircraft operations, even to a greater extent than those of subsonic jets, will be conducted at the larger and most congested air terminals. Additionally, decreased flight time between points means that proportionately more of the total flight time will be spent in the terminal areas where the exposure to damage is relatively high.

3.86 Insurance rate levels are approximately the same for foreign carriers as for U.S. carriers according to the advice obtained from insurance industry sources.

Insurance CER

3.87 The CER derived for insurance and damage costs, unlike the CER derived for flight crew and fuel costs, is a marginal cost function only in the long-run, i.e. when the increase, decrease, or change in flight activity results in a change in the investment in flight equipment. When fleet size and composition are determined and fixed, changes in flight activity are not associated with changes in insurance costs. The form of the derived CER is

$$C_5 = \frac{k_5 P_o t_b}{U}$$

where

P_o = investment cost per aircraft, including the value of installed flight engines and flight equipment but excluding the value of spare parts and equipment

U = annual revenue block hours per aircraft for aircraft of the type used in operations over the given flight segment

t_b = flight segment block time per flight in hours.

and where the value of k_6 is

	Subsonic Aircraft	Supersonic Aircraft
k_6 =	.025	.050

MAINTENANCE OF FLIGHT EQUIPMENT

Composition

3.88 Flight equipment maintenance costs encompass the cost of labor and materials incurred directly in the maintenance of airframe, engines, avionics, and other flight equipment. It does not include the costs of rotable depreciable parts.

3.89 For convenience flight equipment maintenance has been analyzed under the following four categories.

a. Airframe labor cost. Includes labor and related payroll costs on airframe, avionics, landing gear, and other flight equipment, excluding engines. This category includes CAB accounts 5225.1 and 5125.3 and parts of accounts 5243.1, 5243.3, 5272.1, and 5272.2.

b. Airframe material cost. Covers materials consumed in maintenance of airframe and other flight equipment. This category includes CAB account 5246.2 and parts of accounts 5243.2, 5272.6, and 5272.7.

c. Engine labor cost. Covers labor and related payroll costs incurred directly in the maintenance of engines. This category includes accounts 5246.2 and parts of 5343.2, 5272.6, and 5272.7.

d. Engine material cost. Includes materials consumed in the maintenance of engines. This category covers CAB accounts 5246.2 and parts of accounts 5243.2, 5272.6, and 5272.7.

Sources of Data

3.90 Direct operating costs are reported quarterly by the airlines and summarized by the Airline Finance and Accounting Conference of ATA. These summaries break out airframe and engine labor and material costs, by airline, by type of aircraft, and by type of service (domestic or international). The maintenance cost categories defined by ATA are those shown in Table 3.17.

3.91 Maintenance data on military aircraft were not included in the analysis since it was felt that the nature and ground rules for such maintenance would not be applicable to commercial transport aircraft.

3.92 The ATA data on maintenance costs were accumulated for the period from the first quarter of 1959 through the third quarter of 1964. The need for a consistent sample size covering as many representative subsonic jets as possible, however, limited the analysis to the years 1962-63, with 1964 data being available as a check.

3.93 For a given airline the direct maintenance costs are aggregated by ATA into three major types of accounts:

a. Direct labor and material furnished by the airline

b. Direct labor and material, plus overhead, fees, etc., supplied by an outside contractor

c. Airworthiness reserve funds.

TABLE 3.17. ATA MAINTENANCE COST CATEGORIES

Category Number	Description of Cost
5200	Direct maintenance—flight equipment
5225.1	Labor-airframes
5225.2	Labor-aircraft engines
5225.3	Labor-other flight equipment
5242.1	Airframe rep.-assoc. cos.
5242.2	Arc. engine rep.-assoc. cos.
5242.3	Other flight equipment rep.-assoc. cos.
5242.7	Intrchg. chgs.-assoc. cos.
5243.1	Airframe rep.-outside
5243.2	Aircraft engine rep.-outside
5243.3	Other flight equipment rep.-outside
5243.7	Aircraft intchg. chgs.-outside
5246.1	Materials-airframes
5246.2	Materials-aircraft engines
5246.3	Materials-other flight equipment
5272.1	Airw. res. prov.-airframes
5272.2	Airw. res. chgs.-airframe (cr)
5272.6	Airw. res. prov.-aircraft engine
5272.7	Airw. res. cgs.-arc. engine (cr)
5278	Total direct maintenance-flight equipment; applied maintenance burden flt. eq.; total flt. equip. maint.

[redacted]

Since the airworthiness reserve fund is usually small representing only a bookkeeping entry that is handled differently by various airlines, the analysis was based only on accounts 5225.1, 5225.2, 5225.3, 5243.1, 5243.2, 5243.3, 5246.1, 5246.2, and 5246.3.

3.94 To develop cost data as a basis for regression, the following steps were taken.

a. Account 5225.3 (labor-other flight equipment) was added to Account 5225.1 (labor-airframe)

b. Account 5246.3 (materials-other flight equipment) was added to Account 5246.1 (materials-airframe)

c. Account 5243.3 (other flight equipment-outside) was added to Account 5243.1 (airframe-rep outside)

d. Account 5243.1 (airframe rep-outside) was allocated proportionately to Accounts 5225.1 and 5246.1 (airframe labor and materials)

e. Account 5243.2 (engine rep-outside) was allocated proportionately to Accounts 5225.2 and 5246.2 (engine labor and materials).

3.95 Final maintenance cost data are displayed in Table 3.18, representing average annual costs for domestic airlines during 1962 to 1963. The costs for each aircraft type is a composite of experience of all domestic airlines reporting data on that type of aircraft. The costs are in dollars per airborne hour, derived using the aircraft-hour figure from the ATA form a portion of which is shown in Table 3.17. Where the total number of aircraft hours is less than 35,000 hr during the years 1962-63, the corresponding cost data were not used.

3.96 Data bearing on physical and performance characteristics of the aircraft were drawn from FAA specifications, supplemented by <u>Jane's All the World's Aircraft</u> (1957-58, 1962-63, 1963-64). Investment cost data were extracted from CAB Account B-43 records and converted to 1963 dollars. Table 3.19 displays the aircraft data. The weights obtained from FAA specifications were operating weights with zero fuel. The weight of engines was subtracted to obtain the statistic W_A. The years in service were applicable to each aircraft model for $t \leq 6$. For aircraft over 6 years of age, $t = 6$ was used.

3.97 Physical, performance, and cost characteristics of the engines were analyzed only for the jet aircraft. Data were obtained from General Electric and Pratt-Whitney with cost data taken from CAB records. Table 3.20 summarizes the jet engine information for the six engine types used by aircraft on which 1962-63 maintenance data were available through ATA.

3.98 The following pages summarize the analysis leading to CERs in each major maintenance area.

AIRFRAME LABOR

Considerations in Formulating Airframe Labor Cost CER

3.99 Airframe labor cost was hypothesized to depend on (a) the stress encountered by the aircraft in terms of speed and its derivatives, and (b) some measure of the amount of airframe material that is being stressed and must be maintained. It was therefore assumed that the aircraft speed and its size or weight would be involved. Further, the relation of cost to weight should be slightly convex upward since certain one-time costs would be

[redacted]

TABLE 3.18. AVERAGE ANNUAL DIRECT MAINTENANCE COSTS
(1962-1963 Dollars per Aircraft Hour)

Aircraft Type	Labor-Airframe and Other	Material Airframe and Other	Labor Engines	Material Engines
B 707-120B	38.30	30.00	8.68	14.10
B 720	32.40	26.15	7.10	12.95
CV 240	25.10	16.05	11.82	8.40
CV 340	16.70	8.44	7.30	6.68
CV 440	16.45	7.08	8.06	2.84
CV 880	44.10	38.10	10.40	17.85
CV 990	53.55	46.80	11.40	22.40
DC 6	25.20	11.62	3.40	5.91
DC 6B	24.55	12.05	3.16	6.47
DC 7	23.05	17.38	5.56	9.87
DC 7B	26.00	10.35	5.28	8.79
DC 7C	20.45	14.50	6.20	15.52
DC-8-10	32.80	34.45	6.15	10.65
Electra	32.55	23.75	6.61	12.50
L1049C	25.30	6.60	4.05	7.40
L1049G	23.85	10.92	6.90	12.85
L1649	25.85	15.45	7.02	3.94
SE-210	31.35	34.18	11.20	21.60
Viscount	25.43	15.68	5.38	7.23

[redacted]

TABLE 3.19. AIRCRAFT CHARACTERISTICS AND COSTS

(for data sources, see footnote on next page)

Commerical Aircraft Type	Zero Fuel Less Engines, W_A	Max. Cruising Speed, kts, V_k	Typical Cost Data		Engine	Years in Service, t*
			Cost, K$	Year		
B 707-120B	147,000	540	4,990.0	1961	4 PW JT 30-1	3
B 720	128,020	484	3,970.0	1962	4 PW JT3C-7	4
B 727	105,018	504	3,851.1	1963	3 PW JT8D-1	1
CV 240	32,620	243	351.8	1948	2 PW R2800-CA18	6
CV 440	40,220	260	636.0	1957	2 PW R2800-CB16	6
CV 880	104,240	534	3,465.0	1961	4 GE CJ 805-3	3
CV 990	142,736	540	3,275.9	1963	4 GE CJ 805-23B	2
DC 6	63,220	272	870.5	1948	4 PW R2800-CA15	
DC 6B	70,440	267	1,102.0	1951	4 PW R2800-CB17	6
DC 7	73,966	317	1,720.0	1956	4 Wright R972TC18DA1	6
DC 7B	84,616	301	1,982.0	1955	4 Wright R972TC18DA4	6
DC 7C	86,920	301	1,990.0	1957	4 Wright R988TC18EA1	6
DC-8-10	145,820	470.5	4,440.5	1961	4 PW JT 3C6	6
Electra	78,976	352	1,560.4	1959	4 Allison Model 501	3
L1049C	88,920	278	1,531.0	1953	4 Wright R3350-DA1	6
L1049G	88,920	278	1,920.0	1956	4 Wright R3350-DA3	
L1649	102,420	297	2,187.0	1957	4 Wright 988 TC 18	6
SE-210	70,202	400	3,019.0	1961	2 Rolls Royce Avon Mk 29/532	3
Viscount-700	45,992	276.0	864.0	1961	4 Rolls Royce Dart 506	6

* For t > 6, the number 6 is used.

[redacted]

TABLE 3.20. ENGINE CHARACTERISTICS AND COST

Aircraft	Engine Type	Max. Turbine Inlet Temp, F^o	Max. Sea-level T/O Thrust, lb	Weight Dry, lb	Cost K$	t	BPR
B 707-120B	JT3D-1	Classified Data, See Volume IV					
B 720	JT3C-7						
CV 880	CJ 805-3						
CV 990	CJ 805-23B						
DC 8-10	JT3C-6						
SE-210	RA 29/532						

involved regardless of the size of aircraft. The relation to speed should be linear or slightly concave upward, since the energy interchange between the aircraft and its environment would become disproportionately greater at high speeds. This hypothesis was strengthened by scatter diagrams (Figures 3.3 and 3.4). Further, the joint relation should be additive or only weakly coupled.

3.100 The fact that weight and speed are themselves correlated was an indication that the regression results would be complex and subject to possible misinterpretation since the basic regression model assumes statistical independence.

Results of Analysis

3.101 The regression analysis for airframe (domestic) labor as a simultaneous function of weight and speed led to negative coefficients because of the intercorrelation between independent variables discussed previously. The function was strongly dependent on V_k. Although the regression showed a reasonably high correlation with cost, it was discarded as being physically unrealistic.

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* Data for Table 3.19 Sources:

Zero fuel weight data from FAA Aircraft Specifications.
Speed data from Jane's All the World's Aircraft supplemented by FAA Aircraft Specifications.
Engine data from Jane's All the World's Aircraft supplemented by FAA Aircraft Specifications.
Cost data from CAB Account B-43 Records.

[redacted]

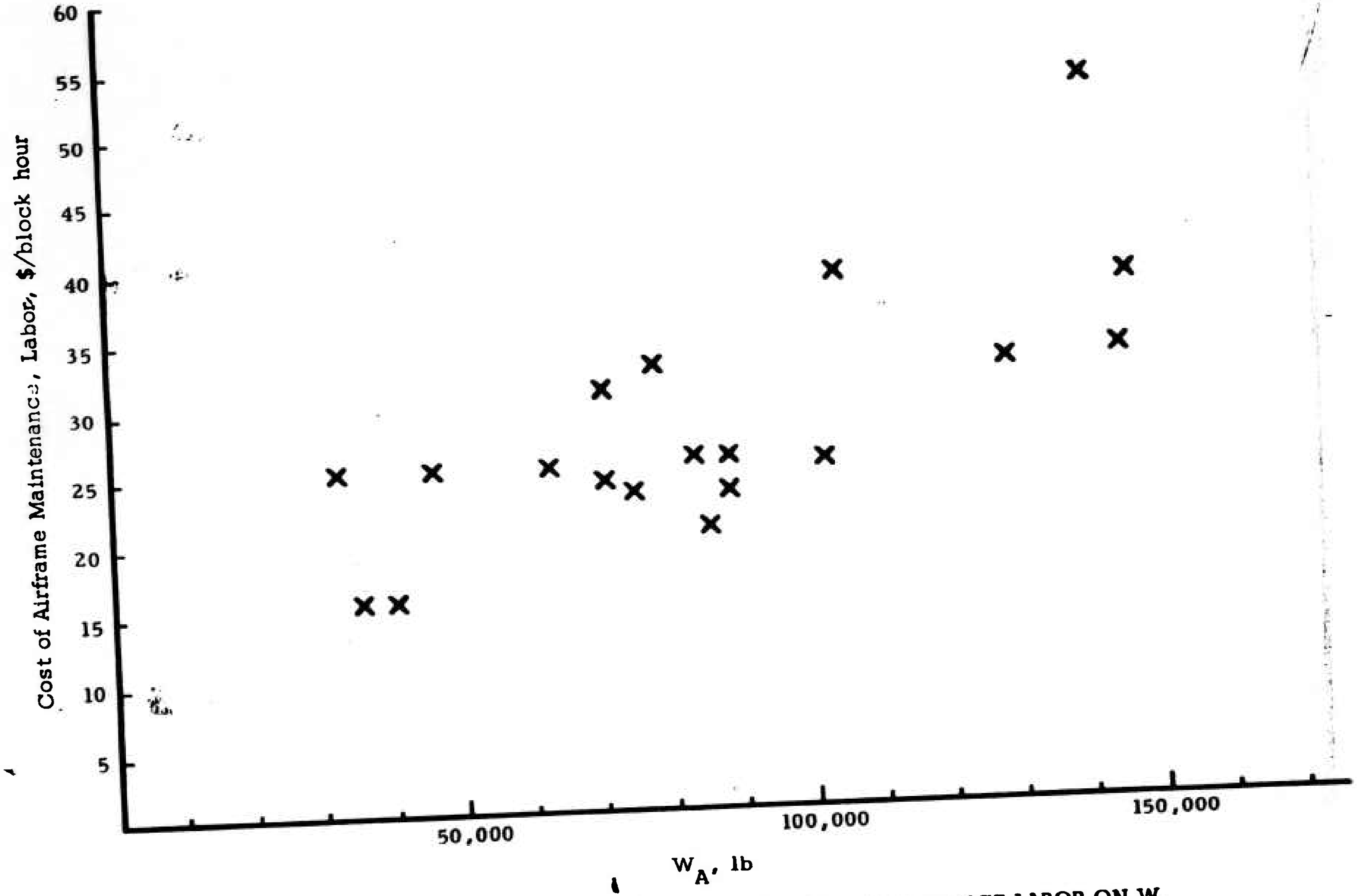

FIGURE 3.3. DEPENDENCE OF AIRFRAME MAINTENANCE LABOR ON W_A

[redacted]

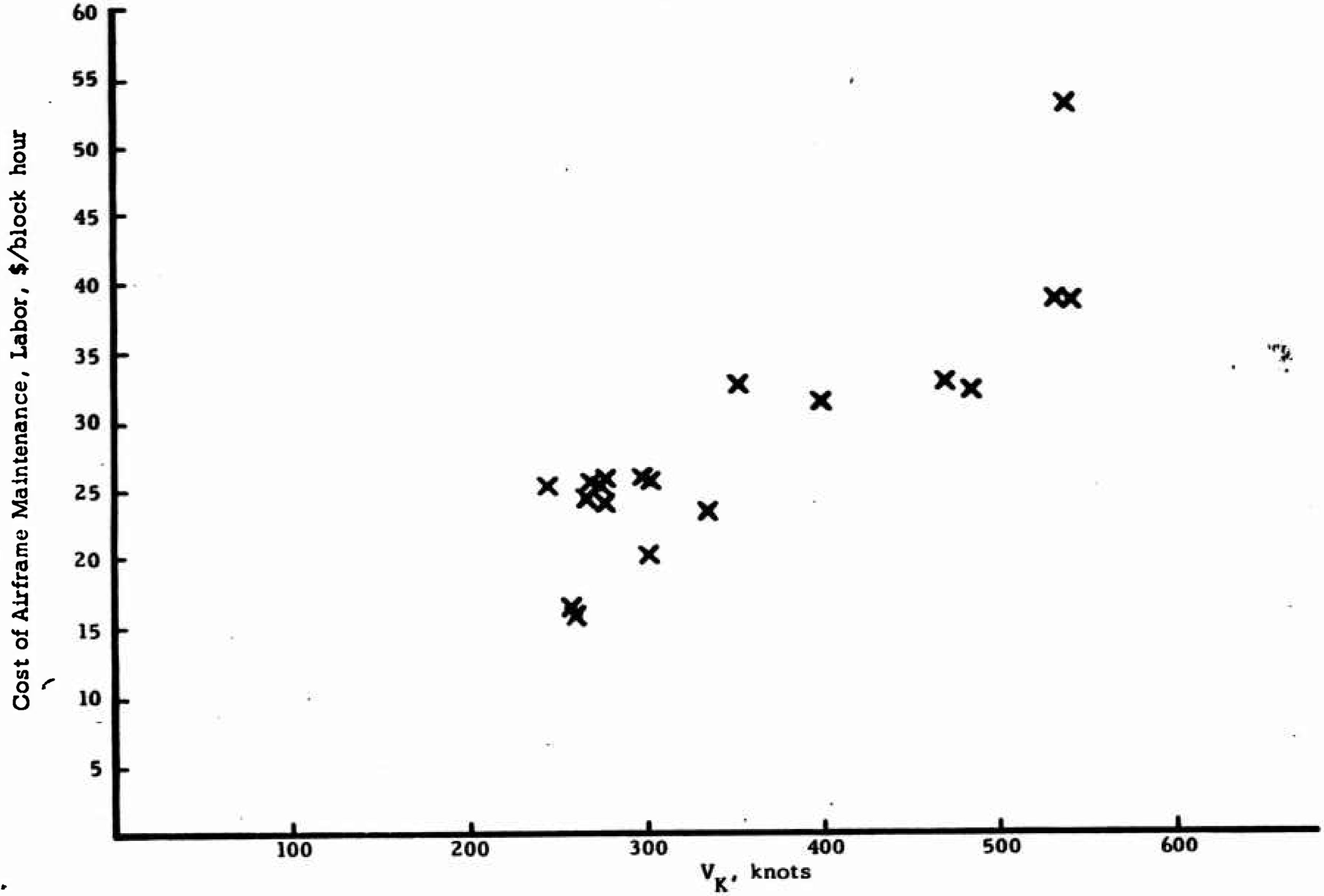

FIGURE 3.4. DEPENDENCE OF AIRFRAME MAINTENANCE LABOR ON V_K

3.102 An independent regression against speed (Table 3.21) showed a reasonably high (87.8 percent) correlation coefficient but requires a large extrapolation to reach the SST operating region.

3.103 The regression against weight (Table 3.22), on the other hand, was less precise but was based on data closer to the SST operating region. In each case the linear fit was preferable to the log-linear form.

3.104 It was determined that a minimum variance prediction for the SST could be made by weighting each of these regression equations inversely proportional the variance at the SST operating point, and combining them into a single CER. The development of the weighting factor is described in Appendix A of this volume.

3.105 The equation thus developed is

$$C_7 = 0.91\,k_7\,t_b\,[(12.915 + .0001825\,W_A)\,W_1 + (2.348 + .0747\,V_k)\,W_2]/(W_1 + W_2),$$

dollars per flight segment

where $W_1 = \left(\frac{40,100}{W_A - 89,800}\right)^2$

$W_2 = \left(\frac{152}{V_k - 392}\right)^2$

W_A = maximum empty weight less engines, lb

V_k = maximum cruising speed at optimum altitude, knots

K_7 = coefficient for various operating conditions

0.91 = factor to account for nonrevenue hours (1.03) and to convert from dollars per airborne hour to dollars per block hour $\left(\frac{1}{1.13}\right)$

[redacted]

TABLE 3.21. COMPUTER PRINTOUT, COST OF AIRFRAME LABOR (SPEED, KNOTS)

```
COEFFICIENT SET NO. 4 OF CLA VS WA E VK G AEB

   RESID SUM OF SQRS. =  3.4344E+02        MUTL. CORR. COEF. =    .8777

        CONSTANT TERM =  2.3481E-00
        VARIABLE    1 =  0.0000E-99
        VARIABLE    2 =  7.4739E-02

     Y OBSERVED  Y CALCULATED       DELTA      PCT DELTA
        25.10         20.50          4.59        18.28         CV240
        38.30         42.70         -4.40        11.50         B707120B
        32.40         38.52         -6.12        18.89         B720
        44.10         42.25          1.84         4.17         CV880
        53.55         42.70         10.84        20.24         CV990
        32.80         37.47         -4.67        14.25         DC8-10
        31.35         32.24          -.89         2.85         SE210
        32.55         28.65          3.89        11.96         ELECTRA
        25.43         22.97          2.45         9.64         VISCO700
        16.70         21.63         -4.93        29.52         CV340
        16.45         21.78         -5.33        32.40         CV440
        25.20         22.67          2.52        10.01         DC6
        24.55         22.30          2.24         9.15         DC6B
        23.05         26.04         -2.99        12.97         DC7
        26.00         24.84          1.15         4.44         DC7B
        20.45         24.84         -4.39        21.48         DC7C
        25.30         23.12          2.17         8.59         L1049C
        23.85         23.12           .72         3.03         L1049G
        25.85         24.54          1.30         5.04         L1649

            MEAN Y OBSERVED =          28.57
     STANDARD ERROR =           4.633     FRAC. S.E. =     .1621
     MEAN DEVIATION =           3.552     FRAC. DEV. =     .1243
```

[redacted]

TABLE 3.22

COMPUTER PRINTOUT, COST OF AIRFRAME LABOR vs OPERATING WEIGHT (LESS ENGINES)

```
COEFFICIENT SET NO. 2 OF CLA VS WA E VK G AEB

   RESID SUM OF SQRS. = , 7.2356E+02        MUTL. CORR. COEF. =   .7186

      CONSTANT TERM =  1.2915E+01
      VARIABLE    1  =  1.8249E-04
      VARIABLE    2  =  0.0000E-99

    Y OBSERVED  Y CALCULATED      DELTA       PCT DELTA
       25.10          18.86         6.23          24.82          CV240
       38.30          39.74        -1.44           3.76          B707120B
       32.40          36.27        -3.87          11.95          B720
       44.10          31.93        12.16          27.57          CV880
       53.55          38.96        14.58          27.24          CV990
       32.80          39.52        -6.72          20.50          DC8-10
       31.35          25.72         5.62          17.94          SE210
       32.55          27.32         5.22          16.04          ELECTRA
       25.43          21.30         4.12          16.20          VISCO700
       16.70          19.38        -2.68          16.06          CV340
       16.45          20.25        -3.80          23.12          CV440
       25.20          24.45          .74           2.96          DC6
       24.55          25.76        -1.21           4.96          DC6B
       23.05          26.41        -3.36          14.59          DC7
       26.00          28.35        -2.35           9.06          DC7B
       20.45          28.77        -8.32          40.71          DC7C
       25.30          29.14        -3.84          15.18          L1049C
       23.85          29.14        -5.29          22.18          L1049G
       25.85          31.60        -5.75          22.26          L1649

            MEAN Y OBSERVED =          28.57
      STANDARD ERROR =          6.724     FRAC. S.E. =    .2353
      MEAN DEVIATION =          5.125     FRAC. DEV. =    .1793
```

AIRFRAME MATERIALS

Considerations in Formulating CER

3.106 **ATA** equations developed in 1960 relate airframe materials cost to the price of the aircraft. Since this cost is generated by replacement of parts, and since each part has a cost that is related to the total aircraft cost, this relation seemed a valid working hypothesis.

3.107 It was felt, however, that this cost would probably be time dependent since early maintenance would involve a certain amount of debugging as well as a learning curve effect. It was also considered that there may be a weak dependence on aircraft weight or speed for the same reasons that prevailed in the case of airframe labor.

Results of Analysis

3.108 A regression analysis was made to examine materials cost as a function of airframe weight, cost, speed, and years in service. Both linear and log-linear forms were examined. The best fit linearly related maintenance cost to airframe cost and to time. This printout is shown in Table 3.23.

3.109 In all cases the linear form developed a closer fit to the data. Furthermore, in the log form the CER was concave upward with weight that did not appear physically reasonable.

3.110 The CER selected is

$$C_8 = 0.91\,k_7 \left[34.637 + .004683\,(P_A + P_f) - 4.7335\,t\right] t_b \text{ ,}$$

dollars per flight segment

where

k_7 = coefficient described in paragraph 3.118 et seq

P_A = investment in avionics and other flight equipment, excluding spares, K$

P_f = investment in airframe less engines, avionics, and other flight equipment and excluding spares, K$

t = years since introduction of aircraft defined for $t \leq 6$

t_b = block hours per flight segment.

[redacted]

TABLE 3.23

COMPUTER PRINTOUT OF AIRFRAME MATERIAL MAINTENANCE vs COST AND TIME

```
COEFFICIENT SET NO. 2 OF CMA VS CT E YRS LIN

   RESID SUM OF SQRS. = , 3.8630E+02        MUTL. CORR. COEF. =    .9190

        CONSTANT TERM =  3.4637E+01
        VARIABLE    1 =  4.6830E-03
        VARIABLE    2 = -4.7335E-00

     Y OBSERVED   Y CALCULATED        DELTA        PCT DELTA
        30.00          29.60            .39           1.31          B707120B
        26.15          34.29          -8.14          31.14          B720
        38.10          36.66           1.43           3.77          CV880
        46.80          40.51           6.28          13.43          CV990
        34.45          27.03           7.41          21.53          DC8-10
        34.18          34.57           -.39           1.15          SE210
        23.75          27.74          -3.99          16.81          ELECTRA
        15.68          10.28           5.39          34.42          VISCO700
        16.05           7.88           8.16          50.88          CV240
         8.44           9.55          -1.11          13.17          CV340
         7.08           9.21          -2.13          30.14          CV440
        11.62          10.31           1.30          11.25          DC6
        12.05          11.39            .65           5.42          DC6B
        17.38          14.29           3.08          17.77          DC7
        10.35          15.51          -5.16          49.92          DC7B
        14.50          15.55          -1.05           7.27          DC7C
         6.60          13.40          -6.80         103.11          L1049C
        10.92          15.22          -4.30          39.44          L1049G
        15.45          16.47          -1.02           6.65          L1649

            MEAN Y OBSERVED =            19.97
     STANDARD ERROR =           4.913    FRAC. S.E. =     .2459
     MEAN DEVIATION =           3.594    FRAC. DEV. =     .1799
```

[redacted]

[redacted]

ENGINE LABOR

Considerations in Formulating CER

3.111 Emphasis on engine maintenance cost relations was directed toward jet engines. Since both maintenance cost data and performance characteristics data are available on only a limited number of jet engines, it has been necessary to consider only CERs that make use of a small number of independent variables.

3.112 It was felt that maintenance labor should vary both with stress, e.g., thrust, turbine inlet temperature, SFC, mass flow, and with difficulty of repair, possibly complexity as represented by the ratio of thrust to weight or by the weight itself. Preliminary use of scatter diagrams indicated little dependence on engine cost or on years in service. Time-between-overhaul (TBO) was discounted since it appeared to be a policy variable that itself depended on more basic underlying parameters rather than a causative factor.

3.113 Linear multiple regressions were examined using turbine inlet temperature, thrust-to-weight ratio, and by-pass ratio as independent variables. The log-linear form was not tested because it was felt that the data were too limited to make a meaningful comparison. The use of temperature and thrust-to-weight ratio in a linear form gave a correlation coefficient of .9690 and reduced the residual sum of squares from 24.25 to 1.48, with four degrees of freedom. In addition, making use of the by-pass ratio decreased the degrees of freedom from four to three (25 percent) while decreasing the residual squares to 1.38 (7 percent). Thus, using the decision criterion described in Section II, the by-pass ratio was excluded, and the CER selected was

$$C_9 = 0.91\, k_7\, N_E \left[-26.41 + .01697\, F^o + 2.0214\, T/W_E\right] t_b$$

where k_7 ≐ coefficient defined in paragraph 3.118 et seq

F^o = maximum turbine inlet temperature

T = maximum augmented T/O thrust, lb

W_E = engine empty, lb

N_E = number of engines installed on aircraft.

3.114 The computer printout leading to this CER is shown in Table 3.24.

[redacted]

[redacted]

TABLE 3.24

COMPUTER PRINTOUT OF ENGINE MAINTENANCE LABOR vs TURBINE INLET TEMPERATURE AND THRUST-TO-WEIGHT RATIO

```
COEFFICIENT SFT NO. 3 OF CLE VS FO T/W BPR L

    RESID SUM OF SQRS. = , 1.4786E-00       MUTL. CORR. COEF. =    .9690

         CONSTANT TERM = -2.6406E+01
         VARIABLE    1  =   1.6972E-02
         VARIABLE    2  =   2.0214E-00
         VARIABLE    3  =   0.0000E-99

      Y OBSERVED   Y CALCULATED       DELTA        PCT DELTA
          6.15          5.76            .38           6.23          JT3C-6
          7.10          8.02          -.92           12.98          JT3C-7
          8.68          8.43            .24           2.86          JT3D-1
         10.40         10.70          -.30            2.97          CJ805-3
         11.40         11.36            .03            .31          CJ805-23
         11.20         10.63            .56           5.06          RA29-532

             MEAN Y OBSERVED =                9.15
         STANDARD ERRCR =              .859   FRAC. S.E. =    .0939
         MEAN DEVIATION =              .411   FRAC. DEV. =    .0449
```

[redacted]

ENGINE MATERIALS

Considerations in Formulating CER

3.115 Considerations bearing on the selection of independent variables were quite similar to those previously discussed regarding engine labor. However, since the by-pass ratio did not seem important in that analysis, and since it was felt that engine cost might be related to engine maintenance material cost in a way analogous to the relation between airframe cost and airframe maintenance material, linear regressions were run against cost, turbine inlet temperature, and thrust-to-weight ratio.

Results of Analysis

3.116 The linear regression against temperature and thrust-to-weight ratio gave a correlation coefficient of .949 and reduced the residual sum of squares from 115.17 to 11.44. The inclusion of cost as an independent variable reduced the degrees of freedom by 25 percent and reduced the residual sum of squares to 1.0 or 91 percent. The cost data, however, were so clustered and the extrapolation required to SST costs so large that it was decided that the former regression would be more useful for prediction. Consequently, the CER selected is

$$C_{10} = 0.91\,k_7\,N_E \left[-60.593 + .03903\,F^o + 3.347\,T/W_E\right] t_b$$

where

k_7 = coefficient defined in paragraph 3.118 et seq

N_E = number of engines installed in aircraft

F^o = maximum turbine inlet temperature

T = maximum augmented T/O thrust, lb

W_E = weight of dry engines, lb

t_b = block hours per flight segment.

3.117 The computer printout leading to this CER is shown in Table 3.25.

[redacted]

TABLE 3.25

COMPUTER PRINTOUT OF ENGINE MAINTENANCE MATERIAL COST vs TEMPERATURE AND THRUST-TO-WEIGHT RATIO

```
COEFFICIENT SET NO. 7 OF CME VS C FO T/W LIN

   RESID SUM OF SQRS. = , 1.1444E+01      MUTL. CORR. COEF. =    .9489

       CONSTANT TERM = -6.0593F+01
       VARIABLE    1  =  0.0000E-99
       VARIABLE    2  =  3.9030F-02
       VARIABLF    3  =  3.3470E-00

     Y OBSERVED  Y CALCULATED        DELTA         PCT DELTA
        10.65          9.94            .70            6.62          JT3C-6
        12.95         14.11          -1.16            9.00          JT3C-7
        14.10         14.02            .07             .51          JT3D-1
        17.85         20.20          -2.35           13.19          CJ805-3
        22.40         21.39           1.00            4.47          CJ805-23
        21.60         19.85           1.74            8.05          RA29-532

            MEAN Y OBSERVED =            16.59
     STANDARD ERROR =            2.391    FRAC. S.E. =    .1441
     MEAN DEVIATION =            1.173    FRAC. DEV. =    .0707
```

[redacted]

[redacted]

CARRIER DIFFERENTIALS

3.118 Since the major maintenance activities of the U. S. domestic and international carriers are commonly performed in the United States, there is little reason to expect a significant difference in unit costs among these two groups of carriers. This expectation is confirmed by recent data for direct maintenance costs. In 1963 U. S.domestic trunk lines reported an average maintenance cost per total block hour of $129 for all 4-engine jet passenger aircraft. In the same period U. S. international carriers reported direct maintenance costs of $127 per total block hour.

3.119 There is, however, a substantial difference in the unit of costs of maintenance between U. S. international and foreign carriers. Unfortunately, the lack of detail in the available comparative cost information makes it impossible to determine the separate differentials for labor and material costs and for aircraft and other flight equipment and engines. The only detail for determining the differentials is in the form of system or divisional aggregates for all maintenance costs including maintenance burden. These data, moreover, are not detailed by aircraft type. Were it not for the fact that the differentials in unit maintenance costs were so obviously considerable, the poor state of the available information would warrant foregoing the effort of determining them. The indications are, however, clear that the maintenance activities of foreign carriers result in higher costs per unit of output.

3.120 The only sources of comparable data for the maintenance costs of U. S. international and foreign carriers are the financial data reports published by ICAO. As noted, these data are as detailed as the reports made to CAB. On the other hand, the carriers do report to ICAO under uniform reporting instructions and, at least so far as the larger foreign carriers are concerned, there is no basis for believing that the reported data are not comparable.

3.121 In 1962, the latest year for which financial data are currently available, pertinent data from ICAO sources regarding revenue hours flown, average size of aircraft operated, and reported maintenance costs per revenue hour flown were as shown in Table 3.26 for the principal U. S. international and foreign carriers operating aircraft of roughly equivalent size.

3.122 On the basis of the data shown in Table 3.26, it appears to be a fair conclusion that the unit maintenance costs of foreign carriers are more than 50 percent greater than those for U. S. international carriers engaging in comparable operations with comparable aircraft. With a further narrowing of gap in wage levels between U. S. and foreign labor and with some allowance for increased efficiency in line with past trends of foreign carrier maintenance operations, it is anticipated that the differential in time will be reduced to about 33 percent. Assuming a cost allocation similar to that for domestic aircraft, the following values of k_7 are established.

	U.S. Domestic	U.S. International	Foreign
k_7 =	1	1	1.33

[redacted]

TABLE 3.26

COMPARATIVE STATISTICAL AND MAINTENANCE COST DATA FOR U. S. INTERNATIONAL AND FOREIGN CARRIERS

(1962)

Carrier	Revenue Hours Flown	Available Ton-Miles per Aircraft Mile	Maintenance Costs per Revenue Hour, dollars
	U. S. International		
Northwest	41,588	9.5	126
Panagra	17,462	10.0	227
Braniff	10,287	10.1	191
Pan American	263,878	13.3	228
Trans World	49,462	13.8	250
	Foreign		
Japan (JAL)	27,635	9.1	310
Avianca	14,695	9.2	337
British Overseas	159,830	10.0	336
Lufthansa	75,043	10.2	210
Air France	109,552	10.6	422
El Al	16,261	10.9	300
Quantas	41,000	13.2	520

FLIGHT EQUIPMENT MAINTENANCE BURDEN

Composition

3.123 Maintenance burden is comprised generally of those costs incurred in connection with maintenance activities that are not consumed directly in periodic maintenance operations and in other maintenance and repair of flight and ground property and equipment. It includes all overhead or general expenses of the maintenance activity and such specific items of costs as those incurred in administration of maintenance stocks and stores, record-keeping, and the scheduling, control, and supervision of maintenance operations. Maintenance burden is applicable to the functions of both flight equipment and ground equipment maintenance. The amount applicable to flight equipment maintenance is reported in CAB Account 5379.6.

Considerations in the Development of CER

3.124 Maintenance burden is generally considered to be wholly variable with the volume of direct maintenance activity; it usually has been estimated as a factor of either the total cost of direct maintenance or of a major component of the total. In past studies both total direct maintenance costs and the labor component of direct maintenance have been used as the basis for estimating maintenance burden costs without a material difference in the results or in the efficiency of estimation. Intuitively, it would appear that the labor component has a more direct bearing on burden activities than the material component since the supervisory activities and the overall size of the maintenance plant seem to be more directly related to the size of the labor force employed in direct maintenance activities than to the dollar value of material consumed. For this reason, direct labor costs, rather than total direct maintenance costs, are adopted as the operating factor in the CER derived in this report.

3.125 Data for direct maintenance labor costs, the proportion of direct maintenance costs associated with maintenance contracted out, and the maintenance burden costs per dollar of direct maintenance labor costs are shown in Tables 3.27 and 3.28 for U. S. domestic and international carriers, respectively. As may be observed from the data, maintenance burden costs per dollar of direct maintenance labor decrease for both groups of carriers as the proportion of outside maintenance costs increases. There are two reasons for this behavior of the maintenance burden ratio: (a) carriers whose direct maintenance operations are not of sufficient scale to bring the ratio down to economic levels are most likely to contract maintenance out, and (b) the effect of outside contracting is to eliminate areas of maintenance activities that involve relatively high burden expense in relation to direct charges.

3.126 In deriving a common CER for all carriers, differences in the experienced ratios attributable to differences in the extent of outside contracting must be eliminated. This is best accomplished by determining the ratio of maintenance burden to direct maintenance labor costs by eliminating the outside maintenance effect, i.e., under a condition where no outside maintenance is contracted. In this way, all carriers are put on the same footing and the possibility of estimating biases are reduced although not entirely eliminated.

3.127 To determine an average ratio, where no outside maintenance is performed, lines were fitted to the

[redacted]

TABLE 3.27

FLIGHT EQUIPMENT DIRECT MAINTENANCE AND MAINTENANCE BURDEN RELATIONSHIPS FOR U. S. DOMESTIC CARRIERS IN DOLLARS (1963)

Carrier	Maintenance Expenses, K				Outside Maintenance per Dollar of Total Direct	Computed Maintenance Burden per Dollar of Direct Labor*	Computed Maintenance Burden per Dollar of Direct Labor*
	Total Direct	Outside Contractors	Direct Labor	Burden			
United	54,357	1,079	23,883	47,513	0.020	1.989	1.995
Continental	8,353	182	3,058	3,936	0.022	1.287	1.294
Northwest	13,681	967	4,336	4,940	0.071	1.139	1.161
Eastern	43,774	3,321	20,623	20,081	0.076	0.998	1.021
Delta	22,499	3,020	7,237	14,012	0.134	1.936	1.977
American	51,138	8,348	19,704	44,229	0.163	2.245	2.295
Trans World	22,853	7,651	13,517	21,523	0.335	1.592	1.694
Braniff	11,070	3,730	3,478	4,812	0.337	1.384	1.487
Western	9,971	4,454	2,235	2,061	0.447	0.922	1.051
Northeast	7,882	3,909	2,135	4,161	0.496	1.782	1.933
National	11,364	6,182	1,743	5,701	0.544	3.271	3.437
Average							1.692

* Adjusted to reflect a condition of no outside maintenance, based on the relationship between outside maintenance per dollar of total direct maintenance X and maintenance burden per dollar of direct labor Y; $Y = 1.242X - .3049$.

Source: CAB Form 41 reports.

[redacted]

[redacted]

TABLE 3.28

FLIGHT EQUIPMENT DIRECT MAINTENANCE AND MAINTENANCE BURDEN RELATIONSHIPS FOR U.S. INTERNATIONAL CARRIERS IN DOLLARS

(1963)

Carrier	Maintenance Expenses, K				Outside Maintenance per Dollar of Total Direct	Computed Maintenance Burden per Dollar of Direct Labor*	Computed Maintenance Burden per Dollar of Direct Labor*
	Total Direct	Outside Contractors	Direct Labor	Burden			
Western	730	228	122	166	0.312	1.361	1.667
Northwest	4,525	1,080	1,075	2,418	0.239	2.245	2.479
Braniff	1,484	351	416	654	0.236	1.572	1.804
Trans World	5,666	80	2,845	5,394	0.141	1.896	2.034
Eastern	4,218	525	1,374	1,919	0.124	1.396	1.518
Pan American-Pacific	8,766	620	3,729	7,506	0.071	2.013	2.023
Pan American-Alaska	554	39	268	475	0.070	1.772	1.841
Delta	543	33	127	285	0.061	2.240	2.300
Pan American-Atlantic	18,091	956	7,986	15,983	0.053	2.001	2.053
Pan American-Latin America	12,183	434	5,031	9,455	0.036	1.879	1.914
American	1,303	46	413	666	0.035	1.612	1.646
United	2,399	34	653	1,877	0.014	2.874	2.888

* Adjusted to reflect a condition of no outside maintenance, based on the relationship between outside maintenance per dollar of total direct maintenance X and maintenance burden per dollar of direct labor Y; $Y = 1.884X - .981$.

Source: CAB Form 41 reports.

[redacted]

[redacted]

relationships between maintenance burden costs per dollar of direct maintenance labor costs and the percent of direct maintenance performed by outside contractors. Lines were fitted to data for both U. S. domestic and U. S. international carriers. The intercept values for the relationships, i.e., the value of the burden ratio when no outside maintenance is performed, are $1.7 and $1.9 per dollar of direct maintenance labor, respectively, for U. S. domestic and international airlines.

Cost Estimating Relationships

3.128 The CER for maintenance burden costs is

$$c_{11} = k_{11} \ (c_7 + c_9)$$

where

c = maintenance burden costs per flight segment

and where the values of k_{11} are

	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k_{11} =	1.70	1.90	1.90

[redacted]

FLIGHT EQUIPMENT DEPRECIATION

Composition

3.129 Flight equipment depreciation accruals reflect write-offs of the original costs and actual reductions in values of flight equipment (airframe, engines, and avionics). Depreciation accruals cover not only the investment costs of equipment installed in operable aircraft but also the investment costs of the stocks of rotatable spare parts and assemblies maintained for replacement purposes. Not covered is the provision made by some airlines for the loss in value of stocks of nonrotatable parts resulting from obsolescence. The amounts involved, however, are relatively small on an industrial basis. The CAB accounts included are detailed in the table of definitions at the end of this volume.

Considerations in Deriving CER

3.130 In normal airline accounting practice, depreciation is determined on a formula basis, in which the factors are (a) the original investment in depreciable assets, including such procurement costs as are capitalized, (b) the expected service life of the assets, (c) the resale or salvage value of the assets at the termination of the service life, and (d) the time phasing of the rate of write-off. In the latter connection, CAB has generally insisted that a straight-line basis of write-off be adhered to, in which case the rate of write-off for a particular asset is constant throughout the service life of the asset. For tax purposes, write-offs are often made at accelerated rates during the early years of service life.

3.131 The CERs derived herein assume a straight-line basis of depreciation and follow the classifications of depreciation expense employed in reporting to CAB. For reporting purposes flight equipment is classified into airframes and related spares, engines and related spares, and other flight equipment (including spares). The same distinction is made here and CERs are derived for each classification.

3.132 The CERs are stated in general terms to permit latitude in the adjustment of the factors to reflect either alternative policies or specific policies of individual carriers that may differ from more-or-less typical policies pursued in the industry. In applying CER, it is necessary, of course, to state values for the factors; consequently, certain tentative values are suggested for use in costing subsonic and SST aircraft operations. The suggested values are not the actual values for all operating airlines or for any one operating airline; however, they do appear to be representative for the industry. For instance, the stocks of spare parts in relation to operating equipment differ among the individual carriers in relation to route structure (location of maintenance bases, extent of maintenance contracted out, and various policy considerations). The values of spare-parts factors suggested herein are believed to be representative, but they will not necessarily conform to the actual factors for any one carrier.

CERs

3.133 The derived CERs are

$$C_{12} = \frac{P_f (1+S_f)(1-R_f)t_b}{L_f \ U}$$

$$C_{13} = \frac{4P_E (1+S_E)(1-R_E)t_b}{L_E \ U}$$

$$C_{14} = \frac{P_A (1+S_A)(1-R_A)t_b}{L_a \ U}$$

where C_{12} = depreciation of airframes and airframe spares per flight segment

C_{13} = depreciation of engines and engine spares and parts per flight segment

C_{14} = depreciation of avionics and other flight equipment and spares per flight segment

P_f = investment in airframe per aircraft, excluding spares

$4P_E$ = investment in engines per aircraft, excluding spare engines and parts

P_A = investment in other flight equipment per aircraft, excluding spares

S_f = investment in airframe spares per dollar investment in airframes

S_E = investment in engine spares and parts per dollar investment in installed engines

S_A = investment in other flight equipment spares per dollar investment in other flight equipment installed in aircraft

R_f = fractional part of original investment in airframes and spares remaining as salvage value at the end of service life

R_E = fractional part of original investment in engines, spare engines, and engine parts remaining as salvage value at the end of service life

R_A = fractional part of original investment in other flight equipment and spares remaining as salvage value at the end of service life

L_f = service life of airframe and spares, in years

L_E = service life of engines, spare engines, and engine parts, in years

L_A = service life of other flight equipment and spares, in years

U and t_b are as previously defined.

3.134 Suggested values of the parameters are given in Table 3.29.

TABLE 3.29

SUGGESTED VALUES FOR ESTIMATING PARAMETERS

Parameter	Subsonic Aircraft	Supersonic Aircraft
S_f	0.15	0.15
S_E	0.50	0.50
S_A	0.50	0.50
R_f	0.05	0.05
R_E	0.00	0.00
R_A	0.00	0.00
L_f	12	15
L_A	12	15
L_E	7	7

AIRCRAFT SERVICING EXPENSES

Composition

3.135 This group of expenses is the aggregate of costs reported to CAB by U.S. airlines in Account 6100, plus an allocated portion of costs reported in Account 6300 (Servicing Administration). The latter is an overhead account relating to both Account 6100 (Aircraft Servicing) and Account 6200 (Traffic Servicing). The allocation is made pro rata to the two primary accounts in relation to the amounts reported in each account. That portion not allocated to Account 6100 is added to Account 6200. There is no comparable grouping of expenses for foreign air carriers.

3.136 The expenses included in this grouping relate to the following principal types of activities:

a. Inflight control by ground personnel

b. Scheduling or preparing flight crews for flight assignments

c. Landing and parking aircraft

d. Ground servicing and fueling

e. Supervisory and administrative functions associated with the foregoing.

The proportion varies from airline to airline, but approximately 15 percent of the reported expenses consists of landing fees. A roughly equal amount is reported for aircraft control personnel costs and related payroll expenses.

Considerations in Deriving Aircraft Servicing Expenses CER

3.137 Examination of the content of the aircraft servicing expense accounts leaves very little doubt that aircraft activity at the airports is the logical costing unit. The essential problem is to determine the relative weights to be assigned to aircraft of different types and to relate these weights to aircraft physical characteristics so that realistic estimates can be derived for all types of aircraft, including supersonic aircraft.

3.138 The following two basic approaches have been attempted:

a. Aircraft departures, by type, were weighted directly by physical characteristics of the aircraft and correlated with costs. Physical characteristics considered, in this connection, were payload (available tons per aircraft), maximum certificated gross weight, and maximum landing weight. Departures were also equally weighted or unweighted and correlated with costs.

b. Aircraft departures were grouped by basic aircraft types i.e., DC-3, small piston, large piston, turboprop, and 2-engine jet, and larger, and correlated with aircraft servicing expenses to determine the relative weights picked up by each type of aircraft in the regression equations. If the weights appeared reasonable and consistent, it was proposed further to correlate them with physical characteristics of the aircraft, such as payload capacity, seating

[redacted]

configuration, maximum certificated gross weight, and landing weight in order to establish relationships that might be reasonably projected for SST aircraft.

3.139 In all cases, three different categories of cost have been used separately in the regressions, i.e., total aircraft servicing expenses, landing fees, and the total less landing fees. Separate regressions have also been run for domestic and international air carriers.

3.140 Consideration was given to the possible use of a finer breakdown of costs, but the idea was rejected because of significant differences in accounting and classification practices among the airlines. Difficulties were experienced even in using aggregates for all aircraft servicing expenses. For example, United Air Lines, to cite one particularly notable example, makes no separation between certain categories of its traffic handling and aircraft servicing personnel. Total aircraft servicing costs reported by United Air Lines, as a result, are three times as great as those reported by the next ranking carrier although by no measure of aircraft activity does United Air Lines exceed the next ranking carrier by more than 50 percent. The problem of accounting variations among the carriers is, of course, even more severe when costs are disaggregated to the levels of subaccounts within the functional groupings. Landing fees and total aircraft servicing costs excluding landing fees have, however, been examined separately for several reasons. First, reporting of landing fees is reasonably uniform, although not entirely so since the airport services compensated by landing fees are not the same among airports. Secondly, landing fees are predicated on established rates at the airports that, in many instances, can be directly ascertained. Thus, it is probably preferable to use the rates quoted for particular locations or estimates thereof, if they can be accurately and readily determined, rather than a statistical average relationship in estimating landing fees. The separate treatment of landing fees permits added flexibility whereas merging of landing fees with aircraft servicing expenses does not.

3.141 Aggregation of aircraft servicing expense does not limit analyses to the relationships between the aggregations of cost, on the one hand, and single exploratory variables, on the other. By employing multiple regressions analyses, the relationships of costs and two or more explanatory variables can be determined, with each variable obtaining the relative weight which produces the "best" estimate of costs according to the criteria of "best" inherent in the technique used for the purpose. Where the data are sufficient to yield valid determinations of the separate weights of two or more explanatory variables, multiple regression is a preferred analytical technique since it avoids the problems of accounting inconsistencies in the more detailed breakdowns of costs that make up the aggregations. It also reduces the need for making intuitive groupings of costs and, thus, provides an analytical tool that is less vulnerable to errors in judgment.

3.142 Although many more analyses were made, only those contributing significantly to the derivation of CER for aircraft servicing costs are included. In the order presented, these regressions are indicated in Table 3.30.

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TABLE 3.30

INDEX OF COMPUTER PRINTOUTS ON AIRCRAFT SERVICING

Page Nos.	Aircraft Servicing Expenses Included	Independent Variables	Carriers	Period
1–15	Total	Weighted and unweighted aircraft departures	Domestic	1962–63
16–30	Total	" " " "	Domestic	1963
31–45	Total	" " " "	Domestic	1962
42–60	Total	" " " "	International	1963
61–64	Landing fees	" " " "	Domestic	1962–63
65–68	Landing fees	" " " "	Domestic	1963
69–72	Landing fees	" " " "	Domestic	1962
73–76	Landing fees	" " " "	International	1963
77–80	Total less landing fees	" " " "	Domestic	1962–63
81–84	Total less landing fees	" " " "	Domestic	1963
85–88	Total less landing fees	" " " "	Domestic	1962
89–92	Total less landing fees	" " " "	International	1963
93–94	Total	Aircraft departures by aircraft type	Domestic	1962–63
95–96	Total	" " " "	Domestic	1963
97–98	Total	" " " "	Domestic	1962
99	Total	" " " "	International	1963

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TABLE 3.30 (cont)

100–101	Landing fees	Aircraft departures by aircraft type	Domestic	1962–63
102–103	Landing fees	" " " "	Domestic	1963
104–105	Landing fees	" " " "	Domestic	1962
106	Landing fees	" " " "	International	1963
107–108	Total less landing fees	" " " "	Domestic	1962–63
109–110	Total less landing fees	" " " "	Domestic	1963
111–112	Total less landing fees	" " " "	Domestic	
113	Total less landing fees	" " " "	Domestic	

3.143 The initial regression studies were designed to determine which of four variables, i.e., aircraft departures weighted by available tons per aircraft, maximum certificated takeoff weight, and maximum landing weight and unweighted aircraft departures, is the best estimator of total aircraft servicing expenses and their component parts (landing fees and total costs less landing fees). The analyses were also directed at determining whether significantly better and realistic relationships could be derived by using combinations of variables. In this connection, the development of a rational CER requires that all coefficients be positive. Clearly, it makes no sense economically that a positive increment in aircraft departures would reduce costs. A particular point of interest was the comparative values of the different weightings used for estimating purposes. This interest stems from the fact that the relationships between available tons per aircraft (payload, landing weight, and takeoff weight) will be different for supersonic and for subsonic aircraft. Takeoff weight, for instance, will be greater in relation to landing weight for supersonic aircraft because of the large difference in enroute fuel consumption. Thus whether gross weight or landing weight is found to be the better factor in estimating aircraft servicing costs will make a difference in the relative costs predicted for supersonic operations relative to subsonic operations.

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3.144 Taking the weighting factors one at a time, the results of the analyses generally point to the superiority of MCGW as compared with either landing weight or payload. This may be seen from Table 3.31 which compares the correlation coefficients obtained by correlating aircraft servicing costs and their components with the aircraft departures weighted by the various weighting factors. As may be seen, MCGW uniformly produces higher correlations than the landing weight and payload factors. Landing weight, in turn, is shown to be somewhat superior to payload.

3.145 The superiority of the MCGW factor is further shown by its behavior when it is combined with other factors in multiple regressions. A summary of the coefficient values for each of the factors in combination with other factors contained in Table 3.32 indicates that MCGW tends to dominate where it is used in combination, and that it has the greatest degree of stability of the three weighting factors used to weight departures. The coefficient values are taken from the regression equations derived from domestic trunkline data for the years 1962 and 1963.

3.146 It is significant that there is no combination of variables in which all the variables meet the standard of logic. In all cases, one or more of the variables in the combination has a negative coefficient. This is particularly true for unweighted aircraft departures used, together with departures weighted by landing weights to estimate aircraft servicing costs in the methodology adopted by the manufacturers. In each case where unweighted departures are used in combination with another factor, the coefficient values were negative.

TABLE 3.31

CORRELATION COEFFICIENTS FOR SERVICING COSTS AS A FUNCTION OF MAXIMUM, LANDING, AND PAYLOAD WEIGHTS

Independent Variable	Correlation Coefficients*		
	Total Aircraft Servicing Costs	Landing Fees	Total Less Landing Fees
Domestic - 1962			
Weighting Factor			
MCGW	+.9607	+.9686	+.9611
Landing wt	+.9535	+.9623	+.9544
Payload	+.9282	+.9474	+.9301
Domestic - 1963			
Weighting Factor			
MCGW	+.9487	+.9559	+.9500
Landing wt	+.9439	+.9509	+.9457
Payload	+.9239	+.9355	+.9264
International - 1963**			
Weighting Factor			
MCGW	+.9942	+.9968	+.9986
Landing wt	+.9941	+.9961	+.9968
Payload	+.9939	+.9975	+.9981

* Not recorded are the correlation coefficients for equally weighted departures. These were all substantially lower than those recorded.

**Since the large jets predominate in international operations, the distinctions are materially reduced.

[redacted]

TABLE 3.32

SUMMARY OF REGRESSION COEFFICIENTS FOR COMBINATIONS OF VARIABLES

In Combination With Departures Weighted by	Coefficients Values for Selected Weighting Factors, dollars			
	GW[1]	LW[2]	P[3]	U[4]
GW		-1,125	-9,821	-23
LW	2,088		-22,069	-46
P	1,931	3,537		-43
U	1,343	1,847	18,756	
GW-LW			-18,274	- 7
GW-P		2,217		62
GW-U		-944	-18,907	
LW-P	782			50
LW-U	1,989		-30,259	
P-U	2,181	3,865		
GW-LW-P				59
GW-LW-U			-26,589	
GW-P-U		2,103		
LW-P-U	1.082			

[1] GW: MCGW

[2] LW: Landing weight

[3] P: Available tons per aircraft

[4] U: Unweighted

[redacted]

[redacted]

3.147 The regressions of aircraft servicing costs and aircraft departures grouped by aircraft types are of interest mainly for their corroborative value. The approach represents an attempt to determine empirically the best weights associated with the major types of aircraft in the hope that the empirical weights would help identify the physical characteristics of aircraft to which costs per aircraft departure are related.

3.148 Although encouraging, the results of the regressions were not sufficiently good or consistent to be used for further analyses without carrying out data aggregations that time did not permit and that, in any event, would reduce the usefulness of the data for developing departure weighting factors related to aircraft characteristics. As might be expected with 5 independent variables and 10 observations, the multiple correlation coefficients were high. This is shown in Table 3.33.

TABLE 3.33

REGRESSION RESULTS BY AIRCRAFT TYPE

Type of Operation	Multiple Correlation Coefficients		
	Total Aircraft Service Costs	Landing Fees	Total Less Landing Fees
Domestic air carriers			
1962	+.9805	+.9749	+.9807
1963	+.9785	+.9599	+.9789
International air carriers			
1963	+.9996	+.9956	+.9992

3.149 The coefficient values determined by the regressions are set forth in Table 3.34. Although these values generally progress in relation to the size characteristics of the aircraft types there are several notable aberrations. For instance, the 1963 domestic value for DC-3 aircraft is plainly out of line. Similarly, the relative values for 4-engine piston aircraft and turboprop and small jet aircraft are materially different in 1962 and 1963.

3.150 Aggregation of the domestic data for 1962 and elimination of DC-3 aircraft departures from the regression analyses (DC-3 operations by U.S. domestic trunklines were minor during the period) produces a significant confirmation of the superiority of the MCGW factor in estimating aircraft servicing expenses. In Table 3.35, the relative values of departure weights determined from the regression analyses for the four major types of aircraft are compared with relative weighting of departures implicit in the use of MCGWs and landing weights. For comparison purposes, the relative values are shown as indexes.

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TABLE 3.34

COEFFICIENTS FOR REGRESSION BY AIRCRAFT TYPE

Type of Operation	Coefficient Values, dollars/departure				
	DC-3	1-Engine Pistons	4-Engine Pistons	Turboprops, Small Jets	Large Jets
Total Aircraft Servicing Costs					
Domestic - 1962	16	28	99	187	410
Domestic - 1963	196	32	123	95	371
International - 1963			299		702
Landing Fees					
Domestic - 1962	+ 28	+ 1	- 3	26	60
Domestic - 1963	68	12	9	18	55
International - 1963			17		204
Total Less Landing Fees					
Domestic - 1962	18	32	78	162	370
Domestic - 1963	194	40	105	84	324
International - 1963			282		499

[redacted]

TABLE 3.35

COMPARISON OF WEIGHTING FACTORS

Type of Aircraft	Average Experienced Weights per Aircraft Departure		
	MCGW	Landing Weight	Coefficient Values From Regressions, dollars
2-engine piston	48,148	44,983	26.8
4-engine piston	111,124	90,997	132.0
2-engine jets and turboprops	97,856	80,475	114.3
4-engine jets	237,659	180,060	338.0
Indexes - (2-engine pistons = 100)			
4-engine pistons	230.8	202.3	492.5
2-engine jets, turboprops	203.2	178.9	426.5
4-engine jets	493.6	400.3	1,261.2
Indexes - (4-engine pistons = 100)			
2-engine jets, turboprops	88.0	88.4	86.6
4-engine jets	213.9	197.9	256.1
Index - (2-engine jets, turboprops = 100)			
4-engine jets	242.9	223.7	295.7

[redacted]

3.151 The comparisons are interesting in two respects. First, the indexes based on 4-engine piston and 2-engine jet and turboprop aircraft are similar, indicating that among the three types of aircraft the empirically determined weighting factors are in essential agreement with the weighting factors implicit in MCGW and landing weight. Secondly, among the three types of aircraft, the MCGW factors are in closer agreement with the empirically determined weighting factors than with the landing weight factors. Thus, the comparisons would appear to affirm the superiority of MCGW as the preferred weighting factor for cost estimation.

Cost Estimating Relationships

3.152 The cost estimating values applicable to aircraft departures weighted by MCGW as determined from the regression analyses are set forth in Table 3.36. The values applicable to estimation of total aircraft servicing costs, landing fees, and total aircraft servicing costs less landing fees are shown separately. The purpose in deriving the three separate sets of values, as has been stated, is to permit a separate estimation of the total of such expenses less landing fees if it is determined that landing fees should be separately estimated on the basis of more particularized information.

TABLE 3.36

COEFFICIENTS OF SERVICING COST EQUATIONS

Type of Operation	Equation Coefficient Value (Dollars per weighted* Aircraft Departure/1000)		
	Total Aircraft Servicing Costs	Landing Fees	Total Less Landing Fees
Domestic -1962	1.26	.14	1.12
Domestic -1963	1.13	.14	0.99
International-1963	2.38	.58	1.84

*Weighted by MCGW.

3.153 Data for foreign carriers are not available in the detail required for a parallel analysis. There is, however, no known reason for believing that the cost factors for foreign carriers differ materially from those for U.S. international air carriers. At least in the case of landing fees, which comprise 15 percent of the total, the rates are generally the same where operations are conducted at the same locations. It is probable that other cost factors, with the possible exception of aircraft control personnel salary rates are also substantially similar. In these circumstances, it may be reasonably assumed that CERs derived for U.S. international air carriers may also be applied to foreign carriers. The derived CER is

$$C_{15} = k_{15} \frac{W_g}{1,000}$$

where C_{15} = cost per flight segment

W_g = maximum certificated gross takeoff weight of aircraft, lb

and where k_{15} has the following values: 6/

	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k_{15} =	\$1.17	\$2.34	\$2.34

6/ Values derived from combined 1962 and 1963 data.

[redacted]

3.154 Aircraft servicing costs are not reported by aircraft type. As a result, there is no effective way of testing the reliability of the CER short of estimating aircraft servicing expenses for carriers operating different mixes of aircraft types and determining how well the CER accounts for differences in reported costs by comparing the estimated with the reported costs. Both the derived CER and the Boeing and Lockheed estimating formulas have been so analyzed. The latter formulas separately estimate costs associated with air traffic control as a function of unweighted departures, the remaining aircraft servicing costs being estimated as a function of aircraft departures weighted by landing weights. Since the use of unweighted departures and departures weighted by landing weights will result in lower estimates of aircraft servicing costs than the use of departures weighted by MCGW as the estimating factor, a comparison of the relative effectiveness of the two estimating approaches is pertinent. The results of the analyses, which are presented in Tables 3.37 and 3.38 indicate that the derived CER appears to be significantly more effective in explaining differences in the cost experience of carriers operating larger and smaller aircraft than do the Boeing-Lockheed formulas. United Airlines has been omitted from both tables because of an atypicality in its reporting. Northeast does not appear in the sample of carriers used by the manufacturers in establishing their costing formulas.

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TABLE 3.37

COMPARISON OF ACTUAL AIRCRAFT SERVICING COSTS IN DOLLARS FOR U.S. DOMESTIC TRUNK LINES WITH ESTIMATES DERIVED FROM BOEING-LOCKHEED FORMULAS

(1963)

Carrier	Actual Expense, K	(Overestimate) or Underestimate	
		Amount, K	Percent
Trans World	31,910	6,200	19.4
National	6,625	(6,297)	(95.0)
Northwest	10,910	(2,514)	(23.0)
American	50,903	16,556	32.5
Western	5,520	(5,580)	(101.0)
Eastern	38,344	(11,381)	(29.7)
Delta	20,104	(1,182)	(5.9)
Continental	5,561	(2,571)	(46.2)
Braniff	6,752	(5,181)	(76.7)
Top ranking five	105,868	8,365	7.9
Low ranking four	70,761	(20,315)	(28.7)

[redacted]

[redacted]

TABLE 3.38

COMPARISON OF ACTUAL AIRCRAFT SERVICING COSTS IN DOLLARS FOR U.S. DOMESTIC TRUNK LINES WITH ESTIMATES FROM DERIVED COST ESTIMATING RELATIONSHIP

(1963)

Carrier*	Actual Expense ,K	(Overestimate) or Underestimate	
		Amount , K	Percent
Trans World	30,053	1,442	4.8
National	5,839	(5,238)	(89.7)
Northwest	10,950	359	3.2
American	48,005	11,688	24.3
Western	5,090	(2,741)	(53.8)
Eastern	44,614	(7,315)	(16.4)
Delta	20,908	832	4.0
Continental	4,950	(1,964)	(39.7)
Braniff	6,399	(1,868)	(29.2)
Northeast	5,314	4,814	90.6
Top ranking five	99,937	5,510	5.5
Low ranking five	82,185	(5,501)	(6.7)

*In rank order of decreasing maximum landing weight per aircraft departures.

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TRAFFIC SERVICING COSTS

Composition

3.155 Traffic servicing costs include the aggregate of costs reported by U.S. domestic and international carriers in Accounts 5500, 6200, 6500, and 6600 and in the portion of Account 6100 remaining after the allocation of aircraft servicing administration. There is no precisely comparable grouping of costs for foreign carriers because the reports to ICAO do not separate the costs of ground station activities between those associated with traffic servicing and aircraft servicing.

Considerations in Deriving CER

3.156 Traffic servicing costs are responsive to a multiplicity of factors, no one of which can be uniquely related to a determinable subgrouping of such costs. The difficulties here are partially in the reporting of the information; significant differences exist among the carriers in the classification of costs by objective and functional accounts. The problem is also, in part, that some subgroupings of costs are generally affected by two or more influencing factors. Further, it is a characteristic of most of the subaccounts making up the total of traffic servicing costs that the levels of costs are influenced by discretionary or budgetary considerations.

3.157 Thus, rather than attempting to subdivide traffic servicing expenses and relating each subdivision of the costs individually to presumed influencing factors, the approach adopted is to relate the total of traffic servicing costs by regression analysis to a number of likely variables in an effort to determine which one or more of the influencing variables best relates to reported total costs.

3.158 The number and complexity of factors influencing traffic servicing costs is shown by the following listing of some of the factors that can be presumed to have some significant effect on experienced costs.

a. Volume of traffic physically handled—different amounts of work load being associated with originating passengers, connecting passengers, freight, mail, and express traffic originations and transshipments, and whether the traffic is handled through a reservation system.

b. Volume of sales—promotional efforts and ground complements being geared to anticipated sales and travel agent commission being directly related to revenues volume.

c. Distance of movement—communications costs, ticket costs to some extent, and inflight servicing costs are related to the distance over which traffic is transported, there being differences in unit costs per mile associated with the type of traffic, class of service, time of day, and other considerations.

3.159 In general, the traffic servicing costs can be expected to be structured in the same way as the pricing of airline services because the pricing structure reflects the behavior of traffic servicing costs and because the pricing structure exerts an influence on traffic servicing costs. With this in mind, traffic servicing costs analyses have been made of the relationship between traffic servicing costs, on the one hand, and passenger revenues, on

[redacted]

the other. Because the SST will substantially reduce the inflight time per trip and hence presumably reduce inflight costs, the variable passenger hours has also been introduced in the analysis.

3.160 The results of analyses of U.S. domestic carrier data for 1962 and 1963 and U.S. international carrier data for 1963 disclose the following:

a. Uniformly high correlation coefficients were obtained for each of the separate variables; however, the poorest results were obtained for passenger hours.

Variables	Correlation Coefficients		
	Domestic		International
	1962	1963	1963
Passenger revenues	+.9923	+.9825	+.9975
Operating revenues	+.9909	+.9844	+.9956
Passenger hours	+.9711	+.9330	+.9851

b. When the variables were introduced two at a time the correlation coefficients were not materially increased; the best results were obtained from the combination of passenger revenues and operating revenues.

Variable Combinations	Correlation Coefficients		
	Domestic		International
	1962	1963	1963
Passenger revenues and operating revenues	+.9935	+.9862	+.9978
Passenger revenues and passenger hours	+.9934	+.9905	+.9976
Operating revenues and passenger hours	+.9926	+.9898	+.9957

c. The cost coefficients behaved erratically for domestic carriers when two or more variables were considered simultaneously; in several cases negative cost coefficients emerged.

d. Much more consistent results were obtained from the analyses of international data; however, the cost coefficient of passenger hours behaved erratically.

3.161 On balance, it appears that a single variable, passenger revenues, is the best explanatory variable for the estimation of traffic servicing costs, although there is not much to choose between this variable and total operating revenues. There are some conceptual limitations to the use of passenger revenues, rather than operating revenues, as the explanatory variable, but its empirical superiority and traditional focus of the industry on passenger traffic—a focus that will be even greater in SST operations owing to the limited cargo capacity of the aircraft—appear to provide a preferable basis for CERs.

3.162 There is some evidence that the traffic servicing costs of foreign carriers run higher in relation to passenger revenues than those of U.S. international carriers. Agent commissions, for example, are a relatively larger item of expense for foreign carriers, but the lack of definitive information precludes the determination of the amount of the differential.

Cost Estimating Relationships

3.163 The derived CER is

$$C_{16} = k_{16} Y$$

where C_{16} = traffic servicing costs per flight incurred by operating aircraft over a given city segment

Y = passenger revenues per flight segment

and where the values of k_{16} are

	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k_{16} =	$ 0.262	$ 0.346	$ 0.346

3.164 Because the use of passenger revenues as the sole estimating factor raises conceptual problems and because the gross aggregation of traffic servicing costs may be questionable, analyses have been made to compare the performance of the derived CER with that of the formulas developed by Boeing and Lockheed. The latter formulas represent perhaps the extreme of what may be attempted in the way of subaggregations and, in addition, employ a variety of cost-estimating factors in contrast to the single factor used in the derived CER. The analyses are designed mainly to compare the efficiencies of the two methodologies in estimating the costs of long- and short-haul carriers; the purpose of this is to determine how well the two methodologies explain differences in total and unit costs associated with differences in length of haul. The matter is of interest because it has a direct bearing on the stage lengths over which SST aircraft operations may be conducted economically.

3.165 The results of the analyses are shown in Tables 3.39 and 3.40. Table 3.39 compares the estimates of costs produced by the derived CER with actual costs reported by trunk-line carriers in 1962 and 1963. Table 3.40 compares the cost estimates obtained by use of the Boeing-Lockheed formulas with trunk-line carrier reported costs in 1963. For the reasons previously stated, data for United Airlines are not included in either of the tables and Northeast Airlines is not included in the cost comparisons made in connection with the Boeing-Lockheed formulas.

3.166 It appears to be a fair conclusion from the analyses that the less aggregated and multivariable Boeing-Lockheed formulas do not explain the comparative costs of short- and long-haul carriers nearly as well as the passenger revenue factor used in the derived CER. This is shown by the following comparative data.

Nature of Carrier	Percentage of (Overestimate) or Underestimate of Traffic Expenses	
	Boeing-Lockheed	ORI
Long-haul	8.9	2.5
Short-haul	(19.4)	(4.1)

3.167 It might be noted in this connection that the disparity in average trip length for short- and long-haul carriers is even greater among the carriers included in the derived CER than among the cost comparisons for the derived CER than among the carriers included in the analysis of the Boeing-Lockheed

[redacted]

TABLE 3.39. COMPARISON OF ACTUAL TRAFFIC EXPENSE IN DOLLARS OF U.S. DOMESTIC TRUNK LINES WITH ESTIMATES FROM DERIVED CERs

(1962 and 1963)

Carrier (in Rank Order of Decreasing Passenger Trip Length)	Average Passenger Trip Length, Miles*	1962			1963			1962 and 1963		
		Actual Expense, K	Underestimate or (Overestimate)		Actual Expense, K	Underestimate or (Overestimate)		Actual Expense, K	Underestimate or (Overestimate)	
			Amount, K	Per-cent		Amount, K	Per-cent		Amount, K	Per-cent
Trans World	852.6	77,499	6,279	8.1	92,209	10,535	11.4	169,708	16,814	9.9
American	782.6	107,014	979	0.9	113,265	1,367	1.2	220,279	2,346	1.1
National	739.9	26,809	2,900	10.8	30,116	3,704	12.3	56,925	6,604	11.6
Continental	668.8	15,418	(380)**	(2.5)	17,746	(922)	(5.2)	33,164	(1,302)	(3.9)
Northwest	609.1	18,107	(5,552)	(30.7)	20,453	(5,774)	(28.2)	38,560	(11,326)	(29.4)
Delta	580.0	42,097	(4,737)	(11.2)	45,667	(3,916)	(8.6)	87,764	(8,653)	(9.9)
Western	504.9	20,088	817	4.1	22,923	576	2.5	43,011	1,393	3.2
Northeast	452.3	13,478	997	7.4	12,819	2,498	19.5	26,297	3,495	13.3
Eastern	446.7	54,454	(4,277)	(7.9)	63,071	(12,933)	(20.5)	117,525	(17,210)	(14.6)
Braniff	439.7	23,308	3,489	15.0	24,897	4,365	17.5	48,205	7,854	16.3
Top ranking five	767.5	244,847	4,226	1.7	273,789	8,910	3.3	518,636	13,136	2.5
Low ranking five	484.1	153,425	(3,711)	(2.4)	169,377	(9,410)	(5.6)	322,802	(13,121)	(4.1)

* Based on enplaned passenger totals.

**( )Denotes negative amount.

Note: Traffic expenses include the totals of amounts reported by U.S. domestic trunk lines in Accounts 5500, 6200, 6500, and 6600, plus an allocated portion of Account 6300. Because of a peculiarity in its classification of expenses, data for United are excluded. Estimates are derived from the relationship:

$$\text{Traffic Expenses (000)} = -198.77 + .26373 \times \text{passenger revenue (000)}$$

Source: Form 41 reports to CAB.

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TABLE 3.40. COMPARISON OF ACTUAL TRAFFIC EXPENSES IN DOLLARS WITH ESTIMATES PRODUCED BY BOEING-LOCKHEED FORMULAS FOR U.S. DOMESTIC TRUNK-LINE CARRIERS
(1963)

Carrier (in Rank Order of Decreasing Passenger Trip Length)	Average Psgr. Trip Length, Miles	Item No. 4			Item No. 5			Item No. 6			Item No. 7		
		Actual Expense, K	Formula (Overestimate) or Underestimate Amount, K	Formula (Overestimate) or Underestimate Percent,	Actual Expense, K	Formula (Overestimate) or Underestimate Amount, K	Formula (Overestimate) or Underestimate Percent	Actual Expense, K	Formula (Overestimate) or Underestimate Amount, K	Formula (Overestimate) or Underestimate Percent	Actual Expense, K	Formula (Overestimate) or Underestimate Amount, K	Formula (Overestimate) or Underestimate Percent
Trans World	852.6	$ 8,945	$ 879	9.8	$ 9,850	$ 380	3.9	$ 36,592	$11,713	32.0	$12,033	$2,346	19.5
American	782.6	10,064	386	3.8	15,168	1,631	10.8	43,074	7,182	16.7	23,033	5,971	25.9
National	739.9	2,142	(355)	(16.6)	3,101	59	1.9	13,302	4,019	30.2	2,487	(846)	(34.0)
Continental	668.8	1,935	(382)	(19.7)	2,633	504	19.1	5,031	(2,170)	(43.1)	3,127	503	16.1
United	631.6	14,421	(123)	(.9)	19,705	1,526	7.7	58,305	4,790	8.2	21,003	(494)	(2.4)
Northwest	609.1	2,607	(239)	(9.2)	3,724	286	7.7	9,042	(1,591)	(17.6)	95	(4,284)	(4,509.5)
Delta	580.0	4,380	(287)	(6.6)	5,805	(928)	(16.0)	17,724	(3,232)	(18.2)	6,927	(654)	(9.4)
Western	504.9	1,857	(236)	(12.7)	2,152	(630)	(29.3)	6,922	(4,606)	(66.5)	5,550	2,309	41.6
Eastern	446.7	9,144	536	5.9	8,420	(2,976)	(35.3)	25,078	(17,079)	(68.1)	9,628	(3,790)	(39.4)
Braniff	439.7	1,957	(188)	(9.6)	2,721	(511)	(18.8)	11,992	841	7.0	3,178	(1,605)	(50.5)
Top Ranking 5	725.1	37,507	405	1.1	50,457	4,100	8.1	156,304	25,534	16.3	61 33	7,480	12.1
Low Ranking 5	499.8	19,945	(414)	(2.1)	22,822	(4,759)	(20.9)	70,758	(25,667)	(36.3)	25,378	(8,024)	(31.6)

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TABLE 3.40 (Cont)

Carrier (in Rank Order of Decreasing Passenger Trip Length)	Average Psgr. Trip Length, Miles*	Item No. 8			Item No. 9			Item Nos. 4 through 9		
		Actual Expense, K	Formula (Overestimate) or Underestimate		Actual Expense, K	Formula (Overestimate) or Underestimate		Expense, K	Formula (Overestimate) or Underestimate	
			Amount, K	Percent		Amount, K	Percent		Amount, K	Percent
Trans World	852.6	$26,215	$3,810	14.5	$ 569	$ 43	7.6	$ 94,204	$19,171	20.4
American	782.6	28,198	(1,547)	(5.5)	862	(229)	(26.6)	120,399	13,394	11.1
National	739.9	8,824	1,576	17.8	259	141	54.4	30,115	4,594	15.3
Continental	668.8	5,610	526	9.4	105	1	1.0	18,441	(1,018)	(5.9)
United	631.6	30,295	(5,465)	(18.0)	621	(242)	(39.0)	144,350	(8)	0
Northwest	609.1	6,074	(764)	(12.6)	143	5	3.5	21,685	(6,587)	(30.4)
Delta	580.0	12,774	0	0	274	55	20.0	47,884	(5,046)	(10.5)
Western	504.9	6,694	555	8.3	61	16	26.2	23,236	(2,592)	(11.2)
Eastern	446.7	20,910	1,026	4.9	433	159	36.7	73,613	(22,124)	(30.1)
Braniff	439.7	5,230	0	0	119	28	23.5	25,197	(1,435)	(5.7)
Top Ranking 5	725.1	99,142	(1,100)	(1.1)	2,416	(286)	(11.8)	407,509	36,133	8.9
Low Ranking 5	499.8	51,682	817	1.6	1,030	263	25.5	191,615	(37,784)	(19.7)

Note: The items enumerated and the factors to which they are related are as follow:

Item No.	Description	Estimating Factor
4	Cabin Crew Activity	Seat Hours
5	Passenger Food and Beverages	Passenger Hours
6	Traffic Servicing, Passenger Handling, and Advertising	Passenger Enplanements
7	Cargo Handling and Advertising	Cargo Enplanements
8	Passenger Promotion	Passenger Miles
9	Cargo Promotion	Cargo Ton Miles

Estimates are derived by applying the average constant values for the ten U.S. domestic trunklines (Northeast is excluded) to the parameter values for each airline, as shown in the Boeing-Lockheed Indirect Cost Study.

* Based on enplaned passenger totals.

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formulas, as is indicated in the following tabulation.

Type of Operation	Average Psgr. Trip (Miles)	
	Boeing-Lockheed	ORI
Short-haul carrier	499.8	484.1
Long-haul carrier	725.1	767.5
Amount difference	225.3	283.4
Percent difference	45.1	58.5

3.168 The reason that the Boeing-Lockheed formulas do not explain the difference in experienced costs between short- and long-haul carriers as well as the derived CER is apparent from an examination of the detail. The differences in estimated and reported costs are most pronounced in those areas where a distance variable is abbreviated or eliminated by the use of a variable that is not directly proportional to distance, such as passenger hours that taper in relation to distance (speed increases with distance) and passenger enplanements that have no distance representation. This is shown in the following tabulation.

Type of Operation	Percentage of (Overestimate) or Underestimate of Expenses		
	Item 5 (Passenger Hours)	Item 6 (Passenger Enplanements)	Item 7 (Cargo Enplanements)
Short-haul carriers	8.1	16.3	12.1
Long-haul carriers	(20.9)	(36.3)	(29.5)

3.169 The cause of the problem is probably that even accounts seemingly uninfluenced by distance considerations are not entirely uninfluenced. For instance, baggage handling costs are generally greater per passenger for the passenger traveling longer distances than for the passenger traveling shorter distances because the former generally has more baggage. Similarly, there is more likelihood that a longer distance traveler will require a complex routing at higher ticketing costs than a shorter haul traveler. Significantly, the only account grouping where the experienced cost differences of short- and long-haul carriers are reasonably well explained is Item No. 8 and the variable is passenger miles.

3.170 It seems clear that the passenger revenue factor gives a better explanation of intercarrier differences than the Boeing-Lockheed methodology or any close parallel to this methodology. The finer aggregation and the use of a multiplicity of factors do not reduce the variance; the average percentage deviation for aggregate traffic expenses is 12.7 percent under the Boeing-Lockheed methodology and 9.2 percent for the derived CER. Further, the derived CER seems to provide a far superior distribution of estimates for varying stage lengths. The Boeing-Lockheed formulas substantially overestimate for the shorter stage lengths and substantially underestimate in the longer stage lengths where SST aircraft would be used.

GROUND EQUIPMENT MAINTENANCE AND BURDEN

Composition

3.171 This group of expenses includes those costs of labor, materials, and burden consumed in the maintenance of ground property and equipment. Similar data for foreign air carriers are not available.

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Considerations in Deriving CER

3.172 Intuitively it would appear that ground maintenance costs would be related most directly to a measure of the physical quantity and make-up of ground property and equipment. However, a detailed inventory of ground property and equipment is not available. If such an inventory were available, there would be severe conceptual problems to be solved in making appropriate aggregations of the diversified types of items that comprise the overall category. A reasonable surrogate measure appears to be the dollar value of the property and equipment as reflected by the original cost totals carried on the balance sheet. This measure leaves much to be desired since the dollar values recorded on the books of the airlines represent the original acquisition costs of items acquired at various points in time. These values should be adjusted to eliminate the effects of price level changes, but this is not possible. As a result, it is possible that two carriers having exactly the same consist of ground property and equipment may report different values for inventory simply because the property and equipment were acquired at different times. Further, it is likely that older property and equipment are carried on the books at lower values than comparable items acquired at a later date. Since maintenance would be expected to increase with age, it would be expected that increasing age of the inventory would have an accentuating effect on the overall relationship between the dollar value of the inventory and the costs of maintenance.

3.173 As an alternative to the dollar value of inventory, before depreciation or at original cost, the volume of direct labor used in flight equipment maintenance has been used in cost estimating relationships. The assumption here is that ground property and equipment maintenance is a corollary function of maintaining flight equipment.

3.174 There appeared to be sufficient merit in both dollar value of inventory and direct labor of flight equipment as possible determinants or influencing factors in the volume of ground property and equipment maintenance performed to warrant consideration of both, alternatively and in combination. This was done, using the report system data for U.S. carriers for the years 1962 and 1963. System data, rather than divisional breakdowns (domestic and international), were used for this purpose because the dollar value of ground property and equipment is reported on a system basis only. The resulting correlation coefficients are shown in Table 3.41.

TABLE 3.41

CORRELATION COEFFICIENTS FROM REGRESSION ANALYSIS

Correlating Parameter	Correlation Coefficient 1962	1963
Dollar value	+.9646	+.9578
Direct labor	+.9518	+.9335
Dollar value and direct labor	+.9673	+.9600

3.175 It is apparent from the above table that dollar value, notwithstanding its infirmities, is superior to flight equipment direct labor as a basis for estimating ground property and equipment maintenance. As would be expected the combination of the two variables increases the correlation coefficients. However, it is believed that the degree of improvement thereby achieved is in itself material enough to warrant the additional complication of the cost estimating relationships.

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3.176 Data for foreign air carriers are not available; consequently there is no reasonable alternative to the assumption that the cost coefficients for foreign carriers will correspond with those of U.S. international air carriers.

Ground Equipment and Maintenance CER

3.177 The recommended cost estimating equation is

$$C_{17} = \frac{k_{17}\, k'\, I_o\, t_b}{U}$$

where C_{17} = ground property and equipment maintenance and burden costs per flight segment for a given type of aircraft

I_o and U are as previously defined

and where the values of the k terms are

	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k_{17} =	\$0.0439	\$0.0439	\$0.0439
k' =	.125	.110	.110

k' = investment in ground equipment per dollar investment in flight equipment, including spares.

[redacted]

GENERAL AND ADMINISTRATIVE COSTS

Composition

3.178 This grouping includes expenses reported by U.S. airlines to CAB in Account 6800 and expenses reported by foreign air carriers to ICAO in Account 11. The two accounts appear to be identical in content. The expenses included are those of a general corporate nature, e.g., compensation of president and staff, and those incurred in activities relating to more than one operating function, e.g., financial accounting, purchasing, legal services.

Considerations in Deriving General and Administrative Costs CER

3.179 General and administrative costs have been related to the sum of all other cash expenses in accordance with the generally accepted view among cost estimators that general corporate expenses of the nature included are related to measures of the total size and complexity of the enterprise as reflected in dollar expenditures. On a few occasions, measures of productivity have been used, e.g., available ton-miles flown. It is generally agreed, however, that the productivity measure is inferior to the dollar expenditure measure since general and administrative costs are budgeted, in part, in relation to other cash expenditures, and since the productivity measure is not sufficiently reflective of the effort involved in conducting operations. For example, a carrier operating a route system comprised of 50 stations normally will have substantially higher general and administrative costs than a carrier serving only 10 stations although the total available ton-miles produced by the two carriers is the same. The added complexity of the system of 50 stations, the greater volume of flight and ground activities associated with the available ton-miles performed, and the more difficult supervisory problems all contribute to higher cost levels.

3.180 For U.S. domestic, U.S. international, and foreign air carriers, the relationship between general administrative costs and other cash expenses have been determined by regressions for selected years from 1957 through 1963. The latest data for foreign air carriers are for the year 1962. The data used are shown in Tables 3.42 through 3.52. The regressions disclose that:

a. The ratio between general administrative and other cash expenses, i.e., the slope of the regression line, is approximately .05 for both U.S. domestic and international carriers.

b. There is no appreciable time trend in value of the regression slope for either U.S. domestic or international carriers. There is a slight upward trend of 1 percent per year for international carriers.

c. The slope values for foreign air carriers are higher than for U.S. domestic and international carriers.

d. The slope values for foreign carriers have been trending upward at the rate of 3 percent per year. A projection to 1963 places the value at 0.055, 10 percent higher than the 1963 value for U.S. air carriers.

3.181 Regression coefficients for all groups are high and significant ranging up from +.95. Relatively small intercept values for all groups indicate that general

TABLE 3.42

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

U.S. Domestic Air Carriers

1957

Airline	General and Administrative Expenses (000)[1]	Other Cash Expenses (000)[2]
AA	$13,520	$251,547[2]
EA	6,373	209,948
TW	7,670	183,378
UA	11,794	236,041
BN	1,840	45,440
CA	2,788	84,987
CO	1,286	21,168
DL	2,164	67,429
NA	1,687	42,286
NE	1,090	18,873
NW	3,124	52,305
WA	1,828	33,987

1/ Account 26.

2/ Total operating expenses less depreciation, flight equipment (Account 30 less Account 19).

Source: Handbook of Airline Statistics, CAB 1963.

[redacted]

TABLE 3.43

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

U.S. Domestic Air Carriers

1959

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
AA	$15,162	$320,348
EA	7,193	234,999
TW	8,485	227,744
UA	13,717	269,919
BN	2,435	55,690
CA	3,208	98,887
CO	2,143	38,325
DL	2,951	90,869
NA	1,927	61,376
NE	1,533	33,851
NW	3,811	75,187
WA	2,427	42,745

1/ Account 26.

2/ Total operating expenses less depreciation, flight equipment (Account 30 less Account 19).

Source: Handbook of Airline Statistics, CAB 1963 Edition.

[redacted]

TABLE 3.44

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

U.S. Domestic Air Carriers

1963

Airline	Administrative Expenses (000)[1/]	Other Cash Expenses (000)[2/]
AA	$19,983	$398,039
EA	11,647	292,442
TW	12,907	294,958
UA	24,009	507,617
BN	3,216	75,935
CA	-	-
CO	3,636	61,186
DL	4,803	159,898
NA	3,241	86,802
NE	1,778	49,544
NW	4,033	87,801
WA	3,844	64,934

[1/] Account 24.

[2/] Total operating expenses less flight equipment depreciation (Account 29 less Account 27)

Source: Air Carrier Financial Statistics, CAB, 1963.

[redacted]

TABLE 3.45

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

U.S. International Air Carriers (1957)

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
ALASKA	$ 135	$ 1,864
AA	364	5,233
BN	579	7,354
DL	222	5,005
EA	425	14,945
NA	130	2,791
NW	1,909	21,671
PN	687	8,852
PAG	1,554	17,837
PA-SYS	13,891	266,569
PA-ALA	423	6,493
PA-ATL	5,076	107,972
PA-LAD	4,324	86,423
PA-PAC	3,986	65,599
TWA	4,051	61,346
UA	550	10,591
WA	40	828

1/ Account 26.

2/ Total operating expenses less depreciation, flight equipment (Account 30 less Account 19).

Source: Handbook of Airline Statistics, CAB 1963 Edition.

[redacted]

[redacted]

TABLE 3.46

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

U.S. International Air Carriers (1959)

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
ALASKA	$ 582	$ 7,616
AA	376	6,290
BN	648	7,844
DL	228	4,867
EA	574	20,684
NA	105	3,590
NW	2,620	30,897
PN	781	10,045
PAG	1,630	18,140
PA-SYS	17,036	306,327
PA-ALA	329	5,163
PA-ATL	6,355	128,237
PA-LAD	5,559	94,345
PA-PAC	4,749	78,538
TWA	3,113	74,431
UA	642	11,715
WA	237	3,606

1/ Account 26.

2/ Total operating expenses less depreciation, flight equipment (Account 30 less Account 19).

Source: Handbook of Airline Statistics, CAB 1963 Edition.

[redacted]

[redacted]

TABLE 3.47

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

U.S. International Air Carriers (1963)

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
ALASKA	$ 813	$ 8,727
AA	378	5,520
BN	872	11,864
DL	105	3,361
EA	1,631	36,642
NA	-	-
NW	2,483	39,421
PN	873	13,071
PAG	1,716	18,927
PA-SYS	22,210	436,956
PA-ALA	305	6,280
PA-ATL	9,121	200,831
PA-LAD	6,631	117,080
PA-PAC	6,153	112,771
TW	5,523	118,799
UA	1,599	24,272
WA	319	4,857

1/ Account 24.

2/ Total operating expenses less flight equipment depreciation (Account 29 less Account 27)

Source: Air Carrier Financial Statistics, CAB, 1963.

[redacted]

TABLE 3.48

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

Foreign Air Carriers

1957

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
AIR FRANCE	$14,083	$162,859
BOAC	6,678	138,407
KLM	4,381	104,927
TCA	3,624	100,043
SAS	4,796	87,800
BEA	6,034	68,020
SWISSAIR	2,450	40,467
SABENA	4,347	40,070
QEA	2,271	38,106
DLH	3,694	32,571
CPAL	1,455	28,173
AII	741	18,697
JAL	1,096	18,252
ALITALIA/LAI	2,051	17,523
IBERIA	2,618	16,520
GIA	1,136	12,537
CUBANA	818	10,732
MEA	1,354	10,138
PAL	1,652	9,909
AER LINGUS	792	7,946
FINNAIR	455	6,358
CAT	759	5,536
TEAL	594	5,493
TAP	1,273	5,284
EAAC	291	4,959
AVIACO	201	2,682
AIR CEYLON	75	2,255
PLUNA	558	1,995
LIA	67	1,188

1/ Account 10; 2/ Total operating expenses less flight equipment depreciation.

Source: Financial Data, Digest of Statistics No. 73, ICAO, 1957.

[redacted]

TABLE 3.49

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

Foreign Air Carriers (1959)

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
AIR FRANCE	$ 8,317	$189,202
BOAC	6,453	164,914
TCA	5,132	127,353
KLM	3,311	117,847
SAS	5,379	100,881
BEA	6,535	83,803
BRITISH HONDURAS	25,202	76,834
SABENA	2,587	72,092
DLH	5,851	54,386
SWISSAIR	3,799	51,277
QEA	1,851	50,838
ALITALIA	4,149	49,343
PAB	1,837	39,209
CPAL	1,960	38,003
VARIG	1,724	30,772
JAL	2,251	29,533
LAV	1,915	23,909
AII	992	22,762
IAC	1,797	22,687
SAA	1,337	20,973
AEROVIAS BRASIL	950	20,533
CRUZEIRO	1,003	20,019
AEROLINEAS ARGENTINAS	1,491	19,747
EL AL*	1,857	19,335
TAI	1,241	18,670
REAL	1,158	16,362
IBERIA	869	16,245
PIA**	839	13,403
AVENSA	1,835	12,745
AIR ALGERIE	386	12,709

[redacted]

[redacted]

TABLE 3.50

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

Foreign Air Carriers (1959)

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
PAL	$2,085	$12,699
AER LINGUS	1,075	9,520
GIA	1,074	9,368
BWIA*	797	9,218
THY	1,572	9,153
EAAC	331	8,583
NACIONAL	676	8,456
FINNAIR	633	8,303
CAA	796	7,154
TEAL*	618	6,409
AERLINTE	287	6,256
EAL	784	6,092
LOT	1,646	6,001
CAT	818	5,311
AIR LIBAN	1,614	5,282
TRANSCONTINENTAL	1,751	4,463
PLUNA	563	3,139
AIR CEYLON*	83	2,959
ADEN	326	2,652
THAI AIRWAYS	827	2,365
AVIACO	168	2,126
KAR AIR	153	1,336
BGA	58	752

* Year ending March 31, 1960.

** Year ending June 30, 1960.

1/ Account 10.

2/ Total operating expenses less total depreciation and amortization

Source: Financial Data, Digest of Statistics No. 83, ICAO, 1959.

[redacted]

[redacted]

TABLE 3.51

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

Foreign Air Carriers

1962

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
AIR FRANCE	$17,794	$297,150
BOAC*	12,214	237,261
KLM	10,649	148,981
TCA	7,072	141,790
SAS	6,559	125,990
DLH	6,421	118,453
BEA	10,305	113,866
ALITALIA	4,253	108,644
SWISSAIR	4,584	78,611
SABENA	2,105	71,613
JAL	5,377	69,701
QEA	3,821	65,248
VARIG	2,398	44,673
CPAL	1,978	43,772
AII	1,795	38,086
IBERIA	1,873	36,258
TAI	1,755	33,779
IAC	2,418	31,947
PAB	1,468	30,426
EL AL*	2,946	28,626
AIR CONGO	1,428	28,587
AEROLINEAS ARGENTINAS**	2,148	25,753
AIR AFRIQUE	757	21,863
AVIANCA	2,314	21,786
GIA	832	18,014
SAA	1,149	17,971
MEA	2,828	17,547
CRUZERIO	839	16,213
AER LINGUS	1,404	16,011
LOT	1,322	14,585
EAAC	521	13,705
FINNAIR	838	12,840
PHILIPPINE AIRLINES	1,296	12,535
AERLINTE	953	12,218
VIASA	1,028	11,757

[redacted]

TABLE 3.52

GENERAL AND ADMINISTRATIVE AND OTHER CASH EXPENSES

Foreign Air Carriers

1962

Airline	General and Administrative Expenses (000)1/	Other Cash Expenses (000)2/
LAN	231	$9,033
ROYAL AIR MAROC	275	8,964
CUBANA	681	8,716
CAT	532	8,426
LAV	1,050	8,321
TEAL	571	8,140
MALAYAN	441	8,083
AVENSA	1,221	8,017
CAA	988	7,970
ETHIOPIAN	1,200	7,968
THY	1,071	7,343
GHANA	676	6,321
AYC	290	6,109
ADEN	579	4,746
TRANSAIR	279	4,112
KÁR AIR	326	3,636
TUNIS AIR	739	3,398
FLUGFELAG	118	2,946
AUSTRAL	232	2,555
DETA	313	2,027
JORDANIAN	55	1,969
CONDOR	105	1,356
AEROTRANSPORTES DEL LITORAL	96	1,264
THAI***	141	1,195
AER TAXI	56	722
LUXAIR	40	225
POLYNESIAN	7	115

* Year ending March 31, 1963.
** Year ending October 31, 1962.
*** Year ending September 30, 1962

1/ Account 11.

2/ Total operating expenses less total depreciation and amortization.

Source: Financial Data, Digest of Statistics No. 101, ICAO, 1962.

and administrative costs are almost wholly variable. The intercept values are positive, however, indicating that the slope values are less than the average values that would be derived by dividing the aggregate of general and administrative costs for each carrier group by the aggregate cash operating expenses of the group. That is, the marginal cost is less than the average cost.

General and Administrative Costs CER

3.182 The estimating factors, in units of 1963 dollars are shown in the following tabulation.

Type of Operation	Per Dollar of Other Cost Expenses, dollars	Percent of U.S. Domestic
U.S. domestic	0.050	100
U.S. international	0.050	100
Foreign carriers	0.055	110

Expressed in equation form, the relationship is:

$$C_{18} = k_{18} \left(\sum_{1}^{i=11} C_i + \sum_{15}^{i=17} C_i \right)$$

where

C_{18} = general and administrative costs per flight segment,

and where the values of k_{18} are:

	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k_{18} =	\$ 0.050	\$ 0.050	\$ 0.055

GROUND PROPERTY AND EQUIPMENT DEPRECIATION

Composition

3.183 This cost includes depreciation charges for all types of ground equipment and property that is depreciable.

Considerations in Deriving Ground Property and Equipment Depreciation CER

3.184 The usual basis for depreciating ground property and equipment in connection with reports to the CAB and U.S. airlines is the straight-line method wherein the original cost is written off in equal annual amounts.

3.185 Ground property and equipment investment has historically followed flight equipment investment, although in the course of an aircraft reequipment cycle the attendant ground reequipment tends to occur early in the cycle and to phase out sooner. Data for flight and ground equipment investment, and the year-to-year changes in investments for U.S. domestic and international carriers during the years 1951 through 1963 are shown in Appendix D, together with charts of selected relationships between the investment totals. The historical data for U.S. domestic carriers indicate, that, in the early phase of the aircraft reequipment cycle, ground equipment investment is added at the rate of $0.15 per dollar of flight equipment investment added; in the later phases of the cycle, the proportion of ground equipment to flight equipment added tapers to about $.085 per dollar of flight equipment addition. Over the span of an equipment cycle the proportion is about 12.5 percent. The latter proportion is used in estimating the ground equipment investment for U.S. domestic carriers operating subsonic aircraft. The proportion is lower for international carriers, amounting to about 10 percent. A proportion of about 11 percent per dollar of flight equipment investment is estimated for ground equipment investment related to domestic supersonic operations.

Ground Property and Equipment Depreciation CER

3.186 The derived CER is:

$$C_{19} = \frac{k_{19}\, I_o\, (1 - R_g)\, t_b}{L_g\, U}$$

where

R_g = The fractional part of the original investment in ground property and equipment remaining after the termination of service life,

L_g = Average service life, in years, of ground property and equipment,

I_o and U are as previously defined,

and where the suggested values of k_{19} for subsonic and supersonic aircraft are:

	U.S. Domestic Operations	U.S. International Operations	Foreign Carrier Operations
k' - subsonic	$ 0.125	$ 0.110	$ 0.110

and where suggested values of R_g and L_g are 0.00 and 5.0, respectively.

[redacted]

AMORTIZATION OF PREOPERATING COSTS

Composition

3.187 It is the practice among airlines to defer for subsequent writeoff against income the expenditures made in connection with the training of flight crews for new aircraft and other costs incident to the integration of new aircraft into the operating fleet. The deferred costs are capitalized and amortized through periodic charges to operating expenses. It is these periodic charges that are referred to as the amortization of preoperating costs.

Considerations in Deriving Amortization of Preoperating Costs CER

3.188 Annual charges for the amortization of preoperating costs, in the 5 years since the introduction of subsonic jet aircraft, have averaged about $.008 per dollar of the original cost of investment in all flight equipment for U.S. domestic and international carriers. In relation to the original cost of the investment in subsonic flight equipment, it is estimated that amortization of preoperating costs incurred in connection with jet aircraft amounted to $.01 per dollar of investment.

3.189 The justification in capitalizing and thus deferring the writeoff of preoperating costs lies in the concept that such costs should be related to the periods over which the benefits deriving from activities causing the costs are realized. Conceptually, the length of the period during which benefits are realized is the length of the period during which the aircraft are used in productive service—in short, the service life. However, most airlines do not amortize preoperating costs over the service life of the aircraft. Instead, a shorter period of amortization is used, generally about 5 years in the case of preoperating costs for subsonic jets. As a result, the experienced ratio of the annual amortization of preoperating costs to the original cost of flight equipment is from 2 to 2.5 times the ratio that would have resulted from using a longer amortization period, equal to the service life used in the depreciation of flight equipment investment.

3.190 In deriving an appropriate CER that will produce comparable estimates of subsonic and supersonic operating costs, it is apparent that the experienced rate of amortization for subsonic aircraft cannot be used without impairing comparability. If a relatively short period in relation to aircraft service life is used in the CER, or a rate of amortization based on the shorter period, then in the early years of supersonic aircraft operations, the costs of supersonic aircraft will reflect relatively high amortization rates whereas the amortization for subsonic aircraft will be lower since, by the time of the introduction of supersonic aircraft, preoperating costs will have been largely amortized under current accounting practices. To avoid this problem and to conform the rates of amortization to the underlying conceptual basis for amortization, the derived CER postulates a period of amortization equal to the aircraft service life. On this basis, the rate of amortization applicable to subsonic aircraft is reduced from $.01 to $.004 per dollar of original cost of flight equipment.

3.191 The rate of amortization of preoperating costs incurred in connection with supersonic aircraft is estimated to be the same as the rate for subsonic aircraft soley on the basis of judgment considerations. Among these considerations are greater complications in flight operations conducted with supersonic operations and higher insurance costs during the training period which, it is believed, will offset the longer period of amortization for supersonic aircraft.

Amortization of Preoperating Costs CER

3.192 The derived CER is:

$$C_{20} = \frac{k_{20}\, I_o\, t_b}{U}$$

where

C_{20} = Cost of amortizing preoperating costs per flight segment

and

I_o and U are as previously defined.

and where the values of k_{20} for U.S. domestic and international and foreign carrier operations, and for subsonic and supersonic aircraft are $.004.

[redacted]

IV. INVESTMENT COST EQUATIONS

INTRODUCTION

4.1 Investment cost equations are provided in this report for both subsonic transports and supersonic transports. The cost elements considered in the following analysis include manufacturing labor, manufacturing overhead, tooling, sustaining engineering, materials, avionics, engines, and airframe and engine spares.

4.2 All the equations, with the exception of supersonic transport avionics[1] are provided in a form representing the cumulative average cost of the unit at the Nth unit in a production run. No equation is provided for estimating the cost of avionics on the supersonic transport. Instead, a single estimate of the cost per airplane is provided for the reasons discussed in paragraphs 4.95 et seq.

4.3 Aggregation of costs into the foregoing specific categories resulted from the fact that cost data were only available in these categories. In some instances, it would have been desirable to provide equations for a more detailed set of cost elements. It is expected that if cost data were available in more detail, equations could have been developed which would contain smaller variances and in which greater confidence could be placed. With more detailed cost data, discrepancies in the data could have been more easily uncovered and perhaps explained. Instead, the more gross selection of cost elements obscures discrepancies and irregularities and results in variances which are larger than desired. Additional discussion of difficulties in using available airframe and engine cost data for the development of CERs is included in Section VII.

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[1] The cost of avionics on subsonic transports is not included because these costs are variable over a wide range and are determined at the discretion of the airline user. Consequently, it is felt that a CER would not provide a meaningful result. In addition, the costs of avionics on subsonic transports are small when compared to its total investment cost.

TOTAL INVESTMENT COST EQUATIONS

4.4 The total cumulative average investment cost of the Nth subsonic transport is given by the following equation:

$$\overline{C}_{A/CN} = \overline{C}_{L_N} + \overline{C}_{OH_N} + \overline{C}_{M_N} + \overline{C}_{TO_N} + \overline{C}_{SE_N} + \overline{C}_{E_N} .$$

4.5 The cumulative average cost of only the Nth subsonic airframe is given by the equation:

$$\overline{C}_{A/F_N} = \overline{C}_{L_N} + \overline{C}_{OH_N} + \overline{C}_{M_N} + \overline{C}_{TO_N} + \overline{C}_{SE_N} .$$

4.6 The total cumulative average investment cost of the Nth supersonic transport is given by the equation:

$$\overline{C}'_{A/C_N} = \overline{C}'_{L_N} + \overline{C}'_{OH_N} + \overline{C}'_{TO_N} + \overline{C}'_{SE_N} + \overline{C}'_{AV_N} + \overline{C}'_{E_N} + \overline{C}'_{M_N} .$$

4.7 The cumulative average cost of the Nth SST airframe is given by the equation:

$$\overline{C}'_{A/F_N} = \overline{C}'_{L_N} + \overline{C}'_{OH_N} + \overline{C}'_{M_N} + \overline{C}'_{TO_N} + \overline{C}'_{SE_N} .$$

4.8 The definitions for the terms used in these equations and for those that follow are included in a listing at the back of this volume.

4.9 Note that C_{A/F_N} represents only manufacturing cost. The difference between cost and sales price can be substantial and may be influenced by such factors as:

a. Manufacturer's total investment in R&D and manufacturing, and the return on investment he considers appropriate

b. Amount of funds required as selling expense

c. Amount of funds required for warrantees and guarantees.

4.10 The values to be assigned to the foregoing items will vary from manufacturer to manufacturer, and from time to time within a given manufacturer's plant depending on policies and, perhaps, other considerations.

4.11 The ensuing paragraphs detail the development and results of the CERs for the individual cost elements.

AIRFRAME DIRECT LABOR COST

Definition

4.12 The direct labor costs developed by CERs covers the costs for direct manhours where such hours are defined as:[2]

> " Direct man-hours are the hours expended on or chargeable to such operations as fabrication, processing and assembly, reworking, modification, and experimental production. Experimental hours spent in construction of mock-up models, test articles, reworking during the test program, etc., should be considered as direct man-hours; as should machine set-up time when performed by the operator of machine. Hours expended in the manufacturing area on testing, as well as preparation for flight testing (except servicing), should also be considered direct."

4.13 The direct labor costs used in the regression analysis correspond to direct labor hours, as defined above. To convert hours to cost per hour, a labor rate of $2.95 per hour is used. This rate was provided by the Bureau of Labor Statistics as the average rate for the aircraft industry during 1963. Applying this rate to the direct labor hours results in labor costs in constant 1963 dollars.

Cost Considerations

4.14 In the development of an estimating relationship to determine manufacturing labor costs, a series of independent variables were explored, each of which appeared to have a physical basis for affecting labor costs. These included:

a. Maximum speed at altitude in knots

b. Airframe weight at unit 100 (AMPR)

c. Maximum speed at altitude expressed as mach number

d. Maximum speed at sea level

e. Design load in G's

f. Range in nautical miles

g. Altitude

h. Empty weight

i. Gross takeoff weight

j. Ratio of empty weight to gross takeoff weight

k. Ratio of gross takeoff weight to maximum speed, and,

l. Year reference.

4.15 These independent variables were chosen in various combinations in an attempt to derive an equation that offered high correlation and low standard error.

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[2] This definition of direct labor hours was obtained from a Department of the Air Force document entitled, Aircraft Learning Curves, 60 MCPMA-116, prepared by the Industry Analysis Branch (MCPMA), Industrial Resources Division, Directorate of Procurement and Production, Headquarters, Air Materiel Command, Wright-Patterson Air Force Base, Ohio.

Sources and Nature of Data

4.16 Physical and performance characteristics were readily available on all aircraft except those bearing military classifications where delays in obtaining information were encountered. Sources included FAA specifications submitted by manufacturers and Jane's,[3] the Standard Aircraft Characteristics Reports[4,5] among others.

4.17 The cost basis for CER development was provided by data obtained partly from direct contact with aircraft and engine manufacturer and partly from literature searchs.

4.18 An attempt was made to obtain data on commercial airplanes to determine whether there were significant differences between manufacturing costs on these aircraft and military aircraft. Although the manufacturers were perfectly willing to supply physical or performance data, they were not so willing to release cost data. With the exception of some data on the DC-8, the little cost information that was obtained was not a form allowing inclusion in the regression analysis. In addition to the DC-8 data, information was obtained on the Convair 880 and the Boeing 707. These limited cost data were, however, not in a form adequate for use in the regression analysis.

4.19 Supplemental data sources included several untitled documents obtained from the Office of the Assistant Secretary of Defense, Directorate for Cost and Economic Analysis. The first document contains historical data on the labor hours required to manufacture various airplanes at various points in a production program. The data were graphically represented on plots whose axes were entitled "On Site Plus Off Site Direct Manhours Per Pound" and "Cumulative Plane Number." Regression lines were drawn through the data. Using the regression line, the total hours per pound were obtained for the hundredth aircraft in the production program. Data on approximately 30 aircraft were obtained in this manner.

4.20 The second document consists of an appendix to a report prepared for the Directorate of Cost and Economic Analysis by the Planning Research Corporation on an earlier contract. The appendix, entitled only "Appendix D" consists of the following six exhibits:

D-1 Performance and Production Program Characteristics for Aircraft in the Manufacturing Direct Labor Sample

D-2 Performance and Production Program Characteristics for Aircraft in the Manufacturing Materials, Engineering, and Tooling Samples

D-3 Summary of Contract Production and Weight Data

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[3] Janes' All the World's Aircraft, 1963-1964, Compiled and edited by John W.R. Taylor, Sampson Law, Marston & Co. Ltd.

[4] Standard Aircraft Characteristics, Air Force Guide Vol. 2, No. 2, "Brown Book," 5th edition, March 1964.

[5] Dept. of Navy, Bureau of Aeronautics, Standard Aircraft Characteristics, Engineering Report No. AD-300, NAVAER 00-110A-1 (published by direction of Chief of Bureau of Aeronautics).

D-4 Manufacturing Materials Cost Data

D-5 Engineering Cost Data

D-6 Tooling Cost Data.

4.21 One additional factor regarding the use of the cost data is noted. Because of scheduling commitments, most of the early regression analysis was completed before data were available from the contracted manufacturers. Consequently, in some instances, a cost value may have been used in the more recent analysis which differs from that used in the early analysis. Such differences are not believed to be significant.

Selection of Variables

4.22 Preliminary analysis indicated that weight and speed were by far the most significant independent variables. Any other variables added in combination to weight and space did not contribute significantly to the correlation coefficient. Since a high confidence limit over a narrow span is desirable and is a function of the number of degrees of freedom available, the number of independent variables must not be increased beyond the point at which improvement in the correlation coefficient is significant. This is especially true in the case of a small number of sample aircraft.

4.23 An attempt was made to correlate costs with the year of first flight because it was felt that it might provide some reflection of the state-of-the-art of airframe design. No significant correlation with this factor, however was found.

4.24 Given these considerations, it was decided to base the labor equations for both subsonic and supersonic transports on only weight and speed.

Regression Analysis of Subsonic Airframe Labor

4.25 A regression analysis was performed on a sample of 12 subsonic bomber and cargo aircraft; but it did, however, include one supersonic aircraft, the B-58, which was included to reflect the effects of speed on production labor. The sample was confined to aircraft of this type because it was felt that they are as closely representative of commercial transports in size and speed as can be obtained using only military samples. Data were subsequently obtained on the DC-8 and the derived CER was checked to determine its acceptability as regards this aircraft. Since the equation was considered adequate, correction for estimating costs of commercial aircraft was not considered necessary. A description of the computer program used for the regression analysis is provided in Appendix E.

4.26 From the results summarized in Table 4.1, an equation was selected that provides a correlation coefficient of .9607. The ratio of the standard error to the mean of the sample value of the dependent variable is .1894. The latter factor is regarded as significant since it is inversely related to the width of the band over which a given confidence limit can be assumed. To this end, a small value is desired. The correlation coefficient itself is regarded as somewhat less significant so long as its value exceeds approximately .8. The nature of correlation analysis is such that a high correlation coefficient is a necessary, but not sufficient, condition for a "good" CER; the variation in the observed (uncorrelated) data may result in unacceptably wide confidence intervals. The equation selected is of a linear form:

$$C_{L_{100}} = -126690 + 343.8V_k + 7.796\ W_o$$

[redacted]

where

$C_{L_{100}}$ = the labor cost of the 100th airframe in dollars.

Other definitions are included in the foldout at the end of the volume. The computer printout providing the coefficients for this equation is included as Table 4.2.

TABLE 4.1

AIRFRAME LABOR COST-ESTIMATING RELATIONSHIPS FOR LARGE SUBSONIC AIRCRAFT

Variable*	Correlation Coefficient	Coefficient of Variation**
Total Airframe Labor Cost — Total Sample(Linear Regression)		
1,2	.9559	.2501
2	.9279	.3177
Total Airframe Labor Cost — Subsonic Aircraft Only (Linear Regression)		
1,2	.9669	.2364
2	.9558	.2722
Total Airframe Labor Cost — Bombers or Cargo Aircraft (Linear Regression)		
1,2	.9607	.1894
2	.9101	.2831
Airframe Labor Cost per Pound — Total Sample (Linear Regression)		
1	.5598	.3032
1,2	.7140	.2562
2	.5520	.3051
Airframe Labor Cost per Pound — Subsonic Aircraft Only (Linear Regression)		
1	.5414	.3330
1,2	.7317	.2699
2	.5609	.3279
Airframe Labor Cost per Pound — Bombers and Cargo Aircraft (Linear Regression)		
1	.8768	.1892
1,2	.8838	.1841
Labor Cost per Pound of Airframes — Total Sample (Nonlinear Regression)		
1,2	.8266	.2396
2	.6105	.2982
Labor Cost per Pound — Subsonic Aircraft Only (Nonlinear Regression)		
1,2	.8437	.2389
2	.6749	.2883
Labor Cost per Pound — Bombers and Cargo Aircraft (Nonlinear Regression)		
1	.8608	.1875
1,2	.8774	.1656

* Variable 1 is maximum speed in knots; Variable 2 is weight (AMPR).

** "Coefficient of Variation" is the ratio of the standard error to the mean value of the observed values of the dependent variable.

[redacted]

[redacted]

TABLE 4.2

COMPUTER PRINTOUT OF LABOR COST AS A FUNCTION OF SUBSONIC SPEED AND WEIGHT

```
PHASE III OF REGRESSION ANALYSIS

LABOR COST B
          3 VARIABLES             12 OBSERVATIONS


COEFFICIENT SET NO. 1 OF LABOR COST B

    RESID SUM OF SQRS. = , 6.6016E+10       MUTL. CORR. COEF. =    .9607

        CONSTANT TERM = -1.2669E+05
        VARIABLE    1  =   3.4378E+02
        VARIABLE    2  =   7.7961E-00

      Y OBSERVED   Y CALCULATED       DELTA        PCT DELTA
      540000.00      533568.47       6431.53           1.19            22RB58  1
     1069000.00      882729.36     186270.70          17.42            12B36A  1
      275000.00      291164.12     -16164.12           5.87            12B45A  1
      509000.00      451217.13      57782.87          11.35            12B47A  1
      398000.00      403685.31      -5685.31           1.42            12B50A  1
      830000.00      926198.75     -96198.75          11.59            12B52A  1
      210000.00      169907.53      40092.47          19.09            12B57A  1
      165000.00      143387.60      21612.40          13.09            13C82A  1
      500000.00      593291.15     -93291.15          18.65            13C124  1
      322000.00      320401.35       1598.65            .49            13C130  1
      510000.00      595604.66     -85604.66          16.78            13KC13  1
       96000.00      112821.25     -16821.25          17.52            13C123  1

              MEAN Y OBSERVED =      452000.00
        STANDARD ERROR =      85645.393     FRAC. S.E. =    .1894
        MEAN DEVIATION =      52296.155     FRAC. DEV. =    .1156
```

[redacted]

4.27 Analysis of the manufacturing progress curves[6] for many aircraft leads to the conclusion that these curves are generally log-linear with a slope b. Analysis has also indicated that the average slope of these curves is approximately 77 percent corresponding to b = -.377. Approximately the same average slope is given in Aircraft Learning Curves.[7] The percentage slopes and the corresponding b values for all of the progress curves cited in this section are included in the listing at the back of this volume.

4.28 The labor cost equation developed in the regression analysis provides the estimated unit cost of the one-hundredth airframe. It is necessary to convert the equation to a more general form that expresses the cumulative average cost of the Nth airframe manufactured. To this end, the technology presented by Noah and Smith is employed.[8] The equation is readily converted to:

$$\bar{C}_{L_N} = \frac{(-126690 + 343.8V_k + 7.796\ W_o)}{100^b} \frac{\sum_{x=1}^{N} X_n^b}{N} .$$

4.29 This equation is more readily solved if the summation term is eliminated by the substitution of an approximation form. With this substitution, the final subsonic transport direct labor cost equation becomes:

$$\bar{C}_{L_N} \cong \frac{(-126690 + 343.8V_k + 7.796\ W_o)}{100^b} \frac{N^{b+1}}{N(b+1)} .$$

Regression Analysis to Determine Supersonic Airframe Labor

4.30 To develop a direct labor equation for the SST, regression analysis was performed in an enlarged sample. Data for several supersonic aircraft were added so that the impact of speed on labor costs would be considered. The resulting sample contained aircraft of Aircraft Manufacturers Progress Report (AMPR) weights up to approximately 100,000 lb and speeds to approximately mach 2.25. The addition of the supersonic aircraft minimizes the amount of extrapolation required when considering the SST.

4.31 The results of the regression analysis are presented in Table 4.3. From these results an equation (for which Table 4.4 contains the computer printout) was selected. The equation is:

$$C_{L_{100}} = -99023 + 225.2V_k + 8.11\ W_o$$

The aircraft from which the equation was developed are predominately constructed of aluminum whereas the SST designs are predominantly titanium. Because of the industry's relative lack of experience in working with the latter metal, and because of its substantially different characteristics, a correction needs to be applied before the equation can be used for predicting SST costs. A factor,

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[6] These curves represent unit cost or cumulative average cost vs the number of units produced and illustrate unit cost reduction occurring with increases in production quantities.

[7] Department of Air Force, 60 MCPMA-116, op.cit.

[8] J. W. Noah and R.N. Smith, Cost Quantity Calculator, Rand Corporation, Memorandum RM 2786, January 1962.

[redacted]

T_L, was developed and applied as a multiplying factor to obtain a corrected labor cost estimate.

TABLE 4.3

LABOR COST-ESTIMATING RELATIONSHIPS FOR SUPERSONIC AND LARGE SUBSONIC AIRCRAFT

Variables*	Correlation Coefficient	Coefficient of Variation
Total Labor Cost per Airframe (Linear Regression)		
1,2	.9553	.2096
2	.9062	.2999
Labor Cost per Pound (AMPR) (Linear Regression)		
1	.8819	.2052
1,2	.8933	.1957
Total Labor Cost per Airframe (Nonlinear Regression)		
1,2	.9644	.2304
2	.8366	.3295
Labor Cost per Pound (AMPR) (Nonlinear Regression)		
1	.9121	.1979
1,2	.9225	.1873

* Variable 1 is design maximum speed at the optimal altitude for the aircraft in knots; Variable 2 is weight (AMPR).

4.32 The equation also needs to be modified so that it expresses the cost of the Nth airframe in a production run. With this modification and the T_L factor applied the equation becomes:

$$\overline{C}'_{LN} = T_L \frac{(-99023 + 225.2\, V_k + 8.11\, W_o)}{100b} \frac{N^{b+1}}{N(b+1)}$$

4.33 The derivation of T_L and other such factors is included in Section V. under the heading "Development of Titanium Cost Multipliers." The following equation for T_L was developed expressing the cost multiplier as a function of the amount of titanium in the airframe. The equation is:

$$T_L = 1.55 + .77X$$

where X is the fraction of the AMPR weight of the airframe which is titanium.

4.34 Combined with the previous equation, the following final direct labor cost CER for the titanium SST is developed:

$$\overline{C}'_{LN} = \frac{(1.55 + 77X)(-99023 + 225.2\, V_k + 8.11\, W_o)}{100b} \frac{N^{b+1}}{N(b+1)}$$

4.35 Because of the lack of experience in manufacturing titanium airframes it is expected that the slope of the learning curve will be flatter than that being experienced in aluminum airframe. A slope of 80 percent is therefore recommended, leading to a value of $b = -.322$.

[redacted]

[redacted]

TABLE 4.4

COMPUTER PRINTOUT OF LABOR COST AS A FUNCTION OF SUPERSONIC SPEED AND WEIGHT

```
PHASE III OF REGRESSION ANALYSIS
LABOR COST SUPER LIN
     3 VARIABLES            20 OBSERVATIONS
COEFFICIENT SET NO. 1 OF LABOR COST SUPER LIN
    RESID SUM OF SQRS. = , 1.0009E+11      MUTL. CORR. COEF. =   .9553
         CONSTANT TERM = -9.9023E+04
         VARIABLE   1  =  2.2523E+02
         VARIABLE   2  =  8.1122E-00

      Y OBSERVED  Y CALCULATED       DELTA       PCT DELTA
     1069000.00     902568.29    166431.80         15.56            12B36A 1
      275000.00     278273.23     -3273.23          1.19            12B45A 1
      509000.00     436733.91     72266.09         14.19            12B47A 1
      398000.00     410460.42    -12460.42          3.13            12B50A 1
      830000.00     928854.27    -98854.27         11.91            12B52A 1
      210000.00     148655.47     61344.53         29.21            12B57A 1
      540000.00     435644.05    104355.95         19.32            22RB58 1
      165000.00     150870.26     14129.74          8.56            13C82A 1
      500000.00     615173.38   -115173.38         23.03            13C124 1
      322000.00     324859.55     -2859.55           .88            13C130 1
      510000.00     586313.32    -76313.32         14.96            13KC13 1
       96000.00     125556.52    -29556.52         30.78            13C123 1
      136000.00     158534.47    -22534.47         16.56            21F100A1
      210000.00     150308.80     59691.20         28.42            21F102A1
      106000.00     224970.22   -118970.22        112.23            21F104A1
      351000.00     324573.58     26426.42          7.52            21F105B1
      181000.00     225051.58    -44051.58         24.33            21F8U1 1
      352000.00     342516.00      9484.00          2.69            21A3J1 1
      322175.00     343686.56    -21511.56          6.67            21F4H  1
      237145.00     205614.35     31530.65         13.29            21F101 1
             MEAN Y OBSERVED =     365966.00
         STANDARD ERROR =     76732.518     FRAC. S.E. =    .2096
         MEAN DEVIATION =     54560.935     FRAC. DEV. =    .1490
```

[redacted]

[redacted]

MANUFACTURING OVERHEAD AND GENERAL AND ADMINISTRATIVE (G&A) EXPENSES

General Cost Relationship

4.36 Overhead and G&A rates in the aircraft industry are generally defined as a dollar per hour figure applied to each hour of manufacturing labor. In this analysis, the overhead and G&A costs are combined and assumed to be a percentage of the labor costs. For all practical purposes, the two approaches are equivalent but the latter is somewhat easier to work with because the problem of conversion to 1963 dollars is omitted. The equation for overhead and G&A costs is therefore:

Overhead costs = overhead rate x labor costs.

The term overhead as used in the expression and in the remainder of this section is interpreted to include G&A expenses.

4.37 The overhead rate is not applied to the tooling or engineering costs in this study because the CERs for those costs are based on cost figures that already contain an appropriate overhead adjustment.

Summary of Data Analysis

4.38 Overhead rates at any point in time are dependent on accounting policies as well as on the volume of business that a manufacturer has in process. Since the latter item is especially variable, the overhead rate will vary from time to time in a given manufacturer's organization. Historically these rates have varied from 125 percent to approximately 185 percent in the aircraft industry.[9]

Sources and Nature of Data

4.39 Overhead rates were discussed with General Dynamics/Fort Worth, the Boeing Company, and the Douglas Aircraft Company. General Dynamics indicates that they consider 150 percent an acceptable average. Douglas's current rate is 156 percent. Boeing's rate while constructing the B-52 was 146 percent; it currently is approximately 182 percent.

Final Relationships

4.40 On the basis of the information obtained, a rate of 150 percent is recommended as an approximation to future overhead costs. The rate is appropriate for both subsonic and supersonic aircraft. The final CERs are

Subsonic:

$$\overline{C}_{OH_N} = R_{OH}\,\overline{C}_{L_N}$$

Supersonic Transport:

$$\overline{C}'_{OH_N} = R_{OH}\,\overline{C}'_{L_N}$$

where all terms are defined on the listing included at the end of this volume.

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[9] Edward Yates, Cost Analysis as an Aid to Aircraft Design, Defense Research Corporation, AIAA Paper 64-172, May 1964.

[redacted]

[redacted]

AIRFRAME TOOLING COSTS

Definition of Costs

4.41 The CER developed for tooling costs provides an estimate of costs of tool and production planning, tool and template design, tool manufacturing including basic tools, rate tooling, and sustaining or maintenance tooling, tool checkout, and finally outside tooling including vendor, purchased labor, and subcontractor tooling.

Cost Considerations

4.42 Considerations previously discussed in regard to the labor CER indicate the desirability, where data are limited, of using a minimum number of variables in the final form of the equation. The weight and speed of the aircraft were found to be more significant than any other variables with respect to labor costs. Consequently it was assumed that these variables would also have a significant effect upon the cost of tooling. In addition, the amount and type of tools that are made depends on the quantity of items to be produced, the rate at which they are to be produced, and the type of material in the manufactured items. Consideration of type of material led to the development and application of a titanium cost multiplier which will be discussed below. The interest in quantity and rate of production stemmed from the consideration that once tools are prepared, there is some latitude in the number of airframes that can be made with those tools, and thus, as the number of airframes produced increases, the tooling cost per airframe will decrease. Since the rate of production can be correlated to the quantity to be produced, it was expected that the tooling cost per airframe would be inversely proportional to the production rate.

Selection of Variables

4.43 On the basis of the preceding considerations, the AMPR weight of the airframe and speed were selected as two of the independent variables to be analyzed. Production quantity was not selected as an independent variable because of the large variability that exists in historical data. It was further felt the cost would not be sensitive to the possibly limited quantities proposed for the SST. Production rate could not be used directly as one of the variables because all too often the peak or average rate data related to production runs much longer than those proposed for the SST. It was therefore necessary to locate some variable which would have a cost impact similar to that of production rate, but would also be significant over the range of production quantities appropriate to the SST. To this end it was decided to use the cumulative average delivery rate to the 100th unit as the 3rd independent variable. In using this variable the assumption is made that delivery rates and production rates are not significantly different for the aircraft considered.

Data Sources

4.44 Data for the regression analysis were obtained from the documents referenced in paragraphs 4.16 through 4.21.

Regression Analysis of Tooling Costs for Subsonic Aircraft

4.45 The regression analysis was performed on a sample of ten subsonic aircraft. The results of the analysis are summarized in Table 4.5. The equation selected

[redacted]

[redacted]

from the results has a correlation coefficient of .9710 and a coefficient of variation equal to .3765. The computer output sheet for this equation is given as Table 4.6. The equation is:

$$C_{TO_{100}} = (10{,}745\, X_1^{-.40581} X_2^{5.6555} X_3^{-1.29})\, W_o$$

where $C_{TO_{100}}$ = the cumulative average tooling cost of the 100th unit.

TABLE 4.5

AIRFRAME TOOLING COST-ESTIMATING RELATIONSHIPS—SUBSONIC AIRPLANES

Variables *	Correlation Coefficient	Coefficient of Variation **
Total Tooling Cost (Linear Regression)		
1,2	.6151	.6814
1,2,3	.7609	.5608
1, 3	.7402	.5810
2	.7600	.5617
3	.6973	.6194
Tooling Cost per Pound of Airframe (AMPR) (Linear Regression)		
1,2,3	.8458	.5222
1, 3	.8198	.5605
2,3	.8328	.5419
Total Tooling Cost (Nonlinear Regression)		
1,2	.8819	.4172
1,2,3	.9659	.3134
1, 3	.8585	.7044
2,3	.9124	.5749
Tooling Cost per pound of Airframe (AMPR)(Nonlinear)		
1,2	.9016	.7262
1,2,3	.9710	.3765
1, 3	.8818	.5798
2,3	.9506	.5991

* Variable 1 is airframe weight (AMPR, lb; Variable 2 is maximum speed in Mach numbers; Variable 3 is the cumulative delivery rate per month to unit 100.

** Coefficient of variation is the ratio of the standard error to the mean value of the observed values of the dependent variable.

4.46 When the equation is restructured to provide cumulative average cost to the Nth unit, rather than the cumulative cost of the 100th unit, it becomes:

$$\overline{C}_{TO_N} = \frac{(10{,}745\, W_o^{-.40581} V_m^{5.6555} QAV_{100}^{-1.29})\, W_o N^b}{100^b}$$

where the definitions of the variables are provided on the foldout sheet at the end of this volume.

4.47 An analysis of progress curves for tooling costs indicates that the cumulative average costs per pound are approximately log-linear and that slopes average approximately 65 percent, corresponding to a value of $b = -.622$

<u>Regression Analysis of Tooling Costs for the Supersonic Airframe</u>

4.48 Regression analysis was performed on a sample of 19 subsonic and supersonic aircraft which included bomber

[redacted]

[redacted]

TABLE 4.6

FIRST COMPUTER PRINTOUT OF TOOLING COSTS AS A FUNCTION OF WEIGHT, SPEED, AND PRODUCTION RATE

```
COEFFICIENT SET NO. 2 OF SST TOOLING/LB-LOG-

     RESID SUM OF SQRS. =   5.0435E-01       MUTL. CORR. COEF. =    .9710

          CONSTANT TERM =   9.2823E-00
          VARIABLE    1  = -4.0581E-01
          VARIABLE    2  =  5.6555E-00
          VARIABLE    3  = -1.2902E-00

        Y OBSERVED  Y CALCULATED      DELTA        PCT DELTA
            35.98         32.64         3.33           9.26
             6.39          5.40          .99          15.58
             7.14          9.46        -2.31          32.33
            15.89         16.68         -.78           4.95
            25.99         38.91       -12.92          49.70
            21.49         22.40         -.90           4.20
            49.99         40.22         9.77          19.54
             1.84          2.28         -.43          23.25
             o.59          5.43         1.16          17.61
            17.99         13.27         4.71          26.20

                 MEAN Y OBSERVED =        18.93
          STANDARD ERROR =         7.131    FRAC. S.E. =    .3765
          MEAN DEVIATION =         3.733    FRAC. DEV. =    .1971
```

[redacted]

[redacted]

and fighters. The results of the analysis are summarized in Table 4.7. Table 4.8 is a computer printout of the equation selected. It was necessary to use a mixed sample of subsonic and supersonic aircraft for the SST analysis for two reasons. The first reason is that if only supersonic aircraft were included in the sample, the sample size would be severely restricted. In addition, the supersonic aircraft are relatively small. For the equation to reflect the impact of weight, it is necessary to include larger aircraft as near supersonic as possible, which, as it happens, are all subsonic. The mixed sample results in an equation wherein the amount of extrapolation to the SST weight and speed is minimized.

TABLE 4.7

TOOLING COST-ESTIMATING RELATIONSHIPS—SUBSONIC AND SUPERSONIC AIRCRAFT

Variables*	Correlation Coefficient	Coefficient of Variation
Cost per Airplane (Linear Regression)		
1	.1014	1.1067
1,2	.5919	.8966
1,2,3	.6334	.8607
1, 3	.5314	.9405
2	.5502	.9289
2,3	.6292	.8646
3	.5273	.9452
Cost per Pound (Linear Regression)		
1	.3001	.6559
1,2	.6591	.5171
1,2,3	.6949	.4994
1, 3	.6021	.5490
2	.6356	.5308
2,3	.6436	.5262
3	.3870	.6340
Cost per Plane (Nonlinear Regression)		
1	.4085	1.1232
1,2	.7686	.7584
1,2,3	.8159	.7255
1 3	.7405	.8419
2	.6283	.9573
2,3	.8017	.7768
3	.7405	.8420
Cost per Pound (Nonlinear Regression)		
1	.3914	.7588
1,2	.7653	.6009
1,2,3	.8134	.5563
1 3	.7359	.6684
2	.6775	.5716
2,3	.6781	.5746
3	.3043	.6800

* Variable 1 is airframe weight (AMPR) pounds; Variable 2 is the maximum speed of the aircraft in Mach numbers; Variable 3 is the cumulative average delivery rate per month to the 100th unit.

4.49 The equation, when put in non-log form is:

$$C_{TO_{100}} = (70{,}968\ W_o^{-.7848}\ V_m^{.9176}\ Q_{AV_{100}}^{-.8325})\ W_o$$

4.50 Since the SST is to contain large quantities of titanium it is necessary to modify the tooling estimate

[redacted]

[redacted]

TABLE 4.8

SECOND COMPUTER PRINTOUT OF TOOLING COSTS AS A FUNCTION OF WEIGHT, SPEED, AND PRODUCTION RATE

```
COEFFICIENT SET NO. 4 OF TOOL C/LB  ALL   LOG
    RESID SUM OF SQRS. = , 5.0873E-00        MUTL. CORR. COEF. =   .8134

        CONSTANT TERM =   1.1166E+01
        VARIABLE    1  = -7.4844E-01
        VARIABLE    2  =  9.1766E-01
        VARIABLE    3  = -8.3252E-01

      Y OBSERVED  Y CALCULATED        DELTA         PCT DELTA
                                      17.23           47.89
         35.98        18.74           -8.10          126.70
          6.39        14.50           -1.06            7.11
         14.99        16.06           -5.37           33.79
         15.89        21.26             .07             .28
         25.99        25.92            5.26           24.50
         21.49        16.22            8.42           16.84
         49.99        41.57           -1.84           99.76
          1.84         3.69            -.69           10.55
          6.59         7.29            8.24           45.81
         17.99         9.75           14.15           22.46
         62.99        48.84          -32.17          134.08
         23.99        56.17          -17.80           89.09
         19.98        37.79           -2.46            7.04
         34.98        37.45           -5.27           12.55
         41.97        47.24           -6.18           13.46
         45.97        52.15           36.43           68.76
         52.98        16.54            1.74            4.37
         39.96        38.21           30.95           44.24
         69.96        39.01

            MEAN Y OBSERVED =            31.05
       STANDARD ERROR =         17.275    FRAC. S.E. =   .5563
       MEAN DEVIATION =         10.711    FRAC. DEV. =   .3449
```

based on historical costs for aluminum airframes, to reflect the increases caused by the titanium. To this end a multiplying factor T_{TO} is defined. With the addition of this factor and modification to obtain the cumulative average cost of the Nth unit, the equation becomes:

$$\bar{C}'_{TO_N} = T_{TO}(70{,}968\, W_o^{-.7484} V_m^{.9176} Q_{AV_{100}}^{-.8325}) \frac{W_o N^b}{100b}$$

4.51 An equation for T_{TO} is developed expressing the cost multiplier as a function of the amount of titanium in the air frame. The equation developed in Section VI of this report, is:

$$T_{TO} = 1.50 + .71\, X$$

where X is the fraction of the AMPR weight of the airframe which is titanium.

4.52 Combined with the previous equation, the final tooling CER for the titanium SST is:

$$\bar{C}'_{TO_N} = \left[(1.50 + .71\, X) \times (70{,}968\, W_o^{-.7484} V_m^{.9176} Q_{AV_{100}}^{-.8325})\, W_o \frac{N^b}{100b} \right]$$

4.53 Because of the lack of experience in using titanium it is not expected that the learning curve for the SST can be quite as steep as that experienced in tooling for an aluminum airframe. It is therefore recommended that a slope of 70 percent be used rather than the 65 percent characteristic of the aluminum tooling experience. The 70 percent slope has a corresponding value of b = -.515.

AIRFRAME SUSTAINING ENGINEERING COSTS

Definition

4.54 The sustaining engineering includes those recurring engineering activities required to support the production line and continues throughout the production activity. It is defined to include such items as quality control, shop liaison, preparation of service publications and weight data and other services of an engineering nature required during the production of the airframe. These services would include maintenance of the manufacturing drawings, and design changes for cost reduction and improved manufacturability.

Data Sources

4.55 The data used for the analysis were derived from the sources outlined in paragraphs 4.16 through 4.21 above. It is noted, however, that because of the difficulties in differentiating between the various types of engineering costs, as reported by the different accounting systems, the exact content of the cost figures cannot be defined. It is possible that some R&D costs are included in the figures. Further, it is likely that the cost of ECN's is also included in the cost data and consequently a separate CER for this item is not included.

Cost Considerations and Selection of Variables

4.56 It was considered desirable to develop a set of CERs to express the sustaining engineering costs in terms of the individual tasks within the category; however, data were not available to permit this. Accounting practices obscure the differences between design, development, product improvement, factory liaison, engineering changes, and other types of engineering endeavors. As a result it has been found impractical to develop CERs that individually consider the cost of each engineering activity. The effort was therefore directed to developing an equation based on available data that pertain only to total recurring engineering.

4.57 Because of limited sample size and considerations of the number of degrees of freedom and confidence limits, the number of independent variables was purposely limited. Aircraft weight and speed were selected because of their obvious impact on cost. In addition, the cumulative average delivery rate to unit 100 was also selected. This item was tried on the basis that engineering costs incurred while supporting a production line are a function of the level of activity on that line. The justification for using this particular variable is identical to that previously provided in connection with its selection and use in developing the tooling cost CER. As before, both total cost and cost per pound were used as dependent variables. The initial results of the regression analysis performed on a sample of 11 subsonic aircraft is summarized in Table 4.9. Subsequently, additional data were obtained from the Douglas Aircraft Company on the DC-8. The data arrived at a point where there was sufficient time to rework the regression analysis with this aircraft included. The results of the second analysis are summarized in Table 4.10. From the latter analysis an equation was selected. The computer printout is provided as Table 4.11.

Regression Analysis of Subsonic Sustaining Engineering Costs

4.58 The equation selected has a correlation coefficient of .9558 and a coefficient of variation equal to

[redacted]

TABLE 4.9

AIRFRAME SUSTAINING ENGINEERING COST-ESTIMATING RELATIONSHIPS—SUBSONIC AIRPLANES—INITIAL ANALYSIS

Variable*	Correlation Coefficient	Coefficient of Variation
Total engineering cost (Linear Regression)		
1,2,3	.8333	.5158
1,3	.8137	.5424
Engineering cost per pound of airframe (Linear Regression)		
1,2,3	.7254	.8308
1,3	.7109	.8490
2,3	.7110	.8488
Total engineering cost (Nonlinear Regression)		
1,2,3	.9439	.6165
1,3	.9411	.6411
2,3	.9438	.6212
3	.9377	.6013
Engineering cost per pound of airframe (AMPR) (Nonlinear Regression)		
1,2,3	.9402	.4943
1,3	.9372	.5754
2,3	.8364	.8379

* Variable 1 is airframe weight (AMPR).
Variable 2 is maximum speed in machine number.
Variable 3 is the cumulative average delivery rate per month to unit 100.

[redacted]

TABLE 4.10

AIRFRAME SUSTAINING ENGINEERING COST-ESTIMATING RELATIONSHIP—SUBSONIC AIRPLANES—SECOND ANALYSIS

Variable*	Correlation Coefficient	Coefficient of Variation
Total Sustaining Engineering Cost (Linear Regression)		
1,2,3	.8847	.5180
1,2	.8819	.5420
Total Engineering Cost (Nonlinear Regression)		
1,2,3	.9558	.3726
1,2	.8492	.4820
1,3	.8349	1.0147
2,3	.8978	.9054
3	.8342	1.0281

* Variable 1 is airframe weight (AMPR)
Variable 2 is maximum speed in machine number
Variable 3 is the cumulative average delivery rate per month to unit 100.

[redacted]

TABLE 4.11

COMPUTER PRINTOUT FOR SUSTAINING ENGINEERING AS A FUNCTION OF WEIGHT, SPEED, AND DELIVERY RATE

```
      COEFFICIENT SET NO. 2 OF ENG TOTAL SUB LOG

         RESID SUM OF SQRS. = , 1.0493E-00       MUTL. CORR. COEF. =   .9558

             CONSTANT TERM =  1.0420E+01
             VARIABLE    1   =  5.3003E-01
             VARIABLE    2   =  5.8648E-00
             VARIABLE    3   = -1.6656E-00

          Y OBSERVED  Y CALCULATED      DELTA        PCT DELTA
           38561.12      27363.87      11197.25          29.03
           40538.19      52630.44     -12092.24          29.82
          113550.16     234512.45    -120962.29         106.52
          125492.33     131769.30      -6276.97           5.00
          503832.92     464671.97      39160.95           7.77
          484077.35     369381.03     114696.32          23.69
          514011.02     622671.26    -108660.24          21.13
          337729.31     234368.27     103361.04          30.60
          198789.15     222905.90     -24116.75          12.13
          157944.66     149402.30       8542.36           5.40
          376999.82     386260.38      -9260.56           2.45
         1202604.20     926145.84     276458.40          22.98

                  MEAN Y OBSERVED =    341177.50
             STANDARD ERROR =     127127.800    FRAC. S.E. =   .3726
             MEAN DEVIATION =      69565.447    FRAC. DEV. =   .2038
```

[redacted]

.3726. The equation is:

$$C_{SE_{100}} = 33524\ W_o^{.53}\ V_m^{5.86}\ Q_{AV_{100}}^{-1.665}$$

where $C_{SE_{100}}$ is the cumulative average sustaining engineering cost of the 100th unit.

4.59 When modified to provide the cumulative average engineering cost of the Nth airframe, the equation becomes:

$$\bar{C}_{SE_N} = (33524\ W_o^{.53}\ V_m^{5.86}\ Q_{AV_{100}}^{-1.665})\frac{N^b}{100^b}$$

4.60 Analysis of progress curves results in a conclusion that cumulative average engineering costs per pound (AMPR) are approximately log-linear and that slopes average approximately 65 percent, corresponding to a value of $b = -.622$.

Regression Analysis to Determine Supersonic Sustaining Engineering Costs

4.61 Regression analysis was performed on a sample consisting of 21 subsonic and supersonic airframes. The sample consisted of 15 fighters, 5 bombers, and the DC-8. The results of the analysis are summarized in Table 4.12. An equation with correlation coefficient of .8151 and coefficient of variation of .6687 was selected and analyzed. This equation uses only two variables and would appear to be among the better equations available, although the coefficient of variation is still very high. The equation omits the variable expressing the cumulative average delivery rate. This equation, however, was felt to be unduly sensitive to both speed and weight, and would be of little use for prediction of costs at large extrapolations. A second equation of correlation coefficient equal to .8367 and coefficient of variation equal to .7299 provides more realistic extrapolation characteristics for predicting sustaining engineering cost. The computer output for this equation is provided as Table 4.13. The equation is:

$$\bar{C}'_{SE_{100}} = (21,400\ W_o^{-.61275}\ V_m^{1.6798}\ Q_{AV_{100}}^{-.83112})\, W_o$$

where $\bar{C}_{SE_{100}}$ is the cumulative average sustaining engineering cost of the 100th airframe.

4.62 There is no apparent reason why the amount of sustaining engineering on the titanium airframe should be any different than on any other airframe. Consequently no adjustment for the effect of titanium is considered for this equation.

4.63 The equation, when modified to provide the cumulative average cost of the Nth SST becomes:

$$C_{SE_N} = 21,400\left[W_o^{-.61275}\ V_m^{1.6798}\ Q_{AV_{100}}^{-.83112}\right] W_o\ \frac{N^b}{100^b}$$

As with the subsonic aircraft, it is recommended that a progress curve of 65 percent slope be used solving the above equation.

[redacted]

TABLE 4.12

SUSTAINING ENGINEERING COST-ESTIMATING RELATIONSHIPS FOR SUBSONIC AND SUPERSONIC AIRCRAFT

Variables*	Correlation Coefficient	Coefficient of Variation	Variables	Correlation Coefficient	Coefficient of Variables
Engineering Cost/Pound (Linear Regression)			Engineering Cost/Pound (Nonlinear Regression)		
1	.3016	.8516	1	.3215	.9965
1,2	.7341	.6065	1,2	.8116	.7331
1,2,3	.7371	.6035	1,2,3	.8367	.7299
1,3	.5347	.7548	1,3	.7030	.8799
2	.7233	.6168	2	.7765	.7104
2,3	.7233	.6167	2,3	.7766	.7106
3	.3198	.8463	3	.3762	.9157
Engineering Cost/Airplane (Linear Regression)			Engineering Cost/Airplane (Nonlinear Regression)		
1	.1053	1.1714	1	.3451	1.2397
1,2	.7005	.8406	1,2	.8151	.6687
1,2,3	.7094	.8301	1,2,3	.8392	.7075
1,3	.5021	1.0186	1,3	.7066	.9342
2	.6443	.9008	2	.6949	.9366
2,3	.6859	.8571	2,3	.8154	.8329
3	.4986	1.0210	3	.7065	.9305

* Variable 1 is airframe weight (AMPR)
Variable 2 is maximum speed in mach number
Variable 3 is the cumulative average delivery rate per month to unit 100

[redacted]

TABLE 4.13

SECOND COMPUTER PRINTOUT FOR SUSTAINING ENGINEERING COST AS A FUNCTION OF WEIGHT, SPEED, AND DELIVERY RATE

```
     COEFFICIENT SET NO. 4 OF ENG C/LB    S/S  LOG

          RESID SUM OF SQRS. = , 9.0441E-00       MUTL. CORR. COEF. =    .8367

               CONSTANT TERM =   9.9666E-00
               VARIABLE    1  = -6.1275E-01
               VARIABLE    2  =  1.6798E-00
               VARIABLE    3  = -8.3112E-01

        Y OBSERVED  Y CALCULATED      DELTA       PCT DELTA
            5.99         11.92          -5.93         98.97
            5.99         14.20          -8.20        136.92
           13.99         21.72          -7.72         55.20
           15.99         19.24          -3.25         20.33
           37.97         19.82          18.15         47.80
           54.98         25.84          29.13         52.99
           20.98         16.68           4.30         20.52
           65.95         36.54          29.41         44.59
            1.89          3.80          -1.90        100.25
            3.17          7.27          -4.09        128.83
           12.98         10.52           2.46         18.99
           44.97        111.87         -66.90        148.78
           99.98        103.54          -3.55          3.55
           51.98         63.83         -11.84         22.79
           89.92         70.45          19.47         21.65
           51.98         90.40         -38.42         73.90
           89.92         95.64          -5.71          6.36
           59.97         57.15           2.82          4.71
          119.94         20.15          99.78         83.19
          109.94         86.51          23.43         21.31
           11.49          5.63           5.86         51.01

                  MEAN Y OBSERVED =          46.19
            STANDARD ERROR =        33.718     FRAC. S.E. =    .7299
            MEAN DEVIATION =        18.687     FRAC. DEV. =    .4045
```

[redacted]

AIRFRAME MATERIALS COSTS

Definition

4.64 Airframe materials costs include the costs of raw materials, hardware, and purchased parts.

Cost Considerations

4.65 It would be desirable to develop separate CERs for each of the three types of materials identified above. Separate CERs cannot be developed, however, because the necessary cost data were not available. Consequently, the research activity was directed toward development of a single CER to be used in developing a cost estimate of the total material content of an airframe.

Selection of Variables

4.66 Because of the shortage of available data, it was necessary to minimize the number of independent variables in the final equation. AMPR weight and speed were again considered to be the more significant parameters to represent the size of the aircraft and the state-of-the-art development.

Sources and Nature of Data

4.67 The data used in the analysis were primarily derived from the material referenced in paragraphs 4.16 through 4.21 above.

Regression Analysis of Material Costs, Subsonic Aircraft

4.68 Regression analysis was performed on a sample of 13 subsonic aircraft. As indicated, weight and speed were taken as the independent variables. Both total airframe material cost and material cost per pound were investigated as dependent variables. The results of the analysis are summarized in Table 4.14. An equation is selected having a correlation coefficient of .9164 and coefficient of variation of .7528. The computer printout presenting the characteristics and coefficients of the equation is presented in Table 4.15. The equation is:

$$C_{M_{100}} = 10.526 W_o^{1.0939} V_m^{3.697} \quad .$$

TABLE 4.14

AIRFRAME MATERIALS COST-ESTIMATING RELATIONSHIPS—SUBSONIC AIRPLANES

Variables*	Correlation Coefficient	Coefficient of Variation**
Total Airframe Material Cost (Linear Regression)		
1,2	.9139	.8429
1	.8083	1.2228
Material Cost Per Pound of Airframe (AMPR) (Linear Regression)		
1,2	.6262	.5207
2	.5403	.5620
Total Airframe Material Cost (Nonlinear Regression)		
1	.8620	1.409
1,2	.9164	.7528
Material Cost Per Pound of Airframe (AMPR) (Nonlinear Regression)		
1,2	.5887	.3745

*Variable 1 is airframe weight (AMPR).
Variable 2 is maximum speed (mach number).

**Coefficient of variation is the ratio of the standard errors to the mean value of the observed values of the dependent variables.

TABLE 4.15

COMPUTER PRINTOUT OF MATERIAL COST FOR SUBSONIC AIRCRAFT AS A FUNCTION OF WEIGHT AND SPEED

(Nonlinear regression)

```
CCEFFICIENT SET NO. 2 OF SST MAT COST

    RESID SUM OF SQRS. = , 2.7209E-00       MUTL. CORR. COEF. =    .9164

         CONSTANT TERM =   2.3527E-00
         VARIABLE    1  =   1.0939E-00
         VARIABLE    2  =   3.6970E-00

       Y OBSERVED   Y CALCULATED       DELTA        PCT DELTA
        56387.34       41662.05       14725.29          26.11
        59278.38       61768.57       -2490.19           4.20
        55270.79       89725.56      -34454.76          62.33
        69563.82      158542.02      -88978.20         127.90
       120571.71      108775.12       11796.59           9.78
       245241.81      291407.52      -46165.71          18.82
       221903.96      181465.16       40438.80          18.22
       479260.70      324636.37      154624.33          32.26
       187212.57       77192.68      110019.89          58.76
       722158.55      620104.93      102053.62          14.13
       154817.14      311504.79     -156687.65         101.20
      3368573.70     2289987.60     1078586.10          32.01
       373248.61      450948.30      -77699.69          20.81

              MEAN Y OBSERVED =      470268.37
         STANDARD ERROR =     354061.730     FRAC. S.E. =    .7528
         MEAN DEVIATION =     147593.900     FRAC. DEV. =    .3138
```

[redacted]

4.69 When rewritten to provide cost estimates for the cumulative average cost for the N^th^ airframe the equation becomes:

$$\bar{C}_{M_N} = \frac{(10.526\,W_o^{1.0939}V_m^{3.697})}{100^b}\ \frac{\Sigma_{i=1}^{n} X_i^{b}}{n}$$

When an approximation form is substituted for the summation term, the equation becomes:

$$\bar{C}_{M_N} \cong \frac{(10.526\,W_o^{1.0939}V_m^{3.697})}{100^b}\ \frac{N^{b+1}}{N(b+1)}$$

4.70 Analysis of the material learning curves on several airframes results in a conclusion that the unit material costs per pound are approximately log-linear. The average slope of the log-linear unit curves is approximately 90 percent with corresponding value of b = -.152, and consequently, the recommendation is made that this value be used for estimating purposes.

Regression Analysis of Material Costs, Supersonic Aircraft

4.71 Regression analysis was performed on a sample of 23 subsonic and supersonic aircraft. The results obtained are summarized in Table 4.16. As can be seen from these results, a combination of high correlation coefficient and low coefficient of variation was not obtained. For this reason, a regression analysis was performed on a stratified sample of supersonic aircraft. The results are summarized in Table 4.17. An equation was selected whose coefficient of correlation is .8797 and whose coefficient of variation is .2424. The computer printout is provided as Table 4.18. The equation resulting from the analysis is:

$$C_{M_{100}} = -235520 + 17.321\,W_o + 227700V_m$$

where $C_{M_{100}}$ = the total material cost of an airframe at the 100th unit.

4.72 When the equation is recast to provide cumulative average materials cost of the N^th^ airframe it becomes:

$$\bar{C}'_{M_N} = \frac{[-235520 + 17.32\,W_o + 227{,}700\,V_m]}{100^b}\ \frac{\Sigma_{x=1}^{N} X_i^{b}}{N}$$

4.73 When the summation is removed by substitution of an approximation form, the equation becomes:

$$\bar{C}'_{M_N} \cong \frac{[-235520 + 17.32\,W_o + 227{,}700\,V_m]}{100^b}\ \frac{N^{b+1}}{N(b+1)}$$

4.74 Before this equation can be used to estimate SST costs, two additional factors must be considered. The first factor is the effect of the use of titanium on the material cost. To this end, a multiplying factor, T_M, is developed and used in the final equation. T_M is developed in Section VI. An expression for this term is:

T_M = 2.75 + 2.47X, where X = the fraction of the airframe weight (AMPR) that is titanium.

4.75 The second factor to be considered results from the fact that sample aircraft from which the basic equation was developed are all relatively small compared to the SST. Because it can be shown that material costs per pound of airframe decrease with increasing airframe size, a correction to the equation should be applied. The discussion that follows is directed to that end.

[redacted]

[redacted]

TABLE 4.16

MATERIAL COST-ESTIMATING RELATIONSHIPS— SUBSONIC AND SUPERSONIC AIRCRAFT

Variables*	Correlation Coefficient	Coefficient of Variation
Material Cost Per Airplane (Linear Regression)		
1	.7915	.9259
1,2	.8218	.8632
2	.0556	1.5130
Material Cost Per Pound (Linear Regression)		
1	.0969	.5562
1,2	.6664	.4166
2	.6652	.4172
Material Cost Per Airplane (Nonlinear Regression)		
1	.7862	.9550
1,2	.8930	.9666
2	.3977	1.5748
Material Cost Per Pound (Nonlinear Regression)		
1	.0812	.5808
1,2	.6892	.42451
2	.6866	.4293

* Variable 1 is weight AMPR.
Variable 2 is speed in mach numbers.

TABLE 4.17

MATERIAL COST-ESTIMATING RELATIONSHIPS— SUPERSONIC AIRCRAFT

Variables*	Correlation Coefficient	Coefficient of Variation
Material Cost Per Pound of Airframe (AMPR) (Linear Regression)		
1,2	.6619	.2792
Total Material Cost Per Airframe (Linear Regression)		
1	.7920	.3112
1,2	.8797	.2424
Material Cost Per Pound of Airframe (AMPR) (Nonlinear Regression)		
1,2	.6609	.2852
Total Material Cost Per Airframe (Nonlinear Regression)		
1,2	.8379	.2441

* Variable 1 is weight (AMPR).
Variable 2 is maximum speed in mach numbers.

[redacted]

TABLE 4.18

COMPUTER PRINTOUT OF MATERIAL COST FOR SUPERSONIC AIRFRAMES AS A FUNCTION OF WEIGHT AND SPEED

```
COEFFICIENT SET NO. 2 OF MATL COST SUPER LIN

  RESID SUM OF SQRS. = , 8.6974E+10      MUTL. CORR. COEF. =   .8797

     CONSTANT TERM = -2.3552E+05
     VARIABLE    1  =  1.7321E+01
     VARIABLE    2  =  2.2770E+05

    Y OBSERVED   Y CALCULATED       DELTA        PCT DELTA
    539544.00      609273.40     -69729.40         12.92          21A3J
    556928.00      582813.68     -25885.68          4.64          21F4H
    378769.00      363040.07      15728.93          4.15          21F8U
    279720.00      358309.43     -78589.43         28.09          21F104
    576720.00      575628.90       1091.10           .18          21F105
    673394.00      473442.11     199951.89         29.69          21F106
    145416.00      254446.87    -109030.87         74.97          21F100
    262220.00      335402.63     -73182.63         27.90          21F101
    371938.00      238706.35     133231.65         35.82          21F102
    813600.00      807061.90       6538.10           .80          22B58

          MEAN Y OBSERVED =     459824.90
     STANDARD ERROR =    111467.320    FRAC. S.E. =    .2424
     MEAN DEVIATION =     71295.968    FRAC. DEV. =    .1550
```

[redacted]

DEVELOPMENT OF AN AIRFRAME MATERIALS COST CORRECTION FACTOR

4.76 For development of an estimating relationship that will be valid at the SST operating point, data on other supersonic aircraft are available. However, these data points represent light military aircraft, and a fairly extensive extrapolation of weight experience at these speeds is required. The average weight (AMPR) of these airframes is 16,310 pounds. The average weight (approximately) of SSTs being considered is 150,000 pounds. It is known that the average materials cost per pound decreases as the weight increases. Therefore, it is necessary to reduce the materials costs developed by the regression equation, by some amount, to reflect the lower cost per pound which will probably be attained. To this end, a multiplying factor, P_M, is developed herein for use in the SST materials equation.

4.77 Materials cost per pound is plotted against AMPR weight of airframe in Figure 4.1. The airframe data are stratified into three groups representing speed ranges of the airframes in the sample. The airplanes plotted with speeds between mach 0.76 and 0.78 are designated by a circle. The airplanes with speeds between mach 0.83 and 0.89 are designated by a triangle. Finally, the airplanes with speeds ranging between mach 1.85 and mach 2.27 are designated by a square.

4.78 Regression lines are drawn through the plotted points for the first and last groupings. The points for the middle range of airplane speeds appear to be almost random and consequently no meaningful regression line can be determined.

4.79 The data plotted were stratified in speed groupings to permit an analysis of the effects of weight. Without the stratification of data, the effect of speed on cost per pound is confused with the effects of weight.

4.80 There were insufficient data points in the sample data to develop a stratified set of data for other speed ranges than those indicated above.

4.81 With the two regression lines developed above, the cost per pound at 16,000 and at 150,000 pounds were compared. For the first set of data on low-speed aircraft, the ratio of cost per pound at 150,000 pounds to cost per pound at 16,000 pounds is found to be 0.38. The corresponding ratio for the last set of data on high-speed aircraft is 0.56. The arithmetic mean of these two ratios is 0.47. In other words, it would appear on the basis of this evidence that the materials cost per pound for 150,000-pound airframes decreases on the average to about half that of 16,000-pound airframes when considering only the effects of increasing weight and holding speed constant.

4.82 In an attempt to substantiate this conclusion using another approach, the following analysis was performed.

4.83 A relationship was found which correlated <u>total airframe</u> costs with airframe weight. This relationship appears as chart 7 in Rand Memo 2336 "Generalized Cost Functions for Mach Three Aircraft," by R.W. Smith, March 1959. A copy of the chart is included herein as Figure 4.2. The chart provides data normalized to a 100,000-pound airframe and is used to develop cost correction multipliers for aircraft weights other than 100,000 pounds. This chart can be used to develop ratios between cost per pound at differing weights. For example, the cost multiplier as a percent of airframe weight at 16,000 pounds is 1.55. At 150,000 pounds, it is .9. Therefore at 150,000 pounds, the cost

[redacted]

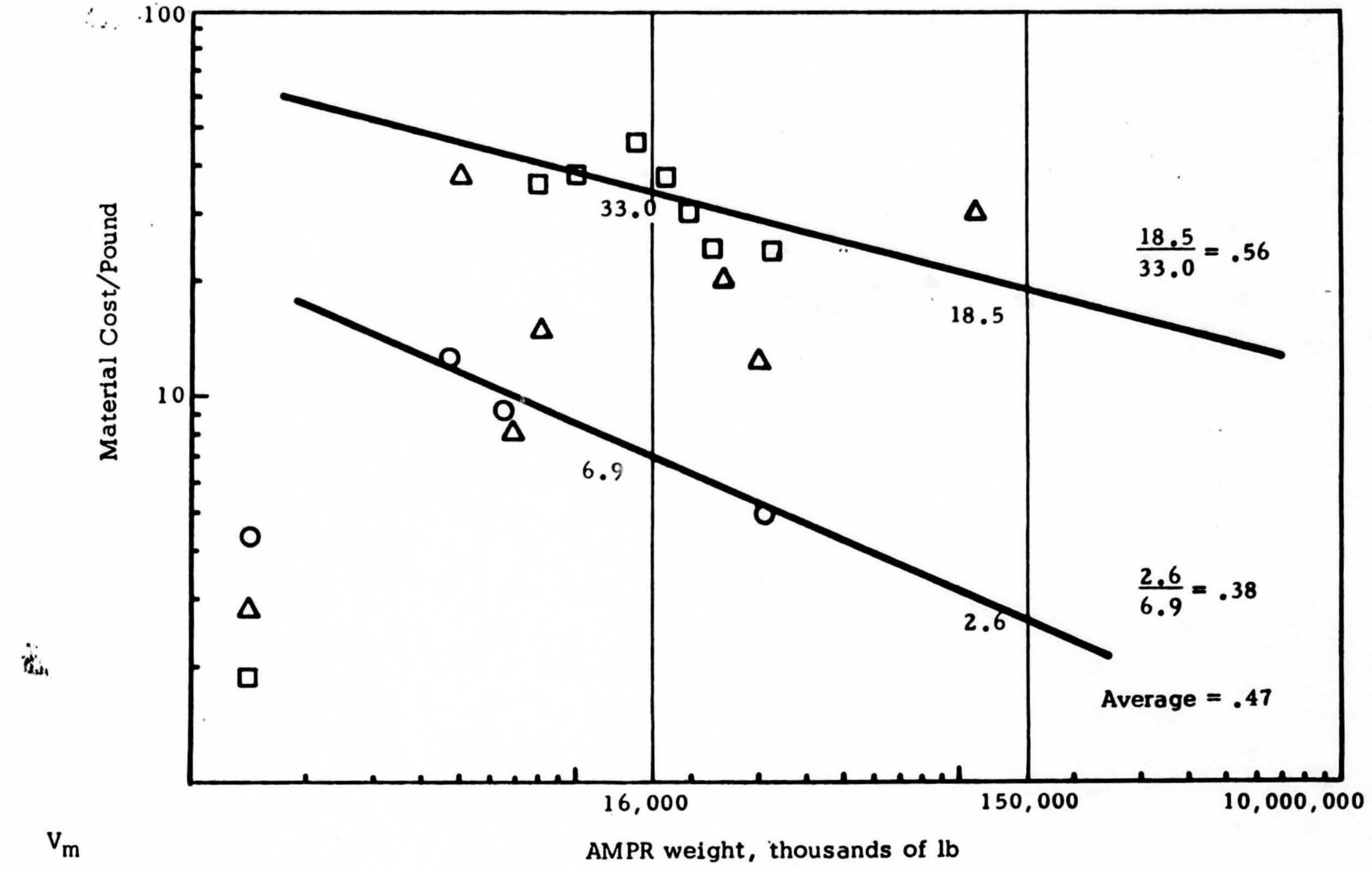

FIGURE 4.1. AIRFRAME MATERIAL COST PER POUND vs TOTAL AIRFRAME WEIGHT

[redacted]

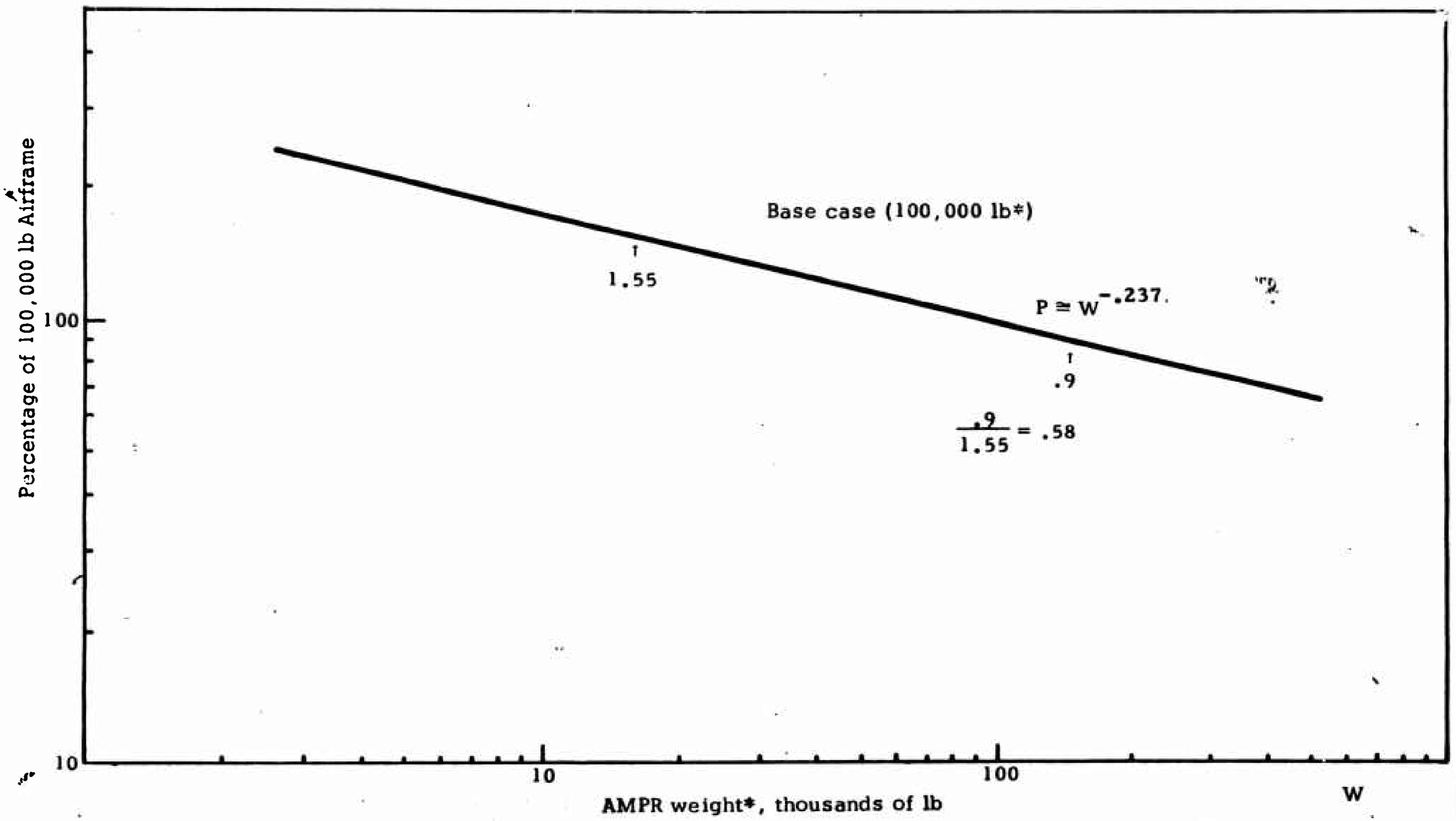

FIGURE 4.2. ADJUSTMENT TO TOTAL AIRFRAME COST

[redacted]

per pound of airframe is .9/1.55 or .58 of the cost per pound at 16,000 pounds. If the assumption is made that material costs per pound exhibit a parallel relationship to the total airframe cost per pound, then it can be concluded that the ratio of 0.58 is usable in predicting the material cost for the larger aircraft. Since material costs represent a significant part of the total cost of an airframe, the assumption is felt to be valid.

4.84 In conclusion, the analysis of material costs per pound for varying aircraft weights indicates that the SST materials equation should contain a factor reducing the cost developed in the regression analysis by a factor of approximately 0.38 to 0.56. The latter analysis indicates a reduction of 0.58 is in order. Based on this information a value of P_M equal to 0.55 is assumed.

4.85 With the application of the factor, T_M and P_M, the final SST materials CER becomes:

$$\overline{C}'_{M_N} \cong \frac{P_M[2.75+2.47X]\,[-235520+17.32W_o+227,700V_M]}{100^b} \; \frac{N^{b+1}}{N(b+1)}$$

4.86 It is recommended that the slope of the progress curve be taken as 90 percent as it was for the subsonic transport.

ENGINE PRODUCTION COSTS

Cost Definition

4.87 Accounting practices among jet engine manufacturers have been such that it is impossible to obtain data detailing the separate cost for labor, overhead, materials, and other cost elements. The cost figures that were obtained represent the total cost to the Government including amortization of tools, labor, materials and overhead, but less profit. The production costs do not include any amortization of development costs.

Cost Consideration

4.88 The analysis was performed using the following variables which were felt to bear significantly on production costs:

a. Thrust
b. Engine dry weight
c. Thrust-to-weight ratio
d. Specific fuel consumption
e. Turbine inlet temperature
f. Engine design mach number limit
g. Pressure ratio
h. Mass flow

4.89 The dependent variable in the analysis was the cumulative average cost of the 1200th unit produced. The cost of this unit was taken because it represents the approximate number of engines that would be produced in a 200-airplane SST program. Jet engines have advanced in complexity and sophistication over the years. Engines currently exist that operate near the high thrusts and temperatures that will be required of SST engines. Large amounts of totally new materials or totally new manufacturing techniques may not be required during the production phase. However the development phases will bear the large costs necessary to prepare for a normal production run. For this reason, it is felt that costs developed directly by the regression equation need not be modified for estimating the production cost of the engines as a direct extrapolation appears valid when considering that production costs are a function of product size and weight more than they are of end use.

4.90 General data used in the analysis were obtained from General Electric, Pratt & Whitney, and the Powerplant Division of the Bureau of Naval Weapons.

Regression Analysis

4.91 Regression analysis was performed using a sample of 15 engines. In the early analysis, it was found that pressure ratio and mass flow did not significantly contribute to improved correlation and therefore these variables were dropped. It was also decided that the costs of the J-47E were abnormally small as a result of the long early development and the long production run, as this engine was a direct result of the developments in World War II and was one of the first post-war engines. This engine was therefore omitted from subsequent regression analysis. The results are summarized in Table 4.19.

4.92 High correlation and adequate coefficients of variation are obtained with several combinations of variables. It was decided that thrust was a necessary variable to the CER, as a measure of stress. With considerations of the numbers of degrees of freedom and the

[redacted]

TABLE 4.19

SUMMARY OF COMPUTER ANALYSIS FOR ENGINE PRODUCTION COSTS

Variables*	Correlation Coefficient	Coefficient of Variation
(Linear Regression)		
1,2,3,4,5	.8698	.4606
1,4,6	.8835	.4374
1,5,6	.8858	.4332
2,4,6	.8858	.4332
2,5,6	.8778	.4472
1,4,5	.8902	.4291
1,4,6	.8801	.4473
2,4,6	.8843	.4399
(Nonlinear Regression)		
1,2,3,4,5,6	.9710	.2014
1,2,3,5,6	.9489	.3076
1,2,5	.8879	.4998
1,2,6	.9239	.5324
1,3,4,5,6	.9667	.2891
1,5,6	.9248	.5217
1,6	.9224	.5147
2,3	.8500	.6029
2,3,4,6	.9573	.3466
2,4,6	.9571	.3528

* Variable 1 is maximum thrust (dry) at sea level.
Variable 2 is engine dry weight.
Variable 3 thrust to weight ration (variable 1 divided by variable 2).
Variable 4 specific fuel consumption.
Variable 5 turbine inlet temperature.
Variable 6 design mach number limit.

[redacted]

physical implications of certain variables, an equation was selected whose correlation coefficient is .8858 and whose coefficient of variation is .4332. The computer printout for the equation selected is given as Table 4.20. The equation selected is:

$$\bar{C}_{E_{1200}} = \bar{C}_{E_{1200}} = -537.57 + .011333\,T + .32166F^{o}$$
$$+ 73.823\,M$$

where the definition of variables is on the foldout at the end of this volume. Profit is not included in this equation. When the equation is converted to provide the engine costs for the Nth aircraft, it becomes

$$\bar{C}_{E_N} = \bar{C}'_{E_N} = N_E\,(1000)\,[-537.57 + .011333T + .32166\,F^{o} + 73.823M]\,\frac{(R_{EM}N)^{b}}{1200^{b}}$$

where the progress curve slope is 90 percent corresponding to a value of $b = -.152$.

[redacted]

TABLE 4.20

COMPUTER PRINTOUT FOR ENGINE PRODUCTION COSTS AS A FUNCTION OF THRUST, TEMPERATURE, AND MACH NUMBER

```
COEFFICIENT SET NO. 3 OF PROD RUN 3 LINEAR

   RESID SUM OF SQRS. = , 1.2506E+05      MUTL. CORR. COEF. =   .8858

       CONSTANT TERM = -5.3757E+02
       VARIABLE    1  =  1.1333E-02
       VARIABLE    2  =  0.0000E-99
       VARIABLE    3  =  0.0000E-99
       VARIABLE    4  =  0.0000E-99
       VARIABLE    5  =  3.2166E-01
       VARIABLE    6  =  7.3823E+01

     Y OBSERVED  Y CALCULATED      DELTA       PCT DELTA
        207.40        150.42        56.97        27.47
        240.00        216.88        23.11         9.62
        163.70        206.29       -42.59        26.02
        265.00        222.58        42.41        16.00
        750.00        468.17       281.82        37.57
        725.00        710.30        14.69         2.02
        260.00        334.08       -74.08        28.49
        580.00        699.37      -119.37        20.58
        181.00        170.45        10.54         5.82
        263.30        236.64        26.65        10.12
        212.70        260.78       -48.08        22.60
        136.00        133.91         2.08         1.53
        136.00        225.13       -89.13        65.54
        199.00        283.88       -84.88        42.65

          MEAN Y OBSERVED =       308.50
       STANDARD ERROR =     133.665    FRAC. S.E. =    .4332
       MEAN DEVIATION =      65.462    FRAC. DEV. =    .2121
```

[redacted]

[redacted]

SPARES

Engine Spares

4.93 Whole engines or engine pieces are provided as initial spares for an aircraft. The number of these spares depends on fleet sizes, whether the aircraft are to be in domestic or foreign service and other factors. The cost of spares varies between 25 and 50 percent of the cost of engines for the aircraft. For a new engine or a new aircraft, the amount of spares would tend towards the higher end of this span. These considerations are equally valid for both a subsonic transport or a new supersonic transport. The cost of engine spares for both transports is given by the following equations:

Subsonic Transport

$$\bar{C}_{SPE_N} = .5\,\bar{C}_{E_N}$$

Supersonic Transport

$$\bar{C}'_{SPE_N} = .5\,\bar{C}'_{E_N}$$

Airframe Spares

4.94 The cost for airframe spares will also depend on fleet sizes and other factors. Generally, the amount of such spares will vary between something slightly less than 10 and 20 percent of the total airframe costs. A value of 15 percent is suggested as an appropriate figure for estimating purposes for a new aircraft. There is no particular reason why the cost relationship for initial airframe spares need differ for the two types of airframes being considered. Consequently the equations adopted are:

Subsonic Transport

$$\bar{C}_{SPF_N} = .15\,\bar{C}_{A/F_N}$$

Supersonic Transport

$$\bar{C}'_{SPF_N} = .15\,\bar{C}'_{A/F_N}$$

AVIONICS

4.95 As previously indicated, CERs are not developed for estimating the cost of avionics equipment. The costs of avionics are variable over a wide range and are determined at the discretion of the airline user. Consequently, it is felt that a CER would not provide a meaningful result.

4.96 Since avionics for the SST are likely to be significantly greater than for a subsonic transport, an attempt has been made to provide an assessment of what these costs might be. To this end, the Collins Radio Company and Sperry Gyroscope have been contacted to determine their impression of SST avionics costs.

4.97 Collins Radio has supplied the listing of equipment shown in Table 4.21 which they feel would be required in an SST, along with their cost estimate, in current dollars, for this equipment.

[redacted]

[redacted]

TABLE 4.21

ESTIMATED COSTS OF SST ELECTRONICS LESS ANTENNAS (COLLINS RADIO COMPANY)

System	Dual
VHF Comm	$ 5,800.00
VHF Nav	8,200.00
HF Comm	13,000.00
Selcal	2,000.00
Marker	1,100.00
ADF	4,650.00
DME	13,700.00
Transponder	7,100.00
Doppler	47,000.00
Weather Radar (with single antenna)	25,000.00
Radio Altimeter	12,000.00
Flight Director (FD-109)	40,000.00
Inertial Platform	150,000.00
Audio (Service & Entertainment)	8,000.00
	$ 337,550.00
Other Systems	
Autopilot	Not available
Flight & Maintenance Recorders	Not available
L. F. Teletype	Not available
LORAN	Not available

4.98 Sperry Gyroscope has provided an estimate of $40,000 to $80,000 for the autopilot. No estimates are available on the remaining items or antennas.

4.99 On the basis of these data, $450,000 per aircraft is assumed as the SST avionics cost.

$$\bar{C}_{AV_N} = \$450,000.$$

[redacted]

V. RESEARCH AND DEVELOPMENT COSTS

INTRODUCTION

5.1 Cost-estimating relationships are developed herein for the airframe R&D and for engine R&D. The engine development is divided into two equations, the first representing development through Military Qualification Test (MQT) and the second representing product development costs after MQT.

AIRFRAME-RESEARCH, DEVELOPMENT, TEST, AND EVALUATION COSTS

The Problem of Estimating RDT&E Costs of Airframe

5.3 The major purpose of this study was to develop methods for relating RDT&E costs in the development of a new aircraft to physical design factors of the aircraft or to economic factors involved in the program. The resulting CERs were applicable to the SST program to obtain an estimate of RDT&E costs.

5.4 It is possible to designate the independent variables on which RDT&E costs are likely to depend and to postulate reasonable alternative forms for the CERs on the basis of physical and economic principles, even without access to data. The coefficients of the CER can then be determined by the use of regression techniques applied to historic data.

5.5 In general, R&D costs result directly from the complexity of the aircraft and are compounded by managerial and economic aspects having to do with urgency of development, variability of time, and safety or other constraints and tolerances.

5.6 The following variables would be expected to have some bearing on RDT&E costs of airframes:

Type of material
Manufacturing processes
AMPR weight
Gross takeoff weight
Speed
Load factor
Number of aircraft produced
Number of components

These factors were screened to remove those having negligible impact or which were covariant with other parameters being considered. It was postulated that nonlinearity with respect to the variables might exist but would be relatively weak. Consequently, regressions against various combinations of sensitive parameters were carried out on both a linear and a nonlinear basis.

Collection of Data

5.7 The problems of obtaining coherent, homogeneous data were found to be difficult in the RDT&E area. These problems result both from the limited amount of data which were made available by the manufacturers and airlines and from poor quality of data resulting from differences in accounting methods and inability

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to determine how RDT&E costs had been aggregated. The problem required careful and laborious standardization of the cost information. In many cases the available data did not permit such standardization. Sources of historical cost information used in the present analysis were the following:

Douglas Aircraft Company
Boeing Company
Convair, San Diego, California
General Dynamics, Fort Worth, Texas
Republic Aviation
WSEG Staff Study No. 97

Regression Analysis

5.8 It would be desirable to develop at least three CERs to express the RDT&E costs. The three should provide estimates for

- a. Research and development studies culminating in prototype and manufacturing drawings,
- b. The manufacture of prototypes and
- c. The testing of prototype and the necessary redesign for manufacture.

5.9 Unfortunately the data with which to develop separate estimates for each of these phases was not available. Therefore, a single CER is developed to estimate all RDT&E costs.

5.10 The development of the CER amounts primarily to determining the coefficients that provide the best fit for each of the alternative CER forms. Screening of the historical cost data was carried out and the computer routine used to determine these coefficients.

5.11 A summary of the results of the regression analysis is provided as Table 5.1. From these results an equation was selected whose multiple correlation coefficient is .9222 and whose coefficient of variation is .6993. The computer printout for this equation is provided as Table 5.2. The equation is

$$C_{RA} = -522.69 + .46035\, V_k + 5.1477\, W_o + 3.0667 \frac{V_k}{W_o}$$

where C_{RA} is the development cost in millions of dollars.

This equation can be used to estimate RDT&E costs for both the SST and a subsonic jet transport.

[redacted]

[redacted]

TABLE 5.1

AIRFRAME RESEARCH AND DEVELOPMENT — COST-ESTIMATING RELATIONSHIPS

Variables*	Correlation Coefficient	Coefficient of Variation
1	.7849	1.1206
1,2	.9034	.7753
1,2,3	.9222	.6993
1,2,3,4	.9250	.6866
1,2,4	.9074	.7601
1,3	.8277	1.0148
1,3,4	.9023	.7793
1,4	.8991	.7918
2,3	.7996	1.0860
2,3,4	.8185	1.0388
3,4	.7693	1.1555

* Variable 1 is maximum speed in knots.
Variable 2 is weight (AMPR) in pounds.
Variable 3 is the ratio of speed in knots to weight (AMPR).
Variable 4 is the gross takeoff weight.

[redacted]

[redacted]

TABLE 5.2

COMPUTER PRINTOUT FOR AIRFRAME RESEARCH AS A FUNCTION OF SPEED AND WEIGHT

```
COEFFICIENT SET NO. 3 OF EST RED COSTS LIN

    RESID SUM OF SQRS. = , 1.9327E+05      MUTL. CORR. COEF. =   .9222

        CONSTANT TERM = -5.2269E+02
        VARIABLE    1 =  4.6035E-01
        VARIABLE    2 =  5.1477E-00
        VARIABLE    3 =  3.0667F-00
        VARIABLE    4 =  0.0000E-99

      Y OBSERVED  Y CALCULATED      DELTA        PCT DELTA
        158.10         145.50        12.59           7.96        CV880
         79.80         155.79       -75.99          95.23        DC8
         45.70         114.45       -68.75         150.45        KC135
         24.30          14.16        10.13          41.69        B47
        221.10         322.65      -101.55          45.92        B52
        292.80         283.58         9.21           3.14        B58
        129.20           7.12       122.07          94.48        F102
        182.00         319.05      -137.05          75.30        F106
         79.40         301.96      -222.56         280.30        F105
       1275.90        1113.73       162.16          12.71        RS70
        159.90         103.39        56.50          35.34        A4
        136.00         -69.93       205.93         151.42        A30
         79.50         -25.32       104.82         131.85        F40
         70.00         147.47       -77.47         110.67        707

            MEAN Y OBSERVED =        209.55
        STANDARD ERROR =        146.542     FRAC. S.E. =    .6993
        MEAN DEVIATION =         97.631     FRAC. DEV. =    .4659
```

[redacted]

[redacted]

PROPULSION—RESEARCH, DEVELOPMENT, TEST, AND EVALUATION COSTS

The Problem of Estimating R&D Costs of Jet Engines

5.12 Although many manufacturers have produced jet engines since the early 1940's, among them being the Allison Division of General Motors, Wright Aeronautical Corporation, Pratt & Whitney, General Electric Company, Lycoming, and Solar aircraft, only two manufacturers—General Electric and Pratt & Whitney—have produced, in terms of thrust, engine weight or dollars, substantially all of the large jet engines to date. All current commercial jet aircraft in the U.S., use either Pratt & Whitney or General Electric engines or, in a few cases, English-built engines. Turboprop engines for commercial aircraft are manufactured by Allison and English engines are also used. The French Caravelle has an English-built engine.

5.13 In many cases, essentially the same engines were used in totally different applications. Examples: the B-52 eight engine swept wing bomber and the F-102 delta wing fighter both use a Pratt & Whitney engine; the straight wing F-104 fighter and the B-58 four-engine delta wing bomber both use the same General Electric engine.

5.14 Furthermore, the current Pratt & Whitney and General Electric Company commercial engines were evolved from a previous generation of experience in military engines, in many cases by a direct conversion to commercial use.

5.15 This then reduces the number of information data points available as there are not as many diverse designs in engines as there are in aircraft. Jet engines may be categorized in terms of diameter and thrust. Two examples are the Pratt & Whitney J-57 and the General Electric J79, both in the 10,000-lb thrust class. The sizing of engines has been somewhat standardized to meet a broad spectrum of airframe requirements. Diameters, for instance, have been held fixed for installation purposes, while thrust has been increased.

5.16 One distinguishing variables of engines, however, is thrust augmentation, accomplished in the past by afterburners which are basically constructed of sheet metal and which add in some cases as much as 50 percent thrust for smaller increases in weight. In attempting to correlate costs to engine characteristics, therefore, engines should be considered without the afterburner weight or thrust where this is possible or where the numbers are significantly different. The other method used to date for thrust augmentation has been the bypass or fan type engine, the fans being in the forward or aft end of the engine producing an air flow that contributes as much as a 30 percent increase to thrust. Engines of this variety to date have many components interchangeable with the basic non-fan engine and they are generally considered as growth versions.

5.17 The SST studies have examined another means of thrust augmentation by introducing a secondary burner that is not in the high thrust noncontinuous operation class of afterburners. However, little cost data are available in this area.

5.18 Therefore, cost relating must necessarily be based on limited historical data, covering only a few engines of quite similar characteristics. This is true despite the long listing of jet engines available

[redacted]

in the literature, since either very few were made or unusual economic factors were involved affecting basic costs. Stratification of engines by fan types only further reduces the number of historical cost samples.

5.19 General Electric Company, Pratt & Whitney, and The Powerplant Division of the USN Bureau of Weapons were extremely helpful in supplying detailed physical parameters and engine costs. These data included thrust, weight, SFC, turbine inlet temperature, bypass ratio, mass flow design, mach number, etc.

5.20 Cost data were obtained in the form of total dollars for production and total dollars for development with some breakouts for specific quantities. Based upon the convex shape of the cumulative cost curve and the assumption that thrust, weight, SFC and turbine inlet temperature, mach number, and pressure ratio would affect cost, various regression analysis computer runs were made.

5.21 Cost would logically be expected to correlate positively with weight, and with increases in efficiency brought about by various refinements; thus decreasing the SFC would also lead to higher cost. Similarly, increases in specific thrust would require development effort leading to a higher R&D cost.

5.22 It would further be expected that, as operating temperatures increase, costs of materials, of processes, of design, to handle these higher temperatures, would all go up, as would subsequent overhaul and maintenance costs. Pressure ratios and operation mach number would be expected to affect costs by placing constraints upon the aerodynamic designer.

5.23 Initially two engine development cost regression analyses were made. The first run utilized thrust, weight, specific weight, SFC, turbine inlet temperature and maximum mach number. The independent variable was total development dollars.

5.24 The second run used as independent variables thrust, specific weight, SFC, turbine inlet temperature, pressure ratio, total development time in months against total development dollars as the independent variable.

5.25 An analysis of the correlations revealed that development costs should be divided into two phases—initial design phase and the product development phase that occurs basically after the unit has gone into production and after the MQT and is utilized to make refinements in reliability and performance of engines.

5.26 A subsequent run was made separating these two phases and the variables used.

Regression Analysis—Initial Design Phase

5.27 Total engine development costs up to and including military qualification test (MQT) can be estimated by the equation derived from the input data and the computer run shown in Tables 5.3 and 5.4.

5.28 Although better correlations showed up in other runs, the independent variables were not representative of current engine cost factors nor especially significant to the SST engines where the extrapolations in thrust may be up to 100 percent more than the

[redacted]

TABLE 5.3

ENGINE INPUT DATA DEVELOPMENT COSTS TO MQT

Max. Thrust	Weight	T/W	SFC	Max. Mach No.	Development Dollars (000000)
DEV RUN1	LINEAR	7	.550		
DEV RUN1	LOG	7	.550		
10600.	4065.	2.61	.785	0.90	112.0
17000.	4140.	4.11	.555	0.90	149.0
8500.	2044.	4.16	.820	1.80	95.8
15800.	5960.	2.65	.907	0.90	160.0
18500.	3838.	4.18	.620	2.20	147.0
32500.	6300.	5.00	1.530	3.20	300.0
10900.	3345.	3.26	.860	2.40	136.0
30000.	5220.	5.45	1.030	3.00	310.0
3450.	325.	7.54	.975	1.90	101.0
10000.	3980.	2.51	.960	2.00	70.3

[redacted]

[redacted]

TABLE 5.4

COMPUTER PRINTOUT FOR ENGINE DEVELOPMENT COSTS TO MQT

```
COEFFICIENT  SET  NO. 6 OF  DEV  RUN1  LINEAR

    RESID  SUM  OF  SQRS. = , 5.5814E+03       MUTL. CORR. COEF. =    .9530

        CONSTANT  TERM  = -7.8195E+01
        VARIABLE    1   =  6.9417E-03
        VARIABLE    2   =  0.0000E-99
        VARIABLE    3   =  0.0000E-99
        VARIABLE    4   =  0.0000E-99
        VARIABLE    5   =  6.9845E-02
        VARIABLE    6   =  3.0881E-00

      Y OBSERVED   Y CALCULATED        DELTA        PCT  DELTA
        112.00        108.52            3.47           3.10
        149.00        150.15           -1.15            .77
         95.80         98.12           -2.32           2.42
        160.00        146.01           13.98           8.74
        147.00        194.61          -47.61          32.39
        300.00        296.98            3.01           1.00
        136.00        128.85            7.14           5.25
        310.00        285.99           24.00           7.74
        101.00         66.16           34.83          34.48
         70.30        105.65          -35.35          50.29

                MEAN Y OBSERVED =          158.11
            STANDARD ERROR =          43.133      FRAC. S.E. =    .2728
            MEAN DEVIATION =          17.291      FRAC. DEV. =    .1093
```

[redacted]

largest current engine, turbine inlet temperatures may be 30 percent higher, and a mach number of 3 as compared to 0.9 for present commercial jets. It was felt that R&D costs would be most sensitive to these parameters. Therefore, an equation of lower correlation but using thrust, turbine inlet temperatures, and mach number was selected. When time is available for a more penetrating assessment of data and the possible addition of more data points by detailed examination of all engines manufactured to date, a greater correlation will definitely be possible.

5.29 The CER for engine developments costs to MQT is

$$C_{ED} = .0069417\,T + .069845\,F^{O} + 3.0881\,M - 78.195$$

where

T = Maximum thrust (augmented) in pounds — sea level static standard day

F^{O} = Maximum temperature at turbine inlet in Fahrenheit degrees

M = Maximum design mach number for engine

C_{ED} = Estimated total development cost in millions of dollars through MQT or commercial equivalent. Profit not included.

5.30 Total engine product development costs after MQT and occurring during the production cycle were developed from data in Tables 5.5 and 5.6.

Regression Analysis—Post MQT Phase

5.31 Examination of the computer runs reveals that the number of months an engine is in production will be a major factor affecting production development costs. This fact is graphically depicted by data from the Powerplant Division of the USN Bureau of Weapons.

5.32 Therefore, the equation for production development cost has as an independent variable the time in months of the production development cycle. It is apparent that after the design phase has been completed, development emphasis shifts from items such as air speed or engine temperature, to factors such as the length of time required to refine engine performance and reliability.

5.33 An example of higher costs in both the production and product development phases occurs in design sophistications, i.e., cooling methods to accommodate high turbine inlet temperatures.

5.34 Although it is known that considerable testing—primarily military—preceded the advent of commercial jet engines, the time allotted to this study would not permit further analysis of this potentially high cost factor in the development of SST propulsion systems. Recommendations for this area of investigation coupled with the future possibility of access to classified data on current high-temperature, high mach engines could result in an estimate of the expected additional cost of tests.

5.35 The CER equation for engine product development is

$$C_{PD} = .0033063\,T + .097411\,F^{o} + 1.8758\,D_P - 193.86$$

where

T = Maximum thrust (augmented) in pounds — sea level static standard day

F^{o} = Maximum temperature at turbine inlet in Fahrenheit degrees

D_P = Product development time in months

C_{PD} = Estimated production development costs — millions of dollars after MQT.

[redacted]

TABLE 5.5

JET ENGINE PRODUCT DEVELOPMENT INPUT-PHYSICAL CHARACTERISTICS AND COST DATA

Thrust	T/W	SFC	Development Dollars per Month In (000)	Months of Product Development	Product Development Cost
SD-5 PRODUCT DEV		7			
10600.	2.61	.785	2165.	133.	288.0
17000.	4.11	.555	2227.	44.	98.0
8500.	4.16	.820	1189.	54.	54.2
15800.	2.65	.907	1786.	84.	150.0
18500.	4.18	.620	2294.	34.	78.0
10900.	3.26	.860	3114.	88.	274.0
3450.	7.54	.975	1000.	50.	50.0
7700.	2.80	.915	1048.	126.	132.0
10000.	2.51	.960	3088.	42.	129.7

[redacted]

[redacted]

TABLE 5.6

JET ENGINE PRODUCT DEVELOPMENT SELECTED EQUATION

```
COEFFICIENT SET NO.14 OF SD-5 PRODUCT DEV

    RESID SUM OF SQRS. = , 2.5462E+04       MUTL. CORR. COEF. =   .7567

         CONSTANT TERM = -1.9386E+02
         VARIABLE    1  =  3.3063E-03
         VARIABLE    2  =  0.0000E-99
         VARIABLE    3  =  0.0000E-99
         VARIABLE    4  =  9.7411E-02
         VARIABLE    5  =  0.0000E-99
         VARIABLE    6  =  1.8758E-00

      Y OBSERVED  Y CALCULATED        DELTA        PCT DELTA
        288.00         244.57          43.42          15.07
         98.00          94.89           3.10           3.16
         64.20          91.39         -27.19          42.35
        150.00         171.80         -21.80          14.53
         78.00         122.98         -44.98          57.67
        274.00         180.15          93.84          34.25
         50.00          71.09         -21.09          42.18
        132.00         217.96         -85.96          65.12
        129.70          68.97          60.72          46.82

            MEAN Y OBSERVED =        140.43
         STANDARD ERROR =       112.833     FRAC. S.E. =   .8034
         MEAN DEVIATION =        44.681     FRAC. DEV. =   .3181
```

[redacted]

VI. SPECIAL COST CONSIDERATIONS

INTRODUCTION

6.1 The supersonic transport represents state-of-the-art development in many different respects. It is an aircraft that differs substantially from any other commercial transport ever designed and also differs significantly from any operational military aircraft. This chapter is provided to discuss the effects on cost of some of the state-of-the-art advances and their implication on the CERs.

STATE-OF-THE-ART ADVANCES

6.2 The SST is a heavy, mach 3 aircraft whose operational modes present design and manufacturing problems in which experience is minimal and localized. Consequently, the builder of the SST can look forward to problems of

a. Articulated fuselage or wing sections

b. Design and manufacture of titanium components and sections

c. Design and manufacture of high-temperature aircraft systems

d. Design and manufacture of high-performance mach 3 engines and engine inlets

e. Design and manufacture of avionic systems using increased automation

f. Design and manufacture of an economical aircraft for airline users

g. Design of an aircraft whose noise and sonic boom characteristics meet acceptable standards and, perhaps, many other problems as well.

6.3 The history of aircraft design has been such that aircraft, both military and commercial, have grown continually in sophistication and complexity. The growth is reflected in increased costs as aircraft have become larger and faster. Multivariate regression analysis using cost as the dependent variable therefore develops equations that reflect the historical engineering and manufacturing progress made. In using the resulting equations as predictors of cost when extrapolating beyond the sample range of independent variables, the assumption is implicitly made that the rate of future progress is the same as past progress. If the assumption cannot be made as regards some specific technological advance, then a correction to the regression equation should be made.

6.4 In using the regression equation for the SST, it must be decided which known advances fall within the area of normal advance and which are so special that the equation should be modified to reflect the implication on cost. A normal advance could be defined as one where the slope of the regression line adequately reflects the increase in cost resulting from the incremental increase in an independent variable.

6.5 An examination of SST design indicates two characteristics that suggest cost increases that cannot be explained by the slope of the regression line:

a. The articulated features of nose or wings, and

b. The extensive use of titanium.

All other design and manufacturing advances were considered normal state-of-the-art advances, and, consequently, no special implications on cost were considered.

6.6 An attempt was made to obtain data on the F-111 because this aircraft does have hinged wings designed to move in flight. Unfortunately, however, the manufacturer of that aircraft was not prepared to discuss the implications on cost that this design feature may be causing. No other aircraft design has such features. Therefore, there was no one to whom ORI could address questions of the implications on cost resulting from such design characteristics. Consequently, for lack of data only, the final CERs developed herein did not take special recognition of this peculiar design feature which may be incorporated in SST configurations. It is possible, however, that the articulated nose or wing would not have significant or abnormal effects on cost.

[redacted]

DEVELOPMENT OF TITANIUM COST MULTIPLIERS

6.7 It is necessary to consider the implications on investment cost resulting from the extensive use of titanium in the SST airframes. To this end, multiplying factors are developed which are applied to the CERs developed from the aluminum airframes comprising the samples to provide an estimate of the manufacturing cost of titanium. The cost multipliers are developed herein with consideration given to the fraction by weight of the titanium used.

6.8 The information used for this analysis was obtained from the following sources:

a. An interview with Mr. Kelly Johnson, Vice President of the Lockheed Corporation and developer of the titanium airframe, A11.

b. Titanium cost data received from the Boeing Airplane Corporation.

c. Boeing and Lockheed SST proposals of January and November 1964.

6.9 The following data, obtained from the proposals identified above, are used:

Titanium content of airframes proposed in November 1964 proposals:

Lockheed	71 percent of AMPR weight
Boeing	58 percent of AMPR weight

Labor cost multiplier, T_L:

Lockheed	2.1
Boeing	1.6

Tooling cost multiplier, T_{TO}:

Lockheed	2.0
Boeing	2.1

Materials cost multiplier, T_M:

Lockheed	4.5
Boeing	4.5

6.10 The following assumptions are made to develop the cost multipliers:

a. The cost multipliers for production labor, tooling, and materials vary linearly with changing percentage of titanium in the structure.

b. The data on cost multipliers supplied by the Lockheed Corporation are more nearly correct than that supplied by Boeing. This assumption is made on the basis of the more recent and extensive experience of Lockheed in constructing the A11.

6.11 Boeing and Lockheed use different amounts of titanium in their respective designs. Boeing's design contains 58 percent by weight of titanium and Lockheed's design contains 71 percent. Because of this difference it is necessary to make an additional assumption.

a. It is assumed that the airframe which employs less titanium uses steel and other alloys to make up the difference and that the cost multiplication factor for these other alloys is half that of Lockheed's titanium factor.

6.12 The procedure for determining a specific cost

[redacted]

multiplication factor is described below with references to Figure 6.1. The figure provides a graphical representation of the method used to determine a multiplication factor for an airplane whose titanium content is something less than the 71 percent of the Lockheed design.

a. Point A on the figure is the specific multiplication factor picked by Lockheed for their 71 percent titanium airframe.

b. Because of the assumption that the cost multiplication factor varies linearly with percent titanium content, the line between the origin and A represents the functional relationship between cost multiplier and titanium content. The slope of this line is k_2.

c. To find the cost multiplier for an airframe whose titanium content is X, move to point B on the line vertically above X.

d. If aluminum and titanium were interchangeable in the airframes under consideration, the cost multiplier would correspond to the ordinate of the point B. However, in high-speed aircraft, steel and other alloys would probably be used in the structure where titanium is not used. It is therefore necessary to make a correction to the cost multiplier for these other materials.

e. The cost multiplier for steel and other alloys is assumed to be half that of titanium. The function which expresses the lower cost multiplier is represented by the line between the origin and point D. This line has slope k_1. Line BC is drawn parallel to the line between the origin and point D. Since point B represents an airframe with reduced titanium content (less than Lockheed's design), it is necessary to move up the slope k_1 to point C to reflect the substitution of the steel and other alloys in lieu of titanium. The ordinate of point C which is shown as y_0 is the resulting cost multiplier.

$$k_2 = (y_2 - y_1)/.71$$

$$k_1 = \frac{(y_2 - y_1)/2}{.71}$$

$$y_0 = y_2 - y_3 + y_4$$

$$k_2 = y_3/(.71 - x) \text{ therefore, } y_3 = k_2\,(.71-x)$$

$$k_1 = y_4/(.71 - x) \text{ therefore, } y_4 = k_1\,(.71-x)$$

$$y_0 = y_2 - k_2\,(.71 - x) + k_1\,(.71 - x)$$

$$y_0 = y_2 - (.71 - x)\,(k_2 - k_1)$$

$$y_0 = y_2 - (.71 - x)\left[\frac{(y_2 - y_1)}{.71} - \frac{(y_2 - y_1)}{2(.71)}\right]$$

since $y_1 = 1$

$$y_0 = y_2 - (.71 - x)\left[\frac{(y_2 - 1)}{.71} - \frac{(y_2 - 1)}{2(.71)}\right]$$

where y_0 = the calculated cost multiplier for an airframe whose titanium content is given by X,

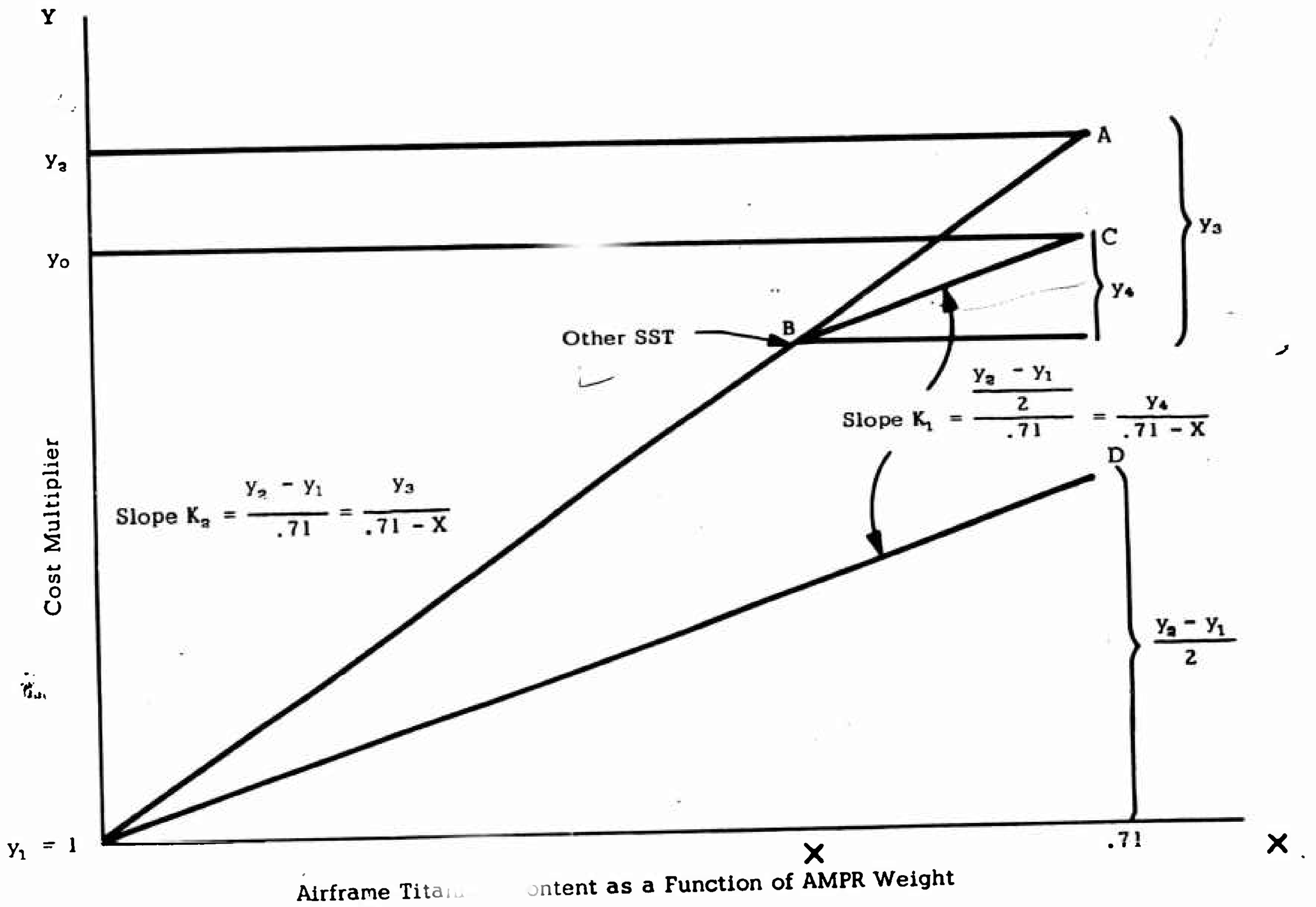

FIGURE 6.1. DEVELOPMENT OF A COST MULTIPLIER TO REFLECT VARYING TITANIUM CONTENT

X = the fraction of the AMPR weight of the airframe which is titanium,

y_2 = the cost multiplier of the 71 percent titanium airframe as calculated by Lockheed.

6.13 By substitution of appropriate terms, the factors T_L, T_{TO}, and T_M are given below:

$$T_L = 2.1 - (.71 - X)\left[\frac{(2.1 - 1)}{.71} - \frac{(2.1 - 1)}{2(.71)}\right]$$

$$T_L = 2.1 - (.71 - X)(1.55 - .775)$$

$$T_L = 2.1 - (.71 - X)(..55)$$

$$T_L = 2.1 - .55 + .775X = 1.55 + .77X$$

$$T_M = 4.5 - (.71 - X)\left[\frac{(4.5 - 1)}{.71} - \frac{(4.5 - 1)}{2(.71)}\right]$$

$$T_M = 4.5 - (.71 - X)(4.93 - 2.46)$$

$$T_M = 4.5 - (.71 - X)(2.47) = 4.5 - 1.75 + 2.47X$$

$$T_M = 2.75 + 2.47X$$

$$T_{TO} = 2.0 - (.71 - X)\left[\frac{(2.0 - 1.0)}{.71} - \frac{(2.0 - 1.0)}{2.(.71)}\right]$$

$$T_{TO} = 2.0 - (.71 - X)(1.42 - .71)$$
$$= 2.0 - (.71 - X)(.71)$$

$$T_{TO} = 1.50 + .71X$$

6.14 The equations for T_L, T_M, and T_{TO} are submitted in the previous listing of SST investment equations.

6.15 The cost multipliers developed herein are based on a limited amount of information pertinent to airframe designs in which the basic structure is predominantly titanium. The raw data used was developed by Lockheed for their design which contains 71 percent titanium. Since it is recognized that the assumptions made, particularly that of linearity of the cost multiple, are probably inadequate over a large range, the use of multipliers should be restricted. It is recommended that they not be used for an airframe whose titanium content is less than 50 percent of the AMPR weight, nor more than 71 percent.

[redacted]

AVIONICS DEVELOPMENT

6.16 The SST designs will require blind landing systems and other flight-control devices that are not currently operational. Therefore, some development costs can be expected before these devices can be installed in an SST. However, it is assumed that such devices will have to be developed in the near future, whether or not an SST is designed. It is concluded that the avionics development costs are not a result of the SST implementation but are instead a totally independent variable that should not be the concern of SST planners. For this reason, avionics development costs have not been considered in the current study.

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VII. RECOMMENDATIONS FOR FUTURE RESEARCH

INTRODUCTION

7.1 During the course of this study, a number of conclusions were noted, bearing both on the immediate problem of developing and applying a method for estimating SST costs and on the longer range problem of improving the applicability and usefulness of CER techniques. These conclusions and recommendations for further study or development effort are indicated in the following paragraphs.

7.2 The recommendations discussed are corollary to the principal findings of the study, which include the specific equations developed and the cost estimates of the various SST configurations derived therefrom. These findings are discussed in other sections of this report and are not repeated in this section.

RESEARCH LEADING TO IMPROVED ESTIMATES OF SST COSTS

Expansion and Refinement of CER Data Base

7.3 The CERs presented in the report are based on the historical data that were obtainable within the required schedule; the data base is therefore necessarily limited in terms of comprehensiveness and accuracy. Specifically, certain data elements—in particular those pertaining to the A-11 and F-111—were not available in time for inclusion in this study. Since these aircraft embody many of the advanced supersonic design characteristics, their cost histories would provide a valuable basis for validating the CERs or introducing the modifications needed to account for particular engineering features. It would also be desirable to refine the CERs by incorporating data from commercial aircraft, subsonic engine programs, and other aircraft that have not been included to date (e.g., the data from "Project Back-fill") as they become available.

7.4 In addition, certain data points that have been included in this analysis require further consideration with regard to their accuracy and validity. The extremely large variances that were observed in the computation of these CERs may be attributable to differences in definition of cost categories or to variations in accounting practices in addition to "real" cost factors. An attempt should be made to segregate the variation attributable to each of these factors in those cases in which the raw data points appear questionable.

7.5 It is recommended that the current cost analysis effort be continued, in parallel with the recently extended manufacturer's studies, in order to permit additional expansion and refinement of the data base used to derive the CERs. Specifically, this effort would include:

a. Acquisition of data pertaining to the A-11 and to the F-111 aircraft with particular attention to the cost impact of design features relevant to the SST, e.g., wing and nose and wing articulation, turbine cooling, use of titanium, etc.

b. Acquisition of additional data pertaining to commercial aircraft.

c. Incorporation of military aircraft data being developed under "Project Back-fill."

d. Analysis of previously acquired data points to assess, where possible, the extent to which differences in cost terminology and accounting practice impair the validity of the data.

Refinement of CER Coefficients

7.6 It is felt that the expanded data base recommended in the foregoing paragraphs will permit a more accurate evaluation of CER coefficients in several important cases.

a. Maintenance. The maintenance CERs were developed from cost data that had a high variability, stemming partly from lack of standard definitions of accounting practice and aircraft characteristics and partly from a lack of data. These equations should be reviewed, using additional data or a selected "typical" sample.

b. Foreign Carrier Differentials. The development of the coefficients relating foreign carrier costs to domestic carrier costs was based on limited data and should be further examined.

c. Ground Equipment and Preoperating Costs. The accuracy of both of these categories is limited, owing to the lack of data and the time constraints that existed.

d. R&D Costs. The small sample size, particularly with respect to airframes, should be expanded and the data refined. Further tests would be desirable, since all available data were incorporated in the CERs.

Engineering and Operational Investigations

7.7 The cost analysis conducted by ORI has pointed up a number of cost sensitive subsystems and operations. It is suggested that future study by the engine airframe manufacturer is needed in the specific areas discussed in the following paragraphs, either to evaluate engineering alternatives or to obtain more accurate estimates of the cost.

7.8 Alternative Engine Configurations. It is assumed that an analysis has already been made by the Govenment or by the engine manufacturer of the feasibility of adapting the British Olympus engine for use

[redacted]

on the SST. If such a study has not been undertaken, it is suggested that engine development costs could be greatly reduced if the Olmpus engine should prove acceptable.

7.9 Development of Fuel Consumption Equation. Fuel consumption for an aircraft depends, in a complex way, upon the engine thrust, L/D ratio, climb out and cruise profile, wind velocity, temperature, and other factors. An examination of existing literature has failed to locate equations in which all these factors are considered simultaneously. Since fuel cost constitutes an important part of the SST operating cost, it is suggested that a computer program be developed to estimate fuel cost as a function of these parameters.

7.10 Analysis of Projected Time Between Overhaul (TBO). It is anticipated that the higher engine operating temperature that the SST will experience, combined with the higher stress and utilization profiles, will lead to a shortened TBO for the engine. Although the cost of such added stress is accounted for in the CERs for engine maintenance, it is likely to be considerably more severe for the SST than the experience on which the CER is based, and the possibility of physical nonlinearities or discontinuities in the resultant strain cannot be overlooked. The SST, for example, will operate at maximum thrust and temperature for a significant portion of its flight time, say 50 percent, as compared with less than 5 percent for current subsonic jets.

7.11 In addition, progenitors of the SST engine do not exist and the engine, when it becomes operational, will not have the advantage of extensive prior flight testing. Consequently, the initial TBO is likely to be low until sufficient experience and confidence can be established. It is recommended that an engineering evaluation of these problems be undertaken to develop relationships between test hours, TBO, and operating temperatures.

Testing and Validation of CERs

7.12 The foregoing recommendations pertain to the expansion of the data base, the derivation of more accurate coefficients for the CERs, and the conduct of engineering studies of particular design and operating features. It is recommended that the results of these efforts be used as the basis for a more thorough program of testing and validation of the CERs than could be undertaken in this initial effort.

7.13 It is felt important that more exact estimates of confidence or uncertainty be developed for each of the CERs, incorporating not only the variance resulting from the statistical sampling, but also the uncertainty caused by changes in physical or engineering characteristics over the range of extrapolation. In this report, development of several of the CERs required the use of every available data point in order to acquire an adequate sample. Consequently, an independent check was not possible. The analysis should therefore be checked more thoroughly by applying the equations to aircraft not included in the present sample.

7.14 A major source of uncertainty in the extrapolation of the CER beyond the range of historical experience lies in the possibility that discontinuities

[redacted]

in behavior of the underlying physical or engineering factors exist. The cost of engine maintenance, for example, should correlate not only with imposed stress, but also with the strength moduli of the material and other physical parameters. It is suggested that equations describing the engineering principles be incorporated into the SST methodology so that valid extrapolations can be made over longer ranges. A feasibility test of this approach is recommended in which data on early subsonic jet engines would be extrapolated on an engineering basis to predict operating costs for modern supersonic engines; the resulting predictions would then be tested against existing data.

LONG-RANGE IMPROVEMENTS OF CER TECHNIQUES

Standardization of Cost Reporting Practices and Definitions

7.15 Available data on investment and development costs from which CERs are derived are ambiguous for a number of reasons:

a. Differences in accounting practices between contractors

b. Changes in accounting structure over a period of time within a given contractor's organization

c. Lack of standard definitions specifically identifying tasks and cost associated with major end-item elements.

7.16 The lack of precision in the underlying data leads to CERs with confidence characteristics that limit their value in cost predicting. It is axiomatic that improvements in cost estimating can be obtained if the level of detailed cost consideration is increased. It is also obvious that confidence characteristics can be improved if historical costs can be positively verified and identified with specifically defined tasks or subsystems. It is clear that significant improvements in developing and using CERs for estimating the cost of airframes or engines cannot be obtained until detailed definitions and standards of reporting are established and implemented.

7.17 It is understood that Department of Defense Directive 5100.39, which establishes a Cost and

Economic Information System (CEIS), requires standardization of definitions of cost categories, establishment of formats for data collection, and development of an information system. In the development of CEIS, it is recommended that attention be directed to the results of this analysis, in particular to the areas where field data were found to be unavailable or ambiguous, and where standardization of accounting procedures would be valuable.

7.18 It is further suggested that definitions of aircraft and engine characteristics be sharpened and that data on such characteristics be made available through a central point associated with the CEIS. Potential sources of ambiguity in present performance data, for example, include the broad range of weight definitions (AMPR, gross takeoff, ramp, operating, etc.) and the alternative speed definitions (maximum, cruising, speed at optimum altitude).

7.19 The combined cost and characteristics data information system should be continually updated and capable of supporting rapid development of CERs. The feasibility of automating the system should be examined so that selected sample data can be drawn from storage according to design criteria, a multivariate analysis performed, and a CER developed or updated. The system should be designed to handle data from both military and commercial aircraft and engines.

Improvement of Statistical Techniques and Practice

7.20 The multiple regression approach to the development of CERs is apparently straightforward and widely used. This approach is based on the assumtions, among others, that the data constitute a homogenous sample and that there is no correlation among the independent variables (usually the speed and performance characteristics). Although it is well known that these assumptions are frequently violated, the magnitude of the resulting error is unknown. Consequently, results are reported without a corresponding statement of the associated nonsampling errors that may be present. This practice is often defended on the grounds that the error is small. Unfortunately this need not be the case; the occurrence of highly peculiar and contradictory results is frequently noted.

7.21 It is recommended that recent research in relevant statistical techniques be reviewed for possible use in the development of CERs and that it be supplemented by additional research where needed. Specific areas to be considered include:

a. Use of recently developed techniques for "the rejection of outliers" to provide an objective test of whether particular data points are too extreme for inclusion in the analysis.

b. Assessment of the "robustness" of the multiple regression techniques, i.e., the extent to which the results are distorted or invalidated if the underlying assumptions are not met. This is particularly important since the design and performance characteristics, assumed to be independent, are instead often strongly interrelated; a flat

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contradiction of a basic assumption underlying the regression model.

These recommendations pertain to the basic CER approach in use today; the following paragraphs suggest alternative approaches that are quite different conceptually and that may replace or supplement existing techniques.

Analysis of the Input-Output History of a Firm

7.22 It appears likely that the cost of major programs conducted by a given company is strongly influenced by the level of corporate activity, the duration of the program, the availability of manpower and facilities, and other factors that are only vaguely related to the specific characteristics of the system under development. These effects are ignored in the conventional CER approach that is program rather than firm oriented. Further, in using data points from programs conducted by different firms there is the possibility that procedures for allocating costs among programs differ from firm to firm.

7.23 An alternative approach to the problem of cost estimation that should be explored is that of relating the fixed and variable costs of a firm, over a period of years, to the nature and mix of programs in process. This may be thought of as an approach to determining the temporal changes in input-output characteristics of a single firm rather than aggregating a number of programs extracted from different firms and time periods.[1]

7.24 Some potentially appealing features of this approach can be summarized as follows:

a. The incremental costs of new programs can be evaluated from the year-to-year differences in costs and outputs, e.g., units produced, developments completed, etc.

b. The allocation of costs among programs can be checked, at least partially, since total costs must be accounted for. Even this relatively gross check is not possible under the usual CER approach.

c. The impact on a particular program of the level and composition of a company's workload is explicitly considered. This is particularly important when, as in the case of the SST, the program will be awarded to a single major firm and performed in a period in which the level of activity will be sharply different from past averages.

d. The effect on cost estimates of firm-to firm differences in accounting systems is minimized.

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[1] The difference is analagous to that between the use of cross-sectional vs time series data in economic analysis. The analogy is also applicable since the approaches are supplementary.

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R&D Cost Estimations Using Time-Cost Functions

7.25 During the course of this study ORI has noted that certain airframe or engine R&D programs exhibit similar cost histories when observed as a function of total R&D cost against time. It is suggested that mathematical equations could be developed to express cumulative R&D costs as a function of time and of the sensitive parameters of the program if the underlying reasons for such similarity were understood. Rather than relating R&D cost to design (or other) parameters at a single point in the program, this approach would propose to relate similar cost histories to underlying design or program parameters. Potentially, this approach represents a powerful tool in program planning. A detailed analysis would be made of similar R&D projects in an attempt to determine their areas of similarity and the relationships between tasks and time to accomplish them. The resultant equations would permit a priori description of the most likely cost buildup during the program and of the final cumulative cost.

7.26 It is further suggested that the initial rate of expenditure during the early stages of the program would provide a means for dynamically updating and modifying the original estimate of cost history.

7.27 It is recommended that a study be undertaken to examine the feasibility of predicting cumulative R&D costs by developing standard expenditure curves for different types of programs, using such curves to extrapolate total cost histories, and updating these histories by reference to the R&D expenditures made early in the program. The study would consist of detailed analyses of R&D expenditures of similar projects to determine the underlying relationships between the development tasks, the time required, and the ultimate cost.

7.28 If successful, the resulting models would provide an independent check for development programs that are already underway of the R&D cost estimates developed from conventional CERs. Further, it would provide an improved capability to predict the effect on cost of accelerating or decelerating the project schedule.

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VIII. DATA SOURCES

CONTACTS AND DATA SOURCES

8.1 Planned contacts with the aircraft and engine industries were carried out to develop data bases of performance, physical characteristics, and cost information. In addition, many Government contacts were of value to the data collection portion of this study. Table 8.1 shows the six areas of information requirements and the general availability. Performance, physical characteristics, and cost data were obtained in varying degrees by direct contact on the aircraft and engines indicated in Table 8.2.

TRIP REPORTS

8.2 . A brief description of plant visits is given, outlining the basic results. The collected data is exhibited in Volume IV, Appendix A.

BIBLIOGRAPHY

8.3 A listing of direct and associated literature in the general field of cost estimating and some specific articles on the SST are provided. The bibliography resulted from ORI's contacts which uncovered much of the standard information in existence, and from actual reference to previous published bibliographies.

8.4 The following pages provide details in each of these areas.

TABLE 8.1
GENERAL AVAILABILITY OF DATA

	RD T&E	Production (Investment)	Operations and Maintenance
Aircraft	Fair[1] to Poor	Good[2] to Excellent	Good
Engines	Good to Excellent	Excellent[3]	Good[4]

[1] Difficult to separate out R&D costs.

[2] Changing designs and overhead structures require analysis of data.

[3] Fixed high production but only a few types.

[4] Costs may reflect peculiar immediate problems or be prorated.

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TABLE 8.2

REPRESENTATIVE AIRCRAFT AND ENGINES ON WHICH DATA HAVE BEEN OBTAINED

Aircraft	Engines
F-102	JT3C
F-104	JT4A
F-105	JT3D
F-106	J57-P
A 3	TF33-P
F 4D	J75
A 4D	J52
B-47	JT8D
B-52	J93
KC-135	J79
B-58	J47
B-70	J85
DC-8	CJ805
DC-6,7	J65
CV 880, 990	J71
707	J58
720 B	
Constellation	

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CONTACTS AND DATA SOURCES

ORGANIZATION	NAME
Boeing Airplane Co. Box 707, Renton, Wash. (206) 237-	Robin K. Little, Manager Market Research Ext. 2121
	Waldo E. Johnson, Tooling - Supvr, SST Ext. 4389
	Walter C. West, Finance Manager, SST Ext. 4389
	Richard E. Lingen, Proj. Chief Mgr. Dev. SST
Convair 3302 Pacific Highway Box 1950, San Diego, Cal. (717) 296-	L. J. Bordelon, Assistant to Pres., Contract & Sales Ext. 6611
	C. L. Meador, Vice Pres. of Contracts, Ext. 2064
	D. W. Diggs, Special Asst., Ext. 694
	G. R. Vetter, Contracts Ext. 666
Washington, D.C. 298-6600	Clifford Leachelien

ORGANIZATION	NAME
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	Cliff C. Walton, Mgr. of Pricing Ext. 2092
	Frank R. Ruelke, Supervisor R&D Advanced Sys. Pricing Ext. 3719
General Dynamics P. O. Box 748 Fort Worth, Texas (817) PE 2-	J. T. Cosby, Vice Pres., Prog. Director F111 Ext. 4811
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	Thomas F. Fowlkes, Chief of Cost Research Ext. 3283
	C. G. Fuqua, Project Operations Analysis
	Gordon W. Ferguson

[redacted]

ORGANIZATION	NAME
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	J. F. McBrearty, Vice Pres. and Gen. Mgr. SST
	John E. Reed, Pricing
	F. A. Peasley
	R. F. Stoessel
	Frank A. Mathey
	J. M. Stinson
	Frank Walters
	William T. Kennedy, SST Economics Manager
North American Aviation 1700 E. Imperial Highway El Segundo, Calif. (213) OR 0-9151	F. W. Schmitt, Director of Corporate Planning Ext. 3838
	Joseph McCloskey, Director of Market Analysis
	Richard L. Biskey
	E. E. Prouty, Administrator Pricing Contracts
North American Aviation (Cont'd.)	C. L. Blake, Chief, Marketing, Program & Pricing
	D. C. Lefler, Chief, Pricing
Republic Aviation Long Island, N.Y.	Irving Watman C. Z. Michael John Shusko
American Airlines Tulsa, Oklahoma	William Neely, Chief, Power Division
	Percy Wood, Vice Pres. of Maintenance
United Airlines, Inc. International Airport San Francisco, Calif.	
General Electric Evendale, Ohio (513) 761-4100	Edward Hood, Proj. Mgr., SST Ext. 3436
	J. E. Stiles, Bus. Mgr.SST Ext. 2129
	Dave R. Moss, Reg. Sales Mgr, Commercial Engine Ext. 1807
	John Melzer, Mgr of Applications & Installations Ext. 1717

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ORGANIZATION	NAME
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Center for Naval Analysis 1710 H St. N.W. Washington, D.C. 298-6770	Joseph Noah
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TEMPO 735 State Street Santa Barbara, Calif. (803) 965 0551	Don Klegg Klaus Liebhold
Collins Radio New York, N. Y. (212) JU 6-5678	J. McKnight, Director
Washington, D.C. DE 2-9211	George Wentworth
Sperry Gyroscope 1625 I St. N.W. Washington, D.C.	D. A. Few, Representative Richard Van der Meulen

ORGANIZATION	NAME
Planning Research Corp. 1875 Connecticut Ave NW Washington, D.C. 462-7300	T. J. Willette Lew Sanchez
Rand Corporation Santa Monica, Calif.	A. R. Margolis Gill Levenson
Hexcell Products, Inc. Berkeley, Calif. (415) TH 3-4664	Dr. Garrett, Mgr.
Inglewood, Calif. (213) OR 8-4121	Hal Lummis, Sales Mgr. John P. Schafer, Sales Mgr.
Washington, D.C.	Frank Alexander, Wash.
American Petroleum Institute 1625 K St. N.W. Washington, D.C. DI 7-2820	William Harper
Defense Fuel Supply Center Washington, D.C.	R. J. Miller
DOD-OSD (Comptroller) OX-	Dr. Harold Asher, Deputy Asst. Secretary of Defense (Programming) Ext. 57341 S. Hoch, Director of Cost and Economic Analysis Ext. 54177 Harry P. Hatry, Operations Research, Ext. 59898

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ORGANIZATION	NAME
DOD - WESG	V. Bassett
Air Force	Col. David Faulk Col. Lewis Andre
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	Allen D. Yaross
	J. Naiman
	E. G. Cohoon
	Dr. William Dickerson
Navy Department Power Plant Division BuWeps OX-	Richard J. Maurer, Tech. Asst. to Director
	A. S. Atkinson, Plans and Programs Officer 62766
	Capt. C. Fernandez, Div. Director, Power Plant Div.
Dept. of Commerce ST 3-9200	Abraham Katz, Asst. to the Secretary of Commerce Ext. 5403
	John Lowery
FAA WO 2-0728	Robert Parsons

ORGANIZATION	NAME
Defense Research Corp. Santa Barbara, Calif.	Edward Yates

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TRIP REPORTS

8.5 With considerable assistance from Harry P. Hatry, DOD-OSD (Comptroller), ORI made a number of visits to aircraft and engine manufacturers. In addition to actual trips, telephone calls elicited more detail in response to specific questions arising from the materials supplied or of further pertinence to this study.

8.6 Primarily, the objective of the trips was to introduce the concepts of the project, to discuss the data requirements and the format for their documentation, to request support, and to discuss peripheral areas of information useful in the development of CERs.

8.7 The formal visits are synopsized in trip reports, and Table 8.3 is a chronological listing of the trips.

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TABLE 8.3

CHRONOLOGICAL LISTING OF VISITS MADE DURING STUDY

Visit Dates	Company	Location
September 18	North American	El Segundo, California
September 21	Douglas	Long Beach, California
September 22	Lockheed	Burbank, California
September 23	Rand Corporation	Santa Monica, California
September 23	Douglas	Long Beach, California
September 25	Boeing	Seattle, Washington
September 28	Convair	San Diego, California
September 29	General Dynamics	Fort Worth, Texas
September 30	WPAFB	Dayton, Ohio
September 30	American Airlines	Tulsa, Oklahoma
October 1	Pratt and Whitney	Hartford, Connecticut
October 6	General Electric	Cincinnati, Ohio
October 8	North American	El Segundo, California
October 22	WPAFB	Dayton, Ohio

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TRIP REPORT

SUBMITTED BY: J. P. Bowling - ORI

COMPANY VISITED: North American Aviation Company, 1700 E. Imperial Highway, El Segundo, California

DATE: 18 September 1964, 8 October 1964

PERSONS CONTACTED: F. W. Schmitt, Director of Corporate Planning
Joseph McCloskey, Director of Market Analysis
Richard L. Biskey
E. E. Prouty, Administrator Pricing Contracts
C. L. Blake, Chief, Marketing, Program and Pricing
D. C. Lefler, Chief, Pricing

AREAS OF DISCUSSION AND INFORMATION OBTAINED:

1. Total program costs were received on the B-70, F-86, F-100 and A5.
2. Information about titanium sheet costs was discussed, particularly the relationship of thickness to cost.
3. NAA's SST proposal, as previously submitted, was discussed.

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TRIP REPORT

SUBMITTED BY: J. P. Bowling - ORI

COMPANY VISITED: Douglas Aircraft Company, 3855 Lakewood Blvd., Long Beach, California

DATE: 21 September 1964, 23 September 1964

PERSONS CONTACTED: William A. Hough, Manager of Contracts and Pricing
Cliff C. Walton, Manager of Pricing
Frank R. Ruelke, Supervisor R&D Advanced System Pricing

AREAS OF DISCUSSION AND INFORMATION OBTAINED:

1. A considerable amount of cost detail, including curves, was furnished on the A4, the A3D, F4D, DC8 and, to some degree, the DC6 and DC7.
2. DAC has defined for costing purposes a parameter that they call cost weight, which has been useful in estimating. Studies have been made to determine the relationship between costs per pound of various transportation systems, as well as aircraft.
3. Relevant information on historical changes in overhead, maintenance, and associated costs was received.

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TRIP REPORT

SUBMITTED BY: Dr. D. S. Orkand, J. P. Bowling - ORI H. P. Hatry, DOD, attended.
COMPANY VISITED: Lockheed Aircraft Company, Hollywood Way, Burbank, California
DATE: 22 September 1964
PERSONS CONTACTED: R. A. Barnard, SST Program Administrator
Kelly Johnson, Vice President
J. F. McBrearty, Vice President and General Manager SST
John E. Reed, Pricing
F. A. Peasley
R. F. Stoessel
Frank A. Mathey, Director for Operations
J. M. Stinson, Manager Program Control Division
Frank Walters
William T. Kennedy, SST Economics Manager

AREAS OF DISCUSSION AND INFORMATION OBTAINED:

1. Specialized group discussions in various parts of the organization took place, indicating that Lockheed has historical cost curves and, in addition, does some cost analysis using learning curves.

2. Lockheed has submitted an indirect operating cost estimation method to the airlines as of 11 September. A series of meetings have occurred between ATA and Lockheed relative to the establishment of new formula.

3. Subsequent to the visit a detailed cost book on the F104 was forwarded to Mr. Hatry for use in this Study. Total annual costs of the Constellation series, with tooling and engineering subdivisions, was also made available.

4. A subsequent meeting took place in Washington, D. C. with Mr. Kelly Johnson, relative to titanium design and manufacturing problems.

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TRIP REPORT

SUBMITTED BY: Dr. D. S. Orkand - ORI H. P. Hatry, DOD, attended

COMPANY VISITED: Rand Corporation, Santa Monica, California

DATE: 23 September 1964

PERSON CONTACTED: A. R. Margolis
Gill Levenson

AREAS OF DISCUSSION AND INFORMATION OBTAINED:

1. The purpose of the meeting was to discuss the results of Rand's current and previous SST research and CER studies and to obtain Rand's views regarding the problems of developing CERs for the SST.
2. Cost uncertainties, such as the use of titanium or variable sweep configurations in the designs, were discussed.
3. AMPR learning curves for many types of planes appear to cluster closely, with no significant differences if stratified by fighter, bomber, transport, etc.
4. A-11 data is highly classified and was not obtainable.
5. The current "D" series reports by Levenson and Watts are not available for release but can be reviewed at Rand or DOD.

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TRIP REPORT

SUBMITTED BY: J. P. Bowling - ORI

COMPANY VISITED: Boeing Airplane Company, Box 707, Renton, Wash.

DATE: 25 September 1964

PERSONS CONTACTED: Robin K. Little, Manager Market Research
Waldo E. Johnson, Tooling - Supvr, SST
Walter C. West, Finance Manager, SST
Gen. A. Pace Jackson
Richard E. Lingen, Project Chief Mgr. Dev. SST

AREAS OF DISCUSSION AND INFORMATION OBTAINED:

1. Considerable historical cost information was received on the B-52, B-47, and KC-135 aircraft. Subsequent phone calls resulted in clarification of test, tooling, and engineering subdivisions. Data on overhead rates, 707 quantities, and titanium technology were subsequently received.

2. There are several titanium forgings in the 707 and 727 commercial jet aircraft and technical discussions have been held between Boeing and Wyman-Gordon Company, Worcester, Mass. relative to the potentially large size titanium forgings which may be required for the SST.

3. Titanium prevents the use of Kirksite dies and epoxy tools. Steel dies are mandatory and in many cases require preheating of the production material. The titanium studies by Battelle need to be updated.

4. Information on the relative percentages of various metals of the propsed SST design was obtained.

5. Spare engine information relative to fleet size and the Boeing response to the PRC questionnaire is available.

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TRIP REPORT

SUBMITTED BY: J. P. Bowling - ORI

COMPANY VISITED: Convair, 3302 Pacific Highway, Box 1950, San Diego, California

DATE: 28 September 1964

PERSONS CONTACTED:
L. J. Bordelon, Assistant to President, Contract and Sales
C. L. Meador, Vice President of Contracts
D. W. Diggs, Special Assistant
G. R. Vetter, Contracts

AREAS OF DISCUSSION AND INFORMATION OBTAINED:

1. Cost and performance information was received on F-102, F-106, CV880 and 990.

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TRIP REPORT

SUBMITTED BY: J. P. Bowling - ORI

COMPANY VISITED: General Dynamics, P. O. Box 748, Fort Worth, Texas

DATE: 29 September 1964

PERSONS CONTACTED: J. T. Cosby, Vice President, Program Director F111
W. T. Alvis, Director of Contracts
Thomas F. Fowlkes, Chief of Cost Research
C. G. Fuqua, Project Operations Analysis
Gordon W. Ferguson

AREAS OF DISCUSSION AND INFORMATION OBTAINED:

1. The B-58 program has been under study in many areas because of the delta wing configuration, relatively high weight, high Mach number, and the extensive use of honeycomb construction. Cost information under a series of cost categories was received and used. Subsequently, under "Operation Back-fill," a detailed costing of the B-58 program was delivered to DOD by Mr. Fowlkes.

2. Discussions were held pertaining to peripheral areas of cost, such as overhead structure.

3. F-111 classified data could not be released.

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TRIP REPORT

SUBMITTED BY: Dr. F. B. Brown - ORI

COMPANY VISITED: American Airlines, Tulsa, Oklahoma

DATE: 30 September 1964

PERSON CONTACTED: William Neely, Chief, Power Division

AREAS OF DISCUSSION AND INFORMATION OBTAINED

1. Discussions took place relative to commercial airlines overhaul experience in GE and P&W engines. Cost and TBO information for the past three years was reviewed indicating the increased TBO, the problem areas encountered and the current degree of reliability.
2. Costs of overhaul, disassembly, and inspection were also reviewed.
3. It appears that American Airlines desires to increase the remote monitoring of engines for preventive maintenance purposes. Considerable work along these lines has been already undertaken.

TRIP REPORT

SUBMITTED BY: J. P. Bowling, Dr. D. S. Orkand - ORI
Wright Patterson Air Force Base, Dayton, Ohio

DATE: 30 September 1964, 22 October 1964

PERSONS CONTACTED: Thomas DeHaven, Branch Chief, Operations Research Division
Allen D. Yaross
J. Naiman
E. G. Cohoon
Dr. William Dickerson

AREAS OF DISCUSSION AND INFORMATION OBTAINED:

1. The OR group at WPAFB participated in discussions of approaches to cost estimating. Some prior SST cost investigations have been made in recent years.

2. A review took place of the cost factors notebook; a copy was subsequently forwarded to Mr. Hatry. The cost factors notebook has some data useful for purposes of comparison.

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TRIP REPORT

SUBMITTED BY: J. P. Bowling

COMPANY VISITED: Pratt and Whitney Aircraft Division, United Aircraft Corp., 400 Main St., Hartford, Conn.

DATE: 1 October 1964

PERSONS CONTACTED: John Craig, Jr., Assistant Sales Manager
Richard H. Hoff, Chief Field Engineering

AREAS OF DISCUSSION AND INFORMATION OBTAINED

1. Extensive information was obtained on JT3C, JT3D, JT4A, JT8D, J52, J57, and TF33 engines.
2. Additional data on various SST engine configurations, overhaul and maintenance studies and cross indexes of engine to aircraft applications was supplied.
3. Mr. Hoff referred us to an excellent source of cost information, Mr. R.J. Maurer, Power Plant Division, BuWeps, U.S.N. and stated that such information represents the official viewpoint of P&W.
4. Suggestions were made pertaining to data formats and explanations of the severe changes in aerodynamic and thermodynamic designs for SST were discussed.

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TRIP REPORT

SUBMITTED BY: J. P. Bowling - ORI

COMPANY VISITED: General Electric Company, Evendale, Ohio

DATE: 6 October 1964

PERSONS CONTACTED: Edward Hood, Project Manager, SST
J. E. Stiles, Business Manager, SST
Dave R. Moss, Regional Sales Manager, Commercial Engines
John Melzer, Manager of Applications and Installations

AREAS OF DISCUSSION AND INFORMATION OBTAINED

1. GE prefers to rely upon very detailed analysis by highly specialized groups, such as manufacturing engineers, to analyze and aggregate the costs for specific designs.
2. Some work has been done on learning curves but it was pointed out that the slope varies considerably for as yet unknown reasons.
3. Information was supplied on performance and costs for J47, J79, and J93 engines. In addition, performance and physical characteristics of CJ805-3, 23 was also made available.
4. GE's analysis of overhaul and maintenance costs on engines was forwarded. A generalized method for costing of fixed price engines was explained.
5. Differences between the J93 engine and the possible SST engine were discussed.

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APPENDIX A

ESTIMATION OF VARIANCE

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APPENDIX A

THE VARIANCE OF A PREDICTION[1]

A.1 Assuming no discontinuities in the underlying behavior of a system, the principal sources of variance in a prediction from a regression equation are: (1) the residual variance of the dependent variable and (2) the range over which extrapolation is required. In the case of linear regression with a single independent variable, the variance of a value of the dependent variable (y) predicted from the regression line is simply

$$\sigma^2_{y_p} = \frac{\sigma^2}{n}\left[1 + \left(\frac{x_p - \bar{x}}{s_x}\right)^2\right] \qquad \text{(A.1)}$$

where x_p = the value of the independent variable at the extrapolated operating point,

y_p = the corresponding value of the dependent variable predicted from the regression line, and

$\sigma^2_{y_p}$ = the variance of y_p

$\bar{x}$ = the mean of the observed values of the independent variable

σ^2 = the variance of the dependent variable around the regression line, i.e., the residual variance of y

n = the sample size.

The variance (A.1) is estimated from the formula

$$s^2_{y_p} = \frac{s^2}{n}\left[1 + \left(\frac{x_p - \bar{x}}{s_x}\right)^2\right] \qquad \text{(A.2)}$$

derived by substituting in (A1.1) the estimate for σ^2,

$$s^2 = \frac{1}{n-2}\,\Sigma\,(\text{res})^2_y \qquad \text{(A.3)}$$

where $\Sigma\,(\text{res})^2_y$ = the sum of the squared residuals of y.

The square root of the estimate (A.2), s_{y_p}, can be used to specify a confidence interval around y_p.

A.2 In the case of multiple linear regression with, say, k independent variables the variance of a predicted value is

$$\sigma^2_{y_p} = \frac{\sigma^2}{n}\left[1 + \sum_{i=1}^{k}\sum_{j=1}^{k} L^{ij}\,(x_{pi} - \bar{x}_i)(x_{pj} - \bar{x}_j)\right] \qquad \text{(A.4)}$$

where $L^{ij} = \dfrac{\text{cofactor of } s_{ij} \text{ in } L}{L}$

L = the determinant of the variance-covariance matrix of the independent variables

s_{ij} = the covariance of x_i and x_j

s_{ii} = the variance of x_i

x_{pi} = the value of the i-th independent variable of the extrapolated operating point.

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[1] A general reference to the underlying theory on which this discussion is based is Cramer, H., Mathematical Methods of Statistics, Princeton University Press (1946), Chapter 37.

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If the independent variables are not highly inter-correlated, (A.4) may be approximated by the expression

$$\sigma^2_{y_p} \doteq \frac{\sigma^2}{n}\left[1+\sum_{i=1}^{k}\left(\frac{x_{pi}-\overline{x}_i}{s_{x_i}}\right)^2\right] . \qquad (A.5)$$

As before, an estimate of $\sigma^2_{y_p}$ can be made by substituting an estimate for σ^2, in this case

$$\frac{1}{n-k-1}\sum (\text{res})^2_y . \qquad (A.6)$$

Equation A.5 will estimate variance of prediction for an average of a large number of systems. To estimate variances of prediction for a <u>specific</u> system, the relation becomes

$$\sigma^2_{y_p} \doteq \frac{\sigma^2}{n}\left[1+\sum_{i=1}^{k}\left(\frac{x_{pi}-\overline{x}_i}{s_{x_i}}\right)^2\right] + \sigma^2 . \qquad (A.7)$$

COMBINING OF TWO CERs

A.3 When dealing with more than one independent variable, linear regression may sometimes give a physically unrealistic equation. For example, cost of airframe maintenance labor is hypothesized to depend on both weight and speed. However, in the multiple linear regression on the two variables the coefficient of the weight term is found to be negative.

A.4 Since each of the two variables separately correlated well with cost, it was decided to use as the CER for prediction and estimation a composite of the two separate CERs weighted inversely according to the variance at the SST operating point. If the residuals from the two separate CERs are uncorrelated this weighting provides the smallest variance for a linear composite. To the extent to which this is not true, the weighting will only more or less approximate the minimum variance weighting. The alternative of constructing a more elaborate nonlinear CER was discarded because of the limited number of data points available.

A.5 Referring again to (A.2) the weighting factor for the i-th variable is found to be

$$w_i = \frac{1}{s^2_{y_{pi}}} \qquad \frac{n(n-2)}{\Sigma\,(\text{res})^2_{y_i}\left[1+\left(\frac{x_{pi}-\overline{x}_i}{s_{x_i}}\right)^2\right]} . \qquad (A.8)$$

If, as for most extrapolations,

$$\left(\frac{x_{pi}-\overline{x}_i}{s_{x_i}}\right)^2 >> 1$$

and if s_{x_i} is estimated by the observed range, the weighting factor may be approximated by the expression

$$w_i \doteq \frac{1}{\Sigma\,(\text{res})^2_{y_i}\left(\frac{E_i}{R_i}\right)^2} .$$

Here $\Sigma\,(\text{res})^2_{y_i}$ = sum of squared residuals from the i-th regression

$E_i = x_{pi}-x_i$ = range of extrapolation with the i-th regression

R_i = range of x_i values over the observations.

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APPENDIX B

MEASUREMENT OF AIRCRAFT PRODUCTIVITY

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CIVIL AERONAUTICS BOARD
Washington, D.C.

Accounting and Reporting (ER Part 241)
Standard Practice Letter No. 4
Effective: April 1, 1959
Revised: March 17, 1959

TO: Chief Accounting Officers
All Certificated Air Carriers

SUBJECT: Computation of Available Capacity

The Uniform System of Accounts and Reports requires that each air carrier file with the Civil Aeronautics Board a detailed statement of its present methods and any subsequent changes thereto in computing available ton-miles and available seat-miles for each aircraft type operated. The primary objective of the foregoing provision is to ensure comparability of the capacity data reported by the several carriers.

Statements initially filed by the carriers in accordance with the foregoing requirement have varied considerably as to scope and detail, resulting in difficulty of interpretation and causing burden to both the carriers and Board staff in preparing and using the statements. Therefore, certain standard practices and a standard format were prescribed and issued as Standard Practice Letter No. 4 under date of July 10, 1958. Subsequently, however, two new amendments to the Uniform System of Accounts were adopted by the Board which necessitate a revision in the prescribed format. Accordingly, in line with these amendments, the revised Standard Practice Letter No. 4 herewith includes a certified statement (a) attesting to the fact that fuel loads used in the computation of available capacity are not in excess of company safety requirements, and (b) giving reasons for any exclusion of installed seats in the computation of available seats, and describing provisions made for protection against the sale of such seats.

As provided in the system of accounts, the computation of available seat-miles should be based upon direct airport-to-airport mileage between points served and the number of installed seats, including lounge seats, exclusive of any lounge seats not offered for sale to the public by the carrier. Similarly, the computation of available ton-miles should be based upon airport-to-airport mileage and the capacity available to traffic.

The over-all capacity of aircraft, for computing available seat-miles and available ton-miles, is controlled by the lower of (1) the capacity computed under the weight basis or (2) the capacity computed under the space basis as illustrated by the attached format. The average lift potential of the aircraft, giving effect to operating limitations, is reflected by the weight basis computation, whereas the space basis computation reflects limitations upon the average lift potential due to configuration, traffic density and available cubic space.

For these purposes the standards prescribed in the manual or otherwise approved for passenger and free baggage weight should be used. Individual carrier standards may be used for the number of installed seats, aircraft lift potential, cargo density, etc., provided that the standards are based upon representative experience, that separate standards are developed, as appropriate, for different classes of service and types of aircraft, and that the manner of determining each standard is fully explained in a statement filed in conformance with Section 22.4 of the manual.

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The objective of the attached format is to express on a uniform basis the average operating characteristics of each aircraft type used by the several carriers. Standards may be adopted to reflect operations for an entire year, part of a year, trip direction or other refinement. However, the detailed data need be provided for only one representative sample of such refinement and the other seasonal or directional standards listed in such manner as to reveal the scope of variation in available seats and tons for the aircraft type. Where standard capacities are not used, data should be provided for a representative illustration of one inter-airport hop for each aircraft type and each aircraft seating arrangement.

Therefore, pursuant to duly delegated authority as set forth in Public Notice 12, effective May 1, 1958, the information indicated in the attached format shall be presented as a matter of standard practice, to comply with the requirements of Section 22.4 of the manual calling for statements on methods of computing available seat-miles and ton-miles. Revised statements on the amended format should be filed as soon as practicable. The action taken herein may be reviewed by the Board provided that request therefor is received on or before April 15, 1959.

(Signed)

Warner H. Hord
Chief, Office of Carrier Accounts and
Statistics

Attachment

[redacted]

FORMAT FOR COMPUTATION OF AVAILABLE CAPACITY FOR REPORTING AVAILABLE TON-MILES AND AVAILABLE SEAT-MILES ON CAB FORM 41

Aircraft Type ____________________ Model: Passenger ____ Cargo ______

Computation of Available Capacity

A. Weight Basis

Maximum gross weight (indicate whether limited by take-off, landing, zero fuel, etc.) _____ lbs.

Less:	Empty weight	_____ lbs.	
	Crew weight	_____	
	Crew baggage	_____	
	Other crew supplies	_____	
	Removable passenger service equipment	_____	
	Removable emergency equipment	_____	
	Oil	_____	
	Minimum fuel (indicate CAB or company rule)	_____	
	Fixed ballast or other (explain)	_____	
	Total		_____

Available Capacity - Weight Basis _____ lbs.

For passenger aircraft types: Seat capacity indicated at ____ lbs. per passenger including free baggage up to the number of installed seats (excluding ____ seats blocked for reasons given on reverse side) _____ seats

B. Space Basis

For cargo types only:

Capacity of ___ cu. ft. in all cargo compartments at average cargo density of ______ lbs. ______ lbs.

For passenger types only:

_____ seats installed (incl. ___ available lounge seats) at _____ lbs. per passenger without free baggage; plus cargo and baggage space of _____ cu. ft., at average cargo density of ____ lbs. ______ lbs.

I, the undersigned ______________________ (Title of Officer in Charge of Accounts) of the ______________________ (full name of reporting carrier) do certify that in the above computation of available capacity the fuel loads are not in excess of company safety requirements, and that the reasons for exclusion of installed seats and the provisions against the sale of such seats are true as stated on the reverse side.

____
(Signature)

(See Reverse Side for Instructions)

[redacted]

[redacted]

INSTRUCTIONS

1. The data to be used in computing standard available capacity should be typical of the average flight by the particular aircraft type. Where unusual capacity conditions prevail on certain flights only the average effect on all operations with the aircraft type should be reflected in this statement.

2. Where component standards are used in either the weight or space basis computation, explain their derivation in footnote. (e.g., standard gross take-off weight, based on average of the respective fleet type.)

3. Fuel load not required by safety operating rules but carried for economic reasons shall be excluded in determining available capacity.

4. Passenger and free baggage weights used in these computations shall be those used in computing passenger and free baggage ton-miles.

5. When Zero Fuel and Oil Weight limitations or equivalent structural limitations are controlling, the operating fuel and oil weight deductions under the Weight Basis should be accordingly adjusted and each explained by footnote.

Reasons for Exclusion of Installed Seats

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APPENDIX C

AIRCRAFT CREW COSTS

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AVERAGE CREW COSTS PER REVENUE AIRCRAFT AND BLOCK HOURS--JET OPERATIONS
U.S. Domestic Trunklines
1959-1963

Aircraft Type	Annual Crew Costs (000)[1]	Annual Revenue Aircraft Hours	Average Crew Costs per Revenue Aircraft Hour	Ratio of Block Hours to Airborne Hours	Average Crew Costs per Block Hour
1962					
B-707[3]	$24,929	177,682	$140.30	111.19	$126.18
B-720[2]	22,551	175,364	128.60	113.64	113.16
DC-8	24,523	190,289	128.87	112.00	115.06
CV-880	14,383	102,121	140.84	115.11	122.35
CV-990	2,302	16,357	140.73	121.80	115.54
1963					
B-707[3]	30,877	209,264	147.55	111.67	132.13
B-720	37,234	294,455	126.45	113.41	111.50
DC-8	27,888	220,415	126.52	112.15	112.81
CV-880	17,161	114,293	150.15	114.94	130.63
CV-990	5,528	38,968	141.86	117.00	121.25

1/ Includes Accounts 23, 24, 28.1, 36, 57 and 68.
2/ American Airlines Excluded.
3/ Eastern Air Lines Excluded.
4/ Delta Air Lines Excluded.
5/ Continental Air Lines Excluded.

Source: Form 41 Reports to CAB.

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AVERAGE CREW COSTS PER REVENUE AIRCRAFT AND BLOCK HOURS--JET OPERATIONS
U.S. Domestic Trunklines
1959-1963

Aircraft Type	Annual Crew Costs (000)[1]	Annual Revenue Aircraft Hours	Average Crew Costs per Revenue Aircraft Hour	Ratio of Block Hours to Airborne Hours	Average Crew Costs per Block Hour
1959					
B-707	$ 7,383	68,364	$108.00	107.10	$100.84
DC-8[2]	721	5,614	128.43	111.08	115.62
1960					
B-707[3] [4]	18,782	159,837	117.51	108.06	108.75
B-707/720	1,704	15,732	108.31	114.57	94.54
DC-8[2]	9,552	86,736	110.13	110.99	99.23
CV-880	738	6,760	109.17	116.77	93.49
1961					
B-707[3] [4]	21,859	159,051	137.43	109.12	125.94
B-720[5]	14,784	116,233	127.19	114.05	111.52
DC-8[2]	20,725	156,480	132.45	111.86	118.41
CV-880	9,766	70,862	137.82	115.44	119.34

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AVERAGE CREW COSTS PER REVENUE AIRCRAFT AND BLOCK HOURS--JET OPERATIONS
U.S. International Air Carriers

1960-1963

Aircraft Type	Annual Crew Costs (000)1/	Annual Revenue Aircraft Hours	Average Crew Costs per Revenue Aircraft Hour	Ratio of Block Hours to Airborne Hours	Average Crew Costs per Block Hour
1960					
B-707	$17,369	98,186	$176.90	106.49	$166.12
DC-8	5,132	27,801	184.60	108.12	170.74
1961					
B-707	23,446	122,354	191.62	106.63	179.71
B-720	464	4,258	108.97	108.24	100.67
DC-8	14,988	87,374	171.54	107.62	159.39
1962					
B-707	27,158	153,276	177.18	106.79	165.91
B-720	1,579	13,079	120.73	109.35	110.41
DC-8	17,853	106,179	168.14	107.51	156.39
1963					
B-707	36,696	198,402	185.00	107.26	172.48
B-720	3,337	25,053	133.20	107.68	123.70
DC-8	19,792	118,941	166.40	106.90	155.66
CV-880	320	2,536	126.18	105.86	119.20

1/ Includes Accounts 23, 24, 28.1, 36, 57, and 68.

Source: Form 41 Reports to CAB.

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AVERAGE CREW COSTS PER REVENUE AIRCRAFT AND BLOCK HOURS--JET OPERATIONS
U.S. Domestic and International Air Carriers

1959-1963

Year	Aircraft Type	U.S. Domestic Carriers		U.S. International Carriers		Excess of U.S. International over U.S. Domestic Carriers--Crew Costs per Rev. Aircraft Hour		Excess of U.S. International over U.S. Domestic Carriers--Crew Costs per Block Hour	
		Average Crew Costs per Rev. Aircraft Hour	Average Crew Costs per Block Hour	Average Crew Costs per Rev. Aircraft Hour	Average Crew Costs per Block Hour	Amount	Percent	Amount	Percent
1959	B-707	$108.00	$100.84	-	-	-	-	-	-
1960	B-707	117.51	108.75	$176.90	$166.12	$ 59.39	50.5	$ 57.37	52.8
	DC-8	110.13	99.23	184.60	170.74	74.47	67.6	71.51	72.1
1961	B-707	137.43	125.94	191.62	179.71	54.19	39.4	53.77	42.7
	B-720	127.19	111.52	108.97	100.67	(18.22)	(14.3)	(10.85)	(9.7)
	DC-8	132.45	118.41	171.54	159.39	39.09	29.5	40.98	34.6
1962	B-707	140.30	126.18	177.18	165.91	36.88	26.3	39.73	31.5
	B-720	128.60	113.16	120.73	110.41	(7.87)	(6.1)	(2.75)	(2.4)
	DC-8	128.87	115.06	168.14	156.39	39.27	30.5	41.33	35.9
1963	B-707	147.55	132.13	185.00	172.48	37.45	25.4	40.35	30.5
	B-720	126.45	111.50	133.20	123.70	6.75	5.3	12.20	10.9
	DC-8	126.52	112.81	166.40	155.66	39.88	31.5	42.85	38.0
	CV-880	150.15	130.63	126.18	119.20	(23.97)	(16.0)	(11.43)	(8.7)

Source: Form 41 Reports to CAB.

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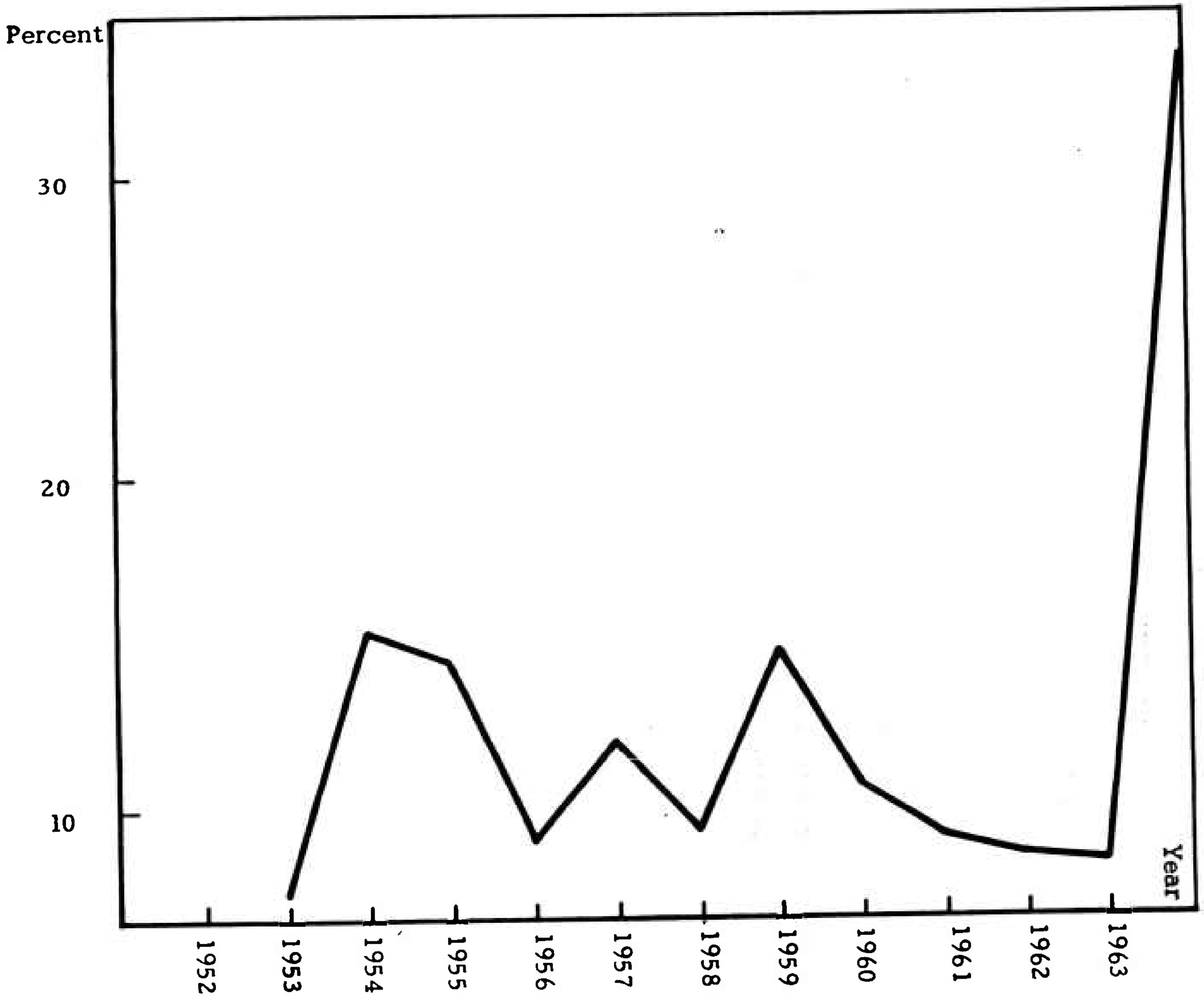
Carrier	Salary (Avg) Pilots and Copilots	Rev Airc Hrs per Pilot or Copilot	Jet Airc Hrs Total Airc Hrs	Avg Salary Other Flight Personnel
AA	18,828	246.43	.417	12,984
BN	21,072	331.74	.151	14,364
DL	17,180	247.71	.307	
EA	19,471	196.35	.209	12,572
NW	19,751	258.25	.368	14,501
PAA (system)	21,302	204.92	.645	15,939
Seaboard	17,874	197.57		13,065
TWA	20,540	216.46	.588	14,967
UA	18,744	258.99	.408	11,975
WA	16,998	349.51	.253	
Subtotal	191,760			
Sabena	10,665	318.90	.323	8,649
TCA	14,169	305.57	.181	11,297
Avianca	5,306	328.51	.066	997
Air France	16,864	331.82	.534	11,870
Lufthansa	7,962	328.20	.297	6,268
Alitalia	10,900	222.16	.586	9,827
JAL	11,256	258.24	.340	6,851
KLM	12,165	192.70	.247	8,106
PAL	4,131	506.34	.019	
SAS	8,054	166.65	.483	7,260
Iberia	7,889	545.67	.201	6,035
Swissair	10,434	203.20	.580	8,043
BEA	8,599	190.10	.166	5,471
BOAC	10,754	199.96	.662	5,845
Subtotal	139,148			
excl Pan Avianca	129,711			

APPENDIX D

DATA COVERING INVESTMENT IN GROUND AND FLIGHT EQUIPMENT

[redacted]

ANNUAL INCREASE IN GROUND INVESTMENT PER DOLLAR
INCREASE IN FLIGHT INVESTMENT
U.S. Domestic Air Carrier
1952-1963



Source: Form 41, Reports to CAB.

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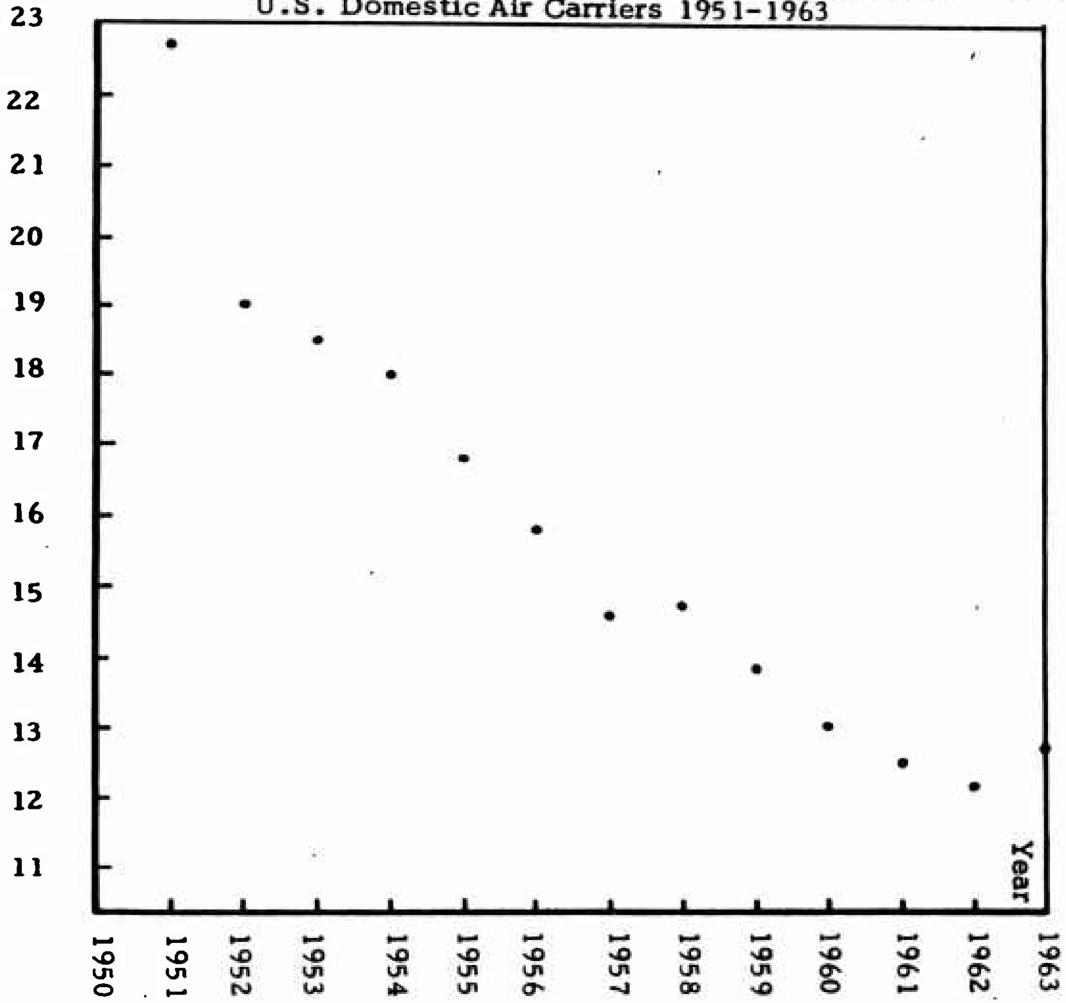
GROUND INVESTMENT (GROSS) AS PERCENT OF FLIGHT INVESTMENT (GROSS)
U.S. Domestic Air Carriers 1951-1963



Source: Form 41, Reports to CAB.

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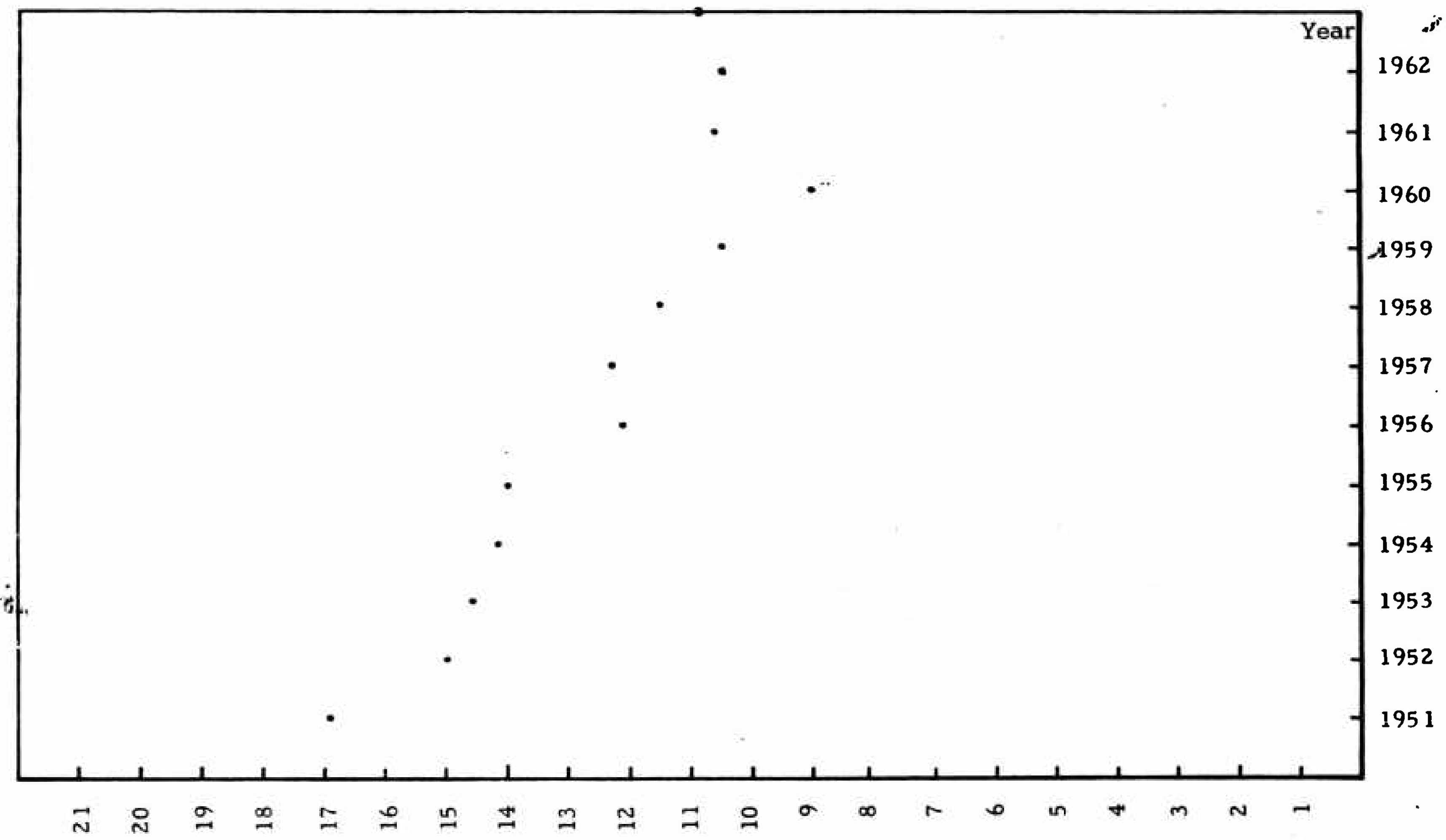
GROUND INVESTMENT (GROSS) AS PERCENT OF FLIGHT INVESTMENT (GROSS)
U.S. International Air Carriers 1951-1963



Source: Form 41, Reports to CAB

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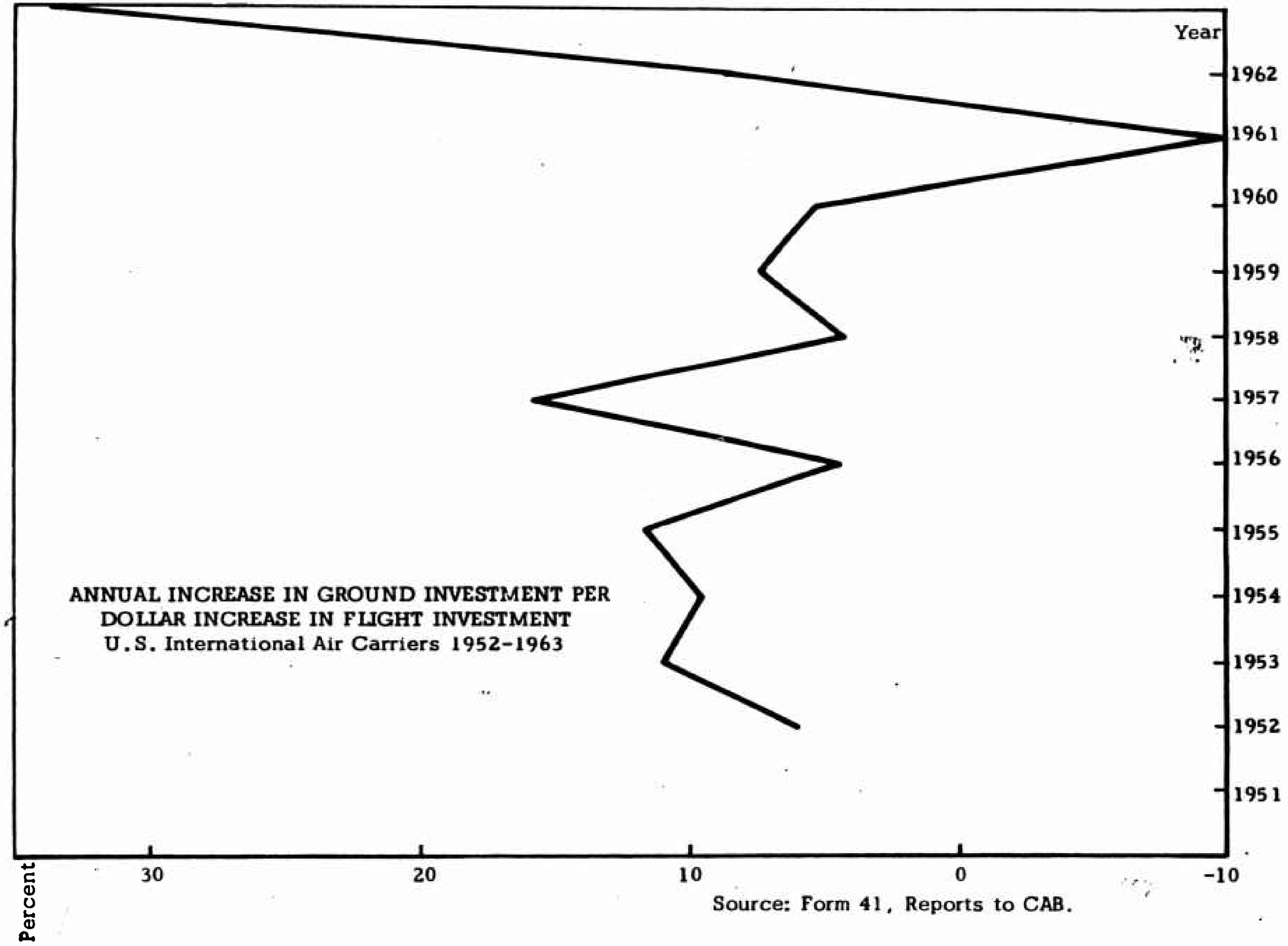

ANNUAL INCREASE IN GROUND INVESTMENT PER
DOLLAR INCREASE IN FLIGHT INVESTMENT
U.S. International Air Carriers 1952-1963

Source: Form 41, Reports to CAB.

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RELATIONSHIP BETWEEN FLIGHT INVESTMENT AND GROUND INVESTMENT

U.S. Domestic and International Air Carriers, 1951-1963

Year[1]	Flight Investment		Ground Investment		Ground Investment as Percent of Flight Investment	
	Gross[2] (000)	Net[3] (000)	Gross[4] (000)	Net[5] (000)	Gross	Net
Domestic[6]						
1963	$3,107,265	$1,780,966	$391,553	$183,428	12.6	10.3
1962	3,047,662	1,846,464	371,593	183,824	12.2	10.0
1961	2,821,818	1,754,153	352,480	177,455	12.5	10.1
1960	2,429,582	1,519,508	318,996	165,559	13.1	10.9
1959	2,003,396	1,182,814	279,737	147,184	14.0	12.4
1958	1,620,586	876,003	230,556	122,786	14.7	14.0
1957	1,412,109	779,566	207,163	106,161	14.7	13.6
1956	1,136,804	583,010	181,284	92,066	15.9	15.8
1955	917,509	469,027	154,653	77,031	16.9	17.5
1954	798,037	403,745	143,882	74,955	18.0	18.6
1953	696,818	375,280	128,992	69,084	18.5	18.4
1952	584,580	326,149	111,458	59,001	19.1	18.1
1951	442,823	232,895	100,837	54,481	22.8	23.4
International						
1963	606,654	337,403	66,004	27,322	10.9	8.1
1962	596,505	365,860	62,633	27,190	10.5	7.4
1961	555,010	357,429	59,003	26,928	10.6	7.5
1960	601,737	396,413	54,524	26,049	9.1	6.6
1959	433,966	262,362	45,608	20,479	10.5	7.8
1958	328,672	179,540	37,917	14,346	11.5	8.0
1957	294,775	163,702	36,411	14,595	12.4	8.9
1956	278,519	160,777	33,768	14,239	12.1	8.9
1955	224,181	121,232	31,367	12,178	14.0	10.0
1954	206,142	110,742	29,314	11,863	14.2	10.7
1953	189,556	100,566	27,678	12,094	14.6	12.0
1952	171,353	91,974	25,706	11,408	15.0	12.4
1951	140,537	71,931	23,831	10,663	17.0	14.8

[1] As of Dec. 31. [2] Include accounts 16, 17, and 23. [3] Include accounts 16, 17, and 23 less account 18.
[4] Include accounts 20 and 22. [5] Include accounts 20 and 22 less acount 21.
Source: Handbook of Airline Statistics - CAB. [6] Include system data for domestic trunkline carriers.

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ANNUAL INCREASES AND DECREASES INFLIGHT AND GROUND INVESTMENT
U.S. Domestic and International Air Carriers 1951-1963

Year [1]	Annual Increase or (Decrease)		Increase in Ground Investment/ Dollar Increase in Flight Investment (cents)
	Flight Investment [2] ($000,000)	Ground Investment [3] ($000,000)	
Domestic Carriers [4]			
1963	59.6	20.0	33.56
1962	225.9	19.1	8.46
1961	392.2	33.5	8.54
1960	426.2	39.3	9.22
1959	382.8	41.1	10.74
1958	208.5	31.4	15.06
1957	275.3	25.9	9.41
1956	219.3	26.6	12.13
1955	119.5	10.8	9.04
1954	101.2	14.9	14.72
1953	112.2	17.5	15.60
1952	141.8	10.6	7.48
International Carriers			
1963	10.1	3.4	33.66
1962	41.5	3.6	8.67
1961	- 46.7	4.5	(- 9.64)
1960	167.8	8.9	5.30
1959	105.3	7.7	7.31
1958	33.9	1.5	4.42
1957	16.3	2.6	15.95
1956	54.3	2.4	4.42
1955	18.0	2.1	11.67
1954	16.6	1.6	9.64
1953	18.2	2.0	10.99
1952	30.8	1.9	6.17

[1] As of Dec. 31. [2] Include accounts 16, 17, and 23. [3] Include accounts 20 and 23.

[4] Include system data for domestic trunkline carriers.

SOURCE: Form 41 reports to CAB - Handbook of Airlines Statistics.

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APPENDIX E

COMPUTER ROUTINE FOR REGRESSION ANALYSIS

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APPENDIX E

COMPUTER ROUTINE FOR REGRESSION ANALYSIS

E.1 The regression analysis used in the development of the CERs was performed on an IBM 1620 computer using a standard IBM program entitled "Linear Regression Analysis of All Combinations of Variables." A copy of the IBM description of this program is attached, along with a copy of the ORI programming format.

E.2 To develop CERs of the form $y = ax_1^{b}x_2^{c}$ the logarithmic values of the dependent and independent variables are used as the input to the program.

E.3 As indicated in the IBM description, the program is divided into two primary routines. ORI has amended the program with the addition of a third routine. The latter routine provides an output containing the following data:

a. Calculated coefficients and constants

b. Residual sum of squares

c. Multiple correlation coefficient

d. Mean value of the observed values of the dependent variables

e. Standard error

f. Coefficient of variation

g. Mean deviation

h. The ratio of the mean deviation to the mean value of the observed data.

E.4 In addition, both the observed and calculated values of the dependent variable are listed along with difference between those values. The percent difference is also listed. An example of the printout is shown in the table at the end of this section.

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DEFINITIONS OF TERMS AND COST AGGREGATIONS USED IN REPORT

Notation Reference	Description
C_i	Cost of the i^{th} aggregate of expenses[1]
C_1, C_2, C_3	Flight crew costs for pilot, engineer, and navigator (CAB accounts 5123, 5124, 5128.1, 5136, 5157, 5168).
C_4	Fuel and oil costs (CAB accounts 5145.1, 5145.2, 5169).
C_5	Insurance, injury, loss, and damage costs (flying operations) (CAB accounts 5155.1, 5155.2, 5158).
C_6	Sonic boom costs
C_7	Maintenance labor costs—airframes and other flight equipment (CAB accounts 5225.1, 5125.3, parts of 5243.1, 5243.3, 5272.1, 5272.2).
C_8	Maintenance material costs—airframes and other flight equipment (CAB accounts 5246.1, 5246.3, parts of 5243.1, 5243.3, 5272.1, and 5272.2).
C_9	Maintenance labor—aircraft engines (CAB accounts 5225.2, parts of 5243.2, 5272.6, and 5272.7).
C_{10}	Maintenance material costs—aircraft engines (CAB accounts 5246.2, parts of 5243.2, 5272.6, and 5272.7).
C_{11}	Flight equipment maintenance burden (CAB account 5379.6).
C_{12}	Depreciation—airframes and airframe parts (CAB accounts 7075.1 and 7075.3).
C_{13}	Depreciation—aircraft engines and engine parts (CAB accounts 7075.2 and 7075.4).
C_{14}	Depreciation—other flight equipment including spares (CAB account 707.5).
C_{15}	Aircraft ground handling and servicing costs (CAB account 6100 and part of 6300).
C_{16}	Traffic costs (CAB accounts 5500, 6200, 6500, 6600, and part of 6300).
C_{17}	Ground property and equipment maintenance and burden costs (CAB accounts 5225.9, 5246.9, 5379.8).
C_{18}	General and administrative costs (CAB account 6800).
C_{19}	Depreciation—ground property and equipment (CAB account 7075.8, 7075.9).
C_{20}	Amortization—preoperating costs (CAB account 7074.1).

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[1] All costs are expressed in 1963 dollars.

$\bar{C}_{A/C_N}$	Cumulative average total cost of N subsonic airplanes exclusive of spares and avionics.
$\bar{C}'_{A/C_N}$	Cumulative average total cost of N^{th} SST airplanes exclusive of spares of avionics.
$\bar{C}_{A/F_N}$	Cumulative average total cost of N^{th} subsonic airframe, exclusive of airframe spares, avionics, and engines.
$\bar{C}'_{A/F_N}$	Cumulative average total cost of the N^{th} SST airframe, exclusive of airframe spares, avionics, and engines.
$\bar{C}_{AV_N}$	Cumulative average cost or avionic equipment on the N^{th} subsonic airframe.
$\bar{C}'_{AV_N}$	Cumulative average cost or avionic equipment on the N^{th} SST airframe.
C_{ED}	Cost of engine development through Military Qualification TEST (MQT) and equivalent.
$\bar{C}_{E_N}$	Cumulative average total engine cost for the N^{th} subsonic airplane.
$\bar{C}'_{E_N}$	Cumulative average total engine cost for the N^{th} SST airplane.
$\bar{C}_{L_N}$	Cumulative average cost of labor on the N^{th} subsonic airframe.
$\bar{C}'_{L_N}$	Cumulative average cost of labor on the N^{th} SST airframe.
$\bar{C}_{M_N}$	Cumulative average cost of materials on the N^{th} subsonic airframe.
$\bar{C}'_{M_N}$	Cumulative average cost of materials on the N^{th} SST airframe.
$\bar{C}_{OH_N}$	Cumulative average cost of overhead and G&A on the N^{th} subsonic airframe.
$\bar{C}'_{OH_N}$	Cumulative average cost of overhead and G&A on the N^{th} SST airframe.
C_{PD}	Cost of engine production development after Military Qualification Test (MQT) or equivalent.
C_{RA}	Cost of airframe development.
$\bar{C}_{SE_N}$	Cumulative average cost of sustaining engineering on the N^{th} subsonic airframe.
$\bar{C}'_{SE_N}$	Cumulative average cost of sustaining engineering on the N^{th} SST airframe.
$\bar{C}_{SPE_N}$	Cumulative average cost of spare engines and parts for the N^{th} subsonic airframe.
$\bar{C}'_{SPE_N}$	Cumulative average cost of spare engines and parts for the N^{th} SST airframe.
$\bar{C}_{SPF_N}$	Cumulative average cost of spare airframe parts for the N^{th} subsonic airframe.
$\bar{C}'_{SPF_N}$	Cumulative average cost of spare airframe parts for the N^{th} SST airframe.
$\bar{C}_{TO_N}$	Cumulative average cost of tooling on the N^{th} subsonic airframe.
$\bar{C}'_{TO_N}$	Cumulative average cost of tooling on the N^{th} SST airframe.

[redacted]

b Logarithimic slope of learning curve (values tabulated below)

	Subsonic Equations		Supersonic Equations		
	slope	-b	slope	-b	type
Labor	77%	.377	80%	.322	log linear unit
Material	90%	.152	90%	.152	log linear unit
Tooling	65%	.622	70%	.515	log linear cumulative average
Engineering	65%	.622	65%	.622	log linear cumulative average
Engines	90%	.152	90%	.152	log linear cumulative average

d	Great circle flight segment distance in statute miles.
D	Density of kerosene fuel, lb/gallon.
D_p	Product development time, months.
F^o	Maximum turbine inlet temperature, degrees Fahrenheit.
G_o	Gallons of oil consumed per engine per block hour.
I_o	Total flight equipment investment per aircraft, including spares.
k_i	Coefficients, described for each equation.
L_A	Service life of avionics and other flight equipment and spares.
L_E	Service life of engines and spares.
L_f	Service life of airframe and spares.
L_G	Service life of depreciable ground property and equipment (average).
M	Maximum design mach number from an engine.
n_1	Number of pilots on aircraft.
n_2	Number of copilots on aircraft.
n_3	Number of flight engineers and navigators on aircraft.
N	Cumulative number of production airplanes manufactured.
N_E	Number of engines per aircraft, excluding spares.
n_s	Number of passenger seats.
p	Payload capacity of aircraft, tons, as defined in CAB Standard Practice Letter No. 4, as revised 17 March 1959. (On SST for space limited capacity use maximum seating configuration).
P_A	Investment in avionics, and other flight equipment per aircraft, excluding spares, K$.
p_c	Percent of coach passengers.
p_f	Percent of first-class passengers.

[redacted]

P_E	Investment per engine, excluding spares K$.
P_f	Investment in airframe, less engines, avionics, and other flight equipment, and excluding spares, K$.
P_M	Complexity factor to account for decreased/lb cost of material for heavier aircraft (=.55).
P_o	Investment per aircraft at original cost of airframe, installed engines and other installed flight equipment (excluding all spares).
$Q_{AV_{100}}$	Average monthly delivery rate to the 100th airframe.
R_A	Fractional value of original cost of avionics and other flight equipment and spares salvageable at end of service life.
r_c	Coach revenue, $/seat mile.
r_f	First-class revenue, $/seat mile.
R_E	Fractional value of original cost of engines and spares salvageable at end of service life.
R_{EM}	Number of engines manufactured per airframe, $= N_E (1 + S_E)$.
R_f	Fractional value of original cost of airframes and spares salvageable at end of service life.
R_G	Fractional part of original investment in ground property and equipment salvageable at end of service life.
R_{OH}	Manufacturing overhead and G&A rate, fraction of labor cost.
S_A	Spare parts factor, investment in avionics and other flight equipment spares per dollar investment in installed equipment.
S_E	Spare parts factor, investment in spare engines and engine parts per dollar investment in installed engines.
S_f	Spare parts factor, investment in airframe spares per dollar investment in airframe.
t	Years since introduction of aircraft, defined for $t \leq 6$. For $t > 6$, the value 6 is used.
T	Maximum sea-level takeoff thrust, lb, augmented.
t_b	Segment flight time, in block hours.
T_L	Factor to account for increased cost of assembling and fabricating a titanium airframe.
T_M	Factor to account for increased cost of materials for titanium airframe.
T_{TO}	Factor to account for increased cost of tooling and tooling maintenance for titanium parts.
U	Annual utilization per aircraft in revenue block hours per year.
V	Maximum design cruising speed, statute miles per hour at optimal altitude.
V_k	Maximum design cruising speed, knots, at optimal altitude.

V_m	Design maximum cruising speed, mach number, at optimal altitude.
W_A	Operator's weight, less fuel and engines.
W_E	Weight of engine, dry, excluding nacelle, lb.
W_f	Weight of kerosene fuel consumed in one segment flight, lb.
W_g	Maximum certificated gross weight of aircraft, lb.
W_o	Weight of airframe, AMPR lb.
W_1	Weighting factor.
W_2	Weighting factor.
X	Fraction of AMPR weight of airframe which is titanium.
Y	Passenger revenue in dollars derived from flight segment, developed from the following data:

	International Flights	Domestic Flights
Load Factor	50	55
% First Class/Revenue	10/8.55¢/ seat mile	20/6.50¢/ seat mile
% Coach/Revenue	90/5.50¢/ seat mile	80/5.66¢/ seat mile

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OPERATIONS RESEARCH, *Incorporated*

SILVER SPRING, MARYLAND

COST-ESTIMATING RELATIONS FOR AIRCRAFT

VOLUME II. SUMMARY OF COST-ESTIMATING RELATIONS (CER)

by

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INTRODUCTION

It is the purpose of this volume to present, in summary form, the cost-estimating relationships that were developed during the course of the study. This volume also contains in tabular form the resultant cost figures obtained by applying the CERs to the configurations prepared by Lockheed, Boeing, General Electric, and Pratt & Whitney in their SST Phase II-A proposals of 1 December 1964.

In most cases the equation formats for each cost element are equally applicable to both subsonic and supersonic aircraft; however, there are differences between the coefficients, both for subsonic and supersonic operations and for operations over different geographic configurations. These differences are indicated where applicable, for each equation.

A summary of nomenclature used in this report is presented on the final page. The specific data used for developing the SST costs and the details of that development are not presented in this volume because of their sensitive nature, but are provided in Volume III.

I. OPERATING COST EQUATIONS

FLIGHT CREW COST—PILOTS

$$C_1A = n_1 \left(k_{1A} + k'_{1A} \log_{10} \frac{pd}{t_b}\right) t_b, \text{ \$/flight segment}$$

(before introduction of a more productive aircraft), and

$$C_1 = n_1 \left(k_1 + k'_1 \log_{10} \frac{pd}{t_b}\right) t_b, \text{ \$/flight segment}$$

(after introduction of a more productive aircraft)

where

k_1, k_{1A} are coefficients defined for various airline operations as follows:

Airline	k_{1A}	k'_{1A}	k_1	k'_1
U.S. Domestic	-56.75	30.14	-50.83	30.14
U.S. International	-68.10	36.17	-61.00	36.17
Foreign	-40.86	21.70	-36.60	21.70

FLIGHT CREW COST—COPILOTS

$$C_2A = n_2 \left(k_{2A} + k'_{2A} \log_{10} \frac{pd}{t_b}\right) t_b, \text{ \$/flight segment}$$

(before introduction of a more productive aircraft), and

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$$C_2 = n_2 (k_2 + k'_2 \log_{10} \frac{pd}{t_b}) t_b, \text{ \$/flight segment}$$

(after introduction of a more productive aircraft)

where

$k_2, k_{2}A$ are coefficients defined for various airline operations as follows:

Airline	k_2A	k'_2A	k_2	k'_2
U.S. Domestic	-32.14	17.07	-28.78	17.07
U.S. International	-38.57	20.48	-34.55	20.48
Foreign	-23.14	12.29	-20.73	12.29

FLIGHT CREW COST—FLIGHT ENGINEER AND NAVIGATOR

$$C_3A = n_3 (k_{3A} + k'_{3A} \log_{10} \frac{pd}{t_b}) t_b, \text{ \$/flight segment}$$

(before introduction of a more productive aircraft, and

$$C_3 = n_3 (k_3 + k'_3 \log_{10} \frac{pd}{t_b}) t_b, \text{ \$/flight segment}$$

(after introduction of a more productive aircraft)

where

k_3, k_{3A} are coefficients defined for various airline operations as follows:

Airline	k_3A	k'_3A	k_3	k'_3
U.S. Domestic	-30.58	16.24	-27.39	16.24
U.S. International	-36.70	19.49	-32.87	19.49
Foreign	-22.02	11.69	-19.72	11.69

FUEL COST

$$C_4 = 1.03 \left(\frac{k_4 Wf}{D} + N_E k'_4 G_0 t_b\right) \text{ \$/flight segment}$$

where

k_4, k'_4 are the costs of kerosene fuel and oil, respectively, in \$/gallon estimated for various airline operations as follows:

Airline	k_4	k'_4
U.S. Domestic	.098	12.00
U.S. International	.118	12.00
Foreign	.118	12.00

INSURANCE COST

$$C_5 = \frac{k_5 P_0 t_b}{U} \text{ \$/flight segment}$$

where

k_5 represents the insurance rates, dollars per year per dollar of investment, estimated as follows:

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Aircraft Speed	k_5
Subsonic	\$0.025
Supersonic	0.050

MAINTENANCE COSTS FOR FLIGHT EQUIPMENT

a. Labor, Airframe, and Other

$$C_7 = .91\,k_7[(12.915 + .0001825\,W_A)\,W_1$$

$$+ (2.348 + .0747\,V_k)\,W_2]t_b/(W_1 + W_2)$$

\$/flight segment

$$W_1 = \left(\frac{40,100}{W_A - 89800}\right)^2 \qquad W_2 = \left(\frac{152}{V_k - 392}\right)^2$$

b. Material, Airframe, and Other

$$C_8 = .91\,k_7[34.637 + .004683(P_f + P_A) - 4.7335t]\,t_b$$

\$/flight segment

c. Labor, Engine

$$C_9 = .91\,k_7\,N_E[-26.41 + .01697\,F^o + 2.0214^T/W_E]\,t_b,$$

\$/flight segment

d. Material, Engine

$$C_{10} = .91\,k_7\,N_E[-60.59 + 0.039F^o + 3.347^T/W_E]\,t_b,$$

\$/flight segment

where k_7 is a coefficient defined as:

Airline	k_7
U.S. Domestic	1.00
U.S. International	1.00
Foreign	1.33

MAINTENANCE BURDEN

$$C_n = k_n\,(C_7 + C_9),\ \$/\text{flight segment}$$

where

k_{11} is the rate of maintenance burden per dollar of engine and airframe maintenance labor cost, estimated for various airline operations as follows:

Airline	k_{11}
U.S. Domestic	1.70
U.S. International	1.90
Foreign	1.90

DEPRECIATION, AIRFRAME AND SPARES

$$C_{12} = \frac{P_f\,(1 + S_f)\,(1 - R_f)\,t_b}{L_f U}\ \ \$/\text{flight segment}$$

DEPRECIATION, ENGINES AND SPARES

$$C_{13} = \frac{N_E P_E\,(1 + S_E)\,(1 - R_E)\,t_b}{L_E U}\ \ \$/\text{flight segment}$$

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DEPRECIATION, AVIONICS AND OTHER FLIGHT EQUIPMENT

$$C_{14} = \frac{P_A (1 + S_A)(1 - R_A)\, t_b}{L_A U} \quad \text{\$/flight segment}$$

AIRCRAFT SERVICING COSTS

$$C_{15} = k_{15} \frac{W_g}{1000} \quad \text{\$/flight segment}$$

where

k_{15} is the coefficient estimated for various airline operations as follows:

Airline	k_{15}
U.S. Domestic	1.17
U.S. International	2.34
Foreign	2.34

TRAFFIC SERVICING COSTS

$$C_{16} = k_{16}\, Y \quad \text{\$/flight segment}$$

where

k_{16} is the coefficient estimated for various airline operations as follows:

Airline	k_{16}
U.S. Domestic	0.262
U.S. International	0.346
Foreign	0.346

GROUND EQUIPMENT MAINTENANCE AND BURDEN

$$C_{17} = k_{17} \frac{k' I_o t_b}{U} \quad \text{\$/flight segment}$$

where

k_{17} is the cost of ground equipment maintenance and burden per dollar of depreciable ground equipment cost, estimated for various airline operations as follows:

Airline	k_{17}
U.S. Domestic	.0439
U.S. International	.0439
Foreign	.0439

and where

k' is the dollar cost of depreciable ground equipment per dollar investment in flight equipment estimated as follows:

Airline	k'
U.S. Domestic	.125
U.S. International	.110
Foreign	.110

GENERAL AND ADMINISTRATIVE COSTS

$$C_{18} = k_{18} \left(\sum_{i=1}^{11} C_i + \sum_{i=15}^{17} C_i \right)$$

[redacted]

where

k_{18} is the coefficient estimated for various airline operations as follows:

Airline	k_{18}
U.S. Domestic	.050
U.S. International	.050
Foreign	.055

DEPRECIATION, GROUND PROPERTY AND EQUIPMENT

$$C_{19} = \frac{k' I_o (1 - R_G) t_b}{L_G U}$$

where

is the coefficient estimated for various airline operations as follows:

Airline	k'
U.S. Domestic	.125
U.S. International	.110
Foreign	.110

AMORTIZATION OF PREOPERATING COSTS

$$C_{20} = \frac{k_{20}\ I_o\ t_b}{U}$$

where

k_{20} is the coefficient estimated for various airline operations as follows:

Airline	k_{20}
U.S. Domestic	.004
U.S. International	.004
Foreign	.004

II. INVESTMENT COST EQUATIONS

Labor Cost

$$\bar{C}_{L_N} \cong \frac{(-126690 + 343.8\ V_k + 7.796\ W_o)}{100^b} \ \frac{N^{b+1}}{N(b+1)}$$

(Subsonic Aircraft)

$$\bar{C}'_{L_N} \cong \frac{[1.55 + .77X][-99023 + 225.2\,V_k + 8.11\ W_o]}{100^b} \times \left[\frac{N^{b+1}}{N(b+1)}\right]$$

(Supersonic Aircraft)

Overhead Cost

$$\bar{C}_{OH_N} \cong R_{OH}\ \bar{C}_{L_N}$$

(Subsonic Aircraft)

$$\bar{C}'_{OH_N} \cong R_{OH}\ \bar{C}'_{LN}$$

(Supersonic Aircraft)

where $R_{OH} = 1.50$.

Materials Cost

$$\bar{C}_{M_N} \cong \frac{(10.526\,W_o^{1.0939}\ V_m^{3.697})}{100^b} \ \frac{N^{b+1}}{N(b+1)}$$

(Subsonic Aircraft)

$$\bar{C}'_{M_N} \cong \frac{P_M\,[2.75 + 2.47X]\left[-235520 + 17.32\,W_o + 227{,}700\,V_m\right]}{100^b} \left[\frac{N^{b+1}}{N(b+1)}\right]$$

(Supersonic Aircraft)

[redacted]

Tooling Cost

$$\bar{C}_{TO_N} = \frac{(10{,}745\, W_o^{-.40581} V_m^{5.6555} Q_{AV_{100}}^{-1.29})\; W_o N^b}{100^b}$$ (Subsonic Aircraft)

$$\bar{C}'_{TO_N} = [1.50 + .71X] \left[70{,}968\, W_o^{-.7484} V_m^{.9176} Q_{AV_{100}}^{-.8325} \right] W_o \frac{N^b}{100^b}$$ (Supersonic Aircraft)

Engineering Cost

$$\bar{C}_{SE_N} = \frac{(33524\, W_o^{.53}\; V_m^{5.86}\; Q_{AV_{100}}^{-1.665})\; N^b}{100^b}$$ (Subsonic Aircraft)

$$\bar{C}'_{SE_N} = 21{,}400\, W_o^{-.61275} V_m^{1.6798} Q_{AV_{100}}^{-.83112} W_o \frac{N^b}{100^b}$$ (Supersonic Aircraft)

Total Airframe Cost

$$\bar{C}_{A/F_N} = \bar{C}_{L_N} + \bar{C}_{OH_N} + \bar{C}_{M_N} + \bar{C}_{TO_N} + \bar{C}_{SE_N}$$ (Subsonic Aircraft)

$$\bar{C}'_{A/F_N} = \bar{C}'_{L_N} + \bar{C}'_{OH_N} + \bar{C}'_{M_N} + \bar{C}'_{TO_N} + \bar{C}'_{SE_N}$$ (Supersonic Aircraft)

Propulsion Cost

$$\bar{C}'_{E_N} = N_E\,(1000)\,[.011333\,T + .32166\,F^o + 73.823\,M - 537.57] \frac{(R_{EM} N)^b}{1200^b}$$ (Subsonic Aircraft)

$$\bar{C}'_{E_N} = N_E\,(1000)\,[.011333\,T + .32166\,F^o + 73.832\,M - 537.57] \frac{(R_{EM} N)^b}{1200^b}$$ (Supersonic Aircraft)

Avionics

CER not developed. A direct estimate was made of the avionic package for the proposed SST configuration and is included in Section IV.

Total Aircraft Cost

$$\bar{C}_{A/C_N} = \bar{C}_{L_N} + \bar{C}_{OH_N} + \bar{C}_{M_N} + \bar{C}_{SE_N} + \bar{C}_{TO_N} + \bar{C}_{E_N}$$ (Subsonic Aircraft)

$$\bar{C}'_{A/C_N} = \bar{C}'_{L_N} + \bar{C}'_{OH_N} + \bar{C}'_{M_N} + \bar{C}'_{SE_N} + \bar{C}'_{TO_N} + \bar{C}'_{E_N} + \bar{C}'_{AV_N}$$ (Supersonic Aircraft)

Spares Costs (Initial)

(Subsonic Aircraft)

$$\bar{C}_{SPE_N} = .5\,\bar{C}_{E_N}$$

$$\bar{C}_{SPF_N} = .15\,\bar{C}_{A/F_N}$$

(Supersonic Aircraft)

$$\bar{C}'_{SPE_N} = .5\,\bar{C}'_{E_N}$$

$$\bar{C}'_{SPF_N} = .15\,\bar{C}'_{A/F_N}$$

III. DEVELOPMENT COST EQUATIONS

Airframe Development

$$C_{RA}\ (M\$) = -522.69 + .46035\ V_k + 5.1477\ W_o + 3.0667\ V_k/W_o$$

Engine Development

$$C_{ED}\ (M\$) = .0069417\,T + .069845\ F^o + 3.0881\,M - 78.195 \qquad \text{(for design phase through MQT)}$$

$$C_{PD}\ (M\$) = .0033063\,T + .097411\,F^o + 1.8758\,D_p - 193.86 \qquad \text{(for design phase after MQT)}$$

[redacted]

IV. SUMMARY OF SST COSTS

The following Tables summarize the costs of the alternative SST configurations, as calculated from the CERs presented in Sections I, II, and III. The details of these calculations are presented in Volume III.

TABLE 4.1. OPERATING COSTS (Dollars for 2,000-mile Flight Segment)

Cost Item	Lockheed/PW	Lockheed/GE	Boeing/PW	Boeing/GE
Crew cost	302	302	310	310
Fuel cost	1478	1478	1486	1486
Insurance	765	662	490	493
Maintenance	746	704	711	690
Maintenance Burden	415	388	432	415
Direct Operating Cost	3706	3534	3429	3394
Depreciation	1600	1335	1036	1082
Aircraft Servicing	531	531	585	585
Traffic Servicing	6750	6750	7030	7030
Ground/Maint/Burd	93	78	59	61
G&A	564	555	565	563
Deprec. Gnd. Equip.	423	355	266	276
Preop. Costs	77	65	49	51
Indirect Operating Cost	10,038	9689	9590	9648
Total	13,744	13,223	13,019	13,042

[redacted]

TABLE 4.2. INVESTMENT COSTS (Cumulative Average of Dollars at 200th Unit)

Cost Item	Lockheed/PW	Lockheed/GE	Boeing/PW	Boeing/GE
Airframe				
Labor	3,577,350	3,577,350	3,718,000	3,718,000
Overhead	5,366,025	5,366,025	5,577,000	5,577,000
Materials	7,656,000	7,656,000	7,851,472	7,851,472
Tooling	2,618,000	2,618,000	2,115,325	2,115,325
Engineering	4,239,000	4,239,000	3,374,000	3,374,000
Total	23,456,375	23,456,375	22,635,797	22,635,797
Engines	4,457,320	3,900,800	4,144,888	3,377,000
Avionics	450,000	450,000	450,000	450,000
Total Aircraft	28,363,695	27,807,175	27,230,685	26,462,797
Spares (Airframe)	3,518,400	3,518,400	3,395,370	3,395,370
(Engines)	2,228,660	1,950,400	2,072,444	1,688,500
Total Investment Cost	34,100,755	33,275,975	32,698,499	31,546,667

TABLE 4.3

DEVELOPMENT COSTS (Dollars)

Cost Item	Lockheed/PW	Lockheed/GE	Boeing/PW	Boeing/GE
Airframe	1,041,500,000	1,041,500,000	1,060,400,000	1,060,400,000
Engine				
per MQT	514,601,000	441,777,000	480,448,000	374,659,000
after MQT	344,154,000	303,366,000	327,876,000	271,526,000
Total Aircraft	1,900,255,000	1,786,643,000	1,868,724,000	1,706,285,000

DEFINITIONS OF TERMS AND COST AGGREGATIONS USED IN REPORT

Notation Reference	Description
C_i	Cost of the i^{th} aggregate of expenses [1]
C_1, C_2, C_3	Flight crew costs for pilot, engineer, and navigator (CAB accounts 5123, 5124, 5128.1, 5136, 5157, 5168).
C_4	Fuel and oil costs (CAB accounts 5145.1, 5145.2, 5169).
C_5	Insurance, injury, loss, and damage costs (flying operations) (CAB accounts 5155.1, 5155.2, 5158).
C_6	Sonic boom costs
C_7	Maintenance labor costs—airframes and other flight equipment (CAB accounts 5225.1, 5125.3, parts of 5243.1, 5243.3, 5272.1, 5272.2).
C_8	Maintenance material costs—airframes and other flight equipment (CAB accounts 5246.1, 5246.3, parts of 5243.1, 5243.3, 5272.1, and 5272.2).
C_9	Maintenance labor—aircraft engines (CAB accounts 5225.2, parts of 5243.2, 5272.6, and 5272.7).
C_{10}	Maintenance material costs—aircraft engines (CAB accounts 5246.2, parts of 5243.2, 5272.6, and 5272.7).
C_{11}	Flight equipment maintenance burden (CAB account 5379.6).
C_{12}	Depreciation—airframes and airframe parts (CAB accounts 7075.1 and 7075.3).
C_{13}	Depreciation—aircraft engines and engine parts (CAB accounts 7075.2 and 7075.4).
C_{14}	Depreciation—other flight equipment including spares (CAB account 707.5).
C_{15}	Aircraft ground handling and servicing costs (CAB account 6100 and part of 6300).
C_{16}	Traffic costs (CAB accounts 5500, 6200, 6500, 6600, and part of 6300).
C_{17}	Ground property and equipment maintenance and burden costs (CAB accounts 5225.9, 5246.9, 5379.8).
C_{18}	General and administrative costs (CAB account 6800).
C_{19}	Depreciation—ground property and equipment (CAB account 7075.8, 7075.9).
C_{20}	Amortization—preoperating costs (CAB account 7074.1).

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[1] All costs are expressed in 1963 dollars.

[redacted]

$\bar{C}_{A/C_N}$	Cumulative average total cost of N subsonic airplanes exclusive of spares and avionics.
$\bar{C}'_{A/C_N}$	Cumulative average total cost of N^{th} SST airplanes exclusive of spares of avionics.
$\bar{C}_{A/F_N}$	Cumulative average total cost of N^{th} subsonic airframe, exclusive of airframe spares, avionics, and engines.
$\bar{C}'_{A/F_N}$	Cumulative average total cost of the N^{th} SST airframe, exclusive of airframe spares, avionics, and engines.
$\bar{C}_{AV_N}$	Cumulative average cost or avionic equipment on the N^{th} subsonic airframe.
$\bar{C}'_{AV_N}$	Cumulative average cost or avionic equipment on the N^{th} SST airframe.
C_{ED}	Cost of engine development through Military Qualification TEST (MQT) and equivalent.
$\bar{C}_{E_N}$	Cumulative average total engine cost for the N^{th} subsonic airplane.
$\bar{C}'_{E_N}$	Cumulative average total engine cost for the N^{th} SST airplane.
$\bar{C}_{L_N}$	Cumulative average cost of labor on the N^{th} subsonic airframe.
$\bar{C}'_{L_N}$	Cumulative average cost of labor on the N^{th} SST airframe.
$\bar{C}_{M_N}$	Cumulative average cost of materials on the N^{th} subsonic airframe.
$\bar{C}'_{M_N}$	Cumulative average cost of materials on the N^{th} SST airframe.
$\bar{C}_{OH_N}$	Cumulative average cost of overhead and G&A on the N^{th} subsonic airframe.
$\bar{C}'_{OH_N}$	Cumulative average cost of overhead and G&A on the N^{th} SST airframe.
C_{PD}	Cost of engine production development after Military Qualification Test (MQT) or equivalent.
C_{RA}	Cost of airframe development.
$\bar{C}_{SE_N}$	Cumulative average cost of sustaining engineering on the N^{th} subsonic airframe.
$\bar{C}'_{SE_N}$	Cumulative average cost of sustaining engineering on the N^{th} SST airframe.
$\bar{C}_{SPE_N}$	Cumulative average cost of spare engines and parts for the N^{th} subsonic airframe.
$\bar{C}'_{SPE_N}$	Cumulative average cost of spare engines and parts for the N^{th} SST airframe.
$\bar{C}_{SPF_N}$	Cumulative average cost of spare airframe parts for the N^{th} subsonic airframe.
$\bar{C}'_{SPF_N}$	Cumulative average cost of spare airframe parts for the N^{th} SST airframe.
$\bar{C}_{TO_N}$	Cumulative average cost of tooling on the N^{th} subsonic airframe.
$\bar{C}'_{TO_N}$	Cumulative average cost of tooling on the N^{th} SST airframe.

[redacted]

b Logarithimic slope of learning curve (values tabulated below)

	Subsonic Equations		Supersonic Equations		
	slope	-b	slope	-b	type
Labor	77%	.377	80%	.322	log linear unit
Material	90%	.152	90%	.152	log linear unit
Tooling	65%	.622	70%	.515	log linear cumulative average
Engineering	65%	.622	65%	.622	log linear cumulative average
Engines	90%	.152	90%	.152	log linear cumulative average

d	Great circle flight segment distance in statute miles.
D	Density of kerosene fuel, lb/gallon.
D_p	Product development time, months.
F^o	Maximum turbine inlet temperature, degrees Fahrenheit.
G_O	Gallons of oil consumed per engine per block hour.
I_O	Total flight equipment investment per aircraft, including spares.
k_i	Coefficients, described for each equation.
L_A	Service life of avionics and other flight equipment and spares.
L_E	Service life of engines and spares.
L_f	Service life of airframe and spares.
L_G	Service life of depreciable ground property and equipment (average).
M	Maximum design mach number from an engine.
n_1	Number of pilots on aircraft.
n_2	Number of copilots on aircraft.
n_3	Number of flight engineers and navigators on aircraft.
N	Cumulative number of production airplanes manufactured.
N_E	Number of engines per aircraft, excluding spares.
n_s	Number of passenger seats.
p	Payload capacity of aircraft, tons, as defined in CAB Standard Practice Letter No. 4, as revised 17 March 1959. (On SST for space limited capacity use maximum seating configuration).
P_A	Investment in avionics, and other flight equipment per aircraft, excluding spares, K$.
p_c	Percent of coach passengers.
p_f	Percent of first-class passengers.

V_m	Design maximum cruising speed, mach number, at optimal altitude.
W_A	Operator's weight, less fuel and engines.
W_E	Weight of engine, dry, excluding nacelle, lb.
W_f	Weight of kerosene fuel consumed in one segment flight, lb.
W_g	Maximum certificated gross weight of aircraft, lb.
W_o	Weight of airframe, AMPR lb.
W_1	Weighting factor.
W_2	Weighting factor.
X	Fraction of AMPR weight of airframe which is titanium.
Y	Passenger revenue in dollars derived from flight segment, developed from the following data:

	International Flights	Domestic Flights
Load Factor	50	55
% First Class/Revenue	10/8.55¢/ seat mile	20/6.50¢/ seat mile
% Coach/Revenue	90/5.50¢/ seat mile	80/5.66¢/ seat mile

P_E	Investment per engine, excluding spares K$.
P_f	Investment in airframe, less engines, avionics, and other flight equipment, and excluding spares, K$.
P_M	Complexity factor to account for decreased/lb cost of material for heavier aircraft (=.55).
P_o	Investment per aircraft at original cost of airframe, installed engines and other installed flight equipment (excluding all spares).
$Q_{AV_{100}}$	Average monthly delivery rate to the 100th airframe.
R_A	Fractional value of original cost of avionics and other flight equipment and spares salvageable at end of service life.
r_c	Coach revenue, \$/seat mile.
r_f	First-class revenue, \$/seat mile.
R_E	Fractional value of original cost of engines and spares salvageable at end of service life.
R_{EM}	Number of engines manufactured per airframe, $= N_E (1 + S_E)$.
R_f	Fractional value of original cost of airframes and spares salvageable at end of service life.
R_G	Fractional part of original investment in ground property and equipment salvageable at end of service life.
R_{OH}	Manufacturing overhead and G&A rate, fraction of labor cost.
S_A	Spare parts factor, investment in avionics and other flight equipment spares per dollar investment in installed equipment.
S_E	Spare parts factor, investment in spare engines and engine parts per dollar investment in installed engines.
S_f	Spare parts factor, investment in airframe spares per dollar investment in airframe.
t	Years since introduction of aircraft, defined for $t \leq 6$. For $t > 6$, the value 6 is used.
T	Maximum sea-level takeoff thrust, lb, augmented.
t_b	Segment flight time, in block hours.
T_L	Factor to account for increased cost of assembling and fabricating a titanium airframe.
T_M	Factor to account for increased cost of materials for titanium airframe.
T_{TO}	Factor to account for increased cost of tooling and tooling maintenance for titanium parts.
U	Annual utilization per aircraft in revenue block hours per year.
V	Maximum design cruising speed, statute miles per hour at optimal altitude.
V_k	Maximum design cruising speed, knots, at optimal altitude.

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OPERATIONS RESEARCH, *Incorporated*

SILVER SPRING, MARYLAND

COST-ESTIMATING RELATIONS FOR AIRCRAFT

VOLUME III. APPLICATION TO THE SUPERSONIC TRANSPORT (SST)

by

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Assistant Secretary of Defense (Comptroller)
for the Department of Commerce

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Downgraded at 3 Year Intervals:
Declassified After 12 Years.
DOD Dir 5200.10

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I. INTRODUCTION

1.1 This report is Volume III of three volumes comprising the final report of the research activities of ORI in performing on Contract SD-275 for the Department of Defense.

1.2 The volume provides the results of using cost estimating equations developed by ORI in application to the supersonic transport designs offered by the Lockheed and Boeing Aircraft Companies in their proposals to the Government on 1 November 1964. In addition, subsonic investment equations are applied to the DC-8 aircraft and the resultant cost is compared to cost data received from the Douglas Aircraft Company; the subsonic operating equations are applied to various commercial aircrafts and the results compared with reporting data; and in each major cost area, illustrative estimates of variance are shown.

1.3 This volume is classified because it contains data which are vital to the security of the United States and also because certain data from the aircraft and engine companies contained herein are regarded by them as proprietary.

1.4 It was frequently necessary to reorganize data obtained from various sources to put it into a format compatible with the methodology used to develop the equations. By the same token, on occasion, it was necessary to make judgments regarding the accuracy of conflicting data. For these reasons, ORI accepts full responsibility for the data finally used in the development of the equations.

1.5 This volume contains three basic sections illustrating:

- a. The Application of Operating Cost Equations
- b. The Application of Investment Cost Equations
- c. The Application of R&D Equations.

1.6 All terms used in the equations are defined in a foldout at the back of the volume.

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II. APPLICATION OF OPERATING COST EQUATIONS

INTRODUCTION

2.1 The following equations provide an estimate of the components of aircraft operating costs. The equation formats are applicable both to subsonic and supersonic aircraft; however, there are differences between the coefficients, both for subsonic and supersonic operations and for operations over different geographic configurations. In the estimates shown in this section a 2000-mile domestic flight segment is assumed.

2.2 The equations are evaluated for specific operation points of the SST aircraft proposed by Lockheed and Boeing. Definitions for the terms used in the equations are provided in the foldout at the back of this volume. Values for the variable and coefficients used in the solution of the equations are provided in the tables below.

TABLE 2.1

VARIABLES APPLICABLE TO COSTING PROPOSED SST DESIGNS
(AIRCRAFT DESIGN CHARACTERISTICS)

SST-Related Variable	Contractor			
	Lockheed		Boeing	
	PW	GE	PW	GE
F^o	2300°F	2300°F	2300°F	2300°F
G_o	.085	.085	.0853	.0853*
I_o	$33.6M	$28.2M	$20.9M	$21.6M
p	24.53 tons	24.53 tons	27.42 tons	27.42 tons
P_A	450 K	450 K	450 K	450 K
p_c	80	80	80	80

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TABLE 2.1 (cont)

P_E	$8000 K	$4400 K	$3852 K	$3920 K
P_f	$18,700 K	$18,700 K	$13,070 K	$13,070 K
p_f	20	20	20	20
P_o	$26,700 K	$23,100 K	$16,922 K	$16,990 K
t	0	0	0	0
r_f	$.0650/mi	$.0650/mi	$.0650/mi	$.0650/mi
r_c	$.0566/mi	$.0566/mi	$.0566/mi	$.0566/mi
t_b	1.72 hr	1.72 hr	1.74 hr	1.74 hr
T	60,920 lb	51,500 lb	56,000 lb	41,900 lb
V	1985 mph	1985 mph	1786 mph	1786 mph
V_k	1725 knots	1725 knots	1550 knots	1550 knots
W_A	204,547 lb	204,547 lb	223,209 lb	223,209 lb
W_E	10,319 lb	11,234 lb	9,790 lb	8,545 lb
W_f	96,000 lb	96,000 lb	98,800 lb	98,800 lb
W_g	454,000 lb	454,400 lb	500,000 lb	500,000 lb
Y_{17}	$25,750	$25,750	$26,820	$26,820
n_s	221	221	230	230

*Data provided by the Department of Commerce

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TABLE 2.2
VALUES FOR OTHER VARIABLES

$d = 2000$ miles
$D = 6.7$ lb/gallon
$L_A = 7$ yr
$L_E = 12$ yr
$L_f = 12$ yr
$L_G = 5$ yr
$n_1 = n_2 = n_3 = 1$
$N_E = 4$

$R_A = 0$
$R_E = .05$
$R_G = 0$
$S_A = .50$
$S_E = .50$
$S_f = .15$
$U = 3000$ hr/yr

TABLE 2.3
COEFFICIENTS, k_i, USED IN SOLUTION OF THE OPERATING COST EQUATIONS

	Coefficients defined for various airline operations as follows:				
k_1	Airline	k_1A	$k_1'A$	k_1	k_1'
	U.S. Domestic U.S. International Foreign	-56.75 -68.10 -40.86	30.14 36.17 21.70	-50.83 -61.00 -36.60	30.14 36.17 21.70
	Coefficients defined for various airline operations as follows:				
k_2	Airline	k_2A	$k_2'A$	k_2	k_2'
	U.S. Domestic U.S. International Foreign	-32.14 -38.57 -23.14	17.07 20.48 12.29	-28.78 -34.55 -20.73	17.07 20.48 12.29

[redacted]

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TABLE 2.3 (cont)

k_3	Coefficients defined for various airline operations as follows:				
	Airline	k_3A	k'_3A	k_3	k'_3
	U.S. Domestic U.S. International Foreign	-30.58 -36.70 -22.02	16.24 19.49 11.69	-27.39 -32.87 -19.72	16.24 19.49 11.69
k_4, k'_4	Cost of kerosene fuel, and oil respectively, in $/gallon estimated for various airline operations as follows:				
	Airline	k_4	k'_4		
	U.S. Domestic U.S. International Foreign	.098 .118 .118	12.00 12.00 12.00		
k_5	Insurance rates, dollars per year per dollar of investment, estimated as follows:				
	Aircraft Speed	k_5			
	Subsonic Supersonic	$0.025 $0.050			
k_7	Coefficient estimated for various airline operations as follows:				
	Airline	k_7			
	U.S. Domestic U.S. International Foreign	1.0 1.0 1.33			
k_{11}	Rate of maintenance burden per dollar of engine and airframe maintenance labor cost, estimated for various airline operations as follows:				
	Airline	k_{11}			
	U.S. Domestic U.S. International Foreign	1.70 1.90 1.90			

[redacted]

TABLE 2.3 (cont)

k_{15}	Coefficient estimated for various airline operations as follows:				
	Airline	k_{15}			
	U.S. Domestic U.S. International Foreign	1.17 2.34 2.34			
k_{16}	Coefficient estimated for various airline operations as follows:				
	Airline	k_{16}			
	U.S. Domestic U.S. International Foreign	0.262 0.346 0.346			
k_{17}	Cost of ground equipment maintenance and burden per dollar of depreciable ground equipment cost, estimated for various airline operations as follows:				
	Airline	k_{17}			
	U.S. Domestic U.S. International Foreign	.0439 .0439 .0439			
k_{18}	Coefficient estimated for various airline operations as follows:				
	Airline	k_{18}			
	U.S. Domestic U.S. International Foreign	.050 .050 .055			
k_{20}	Coefficient estimated for various airline operations as follows:				
	Airline	k_{20}			
	U.S. Domestic U.S. International Foreign	.004 .004 .004			

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TABLE 2.3 (cont)

k'	Dollar cost of depreciable ground equipment per dollar investment in flight equipment estimated as follows:				
	Aircraft Operation	k'			
	U.S. Domestic	.125			
	U.S. International	.110			
	Foreign	.110			

APPLICATION OF EQUATIONS TO SST PROPOSALS

2.3 The operating cost equations and their application to the Lockheed, Boeing, Pratt & Whitney, and General Electric design configurations follow. A 2000 statute mile domestic flight segment is assumed.

FLIGHT CREW COSTS—PILOT

$$C_1 = n_1 (k_1 + k_1' \log_{10} \frac{pd}{t_b}) t_b, \text{ dollars/flight segment.}$$

For Lockheed proposal:

$$C_1 = 1 \left[-50.83 + 30.14 \log_{10} \left(\frac{49060 \times 2000}{1.72 \times 2000} \right) \right] (1.72)$$

$$= \$143 \text{ per flight segment}$$

For Boeing proposal:

$$C_1 = 1 \left[-50.83 + 30.14 \log_{10} \left(\frac{54845 \times 2000}{2000 \times 1.74} \right) \right] (1.74)$$

$$= \$147 \text{ per flight segment}$$

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FLIGHT CREW COST—COPILOT

$$C_2 = n_2 (k_2 + k_2' \log_{10} \frac{pd}{tb}) t_b, \text{ dollars/flight segment.}$$

For Lockheed proposal:

$$C_1 = 1 \left[-28.79 + 17.07 \log_{10} \left(\frac{49060 \times 2000}{1.72 \times 2000} \right) \right] (1.72)$$

$$= \$81 \text{ per flight segment.}$$

For Boeing proposal:

$$C_2 = 1 \left[-28.79 + 17.07 \log_{10} \left(\frac{54845 \times 2000}{2000 \times 1.74} \right) \right] (1.74)$$

$$= \$83 \text{ per flight segment.}$$

FLIGHT CREW COST—FLIGHT ENGINEER AND NAVIGATOR

$$C_3 = n_3 (k_3 + k_3' \log_{10} \frac{pd}{t_b}), t_b. \text{ dollars/flight segment.}$$

For Lockheed proposal:

$$C_3 = 1 \left[-27.39 + 16.24 \log_{10} \left(\frac{49060 \times 2000}{1.72 \times 2000} \right) \right] (1.72)$$

$$= \$78 \text{ per flight segment.}$$

For Boeing proposal:

$$C_3 = 1 \left[-27.39 + 16.24 \log_{10} \left(\frac{54845 \times 2000}{1.74 \times 2000} \right) \right] (1.74)$$

$$= \$80 \text{ per flight segment.}$$

FUEL COST

$$C_4 = 1.03 \left(\frac{k_4 \, Wf}{D} + N_E k_4' \, G_0 \, t_b \right) \text{ dollars/flight segment.}$$

For Lockheed proposal:

$$C_4 = 1.03 \left[\frac{.098 \times 96000}{6.7} + 4\,(12)\,(.085)\,(1.72) \right] = \$1478 \text{ per segment.}$$

For Boeing proposal:

$$C_4 = 1.03 \left[\frac{.098 \times 98800}{6.7} + 4\,(12)\,(.0853)\,(1.74) \right] = \$1486 \text{ per segment.}$$

INSURANCE COST

$$C_5 = \frac{k_5 \, P_0 \, t_b}{U} \text{ dollars/flight segment.}$$

For Lockheed proposal:

$$C_5 = \frac{.050 \times 26.7\text{M\$}}{3000} (1.72) = \$765 \text{ per segment with PW engines.}$$

$$C_5 = \frac{.050 \times 23.1 \text{ M\$}}{3000} (1.72) = \$662 \text{ per segment with GE engines.}$$

For Boeing proposal:

$$C_5 = \frac{.050 \times 16.9 \text{ M\$}}{3000} (1.74) = \$490 \text{ per segment with PW engines.}$$

$$C_5 = \frac{.050 \times 17.0 \text{ M\$}}{3000} (1.74) = \$493 \text{ per segment with GE engines.}$$

SONIC BOOM COST

C_6 equation to be developed from other studies.

[redacted]

MAINTENANCE COSTS FOR FLIGHT EQUIPMENT

a. Labor, Airframe, and Other

$$C_7 = .91\, k_7 [(12.91 + .0001825\, W_A)\, W_1$$

$$+ (2.348 + .0747\, V_k)\, W_2]\; t_b/(W_1 + W_2) \text{ dollars/flight segment}$$

$$W_1 = \left(\frac{40,100}{W_A - 89800}\right)^2 \qquad W_2 = \left(\frac{152}{V_k - 392}\right)^2$$

For Lockheed proposal:

$$C_7 = .91 \{12.915 + .0001825\,(204,547)]\;(.1225)$$

$$+ [2.348 + .0747\;(1725)](.01323)\}\;\frac{1.72}{(.1357)} = \$91 \text{ per flight segment}$$

For Boeing proposal:

$$C_7 = .91 \{[12.915 + .0001825\,(223,209)](.09)$$

$$+ [2.348 + .0747\;(1550)](.0171)\}\;\frac{1.74}{.1071} = \$101 \text{ per flight segment}$$

b. Material, Airframe, and Other

$$C_8 = .91 k_7 [34.637 + .004683\,(P_f + P_A) - 4.7335\,t]\; t_b \text{ dollars/flight segment}$$

For Lockheed proposal, first year (t = o):

$$C_8 = .91\;[34.637 + .004683\;(19,150\text{K\$})]\;(1.72)$$

$$= \$196 \text{ per segment}$$

For Boeing proposal, first year (t = o):

$$C_8 = .91\;[34.637 + .004683\;(13,520\text{K\$})]\;(1.74)$$

$$= \$156 \text{ per segment}$$

[redacted]

c. <u>Labor, Engine</u>

$$C_9 = .91k_7 N_E[-26.41 + .01697\ F^o + 2.0214\ {}^T/W_E]\ t_b,\text{dollars/flight segment}$$

<u>For Pratt & Whitney engine to be used by Lockheed:</u>

$$C_9 = .91(4)\left[-26.41 + .01697\ (2300) + 2.0214\ \frac{60920}{10319}\right]\ (1.72)$$

$$= \$153 \text{ per aircraft flight segment}$$

<u>For Pratt & Whitney engine to be used by Boeing:</u>

$$C_9 = .91(4)\left[-26.41 + .01697\ (2300) + 2.0214\ \frac{56000}{9790}\right]\ (1.74)$$

$$= \$153 \text{ per aircraft flight segment}$$

<u>For GE engine to be used by Lockheed:</u>

$$C_9 = .91(4)\left[-26.41 + .01697\ (2300) + 2.0214\ \frac{51500}{11234}\right]\ (1.72)$$

$$= \$137 \text{ per aircraft flight segment}$$

<u>For GE engine to be used by Boeing:</u>

$$C_9 = .91(4)\left[-26.41 + .01697\ (2300) + 2.0214\ \frac{41900}{8545}\right]\ (1.74)$$

$$= \$143 \text{ per aircraft flight segment}$$

d. <u>Material, Engine</u>

$$C_{10} = .91k_7 N_E\left[-60.593 + 0.039 F^o + 3.347\ {}^T/W_E\right] t_b,\ \text{dollars/flight segment}$$

<u>For Pratt & Whitney engine to be used by Lockheed:</u>

$$C_{10} = .91(4)\left[-60.59 + 0.039\ (2300) + 3.347\left(\frac{60920}{10319}\right)\right] (1.72)$$

$$= \$306 \text{ per aircraft segment}$$

[redacted] [redacted]

For Pratt & Whitney engine to be used by Boeing:

$$C_{10} = .91(4)\left[-60.59 + 0.039\,(2300) + 3.347\left(\frac{56000}{9790}\right)\right](1.74)$$

= \$301 per aircraft segment

For GE engine to be used by Lockheed:

$$C_{10} = .91(4)\left[-60.59 + 0.039\,(2300) + 3.347\left(\frac{51500}{11234}\right)\right](1.72)$$

= \$280 per aircraft segment

For GE engine to be used by Boeing:

$$C_{10} = .91(4)\left[-60.59 + 0.039\,(2300) + 3.347\left(\frac{41900}{8545}\right)\right](1.74)$$

= \$290 per aircraft segment

MAINTENANCE BURDEN

$C_{11} = k_{11}\,(C_7 + C_9)$, dollars/flight segment

For Lockheed proposal using Pratt & Whitney engine:

$C_{11} = (1.70)\,(263) = 447$ dollars/segment

For Lockheed proposal using GE engine:

$C_{11} = (1.70)\,(247) = 420$ dollars/segment

For Boeing proposal using GE engine:

$C_{11} = (1.70)\,(257) = 437$ dollars/segment

For Boeing proposal using Pratt & Whitney engine:

$C_{11} = (1.70)\,(267) \doteq 454$ dollars/segment

[redacted] [redacted]

DEPRECIATION, AIRFRAME, AND SPARES

$$C_{12} = \frac{P_f (1+S_f)(1-R_f)\, t_b}{L_f U} \text{ dollars/flight segment}$$

For Lockheed proposal:

$$C_{12} = \frac{(19.15\text{M\$})(1.15)(0.95)(1.72)}{12\,(3000)} = \$1000 \text{ per segment}$$

For Boeing proposal:

$$C_{12} = \frac{(13.52\text{M\$})(1.15)(0.95)(1.74)}{12\,(3000)} = \$715 \text{ per segment}$$

DEPRECIATION, ENGINES, AND SPARES

$$C_{13} = \frac{N_E P_E (1+S_E)(1-R_E)\, t_b}{L_E U}$$

For Pratt & Whitney/Lockheed engine:

$$C_{13} = \frac{(8000\text{K\$})(1.50)(0.95)(1.72)}{12\,(3000)} = \$545 \text{ per segment}$$

For Pratt & Whitney/Boeing engine:

$$C_{13} = \frac{(3852\text{K\$})(1.50)(0.95)(1.74)}{12\,(3000)} = \$265 \text{ per segment}$$

For GE/Lockheed engine:

$$C_{13} = \frac{(4400\text{K\$})(1.50)(0.95)(1.72)}{12\,(3000)} = \$300 \text{ per segment}$$

For GE/Boeing engine:

$$C_{13} = \frac{(3920\text{K\$})(1.50)(0.95)(1.74)}{12\,(3000)} = \$271 \text{ per segment}$$

DEPRECIATION, AVIONICS, AND OTHER FLIGHT EQUIPMENT

$$C_{14} = \frac{P_A\,(1 + S_A)\,(1 - R_A)\,t_b}{L_A U} \quad \text{dollars/flight segment}$$

For Lockheed proposal:

$$C_{14} = \frac{(450\ \text{K})\,(1.5)\,(1)\,(1.72)}{(7)\,(3000)} = \$55 \text{ per segment}$$

For Boeing proposal:

$$C_{14} = \frac{(450\ \text{K})\,(1.5)\,(1)\,(1.74)}{(7)\,(3000)} = \$56 \text{ per segment}$$

AIRCRAFT SERVICING COSTS

$$C_{15} = k_{15}\,\frac{W_g}{1000} \quad \text{dollars/flight segment}$$

For Lockheed proposal:

$$C_{15} = 1.17\left(\frac{454{,}000}{1000}\right) = \$531 \text{ per flight segment}$$

For Boeing proposal:

$$C_{15} = 1.17\left(\frac{500{,}000}{1{,}000}\right) = \$585 \text{ per flight segment}$$

TRAFFIC SERVICING COSTS

$$C_{16} = k_{16} Y \quad \text{dollars/flight segment}$$

$$= k_{16}\, n_s d\,[p_f r_f + p_c r_c]$$

For Lockheed proposal:

$$C_{16} = 0.262\ (221)\ (2000)\ \left[(80)\ (.0566) + (20)\ (.0650)\right]$$

$$= \$6750 \text{ per segment}$$

For Boeing proposal:

$$C_{16} = 0.262\ (230)\ (2000)\ \left[(80)\ (.0566) + (20)\ (.0650)\right]$$

$$= \$7030 \text{ per segment}$$

GROUND EQUIPMENT MAINTENANCE AND BURDEN

$$C_{17} = k_{17} \frac{K'\ I_o\ t_b}{U} \quad \text{dollars/flight segment}$$

For Lockheed proposal (assuming PW engine):

$$C_{17} = \frac{.0439\ (.110)\ (33.6M\$)\ (1.72)}{(3000)} = \$93 \text{ per segment}$$

For Lockheed proposal (assuming GE engine):

$$C_{17} = \frac{.0439\ (.110)\ (28.2M\$)\ (1.72)}{(3000)} = \$78 \text{ per segment}$$

For Boeing proposal (assuming PW engine):

$$C_{17} = \frac{.0439\ (.110)\ (20.9M\$)\ (1.74)}{(3000)} = \$59 \text{ per segment}$$

For Boeing proposal (assuming GE engine):

$$C_{17} = \frac{.0439\ (.110)\ (21.6M\$)\ (1.74)}{(3000)} = \$61 \text{ per segment}$$

GENERAL AND ADMINISTRATIVE COSTS

$$C_{18} = k_{18} \left(\sum_{i=1}^{11} C_i + \sum_{i=15}^{17} C_i \right)$$

For Lockheed/PW proposal:

$$C_{18} = .050\ (11289) = \$564 \text{ per segment}$$

For Lockheed/GE proposal:

$$C_{18} = .050\ (11093) = \$555 \text{ per segment}$$

For Boeing/PW proposal:

$$C_{18} = .050\ (11291) = \$565 \text{ per segment}$$

For Boeing/GE proposal:

$$C_{18} = .050\ (11254) = \$563 \text{ per segment}$$

DEPRECIATION, GROUND PROPERTY, AND EQUIPMENT

$$C_{19} = \frac{k'\ I_o\ (1\text{-}RG)\ \ t_b}{L_G U}$$

For Lockheed/PW proposal:

$$C_{19} = \frac{.125\ (33.6M\$)\ (1)\ (1.72)}{(5)\ (3000)} = \$482 \text{ per segment}$$

For Lockheed/GE proposal:

$$C_{19} = \frac{.125\ (28.2M\$)\ (1)\ (1.72)}{(5)\ (3000)} = \$403 \text{ per segment}$$

For Boeing/PW proposal:

$$C_{19} = \frac{.125\ (20.9M\$)\ (1)\ (1.74)}{(5)\ (3000)} = \$303 \text{ per segment}$$

For Boeing/GE proposal:

$$C_{19} = \frac{.125\ (21.6M\$)\ (1)\ (1.74)}{(5)\ (3000)} = \$314 \text{ per segment}$$

AMORTIZATION OF PREOPERATING COSTS

$$C_{20} = \frac{k_{20}\ Io\ tb}{U}$$

For Lockheed/PW proposal:

$$C_{20} = \frac{.004\ (33.6M\$)\ 1.72}{3000} = \$77 \text{ per segment}$$

For Lockheed/GE proposal:

$$C_{20} = \frac{.004\ (28.2M\$)\ (1.72)}{3000} = \$65 \text{ per segment}$$

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For Boeing/PW proposal;

$$C_{20} = \frac{.004\ (20.9M\$)\ (1.74)}{3000} = \$49 \text{ per segment}$$

For Boeing/GE proposal:

$$C_{20} = \frac{.004\ (21.6)\ 1.74}{3000} = \$51 \text{ per segment}$$

[redacted]

[redacted]

TABLE 2.4

COST SUMMARY FOR 2000-MILE AIRCRAFT SEGMENT IN DOLLARS

Cost Item	Lockheed/PW	Lockheed/GE	Boeing/PW	Boeing/GE
Crew Cost	302	302	310	310
Fuel Cost	1478	1478	1486	1486
Insurance	765	662	490	493
Maintenance	746	704	711	690
Maintenance Burden	415	388	432	415
Direct Operating Cost	3706	3534	3429	3394
Depreciation	1600	1355	1036	1082
Aircraft Servicing	531	531	585	585
Traffic Servicing	6750	6750	7030	7030
Ground Maint/Burd	93	78	59	61
G&A	564	555	565	563
Deprec. Gnd. Equip.	482	403	303	314
Preop. Costs	77	65	49	51
Indirect Operating Cost	10,038	9689	9590	9648
Total	13,803	13,271	13,056	13,080

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TEST OF EQUATIONS AGAINST CURRENT AIRCRAFT DATA

2.4 In order to confirm the usefulness of the CERs for prediction, the equations were applied to aircraft which had been withheld from the analysis for test purposes. The comparison of predicted data against observed data is shown in Table 2.5.

TABLE 2.5

COMPARISON OF PREDICTED AND OBSERVED COSTS, DOLLARS/REVENUE HOUR
(FORMULA FOR B707-320 ON NYC-LAX SEGMENT vs FAA AVERAGES)

Cost Group	Description	Cost per Revenue Block Hour, dollars	
		Formula	FAA
C_1	Pilot Costs	62.28	
C_2	Copilot Costs	35.28	
C_3	Flight Engineer Costs	33.56	
	Subtotal	131.12	122.54
C_{4a}	Fuel Cost	222.13	185.03 (includes cost of oil)
C_5	Insurance, Injury, Loss and Damage Costs	39.21	39.31
C_6	Sonic Boom (not included)		
C_7-C_{11}	Treated separately*		
C_{12}	Depreciation of Airframes and Spares	125.97	100.02
C_{13}	Depreciation of Engines and Spares	19.32	29.83
C_{14}	Depreciation of Avionics and Spares	3.29	6.95
Subtotal Depreciation		148.58	136.80

*See computer printouts, Vol. I.

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Table 2.6 illustrates the wide range of cost-experience for total direct maintenance by aircraft type for 1962.

TABLE 2.6

RANGE OF DIRECT MAINTENANCE COSTS REPORTED FOR SELECTED AIRCRAFT
IN 1962, DOLLARS/REVENUE HOUR

Aircraft	Low	High
B-707	144	195
B-720	97	126
DC-8	116	176
CV-880	237	284

It will be noted that the variance is high, both between aircraft types and among similar aircraft. In view of this variance and the limited data sample of jet aircraft not already incorporated in the CERs – the B-727 experience for part of 1964 was based on insufficient flight hours – an independent test of C_7 to C_{11} was not conducted.

ILLUSTRATIVE CALCULATION OF STANDARD DEVIATION

2.5 An illustrative calculation of the standard deviation for an operating cost equation follows. A description of the method is included in Appendix A to Volume I. The example used herein is the equation for maintenance cost, material, airframe and is solved using parameters appropriate to the Lockheed airplane. It is applicable to the estimate for <u>average</u> airframe material cost taken over a large number of aircraft.

$$S_{yp}^2 = \frac{S^2}{n}\left[1 + \left(\frac{x_p - \bar{x}}{S_x}\right)^2\right]$$

$$S^2 = \frac{1}{n-2}\,\Sigma\,(\text{res})_y^2 = \frac{1}{19-2}\,(386.3) = 22.7$$

$$S_{yp}^2 = \frac{22.7}{19}\left[1 + \left(\frac{19150 - 2136}{1325}\right)^2\right] = 197.5$$

$$S_{yp} = 14.05$$

2.6 The maintenance cost equation was solved for the case of $t = o$. The standard deviation is calculated on the same basis and consequently S_{yp} represents the standard deviation of the estimated airframe materials maintenance costs in the initial year of operation.

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III. APPLICATION OF INVESTMENT COST EQUATIONS

INTRODUCTION

3.1 Calculations are provided herein which apply to both subsonic and supersonic investment cost equations. The subsonic airframe equations are applied to data pertaining to the DC-8. The supersonic equations, both airframe and engine, are applied to the Boeing, Lockheed, Pratt & Whitney, and General Electric data extracted from their 1 November 1964 proposals.

3.2 Definitions for the terms used in the equations are provided in the foldout at the back of this volume.

VARIABLES APPLICABLE TO COSTING PROPOSED SST DESIGNS

3.3 Table 3.1 provides the aircraft and engine data used in the calculations. Learning curve data are provided in Tables 3.2 and 3.3.

APPLICATION OF EQUATIONS TO SST PROPOSALS

3.4 The investment cost equations are shown and applied to the SST designs on the following pages.

AIRFRAME LABOR

$$\bar{C}'_{L_N} \cong \frac{[1.55 + .77\,X]\,[-99023 + 225.2\,V_k + 8.11\,W_o]}{100^{b}}\;\frac{N^{b+1}}{N\,(b+1)}$$

<u>Lockheed</u>

$$\bar{C}'_{L_{200}} \cong \frac{[1.55 + (.77)(.71)]\,[-99023 + 225.2\,(1725) + 8.11\,(142322)]}{100^{-.322}}\;\frac{200^{1-.322}}{200(1-.322)}$$

$$\bar{C}'_{L_{200}} \cong \$3{,}577{,}350$$

300

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[redacted]

TABLE 3.1

AIRCRAFT AND ENGINE CHARACTERISTICS

		SST		Subsonic
		Lockheed	Boeing	DC-8
Weight AMPR, lb	W_o	142322	163420	100356
Speed, knots	V_k	1725	1550	470
Speed, mach	V_m	3.0	2.7	.85
Cumulative average delivery rate to unit 100	$Q_{AV_{100}}$	2.38	2.7	3.0
The fraction of airframe weight (AMPR) which is titanium	X	.71	.58	—

		P&W		G&E	
		Lockheed	Boeing	Lockheed	Boeing
Thrust, maximum, augmented	T	60920	56000	51500	41900
Maximum turbine inlet temperature	F^o	2300	2300	2200	2200
Mach limit number	M	3.0	2.7	3.0	2.7

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TABLE 3.2

LEARNING CURVE CHARACTERISTICS, SUBSONIC INVESTMENT EQUATIONS

	Slope, percent	-b	Type
Labor	77	.377	log linear unit
Material	90	.152	log linear unit
Tooling	65	.622	log linear cumulative average
Engineering	65	.622	log linear cumulative average
Engines	90	.152	log linear cumulative average

TABLE 3.3

LEARNING CURVE CHARACTERISTICS, SUPERSONIC TRANSPORT INVESTMENT EQUATIONS

	Slope, percent	-b	Type
Labor	80	.322	log linear unit
Materials	90	.152	log linear unit
Tooling	70	.515	log linear cumulative average
Engineering	65	.622	log linear cumulative average
Engines	90	.152	log linear cumulative average

[redacted]

[redacted]

Boeing

$$\bar{C}'_{L_{200}} \cong \frac{[1.55 + .77(.58)][-99023 + 225.2(1550) + 8.11(163,420)]}{100^{-.322}} \, \frac{200^{1-.322}}{200(1-.322)}$$

$$\bar{C}'_{L_{200}} \cong \$3,718,000$$

OVERHEAD

$$\bar{C}'_{OH_N} \cong R_{OH} \, \bar{C}'_{L_N}$$

Lockheed

$$\bar{C}'_{OH_{200}} = 1.5\,(3,577,350) = \$5,366,025$$

Boeing

$$\bar{C}'_{OH_{200}} = 1.5\,(3,718,000) = \$5,577,000$$

AIRFRAME MATERIALS

$$\bar{C}'_{M_N} \cong \frac{P_M\,[2.75 + 2.47\,X]\left[-235520 + 17.32\,W_o + 227,700\,V_m\right]}{100^b \qquad N} \, \frac{N^{b+1}}{(b+1)}$$

Lockheed

$$\bar{C}'_{M_{200}} \cong \frac{(.55)\,[2.75 + 2.47(.71)][-235520 + 17.32\,(142322) + 227700\,(3.0)]}{100^{-.152}}$$

$$X \left[\frac{200^{1-.152}}{200\,(1-.152)}\right]$$

$$\bar{C}'_{M_{200}} \cong \$7,656,000$$

[redacted]

Boeing

$$\bar{C}'_{M_{200}} = \frac{(.55)\ [2.75+2.47(.71)]\ [-235520 + 17.32\ (163420 + 227{,}700\ (2.7)]}{100^{-.152}}$$

$$X \quad \left[\frac{200^{1-.152}}{200\ (1-.152)}\right]$$

$$\bar{C}_{M_{200}} = \$7{,}851{,}472$$

AIRFRAME TOOLING

$$\bar{C}'_{TO_N} = [1.50 + .71\ X]\left[70{,}968\ W_o^{-.7484} V_m^{.9176} Q_{AV_{100}}^{-.8325}\right] W_o \frac{N^b}{100^b}$$

Lockheed

$$\bar{C}'_{TO_{200}} = [1.50 + .71\ (.71)]\left[70{,}968(142322)^{-.7484}(3.0)^{.9176}(2.38)^{-.8325}\right]$$

$$X \quad \left[\frac{(142322)\ 200^{-.515}}{100^{-.515}}\right]$$

$$\bar{C}'_{TO_{200}} = \$2{,}618{,}000$$

Boeing

$$\bar{C}'_{TO_{200}} = [1.50 + .71\ (.58)]\left[70968\ (163420)^{-.7484}(2.7)^{.9176}(2.7)^{-.8325}\right]$$

$$X \quad \left[\frac{(163420)\ 200^{-.515}}{100^{-.515}}\right]$$

[redacted]

$\overline{C}'_{TO_{200}} = \$2,115,325$

AIRFRAME SUSTAINING ENGINEERING

$$\overline{C}'_{SE_N} = 21,400\ W_o^{-.61275} V_m^{1.6798} Q_{AV_{100}}^{-.83112}\ W_o \frac{N^b}{100^b}$$

Lockheed

$$\overline{C}'_{SE_{200}} = 21,400\ (142322)^{-.61245}(3.0)^{1.6798}(2.38)^{-.83112}(142322)\frac{200^{-.622}}{100^{-.622}}$$

$$\overline{C}'_{SE_{200}} = \$4,239,000$$

Boeing

$$\overline{C}'_{SE_{200}} = 21400\ (163420)^{-.61275}(2.7)^{1.6798}(2.7)^{-.83112}(163420)\frac{200^{-.622}}{100^{-.622}}$$

$$\overline{C}'_{SE_{200}} = \$3,374,000$$

TOTAL AIRFRAME

$$\overline{C}'_{A/F_N} = \overline{C}'_{L_N} + \overline{C}'_{OH_N} + \overline{C}'_{M_N} + \overline{C}'_{TO_N} + \overline{C}'_{SE_N}$$

Lockheed

$$\overline{C}'_{A/F200} = \$3,577,350 + 5,366,025 + 7,656,000 + 2,618,000 + 4,239,000$$

$$\overline{C}'_{A/F200} = \$23,456,375$$

[redacted]

[redacted]

Boeing

$$\overline{C}'_{A/F_{200}} = \$3{,}718{,}000 + 5{,}577{,}000 + 7{,}851{,}472 + 2{,}115{,}325 + 3{,}374{,}000$$

$$\overline{C}'_{A/F_{200}} = \$22{,}635{,}797$$

PROPULSION

$$\overline{C}'_{E_N} = N_E(1000)\left[.011333T + .32166F^{o} + 73.823M - 537.57\right]\frac{(R_{EM}N)^{b}}{1200^{b}}$$

Pratt & Whitney (for Lockheed

$$\overline{C}'_{E_{200}} = 4(1000)\left[.011333\,(60920) + .32166(2300) + 73.823(3.0) - 537.57\right]\frac{[6.0(200)]^{-.152}}{1200^{-.152}}$$

$$\overline{C}'_{E_{200}} = \$4{,}457{,}320$$

Pratt & Whitney (for Boeing)

$$\overline{C}'_{E_{200}} = 4(1000)\left[.011333(56000) + .32166(2300) + 73.823(2.7) - 537.57\right]\frac{[6.0(200)]^{-.152}}{1200^{-.152}}$$

$$\overline{C}'_{E_{200}} = \$4{,}144{,}888$$

General Electric (for Lockheed)

$$\overline{C}'_{E_{200}} = 4(1000)\left[.011333(51500) + .32166(2200) + 73.823(3.0) - 537.57\right]\frac{[6.0(200)]^{-.152}}{1200^{-.152}}$$

$$\overline{C}'_{E_{200}} = \$3{,}900{,}800$$

[redacted]

General Electric (for Boeing)

$$\overline{C'}_{E_{200}} = 4(1000)\left[.011333(41900) + .32166(2200) + 73.823(2.7) - 537.57\right]\frac{[6.0(200)]^{-.152}}{1200^{-.152}}$$

$$\overline{C'}_{E_{200}} = \$3,377,000$$

AVIONICS

$$\overline{C'}_{AV_{200}} = \$450,000$$

TOTAL AIRCRAFT COST

$$\overline{C'}_{A/C_N} = \overline{C'}_{L_N} + \overline{C'}_{OH_N} + \overline{C'}_{M_N} + \overline{C'}_{SE_N} + \overline{C'}_{TO_N} + \overline{C'}_{E_N} + \overline{C'}_{AV_N}$$

Lockheed (with P&W engines)

$$\overline{C'}_{A/C_{200}} = \$23,456,375 + 4,457,320 + 450,000$$

$$\overline{C'}_{A/C_{200}} = \$28,363,695$$

Lockheed (with GE engines)

$$\overline{C'}_{A/C_{200}} = \$23,456,375 + \$3,900,800 + 450,000$$

$$\overline{C'}_{A/C_{200}} = \$27,807,175$$

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Boeing (with P&W engines)

$$\bar{C}'_{A/C_{200}} = \$22,635,797 + 4,144,888 + 450,000$$

$$\bar{C}'_{A/C_{200}} = \$27,230,685$$

Boeing (with GE engines)

$$\bar{C}'_{A/C_{200}} = \$22,635,797 + 3,377,000 + 450,000$$

$$\bar{C}'_{A/C_{200}} = \$26,462,797$$

SPARES (Airframe)

$$\bar{C}'_{SPF_N} = .15\ \bar{C}'_{A/F_N}$$

Lockheed

$$\bar{C}'_{SPF_{200}} = .15\ (23,456,000) = \$3,518,400$$

Boeing

$$\bar{C}'_{SPF_{200}} = .15\ (22,635,797) = \$3,395,370$$

SPARES (Engine)

$$\bar{C}'_{SPE_N} = .5\ \bar{C}'_{E_N}$$

Pratt & Whitney in the Lockheed airplane

$$\bar{C}'_{SPE_{200}} = .5\ (4,457,320) = \$2,228,660$$

Pratt & Whitney in the Boeing airplane

$$\bar{C}'_{SPE_{200}} = .5\ (4,144,888) = \$2,072,444$$

General Electric in the Lockheed airplane

$$\bar{C}'_{SPE_{200}} = .5\ (3,900,800) = \$1,950,400$$

General Electric in the Boeing airplane

$$\bar{C}'_{SPE_{200}} = .5\ (3,377,000) = \$1,688,500$$

TEST OF SUBSONIC TRANSPORT EQUATIONS AGAINST MANUFACTURED DATA

3.5 The subsonic airframe equations were applied to the data pertaining to the DC-8. The cumulative average cost of the one hundredth airframe is calculated and the results summarized below:

Labor	$\bar{C}_{L100}$	=	\$1,307,634
Overhead and G&A	$\bar{C}_{OH100}$	=	1,961,451
Sustaining Engineering	$\bar{C}_{SE100}$	=	929,285
Materials	$\bar{C}_{M100}$	=	2,015,503
Tooling	$\bar{C}_{TO100}$	=	973,711
Total Airframe	$C_{A/F100}$	=	\$7,187,584

3.6 Information received from Douglas Aircraft indicates that the actual cumulative average cost of the one hundredth airframe was approximately \$9.8 million.

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ILLUSTRATIVE CALCULATION OF STANDARD DEVIATION

3.7 A typical standard deviation for the SST operating points is calculated below for the case of airframe labor. The data used correspond to the Lockheed airframe.

$$\sigma^2_{y_p} \doteq \frac{\sigma^2}{n}\left[1 + \sum_{i=1}^{k}\left(\frac{X_{pi} - \overline{X}_i}{S_{X_i}}\right)^2\right]$$

$$\sigma^2 = \frac{1}{n-k-1}\,\Sigma\,(\text{res})^2\,y$$

$$\sigma^2 = \frac{100{,}090{,}000{,}000}{20-2-1} = 5{,}887{,}647{,}000$$

$$\sigma^2_{y_p} \doteq \frac{5{,}887{,}647{,}000}{20}\left[1 + \left(\frac{1725-668}{367}\right)^2 + \left(\frac{142{,}322-38772}{31600}\right)^2\right]$$

$$\sigma^2_{y_p} \doteq 590{,}236{,}611$$

$$\sigma_{y_p} \doteq \$24{,}300$$

$$\sigma^*_{y_p} = \sqrt{\sigma^2 + \sigma^2_{y_p}}$$

$$\sigma^*_{y_p} = \sqrt{5{,}887{,}647{,}000 + 590{,}236{,}611}$$

$$\sigma^*_{y_p} = \$80{,}500$$

where:

σ_{y_p} = the standard deviation of the estimate for average airframe labor cost, taken over a large production quantity

$\sigma^*_{y_p}$ = the standard deviation of the estimate of airframe labor cost for the first SST airframe produced.

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IV. APPLICATION OF AIRFRAME AND ENGINE DEVELOPMENT COST EQUATIONS

INTRODUCTION

4.1 The following equations provide estimates of airframe and engine development costs. They are applicable to either subsonic or supersonic aircraft development programs.

4.2 The equations are evaluated for specific characteristics of the designs submitted to the Government in the 1 November 1964 proposals. Definitions for the terms used in the equations are provided in the foldout at the back of this volume. Values for the variables used in the solution of the equations are provided below.

VARIABLES APPLICABLE TO COSTING PROPOSED SST DESIGNS

4.3 The values of the variables as drawn from the SST airframe proposals are as shown in Table 4.1.

TABLE 4.1

AIRFRAME VARIABLES FOR SST

Airframe Variable	Lockheed	Boeing
V_k	1725 knots	1550 knots
W_o	142,322 lb	163,420 lb

4.4 The values of the variables as drawn from the SST engine proposals are as shown in Table 4.2.

[redacted]

TABLE 4.2

ENGINE VARIABLES FOR SST

Engine Variable	Boeing			Lockheed		
	T	F^o	M	T	F^o	M
GE/J4/5	41900	2200	2.7	51500	2200	3.0
P&W STF-219	56000	2300	2.7	60920	2300	3.0

D_p, the engine development time, is 60 months for all engine designs.

APPLICATION OF EQUATIONS TO SST PROPOSALS

Airframe Development

$$C_{RA}\ (M\$) = -522.69 + .46035\ V_k + 5.1477\ W_o + 3.0667\ V_k/W_o$$

Lockheed

$$C_{RA} = -522.67 + .46035\ (1725) + 5.1477\ (142.322) + 3.0667\ \frac{1725}{142.322} = 1041.5\ M\$$$

Boeing

$$C_{RA} = -522.67 + .46035\ (1550) + 5.1477\ (163.420) + 3.0667\ \frac{1550}{163.420} = 1060.4\ M\$$$

Engine Development Through Military Qualification Test

$$C_{ED} = .0069417T + .069845\ F^o + 3.0881M - 78.195$$

4.5 With proper substitution of values, the following results are obtained:

	Boeing	Lockheed
GE	\$374,659,000	\$441,777,000
P&W	480,448,000	514,601,000

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[redacted]

Engine Development After Military Qualification Test

$$C_{PD} = .0033063T + .097411F^{o} + 1.8758D_{P} - 193.86$$

4.6 With proper substitution of values, the following results are obtained:

	Boeing	Lockheed
GE	$271,526,000	$303,366,000
P&W	327,876,000	344,154,000

Illustrative Calculation of Standard Deviation

4.7 The standard deviation is calculated below for the CER providing engine development costs through the military qualification test. The engine parameters used in the calculation are those pertinent to the Pratt & Whitney engine designed for the Lockheed airframe.

$$\sigma^2_{y_p} = \frac{\sigma^2}{n}\left[1 + \Sigma_{i=1}^{k}\left(\frac{x_{pi} - \bar{x}_i}{S_{xi}}\right)^2\right]$$

$$\sigma^2 = \frac{1}{n-k-1}\ \Sigma\,(res)^2_y = \frac{1}{10-3-1}\ [5,581.4] = 930.233$$

$$\sigma^2_{y_p} = \frac{930.233}{10}\left[1 + \left(\frac{60920 - 15725}{8830.1}\right)^2 + \left(\frac{2300 - 1735}{200.5}\right)^2 + \left(\frac{3.000 - 1.92}{.7909}\right)^2\right] = 3442.037$$

$\sigma^2_{y_p}$ = 58.7M$ for an "average" of a conceptually large number of parallel, independent development programs. Similarly, for the specific development program,

$$\sigma^*_{y_p} = \sqrt{\sigma^2 + \sigma^2_{yp}} = \sqrt{930.233 + 3442.037} = 66.123M\$$$

where $\sigma^*_{y_p}$ = the standard deviation of the estimated development cost of 514.6M.

[redacted]

DEFINITIONS OF TERMS AND COST AGGREGATIONS USED IN REPORT

Notation Reference	Description
C_i	Cost of the i^{th} aggregate of expenses[1/]
C_1, C_2, C_3	Flight crew costs for pilot, engineer, and navigator (CAB accounts 5123, 5124, 5128.1, 5136, 5157, 5168).
C_4	Fuel and oil costs (CAB accounts 5145.1, 5145.2, 5169).
C_5	Insurance, injury, loss, and damage costs (flying operations) (CAB accounts 5155.1, 5155.2, 5158).
C_6	Sonic boom costs
C_7	Maintenance labor costs—airframes and other flight equipment (CAB accounts 5225.1, 5125.3, parts of 5243.1, 5243.3, 5272.1, 5272.2).
C_8	Maintenance material costs—airframes and other flight equipment (CAB accounts 5246.1, 5246.3, parts of 5243.1, 5243.3, 5272.1, and 5272.2).
C_9	Maintenance labor—aircraft engines (CAB accounts 5225.2, parts of 5243.2, 5272.6, and 5272.7).
C_{10}	Maintenance material costs—aircraft engines (CAB accounts 5246.2, parts of 5243.2, 5272.6, and 5272.7).
C_{11}	Flight equipment maintenance burden (CAB account 5379.6).
C_{12}	Depreciation—airframes and airframe parts (CAB accounts 7075.1 and 7075.3).
C_{13}	Depreciation—aircraft engines and engine parts (CAB accounts 7075.2 and 7075.4).
C_{14}	Depreciation—other flight equipment including spares (CAB account 707.5).
C_{15}	Aircraft ground handling and servicing costs (CAB account 6100 and part of 6300).
C_{16}	Traffic costs (CAB accounts 5500, 6200, 6500, 6600, and part of 6300).
C_{17}	Ground property and equipment maintenance and burden costs (CAB accounts 5225.9, 5246.9, 5379.8).
C_{18}	General and administrative costs (CAB account 6800).
C_{19}	Depreciation—ground property and equipment (CAB account 7075.8, 7075.9).
C_{20}	Amortization—preoperating costs (CAB account 7074.1).

[1/] All costs are expressed in 1963 dollars.

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$\bar{C}_{A/C_N}$	Cumulative average total cost of N subsonic airplanes exclusive of spares and avionics.
$\bar{C}'_{A/C_N}$	Cumulative average total cost of Nth SST airplanes exclusive of spares of avionics.
$\bar{C}_{A/F_N}$	Cumulative average total cost of Nth subsonic airframe, exclusive of airframe spares, avionics, and engines.
$\bar{C}'_{A/F_N}$	Cumulative average total cost of the Nth SST airframe, exclusive of airframe spares, avionics, and engines.
$\bar{C}_{AV_N}$	Cumulative average cost or avionic equipment on the Nth subsonic airframe.
$\bar{C}'_{AV_N}$	Cumulative average cost or avionic equipment on the Nth SST airframe.
C_{ED}	Cost of engine development through Military Qualification TEST (MQT) and equivalent.
$\bar{C}_{E_N}$	Cumulative average total engine cost for the Nth subsonic airplane.
$\bar{C}'_{E_N}$	Cumulative average total engine cost for the Nth SST airplane.
$\bar{C}_{L_N}$	Cumulative average cost of labor on the Nth subsonic airframe.
$\bar{C}'_{L_N}$	Cumulative average cost of labor on the Nth SST airframe.
$\bar{C}_{M_N}$	Cumulative average cost of materials on the Nth subsonic airframe.
$\bar{C}'_{M_N}$	Cumulative average cost of materials on the Nth SST airframe.
$\bar{C}_{OH_N}$	Cumulative average cost of overhead and G&A on the Nth subsonic airframe.
$\bar{C}'_{OH_N}$	Cumulative average cost of overhead and G&A on the Nth SST airframe.
C_{PD}	Cost of engine production development after Military Qualification Test (MQT) or equivalent.
C_{RA}	Cost of airframe development.
$\bar{C}_{SE_N}$	Cumulative average cost of sustaining engineering on the Nth subsonic airframe.
$\bar{C}'_{SE_N}$	Cumulative average cost of sustaining engineering on the Nth SST airframe.
$\bar{C}_{SPE_N}$	Cumulative average cost of spare engines and parts for the Nth subsonic airframe.
$\bar{C}'_{SPE_N}$	Cumulative average cost of spare engines and parts for the Nth SST airframe.
$\bar{C}_{SPF_N}$	Cumulative average cost of spare airframe parts for the Nth subsonic airframe.
$\bar{C}'_{SPF_N}$	Cumulative average cost of spare airframe parts for the Nth SST airframe.
$\bar{C}_{TO_N}$	Cumulative average cost of tooling on the Nth subsonic airframe.
$\bar{C}'_{TO_N}$	Cumulative average cost of tooling on the Nth SST airframe.

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b	Logarithimic slope of learning curve (values tabulated below)

	Subsonic Equations		Supersonic Equations		
	slope	-b	slope	-b	type
Labor	77%	.377	80%	.322	log linear unit
Material	90%	.152	90%	.152	log linear unit
Tooling	65%	.622	70%	.515	log linear cumulative average
Engineering	65%	.622	65%	.622	log linear cumulative average
Engines	90%	.152	90%	.152	log linear cumulative average

d	Great circle flight segment distance in statute miles.
D	Density of kerosene fuel, lb/gallon.
D_p	Product development time, months.
F^o	Maximum turbine inlet temperature, degrees Fahrenheit.
G_o	Gallons of oil consumed per engine per block hour.
I_o	Total flight equipment investment per aircraft, including spares.
k_i	Coefficients, described for each equation.
L_A	Service life of avionics and other flight equipment and spares.
L_E	Service life of engines and spares.
L_f	Service life of airframe and spares.
L_G	Service life of depreciable ground property and equipment (average).
M	Maximum design mach number from an engine.
n_1	Number of pilots on aircraft.
n_2	Number of copilots on aircraft.
n_3	Number of flight engineers and navigators on aircraft.
N	Cumulative number of production airplanes manufactured.
N_E	Number of engines per aircraft, excluding spares.
n_s	Number of passenger seats.
p	Payload capacity of aircraft, tons, as defined in CAB Standard Practice Letter No. 4, as revised 17 March 1959. (On SST for space limited capacity use maximum seating configuration).
P_A	Investment in avionics, and other flight equipment per aircraft, excluding spares, K$.
p_c	Percent of coach passengers.
p_f	Percent of first-class passengers.

[redacted]

[redacted]

P_E	Investment per engine, excluding spares K$.
P_f	Investment in airframe, less engines, avionics, and other flight equipment, and excluding spares, K$.
P_M	Complexity factor to account for decreased/lb cost of material for heavier aircraft (=.55).
P_o	Investment per aircraft at original cost of airframe, installed engines and other installed flight equipment (excluding all spares).
$Q_{AV_{100}}$	Average monthly delivery rate to the 100th airframe.
R_A	Fractional value of original cost of avionics and other flight equipment and spares salvageable at end of service life.
r_c	Coach revenue, $/seat mile.
r_f	First-class revenue, $/seat mile.
R_E	Fractional value of original cost of engines and spares salvageable at end of service life.
R_{EM}	Number of engines manufactured per airframe, $= N_E (1 + S_E)$.
R_f	Fractional value of original cost of airframes and spares salvageable at end of service life.
R_G	Fractional part of original investment in ground property and equipment salvageable at end of service life.
R_{OH}	Manufacturing overhead and G&A rate, fraction of labor cost.
S_A	Spare parts factor, investment in avionics and other flight equipment spares per dollar investment in installed equipment.
S_E	Spare parts factor, investment in spare engines and engine parts per dollar investment in installed engines.
S_f	Spare parts factor, investment in airframe spares per dollar investment in airframe.
t	Years since introduction of aircraft, defined for $t \leq 6$. For $t > 6$, the value 6 is used.
T	Maximum sea-level takeoff thrust, lb, augmented.
t_b	Segment flight time, in block hours.
T_L	Factor to account for increased cost of assembling and fabricating a titanium airframe.
T_M	Factor to account for increased cost of materials for titanium airframe.
T_{TO}	Factor to account for increased cost of tooling and tooling maintenance for titanium parts.
U	Annual utilization per aircraft in revenue block hours per year.
V	Maximum design cruising speed, statute miles per hour at optimal altitude.
V_k	Maximum design cruising speed, knots, at optimal altitude.

[redacted]

[redacted]

V_m	Design maximum cruising speed, mach number, at optimal altitude.
W_A	Operator's weight, less fuel and engines.
W_E	Weight of engine, dry, excluding nacelle, lb.
W_f	Weight of kerosene fuel consumed in one segment flight, lb.
W_g	Maximum certificated gross weight of aircraft, lb.
W_o	Weight of airframe, AMPR lb.
W_1	Weighting factor.
W_2	Weighting factor.
X	Fraction of AMPR weight of airframe which is titanium.
Y	Passenger revenue in dollars derived from flight segment, developed from the following data:

	International Flights	Domestic Flights
Load Factor	50	55
% First Class/Revenue	10/8.55¢/ seat mile	20/6.50¢/ seat mile
% Coach/Revenue	90/5.50¢/ seat mile	80/5.66¢/ seat mile

[redacted]

[redacted]

METHODOLOGY FOR ESTIMATING DEVELOPMENT, PRODUCTION, AND OPERATING COSTS OF TRANSPORT AIRCRAFT

PRC R-634

15 December 1964

Prepared for

Office of Assistant Secretary of Defense—Comptroller
Deputy Assistant Secretary (Programming)
Directorate for Cost and Economic Analysis
Under Contract SD-274

For the Office of the Secretary
U.S. Department of Commerce

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PREFACE

This report was completed under Contract SD-274 with the Department of Defense. It is one portion of the overall economic analysis study of the Supersonic Transport Program. Responsibility for the economic studies rests with the Department of Commerce, Supersonic Transport Study Group.

The cost estimating equations presented for development and production, including coefficients, are aimed primarily at estimating supersonic transport costs, but should be useful in prediction of program costs for other transport aircraft. The form of operating costs equations are generally applicable to all transport aircraft. However, differing values of performance characteristics of various aircraft will have a decided effect on the operating costs. In this report, recommended coefficient values are given for subsonic jet transports as well as the supersonic transports under consideration.

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I. INTRODUCTION

This report summarizes the results of a study to develop aircraft system performance-cost relationships. Cost estimating relationships (CER's) have been constructed to cover development (R&D) costs, production (investment) costs and airline operating costs (direct and indirect). Primary emphasis in application will be on supersonic aircraft designs proposed by airframe and engine manufacturers on 1 November 1964.

In general terms, the development and production CER's are based on statistical analysis of previous airframe and engine program costs. Data were compiled from manufacturers, previous research studies by Planning Research Corporation and other firms, and from various government sources. Separate analysis was accomplished of airframe and engine costs at various unit production levels. For airframes, the costs were divided into the four categories traditionally used for airframe cost analysis -- tooling, engineering, materials and direct labor (including overhead). General and administrative expenses and profit have been included where they were appropriate.

The operating cost equations are stated in the general format of financial reports submitted by United States airlines to the Civil Aeronautics Board. The CER's were developed from cost methodologies employed by the airline industry and aircraft manufacturers, with necessary adjustments for adaptation to the present study, particularly where this was required for the larger and faster aircraft under consideration.

A. Form of the Report

This summary report is organized in the following manner.

- I Introduction
- II Summary of Equations (All equations developed for manufacturing and operation are listed, together with the appropriate value of coefficients recommended for use in evaluating specific designs proposed by airframe and engine manufacturers.)
- III Manufacturing Costs (The manufacturing equations are examined in detail and the data upon which they are based is presented. Rationale for the equations is set forth, together with non-statistical technical considerations which may be encountered in the manufacturing program.)
- IV Airline Operating Costs (The operating equations are discussed individually with substantiating historical data presented and analyzed. Major considerations in setting values for coefficients and variables are set forth.)
- V Application of Equation to Specific Proposals (The equations in II above are applied to specific designs proposed by airframe and engine manufacturers.)

B. Detail Statistical Data and Computer Tabulations

Detailed statistics that form the basis for the equations in this study are being furnished under separate cover to the Office of Assistant Secretary of Defense - Comptroller, Deputy Assistant Secretary (Programming). This includes computer tabulations of approximately 100 methodologies which were tested in the course of the study.

II. SUMMARY OF EQUATIONS

This section contains equations which were developed to estimate the comparative cost of operating subsonic and supersonic aircraft over long-haul routes. Equations for estimation of development and production costs for airframes and engines are also set forth. The application of these formulas is explained in Section V of this report.

The equations are separated into six groups. The first subsection contains the formulas for determining the direct and indirect operating costs of large subsonic aircraft similar to those in operation today. The second subsection lists similar formulas for determining operating costs for supersonic aircraft of the type proposed by the two comparisons operating costs for the two aircraft types over any given flight segment. Some of the indirect operating cost equations distinguish between costs of carrying passengers in different classes of service. At the end of each of the two subsections, alternate equations have been provided which do not make such a distinction. These should be applied when no information on class of service is available. The alternate equations are based on a domestic ratio of one first class passenger to four coach passengers. In International service, the comparable ratio is one to nine. Both sets of equations enable the computation of total operating costs in dollars per flight segment.

Subsection C contains the general equations for estimating the cumulative average airframe unit cost at a selected production unit, including development and production costs. The equations in this subsection are used to estimate manufacturing costs of the supersonic aircraft proposed by the two airframe manufacturers.

Subsection D presents equations for estimating the airframe development costs from the general equations in the previous subsection. Subsection E provides equations for determining the airframe production costs (or selling price as utilized in the operating cost equations).

Finally, Subsection F contains formulas for estimating engine production and development costs.

A. EQUATIONS FOR ESTIMATING OPERATING COSTS OF SUBSONIC AIRCRAFT

This subsection contains final equations, including values for coefficients and variables, for estimating direct, indirect and total operating costs of current subsonic aircraft. Purchase costs for airframe, engines and avionics are based on manufacturers' estimated current selling prices.

Problem:

Total Operating Costs = Direct Operating Costs
+ Indirect Operating Costs

General Equation:

Total Operating Costs: $C_1 = C_2 + C_{20}$

[redacted]

Direct Operating Costs = Crew Cost + Fuel Cost + Insurance Cost
+ Maintenance Cost + Depreciation Cost

General Equation

Direct Operating Cost: $C_2 = C_3 + C_8 + C_9 + C_{10} + C_{16}$

[redacted]

[redacted]

CREW COSTS

Crew Costs = No. of pilots (pilot cost)
+ No. of copilots (copilot cost)
+ No. of flight engineers (flight engineer cost)
+ No. of navigators (navigator cost)

General Equation

Crew Costs: $C_3 = N_p(C_4) + N_c(C_5) + N_f(C_6) + N_n(C_7)$

Specific Equations

C_4 Pilot Cost: $C_4 = \left[a_1 + a_2(V_b) + a_3\left(\frac{Wg}{1000}\right)\right]\frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_1	41.55	45.36
a_2	.025	.025
a_3	.005	.005

C_5 Copilot Cost: $C_5 = \left[a_4 + a_5(V_b) + a_6\frac{Wg}{1000}\right]\frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_4	25.14	27.31
a_5	.01383	.01383
a_6	.00249	.00249

[redacted]

[redacted]

C_6 Flight Engineer Cost: $C_6 = \left[a_7 + a_8(V_b) + a_9 \frac{W_g}{1000}\right] \frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_7	24.45	26.08
a_8	.01167	.01167
a_9	.00258	.00258

C_7 Navigator Costs: $C_7 = \left[a_{10} + a_{11}(V_b) + a_{12} \frac{W_g}{1000}\right] \frac{D_b}{Vb}$

Necessary Data

Constant	Domestic	International
a_{10}	0	23.01
a_{11}	0	.01167
a_{12}	0	.00258

[redacted]

[redacted]

FUEL AND OIL COSTS

General Equation

Fuel and Oil Cost: C_8

Specific Equations

C_8 Fuel & Oil Cost: $C_8 = \dfrac{(1 + N_r)\, C_f\, F_s}{F_w} + \left[N_e\, C_o\, O_b\right] \dfrac{D_b}{V_b}$

Necessary Data

Variable	Domestic	International
N_r	0.03	0.03
C_f	0.11	0.12
F_w	6.70	6.70
N_e	4	4
C_o	12.00	12.00
O_b	.0835	.0835

[redacted]

[redacted]

INSURANCE COSTS

General Equation

Insurance Costs: C_9

Specific Equation

C_9 **Insurance Costs:** $C_9 = \left[\frac{I_r \; C_t}{U_a}\right]\frac{D_b}{V_b}$

Necessary Data

Variable	**Domestic**	**International**
I_r	0.03	0.03
C_t	6,960,000	6,960,000
U_a	3,600	3,600

[redacted]

[redacted]

MAINTENANCE COST

Maintenance Cost = Airframe Labor + Engine Labor
+ Airframe Material + Engine Material
+ Burden

General Equation

Maintenance Costs: $C_{10} = C_{11} + C_{12} + C_{13} + C_{14} + C_{15}$

Specific Equations

C_{11} Airframe Labor: $C_{11} = \left(a_{18} + a_{19} \frac{W_a}{1000}\right) \frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_{18}	9.27	9.27
a_{19}	0.207	0.207

Variable	Domestic	International
w_a	113,500	113,500

[redacted]

[redacted]

C_{12} **Engine Labor:** $C_{12} = N_e\left[\left(a_{20} + a_{21}\frac{T_h}{1000}\right)\left(\frac{a_{22}}{H_{eo}}\right) + a_{23}\right]\frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_{20}	2.22	2.22
a_{21}	0.098	0.098
a_{22}	4400	4400
a_{23}	1.24	1.24
Variable	**Domestic**	**International**
T_h	18,000	18,000
N_e	4	4

C_{13} **Airframe Material:** $C_{13} = \left[a_{24} + a_{25}\left(\frac{C_{spa}}{1000}\right)\right]\frac{D_b}{V_b}$

Necessary Data

Constants	Domestic	International
a_{24}	1.11	1.11
a_{25}	0.00353	0.00353
Variable	**Domestic**	**International**
C_{spa}	5,925,800	5,925,800

[redacted]

[redacted]

C_{14} **Engine Material:** $C_{14} = N_e\left(\frac{a_{26}C_e - a_{27}}{a_{28}H_{eo} + a_{29}}\right)\frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_{26}	0.07271	0.07271
a_{27}	484	484
a_{28}	.21	0.21
a_{29}	769	769
Variable	Domestic	
C_e	258, 550	258, 550
N_e	4	4

C_{15} **Burden:** $C_{15} = a_{30}(C_{11} + C_{12})$

Necessary Data

Constant	Domestic	International
a_{30}	1.70	1.70

[redacted]

DEPRECIATION COSTS

Depreciation Costs = Airframe + Engines + Avionics

General Equation

Depreciation Costs: $C_{16} = C_{17} + C_{18} + C_{19}$

Specific Equations

C_{17} Airframe: $$C_{17} = \left[\frac{(1 + S_a)(C_a - R_a)}{(D_{ya})\qquad(U_a)}\right] \frac{D_b}{V_b}$$

Necessary Data

Variable	Domestic	International
S_a	0.15	0.15
C_a	5,825,000	5,825,000
D_{ya}	12	12
U_a	3,600	3,600
R_a	0	0

[redacted]

C_{18} Engines

$$C_{18} = N_e \left[\frac{(1 + S_e)(C_e - R_e)}{(D_{ye}) \quad (U_e)} \right] \frac{D_b}{V_b}$$

Necessary Data

Variable	Domestic	International
S_e	0.40	0.50
C_e	258,550	258,550
D_{ye}	12	12
U_e	3,600	3,600
R_e	0	0
N_e	4	4

C_{19} Avionics

$$C_{19} = \left[\frac{(1 + S_r)(C_r - R_r)}{(D_{yr})(U_r)} \right] \frac{D_b}{V_b}$$

Necessary Data

Variable	Domestic	International
C_r	100,000	100,000
R_r	0	0
D_{yr}	12	12
U_r	3,600	3,600
$\check{S}_r$	0.0	0.0

[redacted]

Indirect Operating Costs = Direct Maintenance of GPE
+ Maintenance Burden of GPE
+ Passenger Service
+ Aircraft Servicing
+ Traffic Servicing
+ Servicing Administration
+ Reservations and Sales
+ Advertising and Publicity
+ General and Administrative
+ Depreciation and Amortization GPE

Indirect Operating Costs:

$$C_{20} = C_{21} + C_{24} + C_{27} + C_{31} + C_{36} + C_{39} + C_{45} + C_{49} + C_{52} + C_{53}$$

[redacted]

Direct Maintenance of Ground Property and Equipment
= Local Maintenance + System Maintenance

General Equation

Direct Maintenance of G. P. &E. : .. $C_{21} = C_{22} + C_{23}$

Local Maintenance: $C_{22} = b_1 \frac{L_d}{1000}$

Constant	Domestic	International
b_1	0.05	0.08
Variable		
L_d	207,000	207,000

System Maintenance: $C_{23} = b_2 (C_{11} + C_{12})$

Constant	Domestic	International
b_2	0.04	0.03

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[redacted]

[redacted]

Maintenance Burden of Ground Property and Equipment

= Local Burden + System Burden

General Equation

Maintenance Burden of G. P. & E: $C_{24} = C_{25} + C_{26}$

Local Burden: $C_{25} = b_3 \left(\frac{L_d}{1000} \right)$

Constant	Domestic	International
b_3	0.05	0.04
Variable		
L_d	207,000	207,000

System Burden: $C_{26} = b_4 (C_{11} + C_{12})$

Constant	Domestic	International
b_4	0.03	0.02

[redacted]

Passenger Service = Stewardess Costs + Food Costs
+ Other Passenger Service Costs

General Equation

Passenger Service: $C_{27} = C_{28} + C_{29} + C_{30}$

Stewardess Costs: $C_{28} = \left[b_5 \left(\frac{FS}{b_6} + \frac{CS}{b_7} \right) \right] \frac{D_b}{V_b}$

Constants	Domestic	International
b_5	8.50	11.55
b_6	16	12
b_7	40	24

Food Costs: $C_{29} = b_8 \left[(FS)\ (LF)\ (R) \right] + b_9 \left[(CS)\ (LF)\ (R) \right]$

Constants	Domestic	International
b_8	6.50	14.00
b_9	3.00	4.00
Variable		
R	0.94	0.74

Other Passenger Service Costs: $C_{30} = b_{10} \left[(FS + CS)\ (LF) \right] D_b$

Constant	Domestic	International
b_{10}	0.0013	0.0018

Aircraft Servicing = Aircraft Control + Aircraft Handling + Landing Fees + Other Aircraft Servicing

General Equation

Aircraft Servicing: $C_{31} = C_{32} + C_{33} + C_{34} + C_{35}$

Aircraft Control: $C_{32} = b_{11}$

Constant	Domestic	International
b_{11}	14.35	54.97

Aircraft Handling: $C_{33} = b_{12}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{12}	0.36	0.79
Variable		
L_d	207,000	207,000

Landing Fees: $C_{34} = b_{13}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{13}	0.16	0.82
Variable		
L_d	207,000	207,000

Other Aircraft Servicing: $C_{35} = b_{14}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{14}	0.28	0.58
Variable		
L_d	207,000	207,000

Traffic Servicing = Passenger Handling + Baggage and Cargo Handling

General Equation:

Traffic Servicing: $C_{36} = C_{37} + C_{38}$

Passenger Handling: $C_{37} = b_{15} \left[(FS + CS)(LF) \right] R$

Constant	Domestic	International
b_{15}	1.22	3.06
Variable		
R	0.94	0.74

Baggage and Cargo Handling:

$$C_{38} = b_{16}\Big[(FS)(LF)(R)(B_f) + (CS)(LF)(R)(B_c) + (C)(b_{17})(R)\Big]$$

Constants	Domestic	International
b_{16}	43.22	53.69
b_{17}	0.75	0.75
Variable		
R	0.94	0.74

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Servicing Administration = Control Administration
+ Handling Administration
+ Other Handling Administration
+ Passenger Handling Administration
+ Baggage and Cargo Handling Administration

General

Servicing Administration: $C_{39} = C_{40} + C_{41} + C_{42} + C_{43} + C_{44}$

Control Administration: $C_{40} = b_{18}$

Constant	Domestic	International
b_{18}	2.50	5.83

Handling Administration: $C_{41} = b_{19}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{19}	0.05	0.08
Variable		
L_d	207,000	207,000

Other Handling Administration: $C_{42} = b_{20}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{20}	0.04	0.06
Variable		
L_d	207,000	207,000

Passenger Handling Administration: $C_{43} = b_{21}(FS + CS)(LF)(R)$

	Domestic	International
Constant b_{21}	0.16	0.33
Variable R	0.94	0.74

Baggage and Cargo Handling Administration:

$$C_{44} = b_{22}\Big[(FS)(LF)(R)(B_f) + (CS)(LF)(R)(B_c) + (C)(b_{23})(R)\Big]$$

	Domestic	International
Constants		
b_{22}	5.58	6.11
b_{23}	0.75	0.75
Variable R	0.94	0.74

[redacted]

Reservations and Sales = Passenger Commissions
+ Freight Commissions
+ Other Reservations and Sales

Reservations and Sales: $C_{45} = C_{46} + C_{47} + C_{48}$

Passenger Commissions: $C_{46} = b_{24}(FS + CS)(LF)\ D_b$

Constant	Domestic	International
b_{24}	0.0012	0.0031

Freight Commissions: $C_{47} = \left[b_{25}(C)\right]D_b$

Constant	Domestic	International
b_{25}	0.0006	0.0096

Other Reservations and Sales: $C_{48} = b_{26}\left[(FS + CS)(LF)(R)\right]$

Constant	Domestic	International
b_{26}	2.62	8.21
Variable		
R	0.94	0.74

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[redacted]

Advertising and Publicity = Passenger Advertising and Publicity
+ Freight Advertising and Publicity

General equation

Advertising and Publicity: $C_{49} = C_{50} + C_{51}$

Passenger Advertising and Publicity: $C_{50} = \left[b_{27}(FS + CS)(LF)\right] D_b$

Constant	Domestic	International
b_{27}	0.0017	0.0025

Freight Advertising and Publicity: $C_{51} = \left[b_{28}(C)\right] D_b$

Constant	Domestic	International
b_{28}	0.0061	0.0123

GENERAL AND ADMINISTRATIVE COSTS

General equation

General and Administrative: $$C_{52} = b_{29}\left[C_2 - C_{16} + C_{21} + C_{24} + C_{27} + C_{31} + C_{36} + C_{39} + C_{45} + C_{49}\right]$$

Constant	Domestic	International
b_{29}	0.0475	0.0565

[redacted]

Depreciation and Amortization
of G. P. & E. = Local Depreciation and Amortization
+ System Depreciation and Amortization

General equation

Depreciation and Amortization of G. P. & E: $C_{53} = C_{54} + C_{55}$

Local Depreciation and Amortization: $C_{54} = b_{30}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{30}	0.06	0.15
Variable		
L_d	207,000	207,000

System Depreciation and Amortization: $C_{55} = b_{31}(C_{11} + C_{12})$

Constant	Domestic	International
b_{31}	0.24	0.36

[redacted]

DEFINITIONS

B_c = Baggage per coach passenger in tons

B_f = Baggage per first class passenger in tons

C = Mail, express and freight cargo in tons

C_a = Cost of the airframe

C_e = Cost of one engine

C_f = Cost of fuel in dollars per gallon

C_o = Cost of oil in dollars per gallon

C_r = Cost of avionics

C_{spa} = Cost of aircraft less engines

C_t = Flyaway cost of the aircraft

CS = The number of coach seats in an aircraft

D_b = The great circle distance of a flight segment in statute miles

D_{ya} = Depreciation period in years for the airframe

D_{ye} = Depreciation period in years for the engines

D_{yr} = Depreciation period in years for the avionics

F_s = Block fuel in pounds

F_w = Pounds of fuel per gallon

FS = The number of first class seats in an aircraft

H_{eo} = Hours between engine overhaul

I_r = Annual insurance cost per dollar of flyaway cost

L_d = The maximum design landing weight in pounds

LF = The passenger load factor

N_e = The number of engines

N_r = The non-revenue flying factor

O_b = Oil consumed in gallons per block hour per engine

R = Enplaned to on board ratio

S_a = The spare parts factor for the airframe

S_e = The spare parts factor for an engine

S_r = The spare parts factor for avionics

T = Total operating expenses, less G and A and all amortization and depreciation for the segment

T_h = The maximum take-off thrust per engine in pounds (wet)

U_a = Annual block hours of utilization of airframe

U_e = Annual block hours of utilization of engines

U_r = Annual block hours of utilization of radio

V_b = Block speed in statute miles per hour

W_a = Manufacturers weight empty of the aircraft less engines

W_g = Maximum certificated gross take-off weight of the aircraft in pounds

N_c = Number of copilots

N_f = Number of flight engineers

N_n = Number of navigators

N_p = Number of pilots

R_a = Residual value of airframe and spares

R_e = Residual value of engine and spares

R_r = Residual value of avionics and spares

ALTERNATE EQUATIONS FOR ESTIMATING SELECTED INDIRECT OPERATING COSTS OF SUBSONIC AIRCRAFT

This section contains alternate equations for estimating certain indirect operating costs. These are necessary because of lack of clarity as to the segregation of first and coach passengers, seats and baggage in the final route simulation models. In effect, the alternate equations average these variables on the basis of the FAA ground rules (20 - 80 and 10 - 90 percent split between first class and coach in domestic and international service, respectively).

Passenger Service = Stewardess Costs + Food Costs
+ Other Passenger Service Costs

Passenger Service: $A_{27} = A_{28} + A_{29} + A_{30}$

Stewardess Costs: $A_{28} = k_5 \left(\frac{k_6 TS}{k_7} \right) \frac{D_b}{V_b}$

Constants	Domestic	International
k_5	8.50	11.55
k_6	1.3	1.1
k_7	40	24

Food Costs: $A_{29} = k_8 \left[(TS)\ (LF)\ (R) \right]$

Constants	Domestic	International
k_8	3.7	5.0
Variable		
R	0.94	0.74

Other Passenger Service Costs: $A_{30} = \left[k_{10}\ (TS)\ (LF) \right] D_b$

Constant	Domestic	International
k_{10}	0.0013	0.0018

Alternate to page II-17

[redacted]

Traffic Servicing = Passenger Handling + Baggage and Cargo Handling

Traffic Servicing: $A_{36} = A_{37} + A_{38}$

Passenger Handling: $A_{37} = k_{15} \left[(TS)\ (LF) \right] R$

Constant	Domestic	International
k_{15}	1.22	3.06
Variable		
R	0.94	0.74

Baggage and Cargo Handling: $A_{38} = k_{16} \left[(TS)(LF)(R)(B) + (C)(k_{17})(R) \right]$

Constants	Domestic	International
k_{16}	43.22	53.69
k_{17}	0.75	0.75
Variable		
R	0.94	0.74
B	0.01750	0.02325

Alternate to page II-20

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[redacted]

Servicing Administration = Control Administration
+ Handling Administration
+ Other Handling Administration
+ Passenger Handling Administration
+ Baggage and Cargo Handling Administration

Servicing Administration: $A_{39} = A_{40} + A_{41} + A_{42} + A_{43} + A_{44}$

Control Administration: $A_{40} = k_{18}$

Constant	Domestic	International
k_{18}	2.50	5.83

Handling Administration: $A_{41} = k_{19} \left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
k_{19}	0.05	0.08
Variable		
L_d	207,000	207,000

Other Handling Administration: $A_{42} = K_{20}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
k_{20}	0.04	0.06
Variable		
L_d	207,000	207,000

Alternate to page II-21

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Passenger Handling Administration: $A_{43} = k_{21} \left[(TS)(LF)(R) \right]$

Constant	Domestic	International
k_{21}	0.16	0.33
Variable		
R	0.94	0.74

Baggage and Cargo Handling Administration:

$$A_{44} = k_{22} \left[(TS)(LF)(R)(B) + (C)(k_{23})(R) \right]$$

Constants	Domestic	International
k_{22}	5.58	6.11
k_{23}	0.75	0.75
Variables		
R	0.94	0.74
B	0.01750	0.02325

Alternate to page II-23

[redacted]

Reservations and Sales = Passenger Commissions
+ Freight Commissions
+ Other Reservations and Sales

Reservations and Sales: $A_{45} = A_{46} + A_{47} + A_{48}$

Passenger Commissions: $A_{46} = \left[k_{24} (TS)(LF) \right] D_b$

Constant	Domestic	International
k_{24}	0.0012	0.0031

Freight Commissions: $A_{47} = \left[k_{25}\, C \right] D_b$

Constant	Domestic	International
k_{25}	0.0006	0.0096

Other Reservations and Sales: $A_{48} = k_{26} \left[(TS)(LF)(R) \right]$

Constant	Domestic	International
k_{26}	2.62	8.21
Variable		
R	0.94	0.74

Alternate to page II-24

[redacted]

Advertising and Publicity = Passenger Advertising and Publicity + Freight Advertising and Publicity

Advertising and Publicity: $A_{49} = A_{50} + A_{51}$

Passenger Advertising and Publicity: $A_{50} = \left[k_{27}\,(TS)(LF)\right] D_b$

Constant	Domestic	International
k_{27}	0.0017	0.0025

Freight Advertising and Publicity: $A_{51} = \left[k_{28}\,C\right] D_b$

Constant	Domestic	International
k_{28}	0.0061	0.0123

Alternate to page II-25

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B. EQUATIONS FOR ESTIMATING OPERATING COSTS OF LOCKHEED AND BOEING SUPERSONIC TRANSPORT AIRCRAFT

This subsection contains final equations, including values for coefficients and variables, for estimating direct, indirect and total operating costs of Lockheed and Boeing proposed supersonic transport aircraft. For costing purposes, the Boeing design is assumed to be the 733-290 aircraft (intercontinental version) equipped with General Electric GE4/J5G engines. The Lockheed design utilized is the L-2000-2 version (large international) with Pratt and Whitney STF219-L engines. Purchase costs for airframes and engines were estimated using the equations for production costs in subsections E and F, respectively. Development costs are not included in the purchase costs of either airframes or engines, under FAA ground rules for the SST program.

Problem:

Total Operating Costs = Direct Operating Costs
+ Indirect Operating Costs

General Equation:

Total Operating Costs: $C_1 = C_2 + C_{20}$

[redacted]

Direct Operating Costs = Crew Cost + Fuel Cost + Insurance Cost
+ Maintenance Cost + Depreciation Cost

General Equation

Direct Operating Cost: $C_2 = C_3 + C_8 + C_9 + C_{10} + C_{16}$

[redacted]

CREW COSTS

Crew Costs = No. of pilots (pilot cost)
+ No. of copilots (copilot cost)
+ No. of flight engineers (flight engineer cost)

General Equation

Crew Costs: $C_3 = N_p(C_4) + N_c(C_5) + N_f(C_6)$

Specific Equations

C_4 Pilot Cost: $C_4 = \left[a_1 + a_2(V_b) + a_3\left(\frac{W_g}{1000}\right)\right]\frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_1	65.00	70.00
a_2	.025	.025
a_3	.005	.005

C_5 Copilot Cost: $C_5 = \left[a_4 + a_5(V_b) + a_6 \frac{W_g}{1000}\right]\frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_4	39.00	42.00
a_5	.01383	.01383
a_6	.00249	.00249

C_6 Flight Engineer Cost: $C_6 = \left[a_7 + a_8(V_b) + a_9 \frac{W_g}{1000}\right]\frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_7	38.00	40.00
a_8	.01167	.01167
a_9	.00258	.00258

FUEL AND OIL COSTS

General Equation

Fuel and Oil Cost: C_8

Specific Equations

C_8 Fuel & Oil Cost: $C_8 = \frac{(1 + N_r) C_f F_s}{F_w} + \left[N_e C_o O_b \right] \frac{D_b}{V_b}$

Necessary Data

Variable	Domestic	International
N_r	0.03	0.03
C_f	0.11	0.12
F_w	6.70	6.70
N_e	4	4
C_o	12.00	12.00
O_b	.0835	.0835

INSURANCE COSTS

General Equation

Insurance Costs: C_9

Specific Equation

C_9 Insurance Costs: $C_9 = \left[\frac{I_r \ C_t}{U_a}\right]\frac{D_b}{V_b} + I_s$

Necessary Data

Variable		Domestic	International
I_r		0.03	0.03
C_t	BAC	29,076,000	29,076,000
	LAC	30,259,000	30,259,000
U_a		3,000	3,000

MAINTENANCE COST

Maintenance Cost = Airframe Labor + Engine Labor
+ Airframe Material + Engine Material
+ Burden

General Equation

Maintenance Costs: $C_{10} = C_{11} + C_{12} + C_{13} + C_{14} + C_{15}$

Specific Equations

C_{11} Airframe Labor: $$C_{11} = \left(a_{18} + a_{19} \frac{W_a}{1000}\right) \frac{D_b}{V_b}$$

Necessary Data

Constant		Domestic	International
a_{18}		9.27	9.27
a_{19}		0.207	0.207
Variable		**Domestic**	**International**
	BAC	163,420	163,420
W_a	LAC	146,686	146,686

[redacted]

C_{12} Engine Labor: $$C_{12} = N_e\left[\left(a_{20} + a_{21}\frac{T_h}{1000}\right)\left(\frac{a_{22}}{H_{eo}}\right) + a_{23}\right]\frac{D_b}{V_b}$$

Necessary Data

Constant	Domestic	International
a_{20}	2.22	2.22
a_{21}	0.098	0.098
a_{22}	4400	4400
a_{23}	1.24	1.24

Variable		Domestic	International
T_h	BAC-GE	41,900	41,900
	LAC-PW	61,200	61,200
N_e		4	4

C_{13} Airframe Material: $$C_{13} = \left[a_{24} + a_{25}\left(\frac{C_{spa}}{1000}\right)\right]\frac{D_b}{V_b}$$

Necessary Data

Constants	Domestic	International
a_{24}	1.11	1.11
a_{25}	0.00353	0.00353

Variable		Domestic	International
C_{spa}	BAC	24,644,000	24,644,000
	LAC	22,871,000	22,871,000

[redacted]

C_{14} Engine Material: $$C_{14} = N_e\left(\frac{a_{26}C_e - a_{27}}{a_{28}H_{eo} + a_{29}}\right)\frac{D_b}{V_b}$$

Necessary Data

Constant		Domestic	International
a_{26}		0.07271	0.07271
a_{27}		484	484
a_{28}		.21	0.21
a_{29}		769	769
Variable		Domestic	
C_e	BAC - GE	1,108,000	1,108,000
	LAC - PW	1,847,000	1,847,000
N_e		4	4

C_{15} Burden: $$C_{15} = a_{30}(C_{11} + C_{12})$$

Necessary Data

Constant	Domestic	International
a_{30}	1.70	1.70

[redacted]

DEPRECIATION AND AMORTIZATION COSTS

Depreciation and Amortization Costs = Airframe Depreciation + Engine Depreciation + Avionics Depreciation

General Equation

Depreciation and Amortization Costs: $C_{16} = C_{17} + C_{18} + C_{19}$

Specific Equations

C_{17} Airframe:

$$C_{17} = \left[\frac{(1 + S_a)(C_a - R_a)}{(D_{ya}) \qquad (U_a)}\right] \frac{D_b}{V_b}$$

Necessary Data

Variable		Domestic	International
S_a		0.15	0.15
C_a	BAC	24,344,000	24,344,000
	LAC	22,571,000	22,571.000
D_{ya}		15	15
U_a		3,000	3,000
R_a		0	0

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[redacted]

[redacted]

C_{18} Engines

$$C_{18} = N_e \left[\frac{(1 + S_e)(C_e - R_e)}{(D_{ye})\quad(U_e)} \right] \frac{D_b}{V_b}$$

Necessary Data

Variable		Domestic	International
S_e		0.40	0.50
C_e	BAC-GE LAC-PW	1,108,000 1,847,000	1,108,000 1,847,000
D_{ye}		15	15
U_e		3,000	3,000
R_e		0	0
N_e		4	4

C_{19} Avionics

$$C_{19} = \left[\frac{(1 + S_r)\ (C_r - R_r)}{(D_{yr})\,(U_r)} \right] \frac{D_b}{V_b}$$

Necessary Data

Variable	Domestic	International
S_r	0.00	0.00
C_r	300,000	300,000
R_r	0.00	0.00
D_{yr}	15	15
U_r	3,000	3,000

[redacted]

Indirect Operating Costs = Direct Maintenance of GPE
+ Maintenance Burden of GPE
+ Passenger Service
+ Aircraft Servicing
+ Traffic Servicing
+ Servicing Administration
+ Reservations and Sales
+ Advertising and Publicity
+ General and Administrative
+ Depreciation and Amortization GPE

Indirect Operating Costs: $C_{20} = C_{21} + C_{24} + C_{27} + C_{31} + C_{36}$

$+ C_{39} + C_{45} + C_{49} + C_{52} + C_{53}$

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[redacted]

Direct Maintenance of Ground Property and Equipment

= Local Maintenance + System Maintenance

General Equation

Direct Maintenance of G. P. & E.: $C_{21} = C_{22} + C_{23}$

Local Maintenance: $C_{22} = b_1 \frac{L_d}{1000}$

Constant	Domestic	International
b_1	0.05	0.08
Variable		
L_d BAC	320,000	320,000
LAC	300,000	300,000

System Maintenance: $C_{23} = b_2 (C_{11} + C_{12})$

Constant	Domestic	International
b_2	0.04	0.03

[redacted]

Maintenance Burden of Ground Property and Equipment

= Local Burden + System Burden

General Equation

Maintenance Burden of G. P. & E: $C_{24} = C_{25} + C_{26}$

Local Burden: $C_{25} = b_3 \left(\frac{L_d}{1000} \right)$

Constant	Domestic	International
b_3	0.05	0.04

Variable		Domestic	International
L_d	BAC	320,000	320,000
	LAC	300,000	300,000

System Burden: $C_{26} = b_4 (C_{11} + C_{12})$

Constant	Domestic	International
b_4	0.03	0.02

[redacted]

Passenger Service = Stewardess Costs + Food Costs
+ Other Passenger Service Costs

General Equation

Passenger Service: $C_{27} = C_{28} + C_{29} + C_{30}$

Stewardess Costs: $C_{28} = \left[b_5 \left(\frac{FS}{b_6} + \frac{CS}{b_7} \right) \right] \frac{D_b}{V_b}$

Constants	Domestic	International
b_5	8.50	11.55
b_6	16	12
b_7	40	24

Food Costs: $C_{29} = b_8 \left[(FS)\ (LF)\ (R) \right] + b_9 \left[(CS)\ (LF)\ (R) \right]$

Constants	Domestic	International
b_8	6.50	14.00
b_9	3.00	4.00
Variable		
LF	0.55	0.50
R	0.94	0.74

[redacted]

[redacted]

Other Passenger Service Costs: $C_{30} = b_{10}\left[(FS + CS)(LF)\right] D_b$

Constant	Domestic	International
b_{10}	0.0013	0.0018
Variable		
LF	0.55	0.50

[redacted]

Aircraft Servicing = Aircraft Control + Aircraft Handling
+ Landing Fees + Other Aircraft Servicing

General Equation

Aircraft Servicing: $C_{31} = C_{32} + C_{33} + C_{34} + C_{35}$

Aircraft Control: $C_{32} = b_{11}$

Constant	Domestic	International
b_{11}	14.35	54.97

Aircraft Handling: $C_{33} = b_{12}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{12}	0.36	0.79
Variable		
L_d BAC	320,000	320,000
L_d LAC	300,000	300,000

Landing Fees: $C_{34} = b_{13}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{13}	0.16	0.82
Variable		
L_d BAC	320,000	320,000
L_d LAC	300,000	300,000

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Other Aircraft Servicing: $C_{35} = b_{14}\left(\frac{L_d}{1000}\right)$

Constant		Domestic	International
b_{14}		0.28	0.58
Variable			
L_d	BAC	320,000	320,000
	LAC	300,000	300,000

Traffic Servicing = Passenger Handling + Baggage and Cargo Handling

General Equation:

Traffic Servicing: $C_{36} = C_{37} + C_{38}$

Passenger Handling: $C_{37} = b_{15} \left[(FS + CS)(LF) \right] R$

Constant	Domestic	International
b_{15}	1.22	3.06
Variable		
LF	0.55	0.50
R	0.94	0.74

Baggage and Cargo Handling:

$$C_{38} = b_{16} \left[(FS)(LF)(R)(B_f) + (CS)(LF)(R)(B_c) + (C)(b_{17})(R) \right]$$

Constants	Domestic	International
b_{16}	43.22	53.69
b_{17}	0.75	0.75
Variable		
LF	0.55	0.50
R	0.94	0.74

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Servicing Administration = Control Administration
+ Handling Administration
+ Other Handling Administration
+ Passenger Handling Administration
+ Baggage and Cargo Handling Administration

General

Servicing Administration: $C_{39} = C_{40} + C_{41} + C_{42} + C_{43} + C_{44}$

Control Administration: $C_{40} = b_{18}$

Constant	Domestic	International
b_{18}	2.50	5.83

Handling Administration: $C_{41} = b_{19}\left(\frac{L_d}{1000}\right)$

Constant		Domestic	International
b_{19}		0.05	0.08
Variable			
L_d	BAC	320,000	320,000
	LAC	300,000	300,000

Other Handling Administration: $C_{42} = b_{20}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{20}	0.04	0.06
Variable		
L_d BAC	320,000	320,000
LAC	300,000	300,000

Passenger Handling Administration: $C_{43} = b_{21}(FS + CS)(LF)(R)$

Constant	Domestic	International
b_{21}	0.16	0.33
Variable		
LF	0.55	0.50
R	0.94	0.74

Baggage and Cargo Handling Administration:

$$C_{44} = b_{22}\Big[(FS)(LF)(R)(B_f) + (CS)(LF)(R)(B_c) + (C)(b_{23})(R)\Big]$$

Constants	Domestic	International
b_{22}	5.58	6.11
b_{23}	0.75	0.75
Variable		
LF	0.55	0.50
R	0.94	0.74

[redacted]

Reservations and Sales = Passenger Commissions
+ Freight Commissions
+ Other Reservations and Sales

Reservations and Sales: $C_{45} = C_{46} + C_{47} + C_{48}$

Passenger Commissions: $C_{46} = b_{24}(FS + CS)(LF)\ D_b$

Constant	Domestic	International
b_{24}	0.0012	0.0031
Variable		
LF	0.55	0.50

Freight Commissions: $C_{47} = \left[b_{25}(C) \right] D_b$

Constant	Domestic	International
b_{25}	0.0006	0.0096

Other Reservations and Sales: $C_{48} = b_{26} \left[(FS + CS)(LF)(R) \right]$

Constant	Domestic	International
b_{26}	2.62	8.21
Variable		
LF	0.55	0.50
R	0.94	0.74

[redacted]

[redacted]

Advertising and Publicity = Passenger Advertising and Publicity
+ Freight Advertising and Publicity

General equation

Advertising and Publicity: $C_{49} = C_{50} + C_{51}$

Passenger Advertising and Publicity: $C_{50} = \left[b_{27} (FS + CS)(LF)\right] D_b$

Constant	Domestic	International
b_{27}	0.0017	0.0025
Variable LF	0.55	0.50

Freight Advertising and Publicity: $C_{51} = \left[b_{28} (C)\right] D_b$

Constant	Domestic	International
b_{28}	0.0061	0.0123

[redacted]

[redacted]

General and Administrative Costs

General equation

General and Administrative: $C_{52} = b_{29}[C_2 - C_{16} + C_{21} + C_{24} + C_{27} + C_{31} + C_{36} + C_{39} + C_{45} + C_{49}]$

Constant	Domestic	International
b_{29}	0.0475	0.0565

[redacted]

Depreciation and Amortization
of G. P. & E. = Local Depreciation and Amortization
+ System Depreciation and Amortization
+ Amortization of Preoperating Expenses

General equation

Depreciation and Amortization of G. P. & E: $C_{53} = C_{54} + C_{55} + C_{71}$

Local Depreciation and Amortization: $C_{54} = b_{30}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
b_{30}	0.06	0.15
Variable		
L_d BAC	320,000	320,000
L_d LAC	300,000	300,000

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System Depreciation and Amortization: $C_{55} = b_{31}(C_{11} + C_{12})$

Constant	Domestic	International
b_{31}	0.24	0.36

C_{71} Preoperating Expenses $C_{71} = \left(\frac{a_{31}}{U_a A_p}\right)\frac{D_b}{V_b}$

Necessary Data

Constant	Domestic	International
a_{31}	500,000	500,000
Variable		
U_a	3,000	3,000
A_p	15	15

DEFINITIONS

A_p = Amortization Period in Years

B_c = Baggage per coach passenger in tons

B_f = Baggage per first class passenger in tons

C = Mail, express and freight cargo in tons

C_a = Cost of the airframe

C_e = Cost of one engine

C_f = Cost of fuel in dollars per gallon

C_o = Cost of oil in dollars per gallon

C_r = Cost of avionics

C_{spa} = Cost of aircraft less engines

C_t = Flyaway cost of the aircraft

CS = The number of coach seats in an aircraft

D_b = The great circle distance of a flight segment in statute miles

D_{ya} = Depreciation period in years for the airframe

D_{ye} = Depreciation period in years for the engines

D_{yr} = Depreciation period in years for the avionics

F_s = Block fuel in pounds

F_w = Pounds of fuel per gallon

FS = The number of first class seats in an aircraft

H_{eo} = Hours between engine overhaul

I_r = Annual insurance cost per dollar of flyaway cost

I_s = Sonic boom insurance for the segment under consideration in dollars

L_d = The maximum design landing weight in pounds

LF = The passenger load factor

N_e = The number of engines

N_r = The non-revenue flying factor

O_b = Oil consumed in gallons per block hour per engine

R = Enplaned to on board ratio

S_a = The spare parts factor for the airframe

S_e = The spare parts factor for an engine

S_r = The spare parts factor for avionics

T = Total operating expenses, less G and A and all amortization and depreciation for the segment

T_h = The maximum take-off thrust per engine in pounds (wet)

U_a = Annual block hours of utilization of airframe

U_e = Annual block hours of utilization of engines

U_r = Annual block hours of utilization of radio

V_b = Block speed in statute miles per hour

W_a = Manufacturers weight empty of the aircraft less engines

W_g = Maximum certificated gross take-off weight of the aircraft in pounds

N_c = Number of copilots

N_f = Number of flight engineers

N_p = Number of pilots

R_a = Residual value of airframe and spares

R_e = Residual value of engine and spares

R_r = Residual value of avionics and spares

ALTERNATE EQUATIONS FOR ESTIMATING SELECTED INDIRECT OPERATING COSTS OF SUPERSONIC AIRCRAFT

The following pages contain alternate equations for estimating certain indirect operating costs of supersonic aircraft. These are necessary because of lack of clarity as to the segregation of first and coach passengers, seats and baggage in the final route simulation models. In effect, the alternate equations average these variables on the basis of the FAA ground rules (20 - 80 and 10 - 90 percent split between first class and coach in domestic and international service, respectively).

[redacted]

[redacted]

Passenger Service = Stewardess Costs + Food Costs
+ Other Passenger Service Costs

Passenger Service: $A_{27} = A_{28} + A_{29} + A_{30}$

Stewardess Costs: $A_{28} = k_5 \left(\frac{k_6 TS}{k_7} \right) \frac{D_b}{V_b}$

Constants	Domestic	International
k_5	8.50	11.55
k_6	1.3	1.1
k_7	40	24

Food Costs: $A_{29} = k_8 \left[(TS) \ (LF) \ (R) \right]$

Constants	Domestic	International
k_8	3.7	5.0
Variable		
LF	0.55	0.50
R	0.94	0.74

Other Passenger Service Costs: $A_{30} = \left[k_{10} \ (TS) \ (LF) \right] D_b$

Constant	Domestic	International
k_{10}	0.0013	0.0018
Variable		
LF	0.55	0.50

Alternate to equation on page II-53

[redacted]

Traffic Servicing = Passenger Handling + Baggage and Cargo Handling

Traffic Servicing: $A_{36} = A_{37} + A_{38}$

Passenger Handling: $A_{37} = k_{15} \left[(TS)\ (LF) \right] R$

Constant	Domestic	International
k_{15}	1.22	3.06
Variable		
LF	0.55	0.50
R	0.94	0.74

Baggage and Cargo Handling: $A_{38} = k_{16} \left[(TS)(LF)(R)(B) + (C)(k_{17})(R) \right]$

Constants	Domestic	International
k_{16}	43.22	53.69
k_{17}	0.75	0.75
Variable		
LF	0.55	0.50
R	0.94	0.74
B	0.01750	0.02325

Alternate to equation on page II-57

Servicing Administration = Control Administration
+ Handling Administration
+ Other Handling Administration
+ Passenger Handling Administration
+ Baggage and Cargo Handling Administration

Servicing Administration: $A_{39} = A_{40} + A_{41} + A_{42} + A_{43} + A_{44}$

Control Administration: $A_{40} = k_{18}$

Constant	Domestic	International
k_{18}	2.50	5.83

Handling Administration: $A_{41} = k_{19} \left(\frac{L_d}{1000}\right)$

Constant		Domestic	International
k_{19}		0.05	0.08
Variable			
L_d	BAC	320,000	320,000
	LAC	300,000	300.000

Alternate to equation on page II-58

[redacted]

Other Handling Administration: $A_{42} = K_{20}\left(\frac{L_d}{1000}\right)$

Constant	Domestic	International
k_{20}	0.04	0.06
Variable		
L_d BAC	320,000	320,000
L_d LAC	300,000	300,000

Alternate to equation on page II-59

[redacted]

Passenger Handling Administration: $A_{43} = k_{21} \left[(TS)(LF)(R) \right]$

Constant	Domestic	International
k_{21}	0.16	0.33
Variable		
LF	0.55	0.50
R	0.94	0.74

Baggage and Cargo Handling Administration:

$$A_{44} = k_{22} \left[(TS)(LF)(R)(B) + (C)(k_{23})(R) \right]$$

Constants	Domestic	International
k_{22}	5.58	6.11
k_{23}	0.75	0.75
Variables		
LF	0.55	0.50
R	0.94	0.74
B	0.01750	0.02325

Alternate to equation on page II-60

Reservations and Sales = Passenger Commissions
+ Freight Commissions
+ Other Reservations and Sales

Reservations and Sales: $A_{45} = A_{46} + A_{47} + A_{48}$

Passenger Commissions: $A_{46} = \left[k_{24} (TS)(LF) \right] D_b$

Constant	Domestic	International
k_{24}	0.0012	0.0031
Variable LF	0.55	0.50

Freight Commissions: $A_{47} = \left[k_{25}\, C \right] D_b$

Constant	Domestic	International
k_{25}	0.0006	0.0096

Other Reservations and Sales: $A_{48} = k_{26} \left[(TS)(LF)(R) \right]$

Constant	Domestic	International
k_{26}	2.62	8.21
Variable		
LF	0.55	0.50
R	0.94	0.74

Alternate to equation on page II-61

Advertising and Publicity = Passenger Advertising and Publicity
+ Freight Advertising and Publicity

Advertising and Publicity: $A_{49} = A_{50} + A_{51}$

Passenger Advertising and Publicity: $A_{50} = \left[k_{27}\ (TS)(LF)\right] D_b$

Constant	Domestic	International
k_{27}	0.0017	0.0025
Variable LF	0.55	0.50

Freight Advertising and Publicity: $A_{51} = \left[k_{28}\ C\right] D_b$

Constant	Domestic	International
k_{28}	0.0061	0.0123

Alternate to equation on page II-62

ALTERNATE DEFINITIONS

TS = The total number of seats in an aircraft

B = Baggage per passenger in tons, weighted for first class and coach passenger ratio

C. EQUATIONS FOR ESTIMATING THE CUMULATIVE AVERAGE COST OF EACH AIRFRAME AT A SELECTED UNIT PRODUCTION NUMBER, INCLUDING DEVELOPMENT AND PRODUCTION COSTS

This subsection contains equations for estimating the cumulative average cost of each airframe at a given production number, including development and production costs. In subsections D and E, equations are shown for segregating this total cost into production and development costs. The costs are presented in four major categories: direct labor (including overhead), materials (including purchased parts), engineering and tooling.

To facilitate application to airframe designs proposed by Boeing and Lockheed, the values of variable for the equations are presented. In Section V, the estimated costs based on the equations are compared to the cost estimates in the manufacturers' proposals.

Direct Labor Costs, Including Overhead

$$H_N = R_r \, W_a \, (a \, CV)$$

H_N = cumulative average direct labor cost, including overhead, for each airframe at unit N

R_r = hourly direct labor rate, including overhead

W_a = weight of the airframe in pounds

N = production unit, including development units, at which the cumulative average direct labor cost per airframe is to be estimated

a = direct labor man-hours per pound at the first unit

CV = the conversion value obtained from the table on page II-88 to convert to cumulative average, using the "a" and "b" values from the unit cost curve.

[redacted]

Discussion: Values for "a" and "b" are determined by the simultaneous solution of the following general least squares regression equation:

$$\log Hu_N = \log a + b \log N$$

where Hu_n represents the unit man-hours per pound at units 10, 30, 100 and 300. These values can be estimated by the following equation:

$$Hu_N = h_{0N} + h_{1N} (S_a) + h_{2N} \left[\frac{S_a (10{,}000)}{\sqrt{W_a}} \right]$$

$$+ h_{3N} (\text{Log } T) + h_{4N} (R_1)$$

where

S_a = speed at altitude in Mach number

W_a = weight of the airframe in pounds

$T = 1 + 0.1 (Y - 1944)$

Y = year of delivery of first unit

$$R_1 = \frac{W_e - W_a}{W_a}$$

W_e = manufacturers weight empty

[redacted]

Values for coefficients for the fixed variables are shown in the table below.

N	h_{0N}	h_{1N}	h_{2N}	h_{3N}	h_{4N}
10	0.2451	4.5106	0.0059	0.9356	9.8196
30	0.1178	2.2657	0.0076	1.9291	5.7948
100	0.4618	1.2070	0.0068	0.7203	2.7581
300	0.4484	0.6070	0.0054	0.5783	1.4974

Suggested values for the fixed variables are as follows:

Variables	BAC	LAC
Sa	2.7	3.0
Wa	163,420	146,686
Y	1973	1973
We	213,300	196,763
R_r	$7.51	$7.17

Materials Cost, Including Purchased Parts

$$M_N = W_a \text{ (a CV)}$$

M_N = cumulative average materials cost per airframe, including purchased parts, for each airframe at unit N

N = production unit, including development units, at which the cumulative average materials cost per airframe is to be estimated

a = materials cost per pound at the first unit

CV = the conversion value obtained from the table on page II-88 to convert to cumulative average, using the "a" and "b" values from the unit cost curve.

[redacted]

Discussion: Values for "a" and "b" are determined by the simultaneous solution of the following general least squares regression equation

$$\log Mu_N = \log a + b \log N$$

where Mu_N represents the unit materials cost per pound at units 10, 30, 100 and 300. These values can be estimated by the following equation

$$Mu_N = m_{0N} + m_{1N} (S_a) + m_{2N} (\text{Log } T)$$

$$+ m_{3N} (R_2) + m_{4N} \left(\frac{10{,}000}{W_a}\right)$$

where $R_2 = \dfrac{W_e - W_a - W_q}{W_a}$

W_q = installed weight of the engines

Values for coefficients for the fixed variables are shown in the table below.

N	m_{0N}	m_{1N}	m_{2N}	m_{3N}	m_{4N}
10	-34.09778	27.78798	100.24038	50.74580	-23.26383
30	-21.09548	14.66496	62.88659	27.91719	7.20158
100	-11.90775	6.53329	39.53154	12.62157	19.84675
300	-6.71180	2.50376	26.71694	4.88098	22.46405

[redacted]

Suggested values for the additional fixed variables are as follows:

Variable	BAC	LAC
W_q	36,060	44,469

Engineering Cost

$$E_N = W_a \ E_{cN}$$

E_N = cumulative average engineering cost per airframe at unit N

N = production unit at which the cumulative average engineering cost per airframe is to be estimated

E_{cN} = cumulative average engineering cost per pound at unit N

Discussion: The value of E_{cN} at units 10, 30, 100, and 300 can be estimated by the following equation:

$$E_{cN} = e_{0N} + e_{1N}(S_a) + e_{2N}(\text{Log } T)$$

$$+ e_{3N}(R_2) + e_{4N}\left(\frac{S_a}{\sqrt{W_e - W_q}}\right)$$

Values for coefficients for the fixed variables are shown in the table below.

N	e_{0N}	e_{1N}	e_{2N}	e_{3N}	e_{4N}
10	-333.40825	-57.79344	539.93227	683.38868	55545.10742
30	-141.19510	-38.53570	237.77508	330.42243	23494.32300
100	-58.62400	- 5.67173	84.82815	144.13643	7771.16974
300	-25.99791	4.08845	27.13261	66.84505	2412.65314

To obtain cumulative average engineering cost per pound for the values of "N" other than those shown, a least squares linear regression equation of the general form "log E_{cN} = log a + b log N" should be fitted to the four computed points.

Tooling Cost

$$O_N = W_a \, O_{cN}$$

O_N = cumulative average tooling cost per airframe at unit N

N = production unit at which the cumulative average tooling cost per airframe is to be estimated

O_{cN} = cumulative average tooling cost per pound at unit N

Discussion: The values of O_{cN} at units 10, 30, 100 and 300 can be estimated by the following equation:

$$O_{cN} = t_{0N} + t_{1N} (H_{uN}) + t_{2N} (S_a) + t_{3N} (\text{Log } T) + t_{4N} (R_1)$$

where H_{uN} = direct labor man-hours per pound at unit N

[redacted]

Values for the coefficients for the fixed variables are shown in the table below.

N	t_{0N}	t_{1N}	t_{2N}	t_{3N}	t_{4N}
10	-106.48786	14.01291	43.79728	162.13959	25.19454
30	- 69.95509	9.84039	4.59343	125.60248	57.87845
100	- 37.02983	8.01543	-7.63611	83.43756	37.67874
300	- 18.45602	5.64004	-2.89662	36.40612	21.61352

To obtain cumulative average tooling cost per pound for values of "N" other than those shown, a least squares linear regression equation of the general form "$\log O_{cN} = \log a + b \log N$" should be fitted to the four computed points.

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[redacted]

[redacted]

CONVERSION VALUES FOR DETERMINING CUMULATIVE AVERAGE UNIT COSTS FROM THE COST OF THE FIRST UNIT AND THE SLOPE OF THE UNIT COST CURVE

CONVERSION VALUE AT QUANTITY

Percent of Slope	-b	2	5	10	30	50	100	200	202	300
65	0.6215	0.825	0.589	0.434	0.251	0.191	0.130	0.088	0.087	0.069
66	0.5995	0.830	0.599	0.445	0.262	0.201	0.139	0.095	0.094	0.075
67	0.5778	0.835	0.609	0.457	0.273	0.212	0.148	0.102	0.101	0.082
68	0.5564	0.840	0.619	0.469	0.285	0.223	0.157	0.110	0.109	0.089
69	0.5353	0.845	0.629	0.481	0.297	0.234	0.167	0.118	0.118	0.096
70	0.5146	0.850	0.639	0.493	0.310	0.246	0.178	0.127	0.127	0.104
71	0.4941	0.855	0.649	0.506	0.323	0.259	0.189	0.137	0.137	0.117
72	0.4739	0.860	0.660	0.519	0.337	0.272	0.201	0.148	0.147	0.123
73	0.4540	0.865	0.670	0.532	0.351	0.286	0.214	0.159	0.158	0.133
74	0.4344	0.870	0.681	0.545	0.366	0.300	0.228	0.171	0.170	0.144
75	0.4150	0.875	0.692	0.559	0.382	0.316	0.242	0.184	0.183	0.156
76	0.3959	0.880	0.703	0.573	0.397	0.331	0.257	0.198	0.197	0.169
77	0.3771	0.885	0.714	0.587	0.414	0.348	0.283	0.213	0.212	0.183
78	0.3585	0.890	0.725	0.602	0.431	0.365	0.290	0.229	0.228	0.199
79	0.3401	0.895	0.736	0.616	0.449	0.383	0.308	0.245	0.245	0.215
80	0.3219	0.900	0.748	0.632	0.467	0.402	0.327	0.264	0.262	0.232
81	0.3040	0.905	0.759	0.647	0.486	0.422	0.346	0.283	0.282	0.251
82	0.2863	0.910	0.771	0.663	0.506	0.443	0.367	0.304	0.303	0.271
83	0.2688	0.915	0.782	0.679	0.527	0.464	0.390	0.326	0.325	0.293
84	0.2515	0.920	0.794	0.695	0.548	0.487	0.413	0.349	0.348	0.316
85	0.2345	0.925	0.806	0.712	0.570	0.510	0.438	0.374	0.373	0.341

[redacted]

D. EQUATIONS FOR ESTIMATING DEVELOPMENT COSTS OF AIRFRAMES IN SUPERSONIC TRANSPORT PROGRAM

This subsection contains equations for estimating development costs of airframes. The costs are presented separately for tooling, engineering, materials (including purchased parts), and direct labor (including overhead). General and administrative costs have been added to the sum of the results to obtain total development costs. None of the costs in this subsection are included in operating cost equations in subsections A and B.

Total Development Cost for an Airframe Program

Development Cost = (Labor + Materials + Engineering + Tooling) (G and A Rate)

$$D_d = (dH_d + dM_d + dE_d + dO_d)\ A_d$$

where d = number of production airframes used to estimate the development program cost.

A_d = G and A ratio

Note: Methodology for estimating development costs is identical with that shown for total development and production costs in subsection C, substituting "d" for "N".

Suggested values for additional fixed variables are as follows:

Variable	Boeing	Lockheed
A_d	1.094	1.069

E. EQUATIONS FOR ESTIMATING PRODUCTION COSTS OF AIRFRAMES IN SUPERSONIC TRANSPORT PROGRAM

This subsection contains equations for estimating production costs of airframes. The costs are separated into tooling, engineering, materials (including purchased parts), and direct labor (including overhead). General and administrative costs have been added to the sum of the results of these four equations to obtain total production costs. To this total, profit is added to derive selling price to the airlines, exclusive of development costs prior to certification.

CUMULATIVE AVERAGE UNIT PRODUCTION COST FOR AN AIRFRAME PROGRAM

$$\text{Cumulative Average Production Cost} = \Big[(\text{Labor} + \text{Materials} + \text{Engineering} + \text{Tooling})\,(\text{G and A Rate})\Big]\ \text{Profit Rate}$$

$$P_n = \Big[(H_n + M_n + E_n + O_n)\,A_p\Big]\,P_r$$

where $n = N - d$ or the number of units produced for sale, and:

$$H_n = \frac{(NH_N - dH_d)}{n}$$

$$M_n = \frac{(NM_N - dM_d)}{n}$$

$$E_n = \frac{(NE_N - dE_d)}{n}$$

$$O_n = \frac{(NO_N - dO_d)}{n}$$

Suggested values for additional fixed variables are as follows:

Variables	Boeing	Lockheed
Ap	1.088	1.0489
Pr	1.10	1.10

F. EQUATIONS FOR ESTIMATING DEVELOPMENT AND PRODUCTION COSTS OF ENGINES IN SUPERSONIC TRANSPORT PROGRAM

This subsection contains equations for estimating total development and production cost of engines. The resultant estimates include overhead, general and administration costs, and profit. The production costs represent the selling price to the airlines. As with airframes, development costs prior to certification are excluded. The production equations are presented in a form to estimate cumulative unit engine cost at both 600 and 1200 units.

Cumulative Average Engine Production Cost

$$J = j_0 + j_1 \frac{T_h}{W_q}$$

J = cumulative average engine production cost

T_h = maximum sea level thrust in pounds

W_q = weight of an engine in pounds

j_0 and j_1 = constants depending upon the quantity produced

For 600 engines $j_0 = 291.22709$

$j_1 = 87.00612$

For 1200 engines $j_0 = -209.94459$

$j_1 = 65.71425$

Suggested values for the fixed variables are:

Variable	GE	P&W
T_h	41,900	61,200
W_q	7,825	10,355

Total Engine Development Costs to Certification

$$J_d = d S_a T_h^{\,b}$$

where J_d = total engine development cost to certification

d = constant : 343,050

S_a = maximum true air speed at altitude: measured in Mach number

T_h = maximum sea level thrust in pounds

b = constant : 0.62546

Suggested values for the fixed variables are:

Variable	Boeing	Lockheed
S_a	2.7	3.0
T_h	41,900	61,200

Estimated total engine development costs to certification for the two engines selected for costing the supersonic program are:

PW = $ 1,050,000

GE = 850,000

The PW engine is paired with the Lockheed airframe while the GE engine is utilized with the Boeing configuration.

III. AIRFRAME AND ENGINE MANUFACTURING COSTS

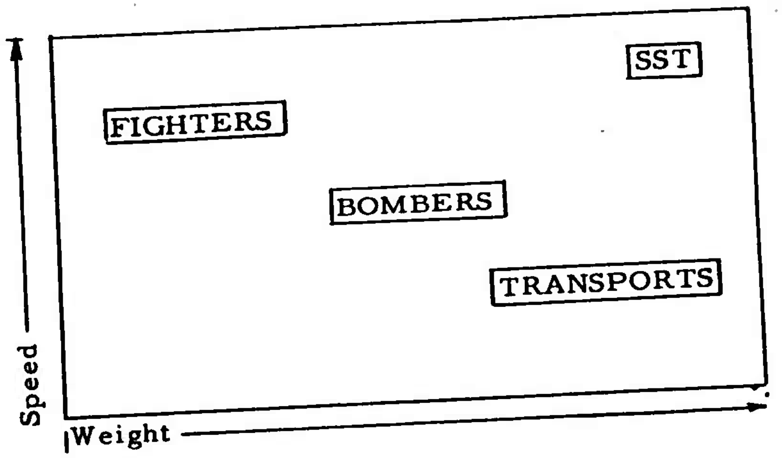
The theory used in developing the cost estimating relationships shown in Section II is discussed in this section. The aircraft used as the basis for the equations are delineated. The reasons for their selection and use in deriving the estimating equations are presented. In addition, the various equation forms tested in the research are listed.

Several forms of equations were utilized in an attempt to explain as much of the variation of the sample aircraft values as possible for each of the four cost components--direct labor, materials, tooling and engineering. A detailed listing of the cost items included in these four categories is shown in Appendix B. Regression equations were sought which minimized standard estimates of error, and all equations were computed in linear form. However, in many cases non-linear relationships were derived by transforming variables into logarithmic, root, or reciprocal form. The equations derived were used to estimate development and production costs for airframes and engines.

The last part of this section deals with some of the technical aspects of developing and producing the airframes and engines for the supersonic transport. These technical discussions identify some areas of uncertainty which should be considered in evaluating the designs proposed, as well as the statistical equations provided in Section II.

A. Airframe Production

A statistical approach was used to estimate the airframe production cost. Aircraft were selected for the sample that had some of the characteristics of the proposed supersonic transports. The chart below depicts the dispersion of the basic aircraft types in relation to speed and airframe weight.



The SST will reflect a combination of high speed and high weight, though none of the aircraft built to date meet this requirement. Bombers approach SST characteristics in some respects but only one supersonic model has been built. This particular bomber, the B-58, is but one-fourth the size of the proposed SST. Some of the late model fighter aircraft approach the required SST speed but are much lighter in weight. Transport weights are similar to the SST, but far slower.

For the aircraft to be used for estimating SST costs, a balanced sample was chosen which contained high speed fighters, bombers, and transports. The aircraft selected and some of their characteristics are shown below. These were utilized for development of the materials, tooling, and engineering equations. For estimation of direct labor costs (including overhead), a sample of 40 aircraft was selected. These are listed in Exhibit III-1. The direct labor costs per pound are less sensitive to size and speed than the other three cost groups; hence this larger sample is felt to yield more valid results than the 13 aircraft samples in prediction of direct labor costs.

Aircraft Model	Speed at Altitude (Mach number)	Weight of Airframe (pounds)
C-130A	0.55	43,586
KC-135A	0.89	70,644
B-36	0.65	113,253
B-45A	0.76	34,456
B-47E	0.86	52,247
B-50A	0.58	53,924
B-52B	0.91	112,519
B-58A	1.65	32,900
B-66B	0.86	30,515
F-105	2.08	19,726
F-106	2.02	15,556
A-3J	1.95	22,499
F-4H	2.23	18,202

Using the samples above (and in Exhibit III-1) cost estimating relationships were developed by comparing the various cost categories with performance and physical characteristics. The cost elements used were:

Direct Labor and Overhead	Man hours per pound of airframe weight to produce the nth unit.
Materials	Dollars per pound of airframe weight for the nth unit.

[redacted]

EXHIBIT III-1 - SAMPLE OF AIRCRAFT UTILIZED FOR ESTIMATION OF DIRECT LABOR COST (Including Overhead)

Aircraft Model	Speed at Altitude (Mach number)	Weight of Airframe (pounds)
F-80	0.78	4,580
F-84A	0.78	6,520
F-84D	0.97	10,680
F-86A	0.85	6,720
F-86D	0.92	8,760
F-89	0.85	18,120
F-94C	0.85	8,210
F-100	1.24	12,120
F-101	1.51	13,400
F-102	1.18	12,050
F-104	2.00	8,010
F-105	2.08	18,900
F-2H	0.77	7,180
F-J2	0.89	8,270
F-3H	0.95	14,200
F-3D	0.72	11,460
F-4H	2.23	18,200
F-7U	0.92	12,350
F-8U	1.85	10,380
AD-1	0.47	6,220
A-3D	0.83	24,210
A-4D	0.89	5,070
B-36	0.64	113,250
B-45	0.76	34,460
B-47	0.86	52,300
B-50	0.55	53,920
B-52	0.89	112,520
B-57	0.80	17,760
B-58	2.00	33,980
P-2V	0.42	22,340

EXHIBIT III - 1 Continued

P-5M	0.38	33,410
C-82	0.40	24,280
C-123	0.32	22,520
C-124	0.45	80,710
C-130	0.54	43,590
KC-135	0.87	70,600
T-28	0.38	3,870
T-37	0.55	2,550
T-2V	0.74	7,720
T-2J	0.68	5,110

[redacted]

Engineering	Cumulative average dollars per pound of airframe weight through the nth unit.
Tooling	Cumulative average dollars per pound of airframe weight through the nth unit.

Each of the cost categories was considered at the 10th, 30th, 100th, and 300th production unit of the aircraft in the sample. All data were adjusted to 1963 dollars. The annual adjustment factors used are set forth in Appendix A.

The performance characteristics selected for consideration are listed below. Not all were used in each of the final equations.

Rng = the maximum ferry range measured in nautical miles

Log Rng = this function is used to decrease the dispersion of data

W_q = total weight of installed engines measured in pounds

W_e = manufacturer's empty weight of the aircraft

W_a = AMPR weight of the airframe in pounds

S_a = maximum speed of the aircraft at its optimum altitude (Mach number)

Log S_a = the log of the above variable

W_{TO} = normal take-off gross weight measured in pounds

$\sqrt{W_{TO}}$ = the square root to the above variable

T = a complexity factor that increases with time. A base year of 1944 was chosen because that was the production year of the oldest aircraft in the sample considered

T = 1 + 0.1 Y

Y = Present year−1944

Log T = the log of the complexity factor

Q = production rate measured as units per month. The rate was calculated by dividing the total production of the months of production from delivery of the first production unit. Separate rates were calculated for the 10th, 30th, 100th, and 300th production unit.

$R_1 = \frac{W_e - W_a}{W_a}$, the ratio of weight of installed equipment, less engines, to airframe weight

$R_2 = \frac{W_e - (W_q + W_a)}{W_a}$, the ratio of weight of installed equipment, less engines, to airframe weight

$W_e - W_q$ = weight of the airframe and installed equipment

$\frac{S_a}{W_e - W_q}$ = the ratio of speed to weight of airframe and installed equipment

$\sqrt{W_a}$ = the square root of the airframe weight expressed in pounds

$\frac{S_a}{W_a}$ = the ratio of speed, in Mach number, to the airframe weight in pounds

M\$P = materials cost in dollars per pound of airframe

MHP = man hours per pound of airframe

Using the variables shown, a series of regression equations using various combinations were calculated. The following is a list of the major equations which were processed:

[redacted]

Equation No.	Cost Categories	Variables
1	Direct Labor and Overhead (man hours per pound)	S_a
2	"	S_a, $\frac{S_a}{\sqrt{W_e - W_q}}$
3	"	S_a, R_1, Log T, $\frac{S_a}{\sqrt{W_a}}$
4	"	S_a, $\frac{S_a}{\sqrt{W_a}}$, Log T
5		S_a, Log T, $\frac{S_a}{\sqrt{W_a}}$, Log T
6	"	S_a, Log T, $\frac{S_a}{\sqrt{W_a}}$, R_1
7	"	S_a, Log T, $\frac{S_a}{\sqrt{W_a}}$
8	"	S_a, Log T

[redacted]

Equation No.	Cost Categories	Variables
9	Direct Labor (Continued)	S_a, Log T, $\frac{S_a}{\sqrt{W_e - W_q}}$
10	"	S_a, R_1, Log S_a, $\frac{S_a}{\sqrt{W_a}}$, Log Rng, Log T
11	"	S_a, Log S_a, $\frac{S_a}{\sqrt{W_e - W_q}}$, Log Rng
12	"	Log S_a, Log Rng
13	"	S_a, $\frac{S_a}{\sqrt{W_a}}$, Log S_a, Log Rng, R_1
14	"	S_a, Log T, $\frac{S_a}{\sqrt{W_e - W_q}}$, Log Rng, Log S_a
15	"	Log S_a

Equation No.	Cost Categories	
16	Direct Labor (Continued)	S_a, Log T, $\frac{S_a}{\sqrt{W_e - W_q}}$, Log S_a, Log Rng
17	"	S_a, Log T, $\frac{S_a}{\sqrt{W_a}}$, Log S_a, Log Rng,
18	"	$\frac{S_a}{\sqrt{W_e - W_q}}$, R_1
19	"	S_a, Log T, $\frac{S_a}{\sqrt{W_e - W_q}}$, Log S_a, Log Rng
20	Materials (dollars per pound)	S_a
21	"	S_a, R_2, Log T
22	"	S_a, Log T

[redacted]

Equation No.	Cost Categories	Variables
23	Materials (Continued)	S_a , Log T, $\sqrt{W_e - W_q}$
24	"	S_a, $\sqrt{W_e - W_q}$ Log T, $\frac{10,000}{W_a}$
25	"	S_a, R_2, Log T, $\frac{S_a}{\sqrt{W_e - W_q}}$
26	"	S_a, R_2, Log T, $\sqrt{W_e - W_q}$
27	"	S_a, R_2, Log T, $\sqrt{W_e - W_q}$, $\frac{S_a}{\sqrt{W_a}}$
28	"	S_a, R_2, Log T, $\frac{10,000}{\sqrt{W_a}}$
29	"	S_a, Log T, $\frac{S_a}{\sqrt{W_a}}$, Log S_a, Log Rng, R_1

[redacted]

[redacted]

Equation No.	Cost Categories	Variables
30	Materials (Continued	S_a, R_2, Log T, $\frac{S_a}{\sqrt{W_e - W_q}}$
31	"	S_a, Log T, $\frac{10,000}{W_a}$
32	"	$\frac{S_a}{\sqrt{W_e - W_q}}$, Log T, R_2, S_a, $\sqrt{W_e - W_q}$
33	"	S_a, R_2, Log T, W_a, $\sqrt{W_e - W_q}$
34	"	$\frac{S_a}{\sqrt{W_e - W_q}}$,
35	"	S_a, R_2, Log T, $\sqrt{W_e - W_q}$ $\frac{S_a}{\sqrt{W_e - W_q}}$
36	"	S_a, Log T, R_2, $\frac{S_a}{\sqrt{W_e - W_q}}$, W_a, $\sqrt{W_e - W_q}$

[redacted]

Equation No.	Cost Categories	Variables
37	Materials (Continued)	$\frac{S_a}{W_a}$, Log T, R_2, $\frac{S_a}{\sqrt{W_a}}$, $\sqrt{W_e - W_q}$
38	"	S_a, Log T, R_2, $\frac{S_a}{\sqrt{W_e - W_q}}$, $\sqrt{W_e - W_q}$
39	"	$\frac{S_a}{\sqrt{W_e - W_q}}$, Log T, R_2, S_a, W_a, $\sqrt{W_e - W_q}$
40	"	S_a, R_2, Log T
41	"	S_a, R_2, Log T, $\sqrt{W_e - W_q}$, $\frac{S_a}{\sqrt{W_e - W_q}}$
42	"	S_a, R_2, Log T, $\sqrt{W_e - W_q}$, $\frac{S_a}{\sqrt{W_a}}$
43	"	S_a, Log T, $\frac{10,000}{W_a}$

Equation No.	Cost Categories	Variables
44	Materials (Continued)	S_a, R_2, Log T, $\frac{10,000}{W_a}$
45	"	S_a, $\sqrt{W_e - W_q}$ Log T
46	Tooling (dollars per pound)	S_a
47	"	S_a, R_1
48	"	S_a, M\$P
49	"	S_a, R_1, Log T, M\$P
50	"	S_a, R_1, Log T
51	"	S_a, MHP
52	"	S_a, Log T, R_1, MHP
53	"	S_a, R_1, Log Rng, Log T, $\frac{S_a}{\sqrt{W_e - W_q}}$

[redacted]

Equation No.	Cost Categories	Variables
54	Tooling (Continued)	Log S_a, $\frac{S_a}{\sqrt{W_e - W_q}}$, $\sqrt{Q_{010}}$, Log Rng
55	"	S_a, R_1 Log Rng, Log T
56	"	Log S_a, Log T, $\sqrt{Q}$, Log Rng, $\frac{S_a}{\sqrt{W_e - W_q}}$
57	"	S_a, R_1, Log T, $\sqrt{W_e - W_q}$, $\frac{S_a}{\sqrt{W_e - W_q}}$
58	"	Log Rng
59	"	Log S_a, $\frac{S_a}{\sqrt{W_e - W_q}}$, Log T, Log Rng, $\sqrt{Q}$
60	"	S_a, R_1, $\frac{S_a}{\sqrt{W_e - W_q}}$, Log T, $\sqrt{Q}$, Log Rng
61	"	S_a, R_1
62	"	MHP, S_a
63	"	MHP, S_a, Log T

[redacted]

Equation No.	Cost Categories	Variables
64	Tooling (Continued)	MHP, S_a, Log T, R_1
65	"	S_a, W_a, R_1
66	"	S_a, W_a, R_1, Log T
67	"	S_a, R_1, $\frac{10,000}{W_a}$
68	"	S_a, R_1, $\frac{10,000}{W_a}$, Log T
69	"	S_a, R_2, W_a
70	"	S_a, R_2, Log T, W_a
71	"	S_a, R_2, $\frac{10,000}{W_a}$
72	"	S_a, R_2, $\frac{10,000}{W_a}$, Log T

Equation No.	Cost Categories	Variables
73	Engineering (dollars per pound)	S_a
74	"	S_a, R_2, $\frac{S_a}{\sqrt{W_e - W_q}}$, Log T
75	"	S_a, M$P
76	"	S_a, R_2, Log T, M$P
77	"	S_a, MHP
78	"	S_a, MHP, Log T, R_2
79	"	S_a, R_2, Log T, Log Rng, $\sqrt{W_e - W_q}$
80	"	S_a, R_2, Log T, Log Rng, $\sqrt{W_e - W_q}$

Equation No.	Cost Categories	Varables
81	Engineering (Continued)	S_a, R_2, Log T, Log Rng
82	"	S_a, R_2, Log T, $\sqrt{W_e - W_q}$
83	"	S_a, Log T, R_2, $\frac{S_a}{\sqrt{W_e - W_q}}$
84	"	S_a, Log T, R_2, $\frac{S_a}{\sqrt{W_e - W_q}}$
85	"	S_a, M\$P
86	"	S_a, Log T, R_2, M\$P

B. Airframe Development

Airframe development costs are the most difficult costs to estimate because of a lack of an agreed definition for development, and the lack of accurate cost data.

For the purpose of this report, airframe development costs include all expenses incurred in the design, manufacture, and test of two prototype aircraft. It also includes the non-recurring engineering and testing associated with the initial production and all static and flight tests up to certification.

FAA certification requirements are for the purpose of insuring the safety of the aircraft. Therefore, certain tests must be accomplished on production and not prototype articles. Most of these tests are concerned with the structural strength of airframe and specific flight performance. The structural tests include static tests of the wing and fuselage, pressurization tests of the fuselage, and fatigue tests on both the wing and fuselage. The flight performance tests include many hours of flying to develop detailed performance charts for airline flight crews who must know specifically what performance capability to expect under all operating conditions, including emergencies such as partial loss of power.

The input data used in the four cost categories of the statistical sample utilized included all prototype and non-recurring costs. Therefore, in calculating the development cost of an SST, the total cost (excluding profit) of the initial two production aircraft was considered to be equal to the development cost. The formulas for airframe development costs were shown in Section II.

It is common practice in the aircraft industry to build two prototype aircraft in advance of initiating production. This was done on the C-130, C-97, and T-37, as well as other aircraft programs. Although these were all military programs, a series of tests similar to FAA certification was accomplished. The total development costs were a combination of costs associated with the prototype manufacturing and testing and the non-recurring testing associated with the initial production articles.

The government financed these prototype developments with Research and Development Funds and all other expenses, including the balance of development costs, from Production Funds. As a result, it is difficult to isolate the total development costs associated with any specific program. Other difficulties, such as different accounting practices by the manufacturers and destruction of old records, similarly hinder the accurate ascertainment of true development costs.

Reliable cost records of previous programs is essential to statistically estimate development cost. Since such information is unobtainable, a different approach had to be made to estimate SST airframe development costs. The methodology chosen was based on examination of available information. The development costs were estimated by using the estimated cost of the first two aircraft as determined from manufacturing formulas in Section II.

This methodology overestimates the tooling cost as compared to estimates of the manufacturers for the two prototype aircraft, but since the estimated total development costs in this study include early production articles for testing, the tooling cost as determined by these equations appears to be a reasonable estimate of the total cost associated with this phase of the program.

Exhibits III-2a, 2b, 2c, and 2d show the actual versus the estimated values per pound at the one-hundredth unit estimated by the equations for each of the aircraft used to develop these cost estimating equations.

C. Engine Production

A statistical approach using historical data was used to construct the engine production cost estimate. Engines selected for the sample met criteria which were established as representative of engines required to power a supersonic transport. Although present engines cannot meet all of the SST engine characteristics, the following criteria were established:

1. Each engine selected for the sample had a production run of 1200 or more.
2. Only turbojet or turbofan engines were considered.
3. Only engines in production during the last ten years were considered.
4. Engines with maximum sea level thrust over 8,000 lbs., were utilized.

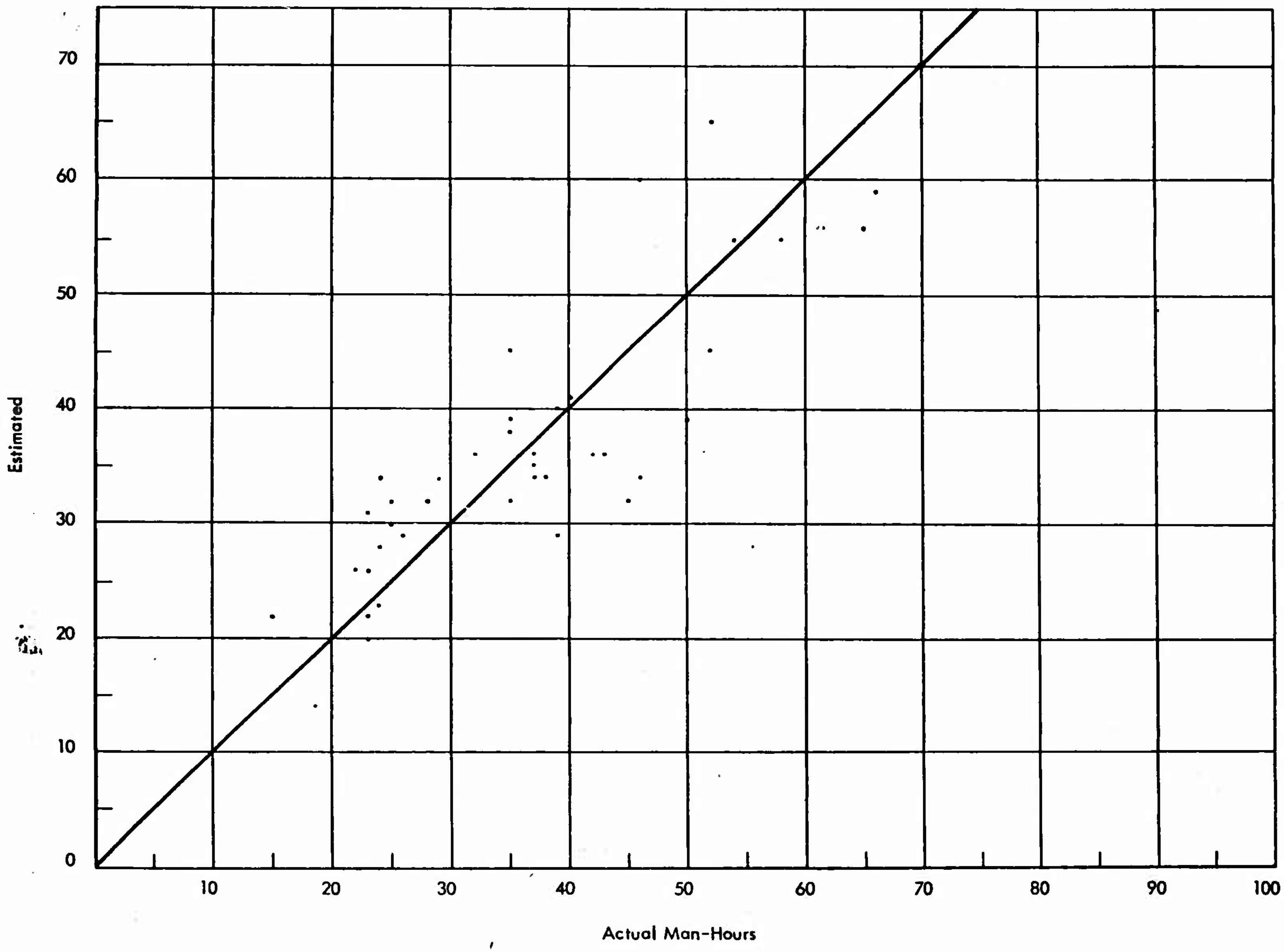
The engines selected for the sample were as follows (all costs adjusted to 1963 dollars):

[redacted]

[redacted]

LABOR COSTS @ 100 UNIT

EXHIBIT III-2a.- ACTUAL VS. ESTIMATED CUM. AVG. MAN-HOURS/POUND



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[redacted]

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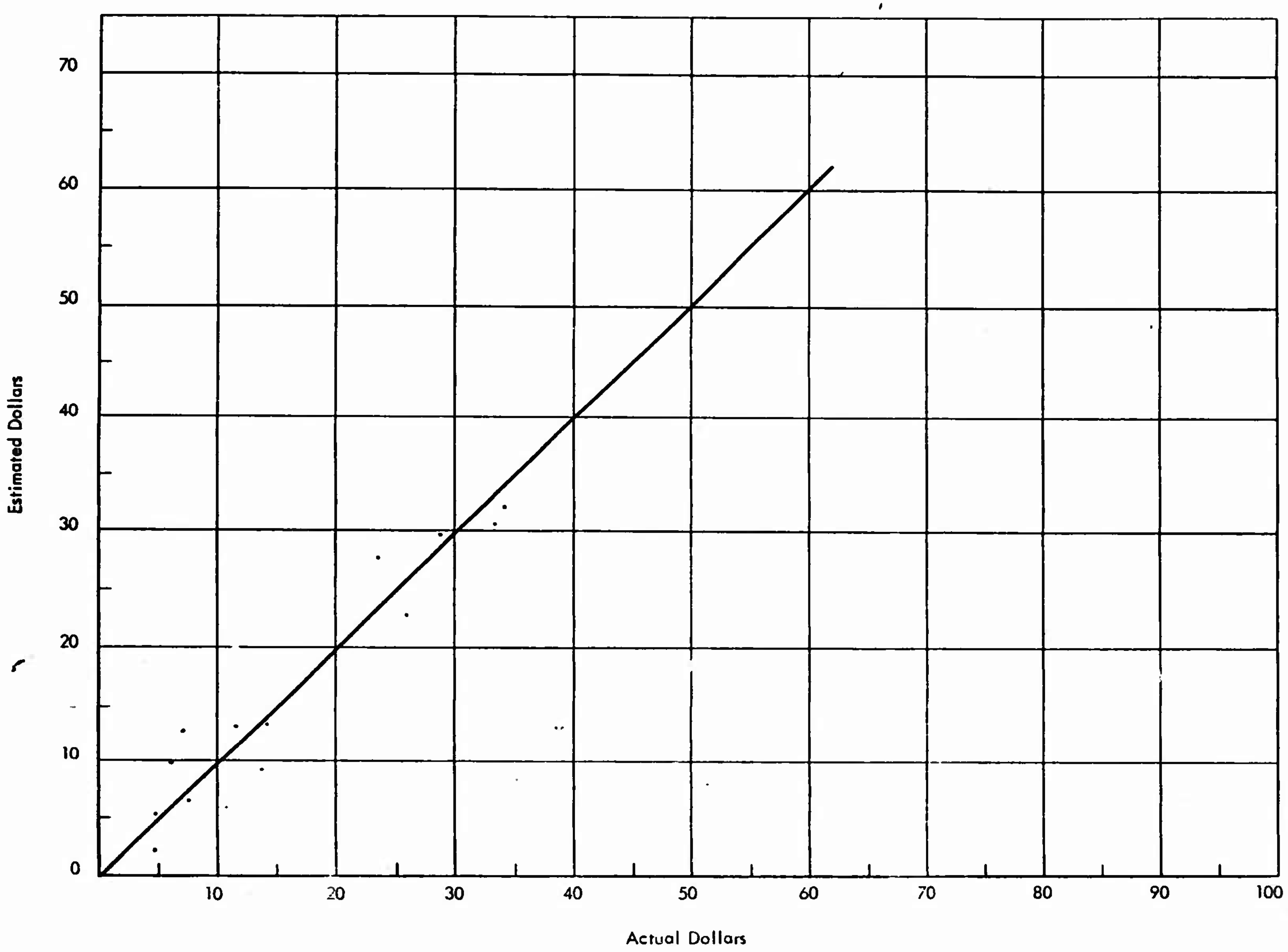
MATERIALS @ 100 UNIT

EXHIBIT III-2b.- ACTUAL VS. ESTIMATED CUM. AVG. DOLLARS PER POUND



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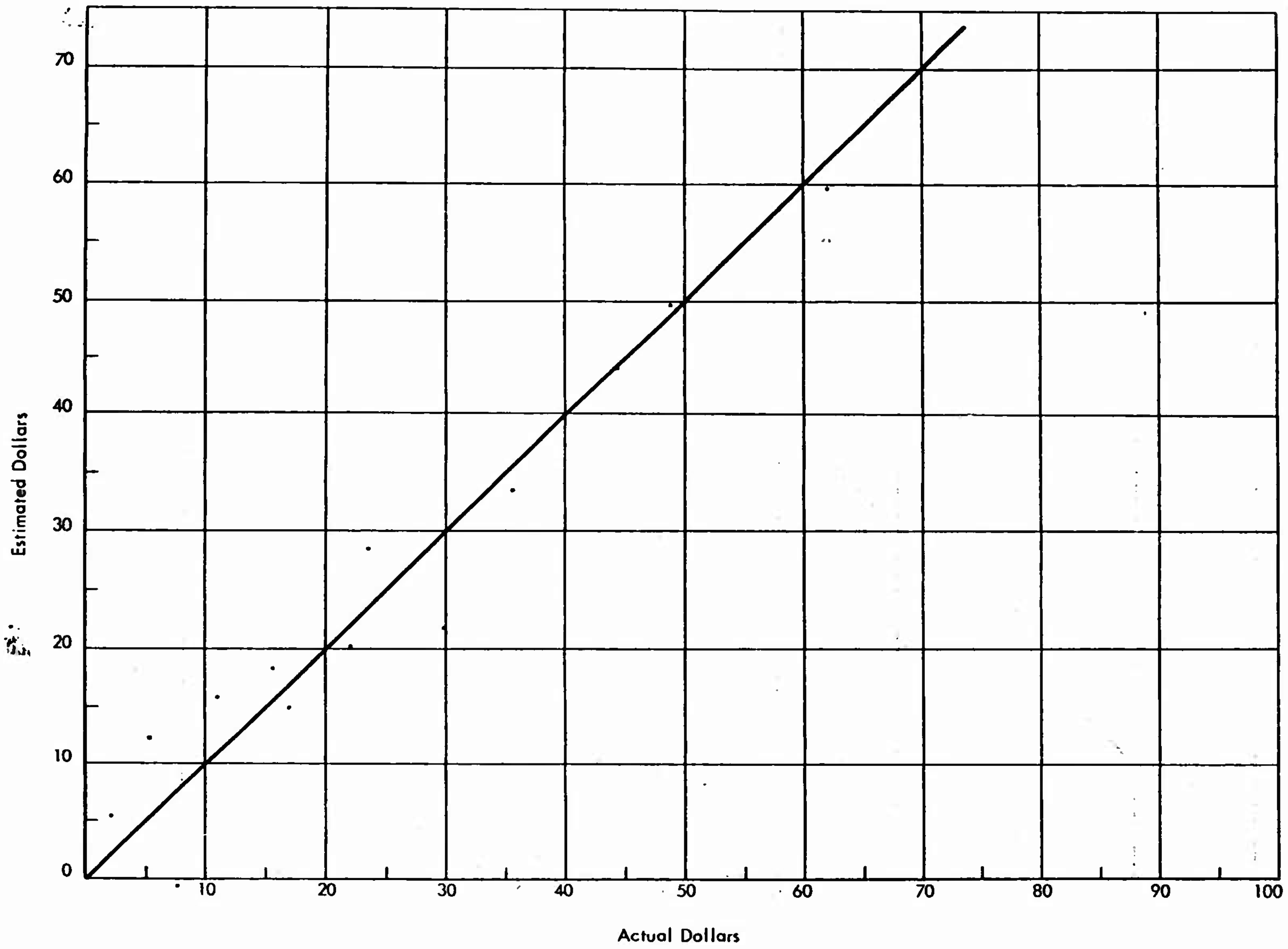
TOOLING @ 100 UNIT

EXHIBIT III-2c.- ESTIMATED CUM. AVG. DOLLARS/LB.



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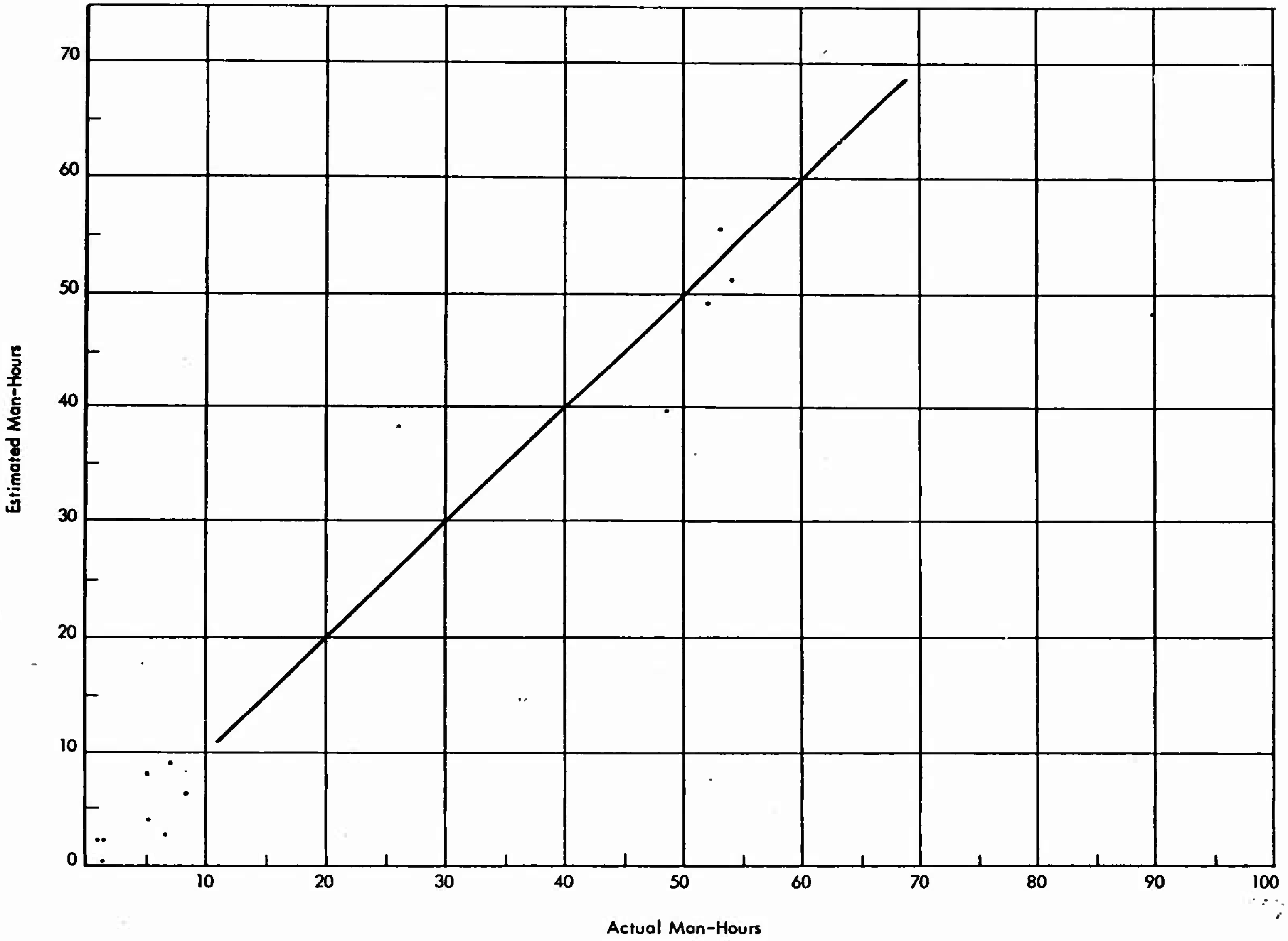
ENGINEERING @ 100 UNITS

EXHIBIT III-2d.- ACTUAL VS. ESTIMATED CUM. AVG. COST/LB.



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Engine Model	Dry Weight (pounds)	Thrust (pounds)	Thrust to Weight Ratio	Cumulative Average Cost at Unit 600 Total	Cumulative Average Cost at Unit 600 Per Pound	Cumulative Average Cost at Unit 1200 Total	Cumulative Average Cost at Unit 1200 Per Pound
J-52P	2,056	8,500	4.13	$141,000	$ 68.58	$146,000	$ 71.01
J-57P	3,870	13,750	3.55	148,000	38.24	146,000	37.73
J-79G	3,255	14,800	4.55	422,000	129.65	345,000	105.99
J-75P	5,950	24,500	4.12	255,000	42.86	200.000	33.61
TF-33P	4,340	18,000	4.15	209,000	48.16	213,000	49.08

The J-52 engine developed by Pratt and Whitney is used on military aircraft for which initial design work began in 1953. By 1957 the engine passed its MQT (Military Qualification Test, i. e., 150-hour test), and by 1963 a fan version, the JT8D, was placed in commercial operation.

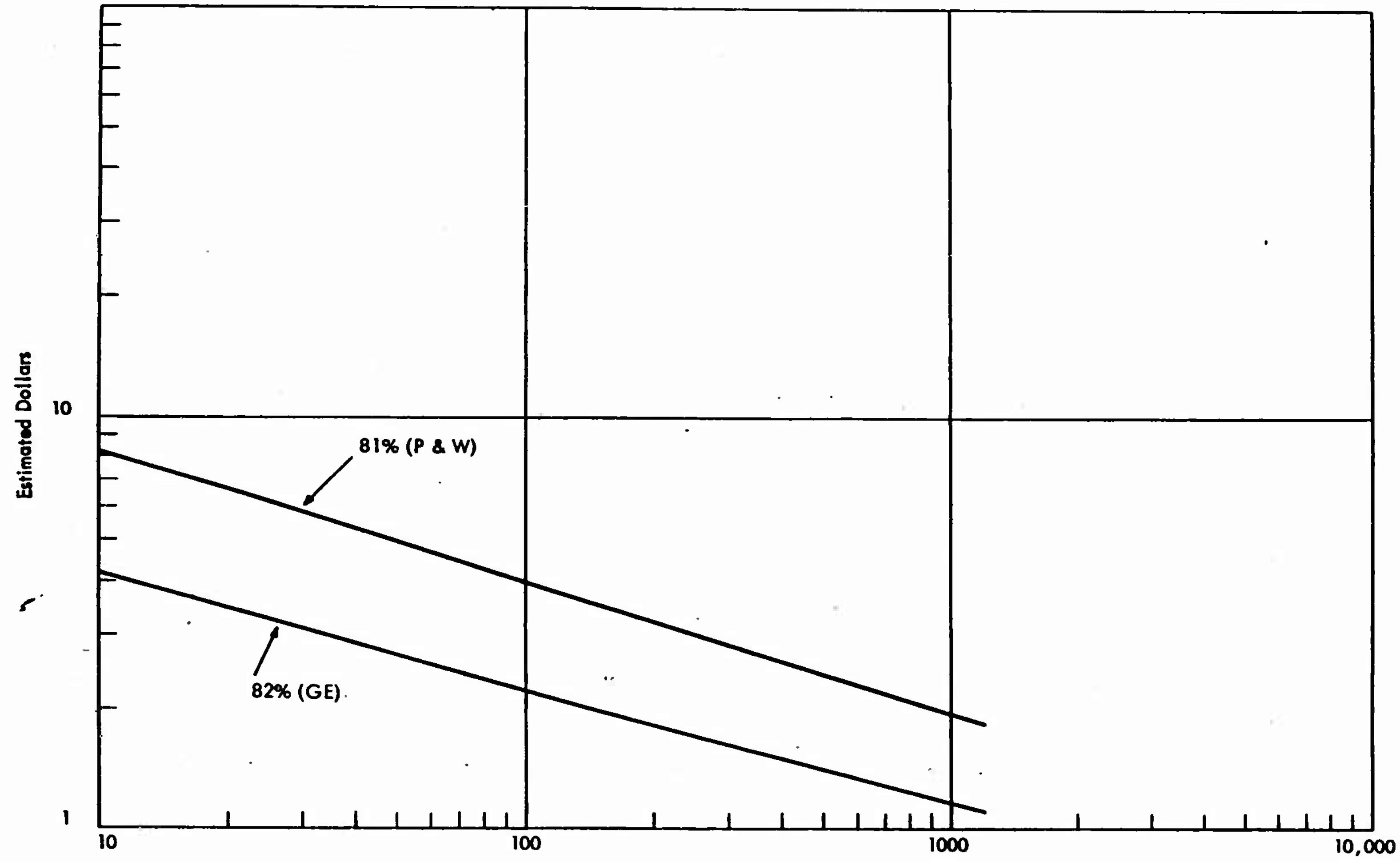
The J-79 engine development was started in 1953 by General Electric. It passed its MQT in 1957 and a commercial version, the CJ805 (a turbofan), was introduced in 1961.

The J-75 development program was started in 1952 by Pratt and Whitney. It passed its MQT in 1957 and in 1960, a commercial version, the JT-4, was placed in service.

Development of the TF-33 engine was begun in 1958 by Pratt and Whitney. This engine is a turbofan version of the J-57 known as the JT3D, for which commercial operations with began in 1961.

These data were used to compute two regression equations, one at 600 production units and another at 1200 production units for each of the two manufacturers in the SST competition. The results of these formulas are plotted on Exhibit III-3. Since the SST is not anticipated to be a military development, its price is expected to follow a normal learning curve. However, as engine improvements are incorporated into the later production items, this will have a tendency to flatten the learning curve.

EXHIBIT III-3 - ENGINE PRODUCTION COST



The formulas for the 600 and 1200 production quantities are as follows:

$$Y = a + b\frac{T_h}{W_q}$$

Y = cumulative average cost per pound

a and b = constants depending upon the quantity produced

For 600 engines: a = -291,22709
b = 87.00612

For 1200 engines: a = -209.94459
b = 65.71429

T_h = maximum sea level thrust in pounds

W_q = dry weight of the engine in pounds

D. Engine Development Costs

The development costs of large turbojet and turbofan engines were examined in order to estimate the development cost of the proposed SST engines. Exhibit III-4a shows the total cost of developing selected engines to commercial certification. Thrust and weight of the different engines are also presented.

The data in the table are plotted in Exhibit III-4b except for commercial engines which were modifications of the military engines shown. The MQT cost of the J-58P is greater than previous engines. This is attributed to the additional complexity associated with higher thrust and speeds. The costs to certification of this engine are not available, in that it has not been certificated for commercial use. The SST engine costs are expected to be even higher because of the greater thrust requirements.

Using the above data, the maximum sea level thrust for each engine in the sample was plotted against the development cost to certification. The TF33 and JT8D were excluded because they are primarily model improvements of the J-57 and J-52, respectively.

The formula for the resulting regression equation is as follows:

$$Y = a\,T_h^{\,b}$$

where Y = the development cost prior to certification in hundreds of millions of dollars

a = constant of 686,100

T_h = maximum sea level thrust of the engine in pounds

b = constant of 0.62546

This equation applies to engines which operate at speeds equal to or below Mach 2. A speed correction factor was calculated to obtain the estimated total development cost of engines that operate at higher Mach numbers. The formula for this correction factor is:

$$J_d = \frac{Y\,Sa}{c}$$

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where J_d = total engine development cost to commercial certification

Y = development costs prior to certification in hundreds of millions of dollars

Sa = speed at altitude in Mach number

c = constant of 2.0

A final equation combining the above two steps is:

$$J_d = d\ T_h^{\,b}\ Sa$$

d = the constant 343,050

[redacted]

EXHIBIT III-4a - DEVELOPMENT COSTS OF SELECTED ENGINES TO COMMERCIAL CERTIFICATION

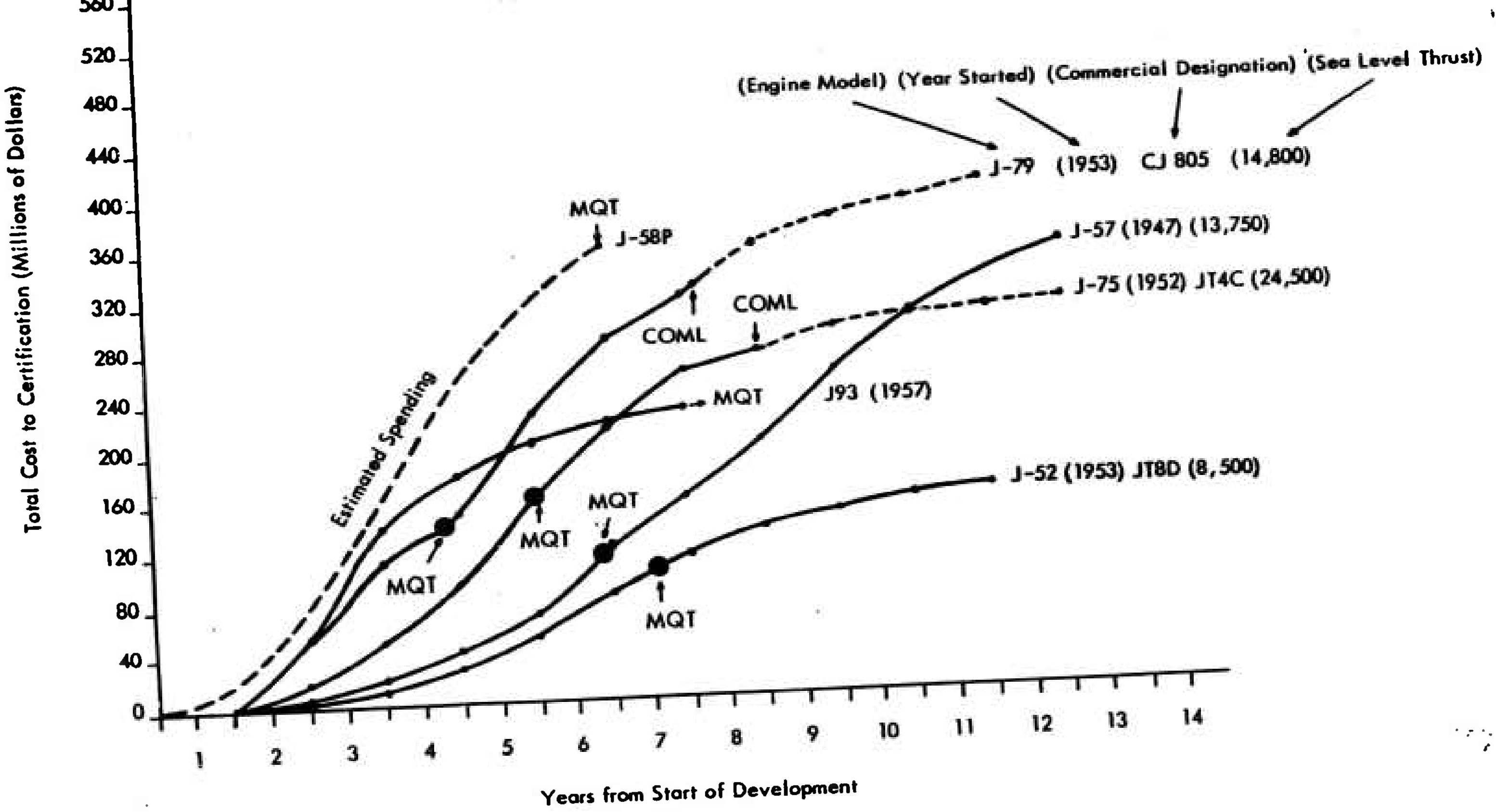
Engine Model	Development Cost to MQT (millions)	Development Cost to Certification (millions)	Maximum Sea Level Takeoff Thrust (pounds)	Dry Weight (pounds)
J-52P	$ 96.0	$160	8,500	2,056
J-57P	112.5	350	13,750	3,870
J-79G	135.0	340	14,800	3,255
J-75P	160.0	275	24,500	5,950
J-52,JT8D	135.0	213	14,000	3,041
J-57,TF33	149.5	422	18,000	4,340
*J-58P	360.0	-	30,000	-

*This engine not considered in computation of development costs to certification.

[redacted]

EXHIBIT III-4b. - ENGINE DEVELOPMENT COST

KEY:
MQT = Military Qualification Test — 150 hour flight engine.
COML = Time when engine was first placed in commercial operation



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E. Technical Considerations in Airframe Production

An engineering analysis of the proposed SST airframes has been made in this subsection. The major technical problems are discussed and related to costs. While the estimates developed here are completely independent of the estimates resulting from application of the equations in Section II, they do serve as a partial check of the statistical approach to estimating airframe and engine manufacturing costs, as well as some aspects of the manufacturers' proposals.

1. Basic Design Criteria

Despite a difference in the approach to the "optimum" aerodynamic configuration for an SST aircraft, several underlying similarities of design exist between the airframe structures of the two competing manufacturers. While this makes the problem of estimating manufacturing costs simpler, the results of the analyses is thereby constrained. This very similarity in airframe type dictates that the results, as such should not be extended to other designs differing greatly from the proposed structures.

The similarities alluded to above are found in the choice of materials for principle airframe structures, i. e. forgings of Ti-6AL-6V-2Sn or Ti-6AL-4V and sheet plates and extrusions of Ti-8AL-1Mo-1V, as well as in the basic concept of structural design.

The similarities in structural design pertain to the extensive use of stressed skin wing and fuselage coverings as well as the use of extruded or formed "Z" channels, "Hat" sections and other conventional structural shapes as reinforcement of bulkhead webs and outer skin coverings. Wing ribs and spars are designed from plate and forged billets of equivalent physical properties, the choice between plate or forging dictated by the physical size of the element and that of the forging press. Wherever possible, forged billets or sections are used in place of heavy rolled plate in order to reduce machining time and weight of scrap. Titanium forgings and rolled plate may be used interchangeably, with the choice depending not upon physical properties (since they are similar) but rather on a comparison of the accumulated cost of raw stock plus machining time for a specific component. In the preliminary SST proposal (January 1964), the weight of forgings used by Lockheed was twice that of Boeing's. The effect of this difference in estimating airframe costs for each design is considered negligible inasmuch as the total end weight of forged components is probably on the order of 5 percent of the airframe weight. One significant conclusion may be drawn from the similarities of structural design of the competing SST

[redacted]

aircraft – the use of titanium alloys lends itself to structural configurations not unlike its aluminum counterparts, even taking into account the difference in physical properties of the two types of material. Because of this, it is not surprising that both Lockheed and Boeing should end up with similar semi-monocoque structures, which has for so many years been the convention in the aircraft industry.

This similarity to conventional aluminum aircraft structures gives rise to the implication that subassembly and major assembly tooling for the titanium airframe of the SST will be similar to that designed for comparable aluminum structures. A cost increment for this type of assembly tooling over that required for a low supersonic aluminum transport is expected.

Where the unique physical properties of titanium differ markedly from aluminum alloys, new methods and new designs in tooling (i. e., hot forming) to match these techniques are being developed. This development makes the forming process of titanium alloy components more costly than its aluminum counterparts. Other factors contributing to increased cost in forming titanium are the high heat treat temperatures required (1800 - 1850°F), necessitating furnaces of larger size (for this temperature range) than are readily available in airframe facilities geared to aluminum alloy fabrication. Heated dies, using a metal base with electrical heating elements embedded in a ceramic heat resistant surface structure, as well as special radiant energy heating systems coupled to forming dies, are part of the never-ending search and development of titanium forming methods. All of these must be charged off to the SST costs.

The ability to maintain its basic physical properties at elevated temperatures, so important to the integrity of the primary structure of an SST aircraft, is the underlying reason for the present high cost of finished titanium alloy extrusions. Titanium billets, even when heated to 1850°F are still resistant to the extrusion process, requiring considerably higher ram pressures than for comparable aluminum sections. This resistance to extruding (even at these elevated temperatures) imposes severe wearing of the extrusion die walls, so that the maintenance of dimensional tolerances in long sections is extremely difficult. In consequence, the variety of different finished extruded shapes and lengths are more limited in titanium alloys than in their aluminum equivalents. Another factor contributing to a limited selection in finished titanium extrusions is the present high cost

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of production (i. e., 4 to 5 times raw material costs in dollars per pound) of this quality of structural shape. The economics of this situation has forced much of the finishing processes out of the suppliers' mills into the airframe industry as manufacturing costs. The same is not generally true with aluminum structural shapes which are all finished and can be used in the "as-received" condition from the mill.

Extruded shapes have long been a serious problem to titanium producers. Until 1963 the smallest wall thickness produced by titanium mills was a quarter inch, and this in only the medium strength alloys. Thus, the high strength alloy (6AL-4V) is unavailable in light sections to the airframe industry, except at "prohibitive" costs. However, new techniques are being developed, through government supported research programs, which will make available to the aircraft industry high strength titanium alloy extrusions with wall thickness of the order of one-sixteenth inch. Some one-eighth inch wall thickness extruded shapes are presently available.

The limitations in mill run lengths of high strength titanium alloys (Ti-8AL-1Mo-1V) imposes an additional step in the manufacturing process when this metal is used, (i. e., joining two or more sheets by welding to obtain the required length). This is not so for most equivalent aluminum structures because of the longer mill lengths attainable in this metal.

In trying to arrive at fabrication costs of titanium alloy structures, direct comparisons between this metal and aluminum alloy should not be sought, as in most cases a direct substitution of titanium for aluminum does not exist. For any structural configuration and stress environment, the physical properties of each metal would be used in its most effective manner. One might therefore safely argue that there is no direct substitution of one metal for another in the SST airframe without contradicting the statement that a similarity exists between the titanium airframe structural configuration and that of conventional aluminum airframes. Furthermore, all basic fabrication processes used in aluminum airframe construction are duplicated in varying degrees in the titanium airframe of the SST aircraft proposed. These different fabrication processes (i. e., forming, machining, welding, riveting, and bolting) are more receptive to cost analysis as individual fabrication processes than the sum total until the proportion of each to the total fabrication of the airframe is known.

Some data comparing the cost of fabricating titanium and aluminum using different fabricating processes (i. e., welding, riveting, etc.) is obtainable from principal airframe manufacturers. The information presented here has been gathered from four principal sources:

- Lockheed Aircraft
- Boeing Aircraft
- North American Aircraft
- Battelle Memorial Institute (DMIC)

Data on basic mill prices for sheet, extrusion and bar stock originated with the Titanium Metals Corpration.

2. Production Material Analysis

A comparison of the Boeing and Lockheed SST design indicates that both manufacturers are employing titanium alloys to about 70 percent of their AMPR weight. Approximately another 15 percent of AMPR weight is estimated to be in aluminum and steel structure, and the remaining 15 percent of AMPR weight chargeable to wiring, cables, electrical connectors, and sealing compounds.

A reasonable distribution of titanium wrought shape within the SST airframe is given in the table on the following page.

Titanium Alloy	Wrought Shape	Percent AMPR Weight	Estimated Mill Price 1964
Ti-8AL-1Mo-1V Ti-4AL-8Mo-1V	Plate	5	6.00
Ti-6AL-6V-2Sn Ti-6AL-4V	Forgings* (incl. bars and billets)	10	8.00
Ti-6AL-4V Ti-6AL-6V-2Sn	Extrusion*	25	11.00
Ti-8AL-1Mo-1V Ti-4AL-3Mo-1V	Sheet	30	14.00

* Rough - Some machining required.

Correlated with the distribution of titanium wrought shapes are manufacturing and complexity factors which provide a measure of the amount of raw materials of each mill shape that must be purchased to yield one pound of finished part. The manufacturing factor is the ratio of pounds of aluminum wrought shape to finished part. The complexity factor represents an additional increment of titanium material (referred to its aluminum counterpart) that must be purchased because of the lower tolerance and smaller variety of wrought shapes presently produced in titanium alloys. In the following table, the representative manufacturing factors for aluminum for each of the wrought shapes used in an airframe design and the complexity factors for titanium corresponding to these same shapes, are shown.

Wrought Shape	Titanium Complexity Factor	Aluminum Mfg. Factor	Titanium Net Buy Factor
Plate	1.2	10.0	12.0
Forging (Including Bars and Billets)	1.3	3.1	4.0
Extrusion	2.0	1.5	3.0
Sheet	1.2	1.4	1.7

The titanium materials per airframe represents only 70 percent of the materials which make up the AMPR weight. Other materials, structural and non-structural that make up the AMPR weight, would cover steel forgings and structural shapes, such as landing gear, aluminum components in areas unaffected by environmental temperatures, wires and cables, electrical plugs and connectors, and pressure sealants.

3. Production Labor Analysis

Production labor estimates (man-hours) are derived from aluminum airframe experience to which titanium complexity factors were applied. To achieve more realistic values, the production man-hours are divided into fabrication labor and assembly labor categories.

a. Fabrication Labor Factor (Ratio of Titanium to Aluminum)

Operation	
Trimming	1.50
Forming	4.50
Machining	3.33
Drilling and Hole preparation	4.50
Miscellaneous Operations	2.10
Composite Factor	3.60

b. Assembly Labor Factor

The assembly labor factors described herein were derived from the best estimates of the design complexity factor of an SST when compared with a large subsonic transport and from the other estimates which relate the assembly man-hours of a predominantly titanium airframe structure to one fabricated from aluminum alloy.

[redacted]

Assembly Operations	Titanium to Aluminum	Percent of Total Labor Operations	Design Complexity Factor	Total
Rivet	2.0	20	1.0	.40
Welding	2.25	15	1.25	.43
Bolted Assy.	1.0	35	1.0	.35
Electrical and Electronics	1.0	12	1.5	.18
Sealing and Paint	1.0	6	1.5	.09
Preflight Mech. Operations	1.0	12	1.5	.18
		100		1.63

4. Tooling Labor

Tooling man-hour requirements are derived from an empirical study of the tooling employed on large subsonic aluminum airframes, extrapolated to the more complex SST aircraft whose structure is predominantly of titanium alloys. This tooling cost evaluation is expressed in terms of an average or composite complexity factor which relates the additional tooling man hours required for fabricating and assembling the SST aircraft over an "equivalent" aluminum structure of which some of the large subsonic transport aircraft serve as representative examples.

[redacted]

Tooling Complexity Factors

(Ratio of Titanium to Aluminum)

Component	Fabrication Tools	Assembly Tools	Tool Master	Manufacturing Aids	Average Component Complexity
Wing	2.85	1.20	1.0	1.0	1.80
Fuselage	2.80	1.10	1.0	1.0	1.70
Tail	2.00	1.15	1.0	1.0	1.50
Nacelles and Powerplant	2.80	1.20	1.0	1.0	1.80
Final Assembly and Flight	1.20	1.20	1.0	1.0	1.10
	2.40	1.18	1.0	1.0	1.60

Tooling man-hours per aircraft may now be obtained from the product of the composite tooling factor (1.60) and the estimated tooling man-hours required for an " equivalent" subsonic aluminum aircraft. Tooling maintenance is estimated at 1.10 times the equivalent maintenance cost of tools supporting high speed transport aircraft.

IV. AIRLINE OPERATING COSTS

Over the 15-year projected operating life of an SST, operating costs will total approximately four times the original purchase price of the aircraft including engines. However, the airline industry has been heavily regulated as to its accounting procedures and a great deal of historical information is available. The Civil Aeronautics Board (CAB), the agency which regulates these procedures, has established a Uniform System of Accounts and Reports which proscribes the separation of expenses into certain major and minor accounts. Although interpretation of the regulations leads to some difference in reporting practices among the airlines, these individual practices are of such consequence that they do not seriously distort the industry aggregate cost data.

Most of the costs encountered in operating an airline vary only in magnitude with the type of aircraft operated. The basic cost categories are the same. Some of the costs, such as fuel or depreciation, are extremely sensitive to type of equipment but others, such as sales and traffic servicing, are not. This factor facilitated the development of equations for estimating operating costs of supersonic as well as subsonic transports.

Direct operating costs are those associated with aircraft operation. The airlines, through the Air Transport Association (ATA), have adopted a methodology for estimating these costs to enable comparison of the economics of various aircraft. The cost functions of this ATA formula are the bases for estimating direct operating costs of aircraft in this study.

The other expenses follow the CAB accounting system and are affected more by the traffic carried than by aircraft. Many of these indirect costs are determined by managerial policy or the degree of competition more than any other factor. Examples are advertising, sales and food and beverage expenses. The allocation of these costs to specific traffic or flight segments becomes somewhat arbitrary, as well as dependent on historical practices.

In this study, the indirect costs of domestic trunk airlines were analyzed for the years 1953 through 1963, with regression techniques employed to correlate total indirect costs to revenue passenger-miles. An extremely high degree of correlation was found. However, it is assumed that the SST will make up only a portion of the total operating fleet of any particular airline and such a gross approach would not enable the estimation of the profitability of the SST. The SST will operate primarily over long segments and those indirect costs which do not vary with flight distance are overstated under such a technique. Hence, cost estimating equations which attempt to allocate indirect costs more in line with the manner in which they are incurred were presented in Section II.

The application of the operating cost equations is predicated upon domestic and international flight segments of 1455 and 1980 miles, respectively. These segment lengths were a parameter established by the Federal Aviation Agency (FAA) in its ground rules for economic analysis by the manufacturers involved in this SST competition.

As stated previously, airline operating costs are separated into two major categories, direct operating costs (DOC) and indirect operating costs (IOC). Normal sub-groupings for DOC include Flight Crew Costs, Insurance, Fuel, Maintenance of Flight Equipment, and Depreciation of Flight Equipment. IOC includes all other expenses of operating the airline, with the following major categories established by the CAB for reporting purposes: Passenger Service, Aircraft Servicing, Traffic Servicing, Servicing Administration, Reservations and Sales, Advertising and Publicity, General and Administrative Expenses, Maintenance of Non-Flight Equipment and Depreciation and Amortization of Non-Flight Equipment. The IOC accounts are designated by their CAB account numbers in this section.

Each of the major DOC and IOC accounts are discussed in terms of philosophy employed in constructing cost equations. The equations are based upon analyses of historical airline operating procedures and cost experience, as well as on the results of previous studies accomplished by the airline industry, the aircraft manufacturers and various research organizations.

A. Direct Operating Costs

1. Crew Costs

The formulas for determining crew costs for subsonic and supersonic aircraft are shown in Section II (equations C_4, C_5, C_6 and C_7). The subsonic crew cost equations reflect the cost of operating the current long-range, four-engine subsonic jet aircraft. The supersonic crew cost formulas reflect the cost of operating supersonic aircraft of the type proposed by the airframe manufacturers. The formulas used to compute these costs are based upon payroll plus overhead items such as vacation, training, insurance and payroll taxes, and crew premiums. The payroll is based upon the base pay of each type of crew member, day/night duty, hours of flight, miles of flight, maximum certificated gross weight of the aircraft, operational duty pay, and a travel expense allowance.

Current subsonic aircraft are operated internationally with a pilot, copilot, engineer, and navigator, with no navigator employed in domestic service. The supersonic aircraft is expected to operate with only a three-man crew for both domestic and international operations.

The SST will have a much greater productivity than current subsonic aircraft. Because of this factor, which will reduce the number of flight crews required in proportion to traffic volume, the number of hours worked is expected to drop to about 55 to 60 per month from the present average of about 80. Past airline-union negotiations indicate that the crew members will still be able to maintain an annual salary equivalent to their present wage. This plus the increased speed of the SST will serve to raise the subsonic hourly crew costs by slightly over 50 percent for the SST.

The ATA formula for crew pay was used as a base to estimate subsonic crew costs. The speed pay factor was not changed while the gross weight factor, a minor cost, was increased slightly. All other factors were combined into a single constant hourly cost. For the SST, the speed and gross weight factor remained unchanged while the constant hourly factor was adjusted upward by about 55 percent, due to decreased flight crew utilization without a commensurate decrease in pay.

The table below shows the cost per block hour for the supersonic and subsonic aircraft using the cost estimating equations developed in this study. They are compared with the crew costs for four-engine subsonic jets reported in 1963 by the airlines to the Civil Aeronautics Board.

Flight Crew Cost (dollars per block hour)

	Estimated Supersonic Costs		Subsonic Aircraft Costs	
	Boeing 733-290	Lockheed 2000-2P	Estimated	1963 Actual
Domestic (1455 miles)	$197	$197	$119	$117
International (1980 miles)	$212	$213	$157	$152

2. Fuel and Oil Costs

These expenses are a direct function of fuel and oil consumed by the aircraft in its normal operation. The consumption is expressed in pounds of fuel burned. The quantity of fuel burned contains certain fixed elements regardless of the length of the particular flight involved. These include ground maneuver fuel, fuel to climb to cruise altitude, fuel required for air maneuver, and fuel needed to descend (including deceleration). The prime variable item is the fuel consumed at cruise altitude, which will vary quite directly with the length of time that the aircraft remains in this portion of the flight profile. The other elements may also vary on individual segments depending on the cruise altitude assigned, the amount of ground and air maneuver time, and the length of hold time (if any) at destination, but these are not considered separately in the equations shown.

The fuel and oil cost formula (equation C_8), for subsonic and supersonic aircraft are based upon identical fuel and oil prices per gallon for the same type of operation. Comparison with data reported for 1963 indicates slightly lower prices for the domestic carriers than the 11 cents per gallon employed in this study. The figures for international operations show a cost in excess of the 12 cents per gallon recommended in this report. However, both prices are in agreement with the Federal Aviation Agency Supersonic Transport Economic Model Ground Rules, dated September 15 1964. These prices are expected to prevail during the 1970-1990 time period (expressed in 1963 dollars).

Fuel and oil costs represent about 25 to 30 percent of the direct operating costs for subsonic jets. The increased speed and weight of the supersonic aircraft are expected to affect this particular portion of direct operating costs disproportionately, increasing fuel and oil costs an additional 5 to 10 percent of direct operating costs.

3. Insurance Costs

Insurance in the DOC consists of coverage of the complete aircraft at its original purchase price plus a mileage factor to cover public liability and property damage. Because the latter is such a minor item, no equation was included to cover it.

The formula for determining insurance costs for subsonic and supersonic aircraft is represented by equation C_9. For subsonic aircraft an average of three percent of the purchase price per year has been the typical insurance rate over the life of the aircraft.

High insurance rates are typically encountered with the inauguration of a new type of aircraft, but as more flight hours are accrued and satisfactory performance is experienced the rate decreases. Only a few carriers self-insure a part of their fleet. Subsequently this factor has not been considered in developing these formulas.

The insurance cost formula for supersonic aircraft provides for sonic boom insurance, while the subsonic formula does not. This permits cost calculations for the risk of damaging structures on the ground due to the overpressures created by the aircraft traveling at supersonic speeds. This cost may vary with different segments and may or may not become a significant cost factor. Since little data is available on this subject, provision has been made for including these costs should other studies arrive at a quantitative cost estimate.

To verify the 3 percent insurance rate, the domestic carriers' reported insurance costs for 1963 were studied. Excluding carriers who reported self-insurance (AAL, BNF and UAL), the hourly costs reported for selected aircraft were $50.78 for the 707-300B, $56.66 for the DC-8-10 and $40.47 for the DC-8-50. Based on 3600 hours utilization, which is close to the average achieved on large jets, the annual insurance costs for the three aircraft would be $183,000, $204,000 and $146,000, respectively. If this equalled 3 percent of their purchase price, their original cost is estimated at $6.1, $6.8 and $4.9 million, respectively. Considering that this is the purchase price of the airframe plus engines, avionics and airline-installed equipment, the 3 percent estimated insurance rate seemed reasonable for subsonic jets.

No reason can be seen to justify a higher rate for the SST. The aircraft will be thoroughly tested prior to certification and crew standards will be rigid. Attrition experience with the subsonic jets will tend to give confidence in SST performance. Also, experience with supersonic military aircraft prior to commercial SST certification, should be sufficient to discover any basic dangers in this type of operation.

4. Maintenance Costs

Maintenance costs are typically separated into five categories: airframe labor, engine labor, airframe materials, engine materials and maintenance burden, with the latter being an allocation of those costs which cannot readily be associated with any particular aircraft or flight.

Formulas C_{11} through C_{15} are used to determine maintenance costs per flight segment. They have been developed from the 1960 Air Transportation Association methodology with appropriate revisions. At the time the 1960 ATA formulas were developed, the airlines had little experience with jet aircraft. The experience of more recent years is reflected in the revised formulas used in this study. Supersonic aircraft maintenance costs have been based on the same methodology as the subsonic aircraft. Changes in hourly cost result, however, from different performance characteristics, operating practices and materials costs.

The 1963 reported maintenance costs for subsonic jets agrees closely with the ATA formula for aircraft labor and engine materials. Aircraft materials and engine labor differ greatly, with reported costs being lower for the former and higher for the latter.

The formula overestimates aircraft materials costs, probably because it assumes that these costs are linear with airframe purchase price. This has not been true of the subsonic jets with costs being some 55 percent lower than computed with the ATA formula. Also, the costs compared to reciprocating aircraft were predicted to be at a ratio of .0079 to .00475 per hour without considering purchase price. The estimates have proven to be high, so the equations used in this study were based on 1963 airframe materials maintenance cost experience with subsonic jets.

In Section III-E, in the discussion of airframe technical considerations, the SST airframe is found to be conventional in its construction compared to present aircraft. Although the materials types differ greatly, the subsonic coefficient to be applied to purchase price is felt to be reasonable. The great difference in price makes the hourly costs much higher for the SST. No reason can be seen to justify a factor for airframe materials maintenance costs greater than that based on subsonic jet experience.

Subsonic turbine engine labor costs, as reported by the airlines, differ greatly from those computed with the ATA formula. In fact, they are about four times as high. The subsonic equations in this study are based on this 1963 experience. The engines proposed for the SST are more powerful versions of present engines. In Section III-F, a rationale was presented which leads to the conclusion that current industry experience on engine maintenance labor will be applicable to the SST engines. Based on this, the same equations (with different values for engine characteristics, such as thrust and cost) are used for the subsonic and SST engine maintenance costs.

To compute SST engine costs, the time between overhaul (TBO) has been estimated at 2100 hours. The engine is assumed to achieve a TBO of only 600 hours at time of certification with a gradual increase to 3000 hours during the ninth year. Assuming a 15-year life, this leads to an average TBO during engine life of 2100 hours. Therefore, this figure is used to compute maintenance costs of the average engine on an SST.

The last factor in maintenance costs is maintenance burden. The factor of 1.7 times the maintenance labor dollars has been used to estimate the maintenance burden. This figure is used in place of the current ATA methodology which applies one rate to maintenance labor and another rate to maintenance materials, and then sums the two. The method used in this report, however, has been checked against 1963 experience and, in addition, the first quarter 1964 operating cost experience of the domestic trunk airlines operating DC-8 and 707 jet aircraft. The results ranged from a ratio of 1.1 to 2.1 with many aircraft types having a ratio of 1.7 exactly. The average of these figures further substantiates the validity of the 1.7 ratio.

The table below compares maintenance costs using methodology developed for the supersonic transports and current subsonic jets to the actual 1963 operating costs for large four-engine jets as reported to the CAB.

Maintenance Costs (dollars per block hour

	Estimated Supersonic Costs		Subsonic Aircraft Costs	
	733-290	2000-2P	Estimated	1963 Actual
Domestic (1455 miles)	$626	$831	$216	$215
International (1980 miles)	$626	$831	$216	$222

5. Flight Equipment Depreciation Costs

These costs are allocated in proportion to the flight hours over the anticipated useful life of the aircraft. The cost for depreciation is computed on the basis of the depreciation period in years, the anticipated annual utilization in hours, the initial price of the item involved, the cost of its spare parts, and the estimated residual value of the item at the end of the depreciation period.

The depreciation cost formulas (C_{17} through C_{19}) have been based upon the assumption of straight line depreciation techniques. Recommended values for subsonic and supersonic jets differ due to the operating characteristics of the two aircraft types. The 3600-hour annual utilization recommended for subsonic jets is based upon a ten-hour daily operating schedule which the airlines are currently reporting. This high degree of utilization is not anticipated for the supersonic aircraft, hence the estimated annual hours of utilization has been lowered to 3000 in those equations. The primary reason is the greater number of segments which can be flown due to higher speed. This leads to more ground time each day in proportion to flight time and is reflected in lower utilization.

B. Indirect Operating Costs

Although the airline industry has adopted a methodology for estimating direct operating costs (DOC) of aircraft, no such guideline is available for indirect operating costs (IOC). The most common procedure is to relate total IOC to DOC, total revenue, or some other broad parameter. Because indirect costs have held fairly stable as a portion of total costs over recent years, such a procedure has some merit. However, this methodology is sufficient only for estimating IOC for an airline or the airline industry in total, and will not necessarily be applicable to operation of different aircraft types.

Aircraft are purchased and operated for specific route structures. Large subsonic jet aircraft are best suited for long-haul, high density route segments. Short flights with few passengers make them highly unprofitable. At the same time, small piston or turbine-powered aircraft are not efficient except on shorter segments. DOC of these types of equipment are readily attainable through periodic financial reports to the Civil Aeronautics Board. However, the very nature of the different operations makes their respective IOC quite different. This is recognized somewhat in the tapering nature of the fare structure. For instance, the regular jet coach fare between New York and Pittsburgh is $23.35 or 6.9¢ per passenger-mile compared to $145.10 or 5.9¢ per passenger-mile between New York and Los Angeles.

On the basis of actual dollars, some IOC are about the same, regardless of the length of flight or type of aircraft. Examples are reservations, ticketing, and traffic servicing. Others, such as food costs and flight attendants' pay are higher for longer flights. Some other costs simply cannot be related to specific flights and must be arbitrarily distributed to the traffic handled. The latter group would include sales, advertising, and general and administrative expenses. A further cost sensitive to type of aircraft would be aircraft servicing, which tends to increase with aircraft size.

Even these breakdowns are not really satisfactory for identifying costs of a particular flight between two stations. Infrequent schedules lead to low utilization of personnel, and hence higher costs per passenger or per flight.

This leads to the conclusion that "average" costing is the only alternative available to estimate the operating economics of any aircraft. In this section data are presented on the cost experience of the major United States air carriers in many of the operating cost functions. The methodology for estimating operating costs used by the two airframe manufacturers in the SST competition will be analyzed in detail. In cases where adjustment made, they are shown and in cases where the manufacturers' methodology was used, the reasons are given.

1. Airframe Manufacturers' Indirect Operating Cost Methodology

Boeing and Lockheed developed a methodology for estimating indirect operating costs, using 1963 experience of domestic and international air carriers. The methodology was based on industry averages. To determine the extent to which the methodology varied in its application to individual carriers, it was applied to the 1963 operating parameters of each of the major airlines. The results are shown in Exhibits IV-1 and IV-2 for domestic and international carriers, respectively.

For the domestic carriers, the ratio of computed costs to reported costs ranged from a low of 81.8 percent for TWA to a high of 130.4 percent for Eastern. In general, the methodology underestimated costs of the three largest airlines which also have the most long-haul routes. The costs of the other seven carriers were overestimated with these equations. the average on-line passenger trip length and average flight stage length appears to be closely related to the degree to which the methodology overestimates or underestimates the reported costs for 1963:

Airline	Percent Computed to Reported IOC	Passenger Trip Length (miles)	Flight Stage Length (miles)
TWA	81.8	942	589
AAL	84.9	845	508
UAL	92.3	702	375
CAL	105.1	670	299
NAL	107.5	796	353
DAL	113.2	636	302
BNF	118.7	488	256
WAL	122.9	539	312
NWA	125.9	654	351
EAL	130.4	488	263

A detailed study of the individual cost items showed that the major area of understatement of the three largest carriers' IOC and overstatement of the seven other carriers' IOC was in costs allocated on the basis of aircraft departures weighted by maximum design landing weight. The specific costs were aircraft servicing and servicing administration. The methodology is probably most affected by the shorter stage lengths of the smaller carriers, and hence more departures in relation to traffic volume than the three largest airlines. However, because the formulas to be utilized in this study are aimed at measuring the costs of long route segments (over 900

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[redacted]

EXHIBIT IV-1. COMPARISON OF REPORTED 1963 INDIRECT OPERATING COSTS WITH COMPUTED COSTS USING MANUFACTURERS' METHODOLOGY

(Domestic)

Airline	Reported Costs (000)	Computed Costs (000)	Percent Computed to Reported Costs
AAL	$196,396	$166,747	84.9
BNF	36,311	43,084	118.7
CAL	30,127	31,655	105.1
DAL	75,213	85,112	113.2
EAL	127,538	166,257	130.4
NAL	40,617	43,672	107.5
NWA	37,616	47,342	125.9
TWA	145,561	119,123	81.8
UAL	254,286	234,616	92.3
WAL	33,242	40,869	122.9

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[redacted]

[redacted]

EXHIBIT IV-2. COMPARISON OF REPORTED 1963 INDIRECT OPERATING COSTS WITH COMPUTED COSTS USING MANUFACTURERS' METHODOLOGY

(International)

Airline	Computed Costs (000)	Reported Costs (000)	Percent Computed to Reported Costs
NWA	$ 19,861	$ 20,220	98.0
PAA - System	247,016	238,776	103.5
Alaska	3,673	3,167	116.0
Atlantic	114,345	109,661	104.3
Latin-America	72,982	62,470	116.8
Pacific	55,997	63,477	88.2
TWA	45,909	53,722	85.5

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[redacted]

miles), the manufacturers' proposed methodology appears to reflect costs as they would be incurred over long stage lengths with few departures in relation to passenger-mile or seat-mile measures of output. This type of operation is entirely different from that of any of the domestic carriers today.

A further item where the actual costs of two of the three large carriers was underestimated by the methodology was in baggage and cargo handling. The reason here is quite obvious--they are the airlines operating substantial fleets of all-cargo aircraft. The costs of loading these are included in their overall reported costs and would make the latter relatively higher in this category than the other airlines. Only two of the remaining eight airlines had reported costs for baggage and cargo handling significantly lower than the computed costs. One of these, EAL, operates many short segments, including "air shuttle" service on the Eastern Seaboard, where little baggage or cargo is handled. The other (NWA) reported costs of only $95,000 in this category in 1963, which is over $4 million less than computed costs. However, the reported costs almost certainly are computed differently from the rest of the industry in that no other carrier reported less than $2.5 million in this category.

A final area of difference between computed and reported costs was in those expenses allocated on the basis of number of revenue passengers. The major cost item involved was for reservations and sales. As with costs discussed earlier, the large carriers' computed costs were less than reported while some of the small carriers' computed costs overestimated the reported costs. The greatest difference in the latter group appeared for EAL which operates a large number of "non-reservation" flights and therefore had actual costs lower than would be expected for a typical airline. The three largest carriers reported costs in this category greater than those derived from the manufacturers' methodology. This is probably due to their transcontinental routes which are much more competitive than the short segments. Passengers tend to select an airline for short trips based on schedules, and little airline preference as such exists. On long routes, sales efforts and efficient reservations service become much more important to the passengers and the airlines expend substantial effort to attract them. In addition, some sales personnel deal only in the cargo field and they are grouped with sales costs in general. This leads to higher costs than the industry average. As will be discussed later, there is some merit to weighting this parameter (number of passengers) with a revenue or distance factor. However, the final methodology in this study was developed for use in estimating IOC for large subsonic and supersonic transports on segments over 900 miles. Therefore, the distance and revenue factors will automatically be given consideration by allocating these costs on the basis of number of passengers.

With minor exceptions, all of the rest of the formulas in the manufacturers' methodology quite accurately reflect the domestic carriers' reported costs for 1963. In the next section, a detailed discussion of each of the major cost areas will be presented, wherein the rationale for accepting or modifying the manufacturers' methodology for domestic carriers will be set forth.

The international carrier methodology was analyzed and compared to 1963 reported costs for the three United States airlines with a substantial volume of international traffic. The results were shown in Exhibit IV-2. The data are dominated by PAA, which accounted for over 75 percent of the total indirect costs of the three carriers combined.

Major areas of difference between computed and reported costs were less prevalent than for the domestic operators. For NWA, baggage and cargo handling costs were significantly different but as in that airline's domestic costs, the reported figure differs greatly from other airlines' reported costs. NWA reported costs of only $32,000 to handle 25,000 tons ($1.28 per ton) compared to between $60 and $70 per ton for PAA and TWA.

For all three carriers, the primary difference between reported and computed costs appeared in the reservations and sales account. PAA computed costs were about $8 million more than reported, while TWA and NWA reported costs of $6 and $1.5 million lower than computed costs, respectively.

As with the domestic operators, a relationship appears to exist between both the average passenger trip length and the flight stage length and the ratio of total computed IOC to reported IOC:

Airline	Percent Computed to Reported IOC	Passenger Trip Length (miles)	Flight Stage Length (miles)
TWA	85.5	3,072	1,455
PAA-Pacific	88.2	3,591	2,051
NWA	98.0	2,723	1,701
(PAA-System Total)	(103.5)	(1,654)	(1,008)
PAA-Atlantic	104.3	1,328	913
PAA-Alaska	116.0	1,038	751
PAA-Latin America	116.8	1,444	782

As with the domestic equations, the international equations developed in this study were to be utilized to estimate IOC for long segments (averaging 1,980 miles). Logically, the IOC will decrease as stage length increases. Hence, the equations appeared to be reasonable as a tool for forecasting IOC with large, fast aircraft over long segments.

From this preliminary analysis, the indirect cost functions were studied to determine if any of the equations used for their estimation appeared not to consider differences in costs that would be encountered in the long-haul operations of large aircraft.

2. Analysis of Individual Indirect Operating Costs

a. Direct Maintenance (plus Burden) of Ground Property and Equipment

Costs for direct maintenance of ground property and equipment, plus the associated maintenance burden, are part of Accounts 5200 and 5300 of the Civil Aeronautics Board (CAB) Form 41 reports. The equations for calculating these costs are labeled C_{22}, C_{23}, C_{25}, and C_{26}.

In 1963, these items totalled only about $29 million for domestic trunk carriers and $4 million for U.S. international airlines. The manufacturers' methodology allocated these costs on the basis of aircraft departures (weighted by maximum design landing weight) and direct maintenance labor dollars. These costs were an insignificant portion of indirect costs so this method of allocation was accepted. Because of the small number of SST aircraft that will be in any particular airline's fleet, no increase in the magnitude of these costs is anticipated.

b. Passenger Service

The detailed expenses in this account are related to some factor or factors associated with passengers. In the equations, constants are shown based on the number of flight attendants other than crew members, the number of passengers handled and the number of passenger-miles generated. For a particular flight segment, the total costs incurred for passenger service have been computed on these bases.

Formulas C_{28}, C_{29}, and C_{30} indicate the method of computing the passenger service costs per flight segment. These costs are reported to the CAB in Account 5500 and represent about one-fifth of the total indirect operating costs. This account includes food and beverage costs, flight attendant costs, and other costs associated with the comfort of passengers.

The manufacturers' methodology allocated these expenses on the basis of block hours (cabin attendants), passenger block hours (food and beverages) and revenue passenger-miles (other passenger service costs).

Analysis of the operating procedures and costs of the major U.S. carriers revealed that the manufacturers' allocation of cabin attendants' costs and food and beverage costs will be unrealistic for a long-haul operation. For example, 51 cents per passenger block hour for domestic food and beverage costs would estimate only about 75 cents per passenger for a 1500-mile trip in an SST. Quite obviously, this is too low.

Similarly, the number of cabin attendants is low compared to actual practice. Most domestic jet flights have approximately 34 first class seats and a minimum of 2 flight attendants are used. Also, because of the trend toward in-flight entertainment and more lavish in-flight services, five cabin attendants are often used. (CAL already has a male cabin attendant to handle ticketing and passenger information.) At least one major transcontinental carrier adds a fifth attendant when the load factors reach a certain level. For these reasons, the first class cabin attendant ratio was increased to one for each 16 first class seats, a 25-percent increase. The international ratios of cabin attendants to seats was in line with airline practices so no changes were necessary.

Food and beverage costs are related more to the number of passengers than to passenger block hours. On flights of the length considered in this study (over 900 miles), a single meal plus beverages will be served. There is a great difference in the cost of these meals, depending on the time of day. For instance, typical first-class meal costs for segments over 1,000 miles are about $2.30 for breakfast, $5.90 for lunch, and $6.10 for dinner. Comparable coach meal costs are $1.00, $1.90, and $2.00, respectively. In addition, beverage costs are about $1.50 for all passengers with lunch and dinner. Based on these figures, meal costs were estimated at $6.50 for first class and $3.00 for coach passengers. The coach figure agrees with the manufacturers' methodology while the first class cost estimates are $1.00 higher.

In international service, the manufacturers estimated $19.25 for first class passengers' food and beverage and $5.50 for coach passengers. This appears higher than actual experience. For first class passengers, one large U.S. carrier pays $2.15 for breakfasts, $6.28 for lunches, and $9.74 for dinners. Beverages cost an additional $2.27 per passenger. For economy passengers, the costs are $1.08, $2.25, and $2.78 for the three meals, respectively. Because of the trip length, snacks are usually served also. However, the $19.25 meal cost used in the manufacturers' methodology appears high for first class passengers, as does the $5.50 for economy passengers. In this study, $14.00 and $4.00 appeared more realistic and were used.

While the allocation on the basis of block hours might be reasonable for all passengers regardless of length of haul, the costs for food and beverages for long-haul passengers is more equitable on a per-passenger basis in that a single meal will be served to each passenger on a trip. This is the method of allocation used in this study.

Other passenger service costs were assigned on the basis of revenue passenger-miles. Because this is a combination of all other services rendered, this allocation seemed reasonably related to distance. No "single occurrence" regular services could be identified as in the case of food and beverages. Therefore, the manufacturer's allocation was accepted for this expense.

An alternate set of equations has been constructed (equations A_{28}, A_{29}, and A_{30}) to provide the route simulation model with a set of formulas for total passengers, should the model not have the capability of distinguishing the class of service of passengers carried on any given segment. The basic equations provide for different costs for the different classes of service.

c. Aircraft Servicing Costs

Equations C_{32} through C_{35} present a method of estimating the aircraft servicing costs per segment. These costs are reported by the airlines in Account 6100 and consist primarily of aircraft handling and control costs, as well as landing fees. These costs, with the exception of control costs, are estimated on the basis of the maximum design landing weight of the aircraft. Control costs were assumed to be constant per segment.

These expenses were similarly allocated by the manufacturers on the basis of aircraft departures and aircraft departures weighted by maximum design landing weight. As discussed earlier, the costs of the largest three domestic trunks tended to be understated with this methodology while the other airlines' 1963 costs were overestimated.

Despite these inconsistencies in the results of comparison of actual to reported costs, the methodology stood the test of logic. Aircraft control costs appear to be relatively constant for any size of aircraft on the basis of departures. Landing fees are fairly measured by weighted departures. Even aircraft handling costs should be related to aircraft size as is done by the manufacturers. Other aircraft servicing costs also used weighted departures as the allocation parameter.

To see the effect of this allocation on airline fleet composition, the formula was applied to three groups of aircraft--four-engine jets, turbo-props and four-engine piston aircraft. The total allocation of Account 6100, and the allocation of Account 6300 (Servicing Administration) on the same parameters, resulted in costs per aircraft mile of 24.6 cents for the jets, 41.8 cents for turbo-props, and 45.2 cents for piston aircraft. Account 6300 allocation was only about 10 percent of the total so this was not sufficient to negate the comparison.

This cost comparison appeared to favor the jets. However, the comparative average stage length during the fourth quarter of 1963 for the aircraft types (as reported by the FAA) was 778 miles for jets, 237 miles for turbo-props, and 225 miles for piston aircraft. This great differential indicated that the allocation by the manufacturers was more in line with the actual cost incurrence than the cost-per-mile figures showed.

No more equitable parameter could be found to allocate these costs. They had to be related to departures (or times handled through terminals) and to aircraft size. Maximum design landing weight was the most consistent measure of size available. Other parameters exist which undoubtedly affect the level of these costs, but they could not be measured. For instance, the total number of daily departures at a terminal affects the utilization of personnel, equipment and facilities and hence the average cost per departure. Costs for fueling vary with the amount of fuel put on board and this will affect costs per departure. Whether the allocation of weighted departures is sufficient to allow for this is problematical. No way of measuring these factors was found.

After this analysis, the manufacturers' domestic allocations were accepted. Because the formulas developed in this study are to be used to estimate costs of long-haul operators, the overstatement of the small carriers' costs was judged to be of minor consequence. Even the underestimation of large carriers' costs is true only for their present operations. For their long segments with large aircraft, the unit costs are expected to be lower than at present in the aircraft servicing area, due to fewer handlings at terminals in relation to aircraft miles. No aircraft in 1963 had an average domestic stage length as high as the 1,455 miles forecast by the FAA. In fact, only one (B-707-100B) had an average stage length over 1,000 miles.

The manufacturers' formula for allocating aircraft servicing costs for international operations agreed quite closely with the carriers' reported 1963 costs. Also, the stage lengths for the four-engine jets in this service were close to the 1,980 miles forecast by the FAA for the SST. For instance, the DC-8-20/30, B-707-300B and B-707-200/300 account for over 80 percent of the number of four-engine jets in international service, and they had average stage lengths of 1437, 1620 and 1659 miles, respectively, in the fourth quarter of 1963. Therefore no changes were made in these allocations by the manufacturers.

d. Traffic Servicing

These costs are determined by the formulas C_{37} and C_{38} (or alternate formulas A_{37} and A_{38}), and appear as Account 6200 in the CAB Uniform Systems of Accounts.

The manufacturers' methodology allocated these expenses on the basis of revenue passengers carried and total cargo tons carried, with the latter, including baggage, mail, express and freight.

Domestic carriers had passenger traffic servicing costs of $1.22 per passenger and only four carriers deviated greatly from this average. These were EAL, whose costs were lower, and TWA, NAL and DAL, whose costs were higher. EAL's difference is undoubtedly due to their large number of "air shuttle" flights on the East Coast. NAL and DAL recently had their route structures extended to the West Coast, although few flights are operated. This may have led to high unit costs for these two carriers on these routes. TWA's service costs of $2.05 per passenger are not readily explainable although they may be due to high costs in terminals handling both domestic and international passengers. However, because the costs were less than 10 percent of TWA's total IOC, the methodology was accepted as satisfactory for most airlines.

For international carriers, the average passenger service cost was $3.06 per passenger with TWA ($5.10), NWA ($6.00) being higher, and PAA System slightly lower ($2.61). Again, no more equitable distribution could be found. All three are long-haul carriers whose costs theoretically should be comparable. PAA's higher volume may have led to better personnel and facilities utilization than the other two. However, the costs should be incurred without regard to the length of haul and on the basis of numbers of passengers. The manufacturers' allocation, on the basis of these factors, was also accepted for the international equations on passenger service costs.

The baggage and cargo handling costs were allocated on the basis of cargo tons for both domestic and international operations. This seems proper, in that comparable service is required for shipments over both short and long route segments. No particular pattern appeared as to the reasonableness of these allocations in application to the costs of individual airlines. An exception is NWA, whose reported domestic and international costs per ton are only a small fraction of those of the other carriers. Their method of reporting was deemed inconsistent with that of the other airlines and the difference ignored.

EAL's reported costs were lower than computed costs, but this was probably due to their short passenger trip lengths and to the "air shuttle" service where little cargo is handled. AAL and TWA domestic costs are underestimated, but their extensive all-cargo operations probably cause this. With these exceptions, the cargo handling costs are estimated with reasonable accuracy by the manufacturers' methodology and so their equations were utilized in this study.

e. Servicing Administration

Equations C_{40} through C_{44} (or A_{40} through A_{44}) represent the method of estimating the costs of servicing administration per flight segment. They reflect the costs of administrative and supervisory functions related to aircraft and traffic servicing and thus are based on the same parameters as the latter cost functions.

The manufacturers suggest they be allocated to Accounts 6100 and 6200 in relation to the portion that each is to the total of 6100 and 6200. For example, if Account 6100 is 40 percent of the total of 6100 and 6200, 40 percent of 6300 is allocated to 6100, and 60 percent to 6200. This, logically, is an equitable method of distribution.

The validity of this method of assigning servicing administration costs is dependent upon the accuracy of the earlier allocation of aircraft and traffic servicing costs. There is, however, one additional consideration. Of approximately $42 million in this account for the ten major domestic trunk carriers in 1963, about $23 million was reported by UAL. The manufacturers' methodology, in effect, averages these costs out over all the airlines' traffic which would appear to overstate the other carriers' allocation of Account 6300.

While this is true, the net effect on total IOC is probably negligible. In the first place, Account 6300 is only about 4 percent of total IOC and a sizeable error in allocation will have a minimal effect. Also, if UAL had been able to separate more of their 6300 expenses into Accounts 6100 and 6200, this would have been reflected in changes in the coefficient values in allocation of the latter expenses. The net effect likely would not differ greatly from that of the methodology used, at least insofar as total IOC are concerned.

The same reasoning applies to the international carriers. Less than 3 percent of IOC was accounted for by servicing administration costs. Of the three carriers involved, most of the Account 6300 dollars were reported by PAA. However, the effect on total IOC is not great enough to warrant an attempt to obtain a more accurate allocation parameter, assuming one existed.

f. Reservations and Sales

CAB Account 6500 contains the reservations and sales costs of the airlines, and are represented by equations C_{46}, C_{47} and C_{48} (or A_{46}, A_{47} and A_{48}). This major account is composed of passenger commissions, freight commissions, and other reservations and sales expense. The first two are allocated by the manufacturers on the basis of revenue passenger-miles and freight ton-miles, respectively. Because these commissions generally are a flat percentage of revenues, such an allocation is equitable. There may be a slight understatement at short ranges, due to higher fares or rates, than for longer distances. However, most tickets or shipments handled by agents or brokers are for longer distances, and the equations were developed for estimating costs for aircraft flights for long stage lengths. This, coupled with the fact that the allocations estimate quite accurately the passenger and freight commissions of the domestic and international airlines, rendered the manufacturers' methodology satisfactory for this study.

The reservations and sales costs, excepting commissions, are allocated by the manufacturers on the parameter of revenue passengers. This would appear to be the basis on which the costs are incurred. Making a passenger reservation for a flight would generate comparable costs for both short and long trips. Similarly, sales expenses accrue on an overall basis. No sales representative knows in advance the types of trips that may result from a call on a company travel office or individual traveler.

However, the fact remains that the 1963 cost per passenger for reservations and sales costs, excepting commissions, ranges among domestic carriers from $3.69 for TWA to $1.84 for CAL, compared to $2.62 for the total group. Internationally, the range was from $16.33 for TWA to $7.10 for PAA, with the three carriers considered averaging $8.21.

The data show that the amount spent on reservations and sales varies greatly in proportion to business volume among airlines. Managerial policy is an important determinant of the level of these costs. Some airlines may substitute advertising for a portion of direct sales effort. Some airlines establish minimum requirements for reservations answering time, i.e., 90 percent of telephone calls answered within ten seconds. Yet others establish their sales and advertising budget at a fixed percentage of gross revenues. All of these factors indicate that any parameter selected would only be accurate for the airlines as a group and not necessarily for any individual carrier.

[redacted]

To determine if revenue passenger-miles might be a better basis for allocation of reservations and sales costs, such a method was applied to the 1963 costs of the domestic trunk carriers. While it yielded slightly better results, as gauged by a closer relationship between estimated and computed costs for several of the airlines, the effect on overall IOC was not sufficient to warrant substitution of passenger-miles for passengers as the allocation parameter. Computed costs increased for four airlines (AAL, TWA, CAL and NAL) and decreased for the other six carriers. None of the changes was very significant (EAL's being the largest). The percentage of computed to reported costs dropped from 130.4 to 123.9 for that airline.

In view of the small improvement realized by changing the parameter and of the influence of managerial policy on the reservations and sales costs, revenue passengers was accepted as the basis for allocation of these costs.

g. Account 6600 - Advertising and Publicity

These costs are determined by using equations C_{50} and C_{51} (or A_{50} and A_{51}). They are allocated on the basis of passenger-miles and freight ton-miles by the manufacturers.

This is another expense which is largely determined by managerial policy. Typically, a percentage of revenues is budgeted for advertising and publicity. For this reason, passenger-miles and freight ton-miles appear to be the proper basis for allocation. Traffic generated as a result of advertising cannot be identified, so the expenditures cannot be allocated to route segments, flights, or aircraft. The level of advertising expenditures will vary from airline to airline, so the only feasible method of estimation is on the basis of industry average. This is the basis of the equations in this study.

h. Account 6800 - General and Administrative Expenses

These expenses are the "overhead" costs. They include items such as accounting, purchasing, legal fees, etc., which are not assignable to a particular function but are a part of an airline's indirect operating costs. They are reported in Account 6800 and are estimated for a given segment by using equation C_{52}.

In general practice, these costs are allocated on the basis of all other cash expenses; that is, excluding Account 6800 and depreciation/amortization. This was done in the manufacturers' methodology as well as in this study.

[redacted]

The expenses in Account 6800 are for the benefit of the airline as a whole and the logical method for estimation would be on the basis of the other costs involved in the operation. For 1963, this methodology estimates costs of the individual airlines quite accurately. Because of this and the fact that the airlines themselves traditionally use this method, the cash expenses were used to estimate general and administrative expenses.

i. Account 7000 - Depreciation and Amortization of Non-Flight Equipment

Equations C_{54} and C_{55} (and C_{71} in the case of supersonic aircraft) represent the depreciation and amortization charges of non-flight equipment. They represent the balance of Account 7000 which was not included in equations C_{17}, C_{18} and C_{19}. The equation C_{71} for pre-operating expenses does not appear in the subsonic methodology because the bulk of the pre-operating expenses associated with most subsonic equipment has already been amortized. Although most airlines have amortized their pre-operating expenses over a three-year period in the past, the amortization period has been extended to fifteen years in the supersonic equations to facilitate its use in the route simulation model. Also, such expenses are expected to be incurred beyond the initial introductory period of the supersonic transport.

The remaining expenses in this group are for depreciation of ground property and equipment. About two-thirds of the total is reported as "system" costs in that it is not identifiable with a particular station or route. The remainder is "local" as it is used for the benefit of a specific station. The former is allocated on the basis of direct labor maintenance dollars, assuming that this parameter is a measure of the amount of investment in ground property and equipment. The latter is estimated on the basis of departures weighted by maximum design landing weight. This allocation assumes that these expenses are incurred for servicing aircraft at transit points and can be identified with specific flights or segments on this basis (weighted departures).

These expenses are less than 5 percent of total IOC. In general, they tend to be higher in proportion to traffic volume for the smaller carriers than for larger carriers. This is probably due to minimum equipment requirements at a station which larger carriers are able to use for more flights than the smaller carriers.

The methodology derived computed costs very close to reported costs for the international carriers and the large domestic carriers. Because of this and the relatively small size of these expenses, the parameters recommended by the manufacturers were also used in this study.

C. Parametric Equation for Estimating Indirect Operating Costs

In this study, a method of estimating indirect operating costs that did not require several variables for each account or portion of account was sought. Specifically, a single formula, requiring no more than two or three variables, was desired that would accurately estimate the indirect operating cost of an aircraft type.

Airlines do not maintain indirect operating cost records by aircraft type, and thus it was not possible to obtain statistical data. Annual data are maintained for each airline, however, and these were used for analysis. Indirect costs of the 11 domestic trunk airlines were analyzed for each year from 1953 to 1963. In cases where traffic data were not available prior to 1957, particularly revenue passenger enplanements, separate analysis was made starting with 1957. Linear regressions were fitted to various combinations of variables (such as revenue passenger-miles, on-line passenger trip length, revenue passenger originations and revenue passenger enplanements) to determine which combination would best estimate the indirect operating costs of the eleven airlines for each year. A second objective was to determine the particular combination of variables which would not only describe a single year but could be used for estimating purposes.

Although several combinations yielded good estimating equations for the year from which they were derived, an analysis of the same combination for other years yielded equations having different coefficients for the same variables. An analysis of the changing coefficient values yielded what appeared to be a possible clue.

The regression using merely revenue passenger-miles appeared to show a slightly increasing trend in the value of the coefficient for the variable and a decreasing trend in the value of the coefficient of the constant. This seemed to indicate that something was underlying the revenue passenger-mile data that would yield the answer. Further analysis showed that during the period 1953 to 1963 a sharp upswing in coach or economy as opposed to first class travel was evident and might explain the problem. A regression was fitted to first class revenue passenger-miles as one variable and coach or economy revenue passenger-miles as a second variable.

The resulting equations reduced the trend effect but still produced equations with different coefficient values for the same variable for different years. Statistical measures resulting from the regression equations are shown in Exhibit IV-3. The coefficients of correlation were quite high (all above 0.99) and the standard errors of estimate were relatively small (within 3 to 9 million dollars). The 1961 formula was selected as a test because of its high correlation and low standard error of estimate. When compared to the actual values in 1961, the estimates never differed more than 10 percent and were often less than 5 percent, with the exception of Northest Airlines. The reported and estimated costs for each of the airlines in 1961 and 1963, using the 1961 regression, are shown in Exhibit IV-4.

In applying this formula to the SST, a problem must be overcome in reconciling the constant which has a negative value and is properly applicable to an airline rather than a single flight or aircraft. If the constant is disregarded, the SST is assumed to be an incremental flight.

In comparing the SST cost estimate, using the 1961 derived formula to the more complex method developed in this study, some adjustment was necessary. The method of reporting airline historical cost data by the CAB in "The Handbook of Airline Statistics" does not separate maintenance burden into the aircraft portion and the ground property and equipment portion. Thus in developing the parametric regression equations, Indirect Operating Costs included all of the maintenance burden costs. To make them comparable to the costs derived from application of formulas in this study, $250.98 was added to the $2432.83 estimated costs of the Boeing 733-290, the derivation of which is shown later in Section V. This yielded an IOC estimate for the 1455-mile domestic segment of $2,683.81 with the methodology in Section II, corrected to the parametric regression formula approach. In applying the 733-290 data for revenue passenger-miles, both first class and coach, the equation yields a segment cost (disregarding the constant) of $ 5,584.90 or slightly more than twice the cost estimated in Section V.

The explanation of the difference is that the regression equations were derived from data with parameters outside the SST range. Average passenger trip length was 645 miles as contrasted with the 1455-mile segment used for the SST, coach revenue passenger-miles were about 60 percent of total rather than the 80 percent used for the SST and the average available seats per aircraft was 80 to 90 rather than the 209 used for the SST. These "inputs," being far lower than the equation parameters, explain the tendency to overestimate with the single variable approach. It does point out, however, the danger of estimating via regression from data that are exclusively on one side of all parameters used.

[redacted]

EXHIBIT IV-3. STATISTICAL MEASURES RELATING TO REGRESSION LINE FITTED TO FIRST CLASS AND COACH OR ECONOMY REVENUE PASSENGER-MILES FOR ESTIMATING INDIRECT OPERATING COSTS FOR DOMESTIC TRUNK AIRLINES

Year	Coefficient of Correlation	Standard Error of Estimate ($000)	Mean ($000)
1953	0.9939	3,643	32,107
1954	0.9928	4,460	35,683
1955	0.9911	5,860	41,653
1956	0.9913	6,811	48,611
1957	0.9913	7,378	55,019
1958	0.9960	5,197	58,596
1959	0.9925	8,319	71,104
1960	0.9971	5,975	81,687
1961	0.9985	4,956	90,603
1962	0.9982	6,220	100,618
1963	0.9981	6,590	107,983

[redacted]

EXHIBIT IV-4 - ADJUSTED INDIRECT OPERATING COSTS DERIVED FROM 1961 FIRST CLASS AND COACH REVENUE PASSENGER-MILE DATA

	1961		1963	
	Reported	Estimated	Reported	Estimated
American	219,067	214,198	242,070	246,006
Eastern	129,516	139,650	148.428	159,537
TWA	145,720	144,538	178,609	178,099
United	247,355	245,510	302,380	297,220
Braniff	36,496	35,290	41,151	38,995
Continental	27,728	27,418	34,016	35,058
Delta	72,326	78,188	90,424	102,680
National	33,398	32,689	46,676	51,451
Northeast	27,123	21,768	25,103	17,189
Northwest	32,335	31,864	43,284	50,871
Western	25,569	25,519	35,673	41,661

This analysis verified the validity of estimating IOC with equations for the individual cost factors rather than a single equation for IOC in total. The parametric approach appears workable for estimating total airline IOC but not for estimating IOC for long-haul segments of large aircraft only.

[redacted]

V. APPLICATION OF EQUATIONS

A. Airframe Manufacturing

In this subsection, the manufacturing equations developed in previous sections are applied to the proposed airframe and engine designs. This is accomplished by using the formulas in Section II, subsections C, D, and E.

The formulas in Section II-C were designed to yield airframe cost functions on a cumulative average unit cost basis, and include both development and production costs. The formulas for both direct labor and materials costs require the determination of an individual unit cost curve prior to developing the cumulative average unit cost. The formulas for engineering and tooling, however, provide the cumulative average unit cost directly.

1. Direct Labor (including overhead)

To estimate the direct labor cost for an airframe, the man-hours per pound of airframe required to build the tenth, thirtieth, one hundredth, and three hundredth airframe were calculated. The Boeing Model 733-290 will be used for illustrative purposes. Using the suggested values in Section II-C, Hu_{10}, Hu_{30}, Hu_{100} and Hu_{300} are determined by multiplying the values h_{1N} by 2.7, h_{2N} by 66.79, h_{3N} by 0.59106, and h_{4N} by 0.30523. The sum of the four products plus h_{0N} results in the following man-hours per pound of airframe for unit N:

N	Hu_n
10	16.38
30	9.65
100	5.44
300	3.25

A fitted regression shows that "b" - 0.47560 and "a" = 49. To compute the man-hours per pound for the 10th unit, the conversion value table at the end of Section II is utilized. For the cumulative average man-hours per pound at unit 10 for the Boeing aircraft, the line showing 72% of slope is selected (-0.4739 being closest to the "b" value of -0.47560 obtained from the regression equation). The conversion value thus would be 0.519. This factor is applied to the man hours required at unit one (49). Thus the cumulative average man-hours per pound required to produce the first ten aircraft would be 25.43 hours. To obtain the cumulative average man-hours to produce each of the ten airframes, this is multiplied by the airframe weight of 163,420 pounds. The result is 4,155,771 man-hours. To

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[redacted]

obtain the cost in dollars, the man-hours are multiplied by the labor rate (including overhead) estimated for Boeing or \$7.51 per man-hour. The product, \$31,209,840, is the estimated cumulative average cost including development of direct labor and overhead for producing each of the first ten Boeing 733-290 airframes.

2. Materials Cost

The same method is employed for calculating the materials cost as was described for direct labor. The results of the materials equation is expressed in dollars, so the last step of the above illustration is avoided. The "b" value obtained for materials for the Boeing 733-290 was -0.5188 and the "a" value was 341.

3. Engineering Cost

To estimate the engineering cost for an airframe at any unit, the cumulative average unit cost per pound of airframe for the tenth, thirtieth, one hundredth and three hundredth airframe is determined. Using the formulas shown in Section II-C, the costs for the Boeing 733-290 of Ec_{10}, Ec_{30}, Ec_{100} and Ec_{300} are calculated by multiplying e_{1N} by 2.7, e_{2N} by 0.59106, e_{3N} by 0.08457, and e_{4N} by 0.00641. The sum of the four products plus e_{0N} results in the following Ec_N values:

N	Ec_N
10	242
30	74
100	38
300	22

If values of N other than the above are desired, a least squares regression line is determined. With the regression equation for this line, the value at any "N" can be estimated. Having the estimated value for the selected unit, it is only necessary to multiply by the airframe weight to arrive at the cumulative average cost for each airframe.

4. Tooling Costs

The same method is employed in calculating tooling costs as was described for engineering. The results are in terms of cumulative average cost per airframe at the selected unit.

B. Airframe Development Equations

To estimate the cost of development, the equations in Section II-D are used. The same equations shown in Section II-C are used, but only the first "d" units are priced of the total production cost. In this study, the production costs of the first two airframes have been used to estimate the development cost of the airframe. The first two units were priced to obtain the development cost estimate for each of the four cost elements. The sum of the four elements results in the cumulative average cost at unit two. The result is multiplied by two to get costs for the first two airframes. After adding the general and administrative expenses, the total cost estimate for development is obtained.

To remove the development cost from the airframe production costs the formulas in Section II-E are used. Since the first two production airframes are assumed equal to the development cost, the cumulative average cost is calculated for the number of production aircraft plus two (for development costs) for each element. Multiplying that total number (including the two) by the cumulative average price, a total value is obtained. Subtracting the cost of the first two units and then dividing the remainder by the number of production units, the cumulative average unit cost is obtained.

Using the estimate of Boeing's direct labor costs as an illustration, the development cost is computed as follows:

a = 49

Conversion Value for unit 2 at
72 percent = 0.860

Airframe Weight = 163,420 pounds

49 x 0.860 x 2 x 163,420 x $7.51 =
$103 million

The production direct labor cost, including development, is computed as follows:

a = 49

Conversion Value for unit 202 at
72 percent = 0.147

Airframe Weight = 163,420 pounds

49 x 0.147 x 202 x 163,420 x $7.51 =
$1,786 million

The cumulative average unit cost for direct labor (including overhead), excluding development costs, for the Boeing 733-290 airframe at unit 200 is computed as follows:

$1,786
- 103
$1,683 million for 200 airframes or
$8.41 million per airframe

C. Engine Production and Development Equations

Using the formulas in Section II-F, the engine production and development costs for both the proposed engines were estimated. The costs at unit 1200 were used in line with ground rules for the SST competition.

1. Engine Development

For the Pratt and Whitney engine, proposed for the Lockheed aircraft, the following data are used to estimate total development cost:

$T_h = 61,900$ pounds

$Sa = 3.0$

then $J_d = 343,050\ (61,900)^{0.62546}(3.0)$

$J_d = \$1030$ million

For the General Electric engine, proposed for the Boeing aircraft, the cost is estimated as follows:

$T_h = 41,200$ pounds

$S_a = 2.7$

then $J_d = 343,050\ (41,200)^{0.62546}\ (2.7)$

$J_d = \$720$ million

However, for cost estimating purposes, the maximum sea level takeoff thrust of 41,200 pounds for the Boeing proposed SST is understated. The engine is designed to deliver 51,000 pounds maximum sea level takeoff thrust, but has been restricted to 41,200 pounds which is sufficient for takeoff. If the development cost is based on the design capability of the engine, (i.e., 51,000 pounds of thrust at sea level), the cost becomes:

$J_d = \$815$ million

The cost estimating equations for engine development are based on data from two manufacturers and only a few types of engines. Therefore, the results of application of equations to the proposed engines may be low because some of the engine programs from which input data were taken were merely outgrowths of previous developments. Because of this, the dollar development costs for the two proposed engines are estimated to be $1,050 million for Pratt and Whitney and $850 million for General Electric.

2. Engine Production

In the formula for estimating the production costs of the proposed engines, the following data were used:

Pratt and Whitney (Engine model STF219-L):

Thrust = 61,200
Weight = 10,355 lbs.
$\frac{Th}{Wq} = 5.91$

[redacted]

[redacted]

General Electric (Engine model GE4/J5G):

Thrust = 41,800 lbs.
Weight = 7,825 lbs.
$\frac{Th}{Wq} = 5.35$

The results of application of these variables in the equation were:

	Cumulative Average Cost at Production Level of	
	600 Units	1200 Units
Pratt and Whitney	$2,309,000 per engine $223 per pound	$1,843,000 per engine $178 per pound
General Electric	$1,362,000 per engine $174 per pound	$1,111,000 per engine $142 per pound

This method of pricing engines includes funds spent for development after certification for commercial operation. This post-certification sum is approximately equal to the development cost prior to certification when 1200 engines are manufactured. General Electric included about half of this post-certification development in their price quote. Therefore, their quoted price of $980,000 must be adjusted upward by approximately $135,000 per engine to make it comparable to the Pratt and Whitney proposed price. This adjustment raises the General Electric price to $1,115,000 per engine at a production level of 1200.

A summary of the manufacturers' proposed and estimated costs adjusted to 1963 dollars is as follows:

	Cumulative Average Cost for 1200 Engines	
	Manufacturers' Proposed Price	Estimated Cost
Pratt and Whitney (Lockheed)	$2,000,000	$1,843,000
General Electric (Boeing)	1,115,000	1,111,000

D. Comparison of Estimated Airframe Manufacturing Costs with Manufacturers' Proposed Costs

In order to compare the cost estimates in this study and the manufacturers' proposals, it was first necessary to segregate the many contractor cost items into the four major cost categories used in the estimating equations. A listing of the detailed items included in labor, material, engineering, and tooling is shown in Appendix B.

The proposed development and production costs were analyzed separately. A detailed analysis of their costs as separated into the PRC categories is given below.

[redacted]

1. Lockheed Proposed Development Costs

The Lockheed development costs were obtained from their Volume XI-A:

Lockheed Development

Engineering		Material		Labor and Overhead		Tooling	
(1)	$135,613,513	(8)	$ 7,205,141	(18)	$ 6,198,498	(39)	$193,126,744
(2)	66,768,154	(9)	3,685,592	(19)	7,322,782		
(3)	4,955,487	(10)	5,272,900	(20)	198,210		
(4)	7,582,900	(11)	1,395,800	(21)	2,365,000		
(5)	6,354,225	(12)	8,337,079	(22)	13,688,463		
(6)	39,951,664	(13)	6,481,100	(23)	17,062,870		
(7)	625,021	(14)	11,377,200	(24)	16,995,344		
	$261,850,964	(15)	301,191	(25)	20,955,026		
		(16)	133,483	(26)	395,458		
		(17)	3,207,200	(27)	765,158		
			$47,395,686	(28)	333,435		
				(29)	19,834,365		
				(30)	25,051,983		
				(31)	595,139		
				(32)	892,915		
				(33)	2,031,800		
				(34)	3,822,393		
				(35)	4,664,435		
				(36)	32,573		
				(37)	160,360		
				(38)	1,845,000		
					$145,211,807		

The total of the four categories above is $647,586,201. This agrees with Lockheed's proposal by making the following adjustments:

Lockheed Proposal	=	$655,939,130
Less AGE and Training	=	8,352,929
		$647,586,201

AGE and Training expenses were deleted from Lockheed's total costs to arrive at comparable figures with the basic data used in the statistical sample.

An explanation of the foregoing figures follows. The numbers in parenthesis refer to the corresponding item in the list above.

(1) Total design engineering

(2) Total engineering associated with the test effort

(3) Total engineering associated with "data" which is primarily a part of the engineering function

(4) Total of the test spares

(5) Total of the test equipment

(6) Total of the program management which is more closely associated with engineering than any of the other categories

(7) Total engineering associated with "other" categories

(8) Materials associated with engineering of the test article fabrication

(9) Materials portion of the subcontracting associated with the test article fabrication. It was derived by prorating the subcontracting figure between materials and labor plus overhead in the same ratio that these appear in the manufacturing portion of the test article fabrication

(10) Raw material for the test article fabrication

(11) Purchased parts for the fabrication

(12) Materials portion of the subcontracting associated with the production of prime item prototypes. It was derived by prorating the subcontracting costs between materials and labor plus overhead in the same ratio that these appear in the manufacturing portion of the production of prime item prototypes.

(13) Raw materials cost for the production of prime item prototypes.

(14) Purchased parts cost for the production of prime item prototypes.

(15) Materials portion of the subcontracting associated with "other" expenses. It was derived by pro-rating the subcontracting costs between materials and labor plus overhead in the same ratio that these appear in the "other" expenses.

(16) Raw materials associated with "other" expenses

(17) Purchased parts associated with "other" expenses

(18) Labor associated with the test article fabrication

(19) Overhead associated with the test article fabrication

(20) Overtime premium applicable to the test article fabrication

(21) Other direct cost associated with test article fabrication

(22) Direct labor associated with test article fabrication

(23) Overhead associated with test article fabrication

(24) Labor and overhead portion of the subcontracting cost associated with the test article fabrication. See (9) above for method of determination

(25) Labor and overhead portion of the subcontracting associated with production of prime item prototypes. See (12) above for method of determination

(26) Overtime premium associated with test article fabrication

(27) Labor and overhead portion of the subcontracting associated with the test article fabrication. See (15) above for method of determination.

(28) Other direct cost associated with the test article fabrication

(29) Direct labor costs associated with the production of prime item prototypes

(30) Overhead associated with the production of prime item prototypes

(31) Overtime premium associated with the production of prime item prototypes

(32) Other direct costs associated with the production of prime item prototypes

(33) Other direct costs associated with data expenses

(34) Direct labor costs associated with "other" program expenses

(35) Overhead costs associated with "other" program expenses

(36) Overtime premium associated with "other" program expenses

(37) Other direct costs associated with manufacturing and "other" costs

(38) Other direct costs associated with "other" costs

(39) Total tooling cost

2. Boeing Proposed Development Costs

The Boeing development costs were obtained from their Vol. XI-A:

Boeing Development

Engineering		Material	
(1)	$ 76,659,490	(9)	$10,916,350
(2)	55,148,687	(10)	7,518,404
(3)	69,651,403	(11)	29,294,714
(4)	5,762,408	(12)	29,957,000
(5)	9,298,503	(13)	148,966
(6)	2,440,346		$77,835,434
(7)	5,600,000		
(8)	287,510		
	$224,848,347		

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Boeing Development (continued)

Labor and Overhead	Tooling
(14) $ 21,351,277	(23) $68,851,079
(15) 36,019,840	$68,851,079
(16) 19,353,961	
(17) 30,967,822	
(18) 52,596,775	
(19) 81,600,834	
(20) 289,008	
(21) 450,169	
(22) 32,162,911	
$274,792,597	

The total of the four categories shown above is $646,327,457.

This agrees with Boeing's proposal by making the following adjustments:

Boeing proposal	=	$658,000,499
Less AGE and Training	=	11,673,042
		$646,327,457

In order to make the Boeing proposal comparable to Lockheed's, it is necessary to remove the General and Administrative costs which are included in overhead in the Boeing proposal. This was done by determining the G& A rate used by Lockheed and then applying this rate to the Boeing data.

Lockheed's G&A as a percentage of G&A plus overhead was calculated by first adding Lockheed's overhead and G &A (excluding AGE and training). This information was obtained for LAC Vol. XI-A, p. 36.

Overhead (No AGE or Training)	$202,520,000
G&A (No AGE or Training)	44,710,000
	$247,230,000

G& A as a percentage of G&A plus overhead $= \frac{\$\ 44,710,000}{\$247,240,000} = 18.08$ percent

Next, Boeing's overhead (including G &A) was determined for engineering, labor and tooling. Materials is not included because no labor or overhead expenses are included in that category.

Engineering	Labor and Overhead	Tooling
$ 40,972,000	$ 36,020,000	$36,050,000
32,524,000	30,968,000	$36,050,000
39,877,000	81,601,000	
3,248,000	450,000	
162,000	$149,039,000	
$122,023,000		

Each of the above totals were multiplied by 18.08 percent in order to estimate the Boeing G&A expenses. The G&A estimates were then subtracted from the cost category totals so that the results would be more comparable to the Lockheed proposal. Complete methodology is shown below.

Engineering G&A =
$122,023,000(0.1808) = $ 22,062,000

Labor G&A =
$149,039,000(0.1808) = 26,946,000

Tooling G&A =
$36,050,000(0.1808) = 6,518,000

Total G & A = $ 55,526,000

Engineering cost without G&A = $224,848,000
- 22,062,000
$202,786,000

Labor and overhead costs without G&A $274,793,000
- 26,946,000
$247,847,000

Tooling cost without G&A $ 68,851,000
- 6,518,000
$ 62,333,000

The Boeing proposal can be summarized as follows:

Engineering	$202,786,000
Material	77,835,000
Labor and Overhead	247,847,000
Tooling	62,333,000
Total (without G&A)	$590,801,000
G&A	55,526,000
Total	$646,327,000

$$\text{The Boeing G\& A rate} = \frac{55,526,000}{590,801,000} = 9.4 \text{ percent}$$

An explanation of the figures in the listing of Boeing development costs follows. The numbers in parenthesis refer to the costs similarly numbered in the listing.

(1) Total prototype design engineering

(2) Total production design engineering

(3) Total engineering associated with the test effort

(4) Total data expense. It is assumed to be primarily a part of the engineering function

(5) Total of the field services

(6) Total of the test spares

(7) Total of the test equipment

(8) Total of the engineering associated with "other" costs

(9) Raw material cost for the test article fabrications

(10) Raw material cost for the test effort

(11) Raw material cost for the production of prime items

(12) Purchased parts costs for the production of prime items

(13) Raw material cost associated with "other" expenses

(14) Direct labor associated with the test article fabrication

(15) Overhead associated with the test article fabrication

(16) Direct labor associated with the test effort

(17) Overhead associated with the test effort

(18) Direct labor associated with the production of prime items

(19) Overhead associated with the production of prime items

(20) Direct labor associated with the "other" expenses

(21) Overhead associated with the "other" expenses

(22) "Other direct charges" associated with manufacturing and "other" expenses

(23) Total of the tooling expenses

3. Lockheed Proposed Production Costs

The Lockheed cost figures are for the LAC model L-2000-2 and were obtained from their volume XII-A. The final allocation into the four cost groups is as follows:

Lockheed Production

	Engineering		Material
(1)	$ 96,295,675	(8)	$ 213,115,400
(2)	5,663,031	(9)	499,627,700
(3)	34,253,959	(10)	327,489,713
(4)	14,896,588		
(5)	15,406,627		
(6)	16,490,380		
(7)	27,935,651		
	$211,041,811		

	Labor and Overhead		Tooling
(11)	$ 376,249,642	(17)	$309,104,123
(12)	491,093,610		$309,104,123
(13)	3,876,246		
(14)	35,637,155		
(15)	398,651,557		
(16)	357,947,000		
	$1,663,455,210		

The total of the four categories listed above amounts to $3,223,833,957. This agrees with Lockheed's proposal with the following adjustments:

LAC proposal	$3,239,987,903
Less AGE and Training	15,153,946
	$3,223,833,957

AGE and Training expenses were deleted from Lockheed's total to arrive at a figure comparable with the basic data used in the PRC statistical sample.

The source for each of these cost numbers is explained below. The numbers in parenthesis correspond to those shown above.

(1) Total design engineering. Some manufacturing which is associated with engineering rather than production is included.

(2) Total engineering associated with the test article fabrication.

(3) Total engineering associated with the test effort.

(4) Total expense connected with data handling and analysis. Since the data is used primarily for engineering purposes, it was considered a part of the engineering expense.

(5) Field service expense, primarily an engineering function.

(6) Test equipment.

(7) Program management which was assumed to be more a part of engineering than of any other category.

(8) Raw materials used in the production of prime items.

(9) Purchased parts used in the production of prime items.

(10) Subcontract cost related to the production of prime items was assumed to consist of materials and labor in the same ratio as materials and labor used by Lockheed.

(11) Direct labor used in the production of prime items.

(12) Overhead allocated to the production of prime items.

(13) Overtime premium related to the production of prime items.

(14) Other direct cost related to the production of prime items.

(15) Labor portion of the subcontract costs. See (10) above for method of allocation.

(16) Other expenses associated with the program.

(17) Total tooling costs associated with manufacturing.

4. Boeing Proposed Production Costs

The Boeing production costs were obtained from Boeing Vol. XIIA, page 4. The following table summarizes the assignment to the four PRC categories.

Boeing Production

	Engineering		Material		Labor and Overhead		Tooling
(1)	$74,305,121	(5)	$ 403,010	(10)	$ 638,031	(16)	$462,203,404
(2)	16,847,310	(6)	1,439,721	(11)	1,060,025		$462,203,404
(3)	7,846,698	(7)	426,981,677	(12)	2,303,712		
(4)	30,102,076	(8)	319,335,700	(13)	3,827,154		
	$129,101,205	(9)	74,516,105	(14)	421,583,815		
			$822,676,213	(15)	766,559,009		
					$1,195,971,746		

The total of the four categories above is $2,609,952,568. This agrees with Boeing's proposal by making the following adjustments:

Boeing proposal:	$3,398,675,963
Less engines	784,000,000
Less AGE and Training	4,723,395
	$2,609,952,568

In order to make Boeing's data comparable to Lockheed's, it was necessary to remove the G&A which was included by Boeing in their overhead expense. The methodology used was the same as that shown previously for development costs. The complete process for doing this for production costs is shown below.

Lockheed's G&A rate as a percentage of G&A plus overhead was calculated as follows:

Overhead (No AGE or Training) = $670,637,694
G&A (No AGE or Training) = 157,845,157
Total $828,482,851

G&A as a percentage of G&A plus overhead = $\frac{\$157,845,157}{828,482,851}$ = 19.1 percent

Boeing's overhead plus G&A was determined for each category except materials, which does not contain overhead.

Engineering	Labor and Overhead	Tooling
$43,820,969	$766,559,009	$258,122,735
9,935,593	1,060,025	$258,122,735
4,627,540	3,827,154	
17,752,506	$771,446,188	
$76,136,608		

Each of the above totals were multiplied by 19.1 percent, the Lockheed G&A rate, to estimate the Boeing G&A expense.

Engineer. G&A = $ 76,136,608 (0.191)=$14,542,092
Labor G&A = 771,446,188 (0.191)=147,346,222
Tooling G&A = 258,122,735 (0.191)= 49,301,442
Total G&A $211,189,756

The Engineering cost without G&A
$129,101,205
- 14,542,092
$114,559,113

[redacted]

The Labor and Overhead	$1,195,971,746
cost without G&A	- 147,346,222
	$1,048,625,524
The tooling cost without	$426,203,404
G&A	- 49,301,442
	$412,901,962

The Boeing proposal can be summarized as follows:

Engineering	$ 114,559,113
Materials	822,676,213
Labor and Overhead	1,048,625,524
Tooling	412,901,962
Total(without G&A)	$2,398,762,812
Plus G&A	211,189,756
Total	$2,609,952,568

$$\text{Boeing G\&A Rate} = \frac{211,189.756}{\$2,393,762,812} = 8.80\%$$

An explanation of the figures in the table follows. The numbers in parentheses correspond to those in the table.

(1) Total Design Engineering.

(2) Total engineering associated with the test effort.

(3) Total engineering associated with data.

(4) Total engineering associated with field service.

(5) Raw materials associated with test article fabrication.

(6) Raw material expense associated with the test effort.

(7) Raw material expense associated with the production of prime items.

(8) Purchased parts expense associated with the production of prime items. Boeing had included an additional $784,000,000 in this item for engines, this engine cost was deleted from Boeing's purchased parts expense. This item also includes approximately $300,000 for avionics which was not removed because of its relative cost insignificance and a desire to simplify the procedural aspects involved in the analysis.

(9) Other materials costs associated with the airframe production.

(10) Direct labor associated with test article fabrication.

(11) Overhead associated with test article fabrication.

(12) Direct labor associated with the test effort.

(13) Overhead associated with the production of prime items.

(14) Direct labor associated with the production of prime items.

(15) Overhead associated with the production of prime items.

[redacted]

(16) Total tooling costs.

5. Comparison of Airframe and Engine Manufacturing Costs

The equations presented in the previous sections were applied to the proposed designs submitted by the airframe and engine manufacturers. The results compared to the cost estimates submitted by the airframe manufacturers for two prototype aircraft were as follows:

Total Development Costs – Airframe (millions)

	Boeing Design		Lockheed Design	
Cost Factor	BAC Estimate	PRC Estimate	LAC Estimate	PRC Estimate
Engineering	$202.8	$218.7	$261.9	$196.3
Labor (plus overhead)	247.8	103.4	145.2	98.6
Materials	77.8	94.7	47.4	92.3
Tooling	62.3	421.6	193.1	434.2
Total	$590.7	$838.4	$647.6	$821.4
G and A (9.4%)	55.6	78.8	-	-
(6.9%)		-	44.7	56.7
Total	$646.3	$917.2	$692.3	$878.1

For production costs, the results of the equations were computed and compared to those of the airframe manufacturers for the first 200 production units.

Cost Factor	Unit Production Costs – Airframe (millions) Boeing Design BAC Estimate	 PRC Estimate	 Lockheed Design LAC Estimate	 PRC Estimate
Engineering	$ 0.573	$ 3.083	$ 1.055	$ 3.004
Labor (plus overhead)	5.243	8.413	8.317	8.019
Materials	4.113[1]	6.662	5.201[1]	6.488
Tooling	2.065	2.183	1.546	2.051
Total	$11.994	$20.341	$16.119	$19.562
G and A (8.80%)	1.056	1.790	-	-
(4.89%)		-	.789	.957
Total	$13.050	$22.131	$16.908	$20.519
Profit (10%)	1.305	2.213	1.691	2.052
Selling Price	$14.355	$24.344	$18.599	$22.571

[1] Includes manufacturers estimated cost of avionics equipment

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For engine production costs, the results of the PRC estimating equations and the engine manufacturers' estimates were:

	Unit Production Costs — Engine (thousands) Boeing Design GE Estimate	 PRC Estimate	 Lockheed Design PW Estimate	 PRC Estimate
Selling Price Quoted	$ 980	—	$2,000	-
Post-Certification Development Adjustment	135	—	—	—
Estimated Selling Price	$1,115	$1,108	$2,000	$1,847

The reason for the adjustment in the estimated selling price is the $135,000 post-certification development cost that GE proposes to recover on spare parts sales. Because P and W included all post certification development costs in its proposal, the GE data were adjusted to be on a comparable basis.

Engine Development costs were estimated using methodology described previously. The results of these estimates and the engine manufacturer's estimates of development costs are:

Total Development Costs-Engines (millions)

Boeing Design		Lockheed Design	
GE Estimate	PRC Estimate	PW Estimate	PRC Estimate
$350	$850	$980	$1,050

For the entire SST development and production program, the following tabulation summarizes the PRC estimates as compared to those of the manufacturers: (see following page).

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(millions of 1963 dollars)

	PRC Estimates		Manufacturers' Estimates	
	Boeing	Lockheed	Boeing	Lockheed
Engine Development:				
GE	$ 850.0		$ 350.0	
PW		$1,050.0		$ 980.0
Airframe Development				
BAC	917.2		646.3	
LAC		878.1		693.3
Engine Production (1200):				
GE	1,329.6		1,338.0	
PW		2,216.4		2,400.0
Airframe Production (200):				
BAC	4,868.8		2,871.0	
LAC		4,514.2		3,719.8
Avionics Production (200):	$ 60.0	$ 60.0	$ 1/	$ 1/
Total Program Costs:	$8,025.6	$8,718.7	$5,205.3	$7,793.1

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[1] Cost of avionics equipment is included in the manufacturer's estimate of airframe production cost.

[redacted]

E. Operating Cost Equations

From the operating cost equations in Section II, the operating cost of a current subsonic jet similar to the DC-8-50 or the 707-320B, as well as the proposed supersonic transports, were computed. The segments used were those recommended in the FAA ground rules. These are a 1455-mile segment for domestic operations and a 1980-mile segment for international operations. Other assumptions are listed in Exhibit V-1 with a column stating whether the assumption agrees with the FAA ground rules of 15 September 1964.

The block speeds used for the calculations were supplied by the manufacturers. They are shown below in statute miles per hour.

	Domestic	International
733-290	996.6	1137.9
2000-2	1006.0	1159.0
707-320B	485	501

1. Crew Costs

A three-man crew was employed for both domestic and international flights with both proposed supersonic aircraft. For the subsonic aircraft, a three-man crew was used for the domestic segment and a four-man crew for the international segment. The gross takeoff weight for the three aircraft are as follows:

733-290	496,500	pounds
2000-2	454,000	"
707-320B	328,000	"

These values have been used for the domestic and international segments.

2. Fuel and Oil

The block fuel requirements for the the block speed and assumed distance were obtained from the manufacturers' reports. These values are:

	Block Fuel in Pounds	
	Domestic	International
733-390	77,864	93,300
2000-2	76,900	95,000
707-320B	42,000	48,000

3. Insurance Costs

The insurance costs are based upon the flyaway costs shown for each aircraft. The values for the supersonic aircraft are as computed earlier in this section using the formulas in Section II. Although provision for sonic boom insurance has been made for the supersonic aircraft, a value of zero has been employed.

4. Maintenance Costs

The airframe labor and materials costs were based upon the computed costs for the supersonic airframe plus the cost of the avionics equipment. The values for the subsonic are as reported by the manufacturer.

The engine labor and materials costs have been based upon estimated costs for the supersonic aircraft engines and the manufacturers' reported costs for subsonic aircraft. The time between engine overhauls used for the supersonic operating cost comparisons are 2100 hours for both the proposed engines. This is the estimate of the average for the 15-year period assuming 600 hours at the start and 3000 hours as the ultimate maximum. The time between overhauls used for the subsonic engine is 4000 hours. This value is currently being obtained by the airlines.

The method of estimating the maintenance burden costs is the same in all instances.

5. Depreciation of Flight Equipment

Here again, the aircraft prices estimated earlier in this section have been used for the supersonic aircraft operating costs and the manufacturers' quoted selling price has been used for the subsonic aircraft operating costs. The depreciation period for the supersonic aircraft is 15 years compared to 12 years for the subsonic aircraft. The shorter period for the subsonic is used because the introduction of supersonic aircraft will tend to reduce the current aircraft useful life.

6. Indirect Costs

Indirect costs have been calculated for both the subsonic and supersonic aircraft, using all of the data previously explained for the direct costs plus the following additional values:

AIRCRAFT SEAT CONFIGURATIONS

	Total	First Class	Coach
Domestic			
Supersonic:			
733-290	209	42	167
2000-2	194	38	156
Subsonic	117	34	83
International			
Supersonic:			
733-290	230	22	208
2000-2	210	20	190
Subsonic	136	20	116

[redacted]

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[redacted]

EXHIBIT V-1 - FACTORS EMPLOYED IN SUPERSONIC AND SUBSONIC AIRCRAFT OPERATING COST CALCULATIONS

	SST	Agrees With FAA	Subsonic
Segment Distances (D_b):			
Domestic	1,455	Yes	1,455
International	1,980	Yes	1,980
Fuel Cost:			
Domestic	11¢/gal	Yes	11¢/gal
International	12¢/gal	Yes	12¢/gal
Oil Cost	$12/gal	Yes	$12/gal
Engine TBO (H_{e_o})	2,100	No	4,000
Utilization	3,000	Yes	3,600
Insurance	3%	Yes	3%
Depreciation:			
Life	15 yrs	Yes	12 yrs
Spares			
Airframe	15%	Yes	15%
Engines:			
Domestic	40%	Yes	40%
International	50%	Yes	50%
Residual Value	0	Yes	0
Mixed Configuration:			
Domestic:			
First class	20%	Yes	30%
Coach	80%	Yes	70%
International:			
First class	20%	Yes	15%
Coach	80%	Yes	85%
Load Factor:			
Domestic	55%	Yes	55%
International	50%	Yes	50%
Express/Mail	3,000 lbs.	Yes	3,000 lbs.

[redacted]

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[redacted]

Baggage for Enplaned Passenger (tons)

	Domestic	International
First Class	0.0175	0.0300
Coach	0.0175	0.0225

The resultant cost per segment and per seat-mile for all operating in Exhibits V-2 and V-3.

[redacted]

[redacted]

EXHIBIT V-2- Estimated Operating Costs for Proposed Supersonic Transports and Current Subsonic Jet Aircraft (International)

	Total Cost for 1980-Mile Segment			Cost Per Available Seat Mile (Cents)		
	Current Jets	733-290	2000-2P	Current	733-290	2000-2P
Direct Operating Costs						
Crew	$ 620.15	$ 368.84	$ 363.95	.230	.081	.088
Fuel and Oil	900.60	1,819.23	1,767.47	.334	.399	.425
Insurance	229.10	504.73	517.43	.085	.111	.124
Maintenance	853.20	1,088.97	1,420.22	.317	.239	.342
Depreciation	770.25	1,351.15	1,418.87	.286	.297	.341
Total	$3,373.30	$ 5,132.92	$ 5,487.94	1.253	1.127	1.320
Indirect Operating Costs						
Direct Maintenance GPE	$ 22.91	$ 30.88	$ 28.94	.009	.007	.007
Maintenance Burden GPE	12.64	16.32	15.29	.005	.004	.004
Passenger Service	814.10	1,042.68	948.31	.302	.229	.228
Aircraft Servicing	508.37	755.77	705.97	.189	.166	.170
Traffic Servicing	262.28	410.90	379.05	.097	.090	.091
Servicing Administration	63.60	91.45	89.55	.024	.020	.022
Reservations and Sales	857.94	1,433.05	1,310.92	.319	.315	.315
Advertising and Publicity	373.28	605.78	556.28	.139	.133	.134
General and Administrative	312.84	461.53	455.01	.116	.101	.109
Depreciation of G.P & E and Amortization of Properating Expenses	109.02	130.67	123.23	.040	.029	.030
Total	$3,336.98	$ 4,979.03	$ 4,612.55	1.239	1.093	1.109
Total Operating Costs	$6,710.28	$10,111.95	$10,100.49	2.492	2.220	2.429
Available Seats	136	230	210			
Available Seat Miles	269,280	455,400	415,800			

[redacted]

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EXHIBIT V-3 - Estimated Operating Costs for Proposed Supersonic Transports and Current Subsonic Jet Aircraft (Domestic)

	Total Cost for 1455-Mile Segment			Cost Per Seat Mile (Cents)		
	Current Jets	733-290	2000-2P	Current	733-290	2000-2P
Direct Operating Costs						
Crew	$ 357	$ 288.22	$ 286.19	.210	.095	.101
Fuel and Oil	723	1,322.57	1,306.23	.425	.435	.463
Insurance	174	424.51	438.76	.102	.140	.155
Maintenance	648	913.74	1,204.27	.381	.300	.427
Depreciation	579	1,119.35	1,179.33	.340	.368	.418
Total	$2,481	$4,068.39	$4,414.78	1.457	1.338	1.564
Indirect Operating Costs						
Direct Maintenance GPE	$ 17.10	$ 21.91	$ 21.58	.010	.007	.008
Maintenance Burden GPE	15.30	20.43	19.94	.009	.007	.007
Passenger Service	471.90	701.97	649.35	.277	.231	.230
Aircraft Servicing	180.00	270.35	254.35	.106	.089	.090
Traffic Servicing	164.40	258.85	243.55	.097	.085	.086
Servicing Administration	42.60	64.99	61.19	.025	.021	.022
Reservations and Sales	271.80	485.10	450.38	.160	.160	.160
Advertising and Publicity	171.90	297.55	277.15	.101	.098	.098
General and Administrative	153.60	240.83	247.61	.090	.079	.088
Depreciation of GP & E and Amortization of Prop.	51.90	70.85	73.59	.030	.023	.026
Total	1,540.50	2,432.83	2,298.69	.905	.800	0.814
Total Operating Costs	$4,021.50	$6,501.22	$6,713.47	2.362	2.138	2.378
Available Seats	117	209	194			
Available Seat Miles	170,235	304,095	282,270			