

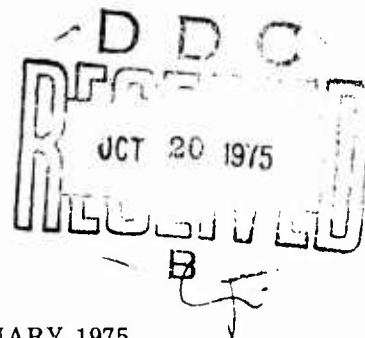
AFFDL-TR-75-44

VOL. II, PART I

**WEAPON SYSTEM COSTING METHODOLOGY
FOR AIRCRAFT AIRFRAMES
AND BASIC STRUCTURES
VOLUME II • ESTIMATING HANDBOOK AND
USER'S MANUAL • PART I**

*GENERAL DYNAMICS CONVAIR DIVISION
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MAY 1975



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FINAL REPORT FOR PERIOD JULY 1972 — FEBRUARY 1975

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Prepared for
AIR FORCE FLIGHT DYNAMICS LABORATORY
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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20. Abstract (Continued)

jected cost of a complete airframe within the context of a weapon system development. This volume describes how to make an estimate using either technique and shows the results of a demonstration case.

Tradeoff capability has been provided for a range of alternative structure and material combinations. A technique for independent assessing complexity factor has been developed and demonstrated. Manufacturing costs are separately estimated for the primary elements of substructure: ribs, spars, covers, leading edges, trailing edges, tips, etc. The trade study method provides an iterative capability stemming from a direct interface with design synthesis programs. A detailed cost data base and system for data expansion is provided. The methods are designed for ease in changing cost estimating relationships and estimating coefficients resulting from cost data update.



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FOREWORD

This report was prepared by the Convair Division of General Dynamics, San Diego, California, under USAF Contract F33615-73-C-2083. The contract, titled "Weapon System Costing Methodology for Aircraft Airframes and Basic Structures," was initiated under Project 1368, "Advanced Structures for Military Aerospace Vehicles," Task 136802, "Structural Integration for Military Aerospace Vehicles."

The work was administered under the direction of the Air Force Flight Dynamics Laboratory, Structures Division, Wright-Patterson Air Force Base, Ohio, under the direction of Mr. R. N. Mueller (AFFDL/FBRB) as Project Engineer.

This report covers work conducted from July 1972 to February 1975 and was submitted by the author in February 1975, under Air Force Flight Dynamics Laboratory Report No. TR-75-44 as a Final Report. This report includes one additional volume: Volume I, Technical Volume. Both Volume I and II are final technical reports.

The following Interim Technical Report volumes have been issued under this program as AFFDL-TR-73-129:

- Volume I: Cost Methods Research & Development
- Volume II: Supporting Design Synthesis Programs
- Volume III: Cost Data Base
- Volume IV: Estimating Techniques Handbook

The principal author and project leader on this program is Mr. R. E. Kenyon, under the administration of Mr. G. E. Vail, Chief of Economic Analysis and Mr. A. Van Duren, Manager of Operations Research. Others who contributed to the studies and who contributed in the preparation of this report include Messrs. J. M. Youngs and R. J. Reid, Economic Analysis; B. H. Oman, W. D. Honeycutt, and T. F. Reed, Mass Properties; L. M. Peterson and G. S. Kruse, Structural Analysis; G. G. Clark, Analytical Programming; and T. Kell, Industrial Engineering.

TABLE OF CONTENTS

PART I

Section		Page
I	INTRODUCTION	1
1.1	HOW TO MAKE AN ESTIMATE	2
1.1.1	Trade Study Estimating Method	2
1.1.2	System Cost Estimating Method	17
1.2	ORGANIZATION OF THE HANDBOOK	24
II	TRADE STUDY COST ESTIMATING METHOD	26
2.1	COSTS ESTIMATED	26
2.2	COST MODEL COMPUTER PROGRAM	34
2.2.1	Control Cards	35
2.2.2	Program Deck	36
2.2.3	Input Cards	37
2.2.4	The COSTC Program	40
2.2.5	Input Organization	41
2.3	COST ESTIMATING RELATIONSHIPS AND INPUT DESCRIPTION	42
2.3.1	First Unit Cost	42
2.3.2	Recurring Production Costs By Structural Element . . .	117
2.3.3	Nonrecurring Design and Development	119
2.3.4	Recurring Airframe Production Costs (Summary)	130
2.3.5	Complexity Factors	135
2.3.6	Derivation of Estimating Coefficients	137
2.4	PROGRAM OPERATION AND INSTRUCTIONS	141
2.4.1	Computer Program Integration	141
2.4.2	Operation of Supporting Programs	142
2.4.3	Time Sharing	142
III	AIRFRAME SYSTEM COST ESTIMATING METHOD	145
3.1	COSTS ESTIMATED	145
3.2	COST MODEL COMPUTER PROGRAM MODULE	146
3.3	COST ESTIMATING RELATIONSHIPS AND INPUT DESCRIPTION	146
3.3.1	Nonrecurring Design and Development	147
3.3.2	First Unit Costs	159
3.3.3	Recurring Production Costs	161
3.4	PROGRAM OPERATION AND INSTRUCTION	165

TABLE OF CONTENTS (Continued)

PART I

Section		Page
IV	DEMONSTRATION RUNS	166
4.1	TRADE STUDY DEMONSTRATION RUN	167
4.2	SYSTEM COST ESTIMATING DEMONSTRATION RUN	168
4.3	COMBINED METHODS OPERATION	170
4.4	ABBREVIATED RUNS	171
4.5	ESTIMATING ACCURACY	171

PART II

Appendix

A	INPUT DATA DECK LISTING AND MODEL CARD EXPLANATION	1
B	INPUT ELEMENTS LISTING	63
C	SAV MATRIX PRINTOUT	68
D	NAMLIST VARIABLES DICTIONARY	76
E	SUMMARY OF F-CARD VARIABLES	85
F	ESTIMATING COEFFICIENTS BACK-UP	91
G	TYPES OF MATERIAL AND CONSTRUCTION TECHNIQUES	192
H	MATERIAL COST ESTIMATING COEFFICIENTS	236
I	TRADE STUDY NONRECURRING COST ESTIMATING FACTORS	243
J	SUPPORTING PROGRAMS DATA TRANSFER	257
K	AIRFRAME SYSTEM COST ESTIMATING PROGRAM MODULE	289
L	SYSTEM COST ESTIMATING METHOD BACK-UP DATA	312
M	TRADE STUDY DEMONSTRATION CASE	343
	REFERENCES	353

LIST OF ILLUSTRATIONS

Figure		Page
1	Trade Study Cost Estimating Method	3
2	Wing First Unit Cost	4
3	Wing RDT&E Costs	5
4	Recurring Airframe Production Cost (Summary)	6
5	Nonrecurring Design and Development Costs	7
6	CER Examples - Trade Study Estimating Method for Manufacturing First Unit Cost	8
7	Computer Program Deck Set-Up	10
8	Examples of Model Card Entries	11
9	Input and Input Source Examples	12
10	Cost Model Input Summary	13
11	Input Development	14
12	Fuselage - Nacelle - Landing Gear Structural Weights	16
13	System Cost Estimating Method	18
14	Nonrecurring Design and Development Cost - Page 1	19
15	Nonrecurring Design and Development Cost - Page 2	20
16	First Unit Costs	21
17	Recurring Airframe Production Cost	22
18	Typical CERs - System Cost Estimating Method	23
19	Wing First Unit Cost	27
20	Horizontal Stabilizer First Unit Cost	28
21	Vertical Stabilizer First Unit Cost	29
22	Fuselage First Unit Cost	30
23	Nacelles First Unit Cost	31
24	Landing Gear First Unit Cost	32
25	Cost Model General Flow Diagram	39

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
26	NAMELIST Inputs for Structural Box and Fuselage Basic Structure Detail Fabrication Hours	51
27	NAMELIST Inputs for Structural Box and Fuselage Basic Structure Subassembly Hours	60
28	NAMELIST Inputs for Structural Box and Fuselage Basic Structure Major Assembly Hours	71
29	NAMELIST Inputs for Secondary Structure Detail Fabrication and Subassembly Hours	75
30	NAMELIST Inputs for Secondary Structure Component Major Assembly Hours	103
31	NAMELIST Inputs for Structural Box and Fuselage Basic Structure Material	108
32	NAMELIST Inputs for Secondary Structure Structural Material Cost	111
33	NAMELIST Inputs for Assembly Material Costs	115
34	Recurring Airframe Production Costs (Summary)	132
35	Costing Process	136
36	Development of Complexity Factors	138
37	Detailed Industrial Engineering Estimates for Complexity Factor Derivation	139
38	Summary of CER Coefficients	140
39	Detail Fabrication Hours Versus Weight for Ribs with Complexity Factor Norm	141
40	Supporting Synthesis Program for Aerodynamic Surfaces	143
41	Supporting Synthesis Program for Fuselage, Nacelles, Landing Gears	144
42	Airframe System Cost Estimating Structures	145

LIST OF TABLES

Table		Page
1	Aerodynamic Surfaces Structural Weights	15
2	Summary of Cost Printouts for a Trade Study Estimate	33
3	Cost Output, CER Equation, and Model Card Cross Reference - Wing First Unit Cost	43
4	Cost Output, CER Equation, and Model Card Cross Reference - Horizontal Stabilizer First Unit Cost	44
5	Cost Output, CER Equation, and Model Card Cross Reference - Vertical Stabilizer First Unit Cost	45
6	Cost Output, CER Equation, and Model Card Cross Reference - Fuselage First Unit Cost	46
7	Cost Output, CER Equation, and Model Card Cross Reference - Nacelle First Unit Cost	47
8	Cost Output, CER Equation, and Model Card Cross Reference - Landing Gear First Unit Cost	48
9	Aerodynamic Surfaces Rib Complexity Factors - Detail Fabrication	52
10	Fuselage Frame and Bulkhead Complexity Factors - Detail Fabrication	53
11	Aerodynamic Surfaces Spars Complexity Factors - Detail Fabrication	54
12	Fuselage Longerons Complexity Factors - Detail Fabrication	55
13	Aerodynamic Surfaces Covers Complexity Factors - Detail Fabrication	56
14	Fuselage Covers Complexity Factors, Detail Fabrication	57
15	Cost Per Pound Factors (HFF ₁) Map	58
16	Aerodynamic Surfaces Rib Complexity Factors - Subassembly	61
17	Fuselage Frame and Bulkhead Complexity Factors - Subassembly	62

LIST OF TABLES (Continued)

Table		Page
18	Aerodynamic Surfaces Spars Complexity Factors, Subassembly	63
19	Fuselage Longerons Complexity Factors, Subassembly	64
20	Aerodynamic Surfaces Covers Complexity Factors - Subassembly	65
21	Fuselage Skin Panel Complexity Factors - Subassembly	66
22	Cost Per Pound Factors (HF_i) Map	67
23	Fastener Type Installation Factor	72
24	Structural Box and Basic Structure Major Assembly Factors - Map and Factor Values	73
25	Secondary Structure Detail Fabrication Complexity Factors, CB_i	77
26	Secondary Structure Subassembly Complexity Factors, CC_i	85
27	Cost Per Pound Factors - (WC_i) Map	93
28	Cost Per Pound Factors - (WF_i) Map	97
29	Factor Values and F-Card Location	104
30	Secondary Structure Assembly Complexity Factor (CMB)	105
31	Primary Structure Raw Material Cost Factor (RMC)	109
32	Primary Structure Material Scrappage Factor (SF)	109
33	Secondary Structure Raw Material Cost Factors (RMC)	113
34	Secondary Structure Scrappage Factor (SF)	113
35	Assembly Material Cost Map and Factor Values	114
36	Fastener Type Complexity Factor Related to Assembly FM	116
37	Cost Output and Model Card Cross Reference - Wing Recurring Production Costs	120
38	Cost Output, CER Equation Number, and Model Card Cross Reference - Nonrecurring Design and Development Costs	121
39	Engineering Labor CER Coefficient	123

LIST OF TABLES (Continued)

Table		Page
40	Tool Manufacturing Hours CER Coefficient	126
41	Cost Output and Model Card Cross Reference Recurring Production Costs (Summary)	131
42	Cost Output, CER Equation, and Model Card Cross Reference - Nonrecurring Design and Development Cost . . .	148
43	Cost Output, CER Equation Number and Model Card Cross Reference - System First Unit Cost	160
44	Cost Output, CER Equation Number and Model Card Cross Reference - System Recurring Production Cost	162

SECTION I

INTRODUCTION

This volume in the form of an Estimating Handbook and User's Manual provides the instructions necessary for making a cost estimate using either what is referred to as the trade study cost estimating method or the airframe system cost estimating method. It describes these estimating techniques in terms of inputs and outputs of the computerized programs used, the cost estimating relationships involved, the organization and sources of inputs, including other supporting computer programs, and the cost model computer program. An example estimate in the form of a demonstration case is also described. The Estimating Handbook together with a Technical Volume comprise the Final Report for Air Force Contract F33615-72-C-2083. The Technical Volume supplements this discussion by describing the development of the methods, by defining cost categories, and by discussing some of the limitations of the methods. The emphasis in this volume is on the user's point of view and thus on the mechanics of the procedure. The two estimating methods to be discussed are distinct in terms of the categories of cost involved, the level of detail at which estimates are made, the cost estimating relationships involved, and the resulting inputs and input sources. The trade study method involves a very detailed level of estimating for basic structure only. The system costing method involves a higher (subsystem) level but includes both structural and mechanical subsystems of the aircraft airframe. The term airframe, which may be used in conjunction with either method, is defined as including only basic structure in the case of the trade study method but as including basic structure plus mechanical subsystems in the case of the system method. The different sets of input required for each method in turn entail a different output from the area of preliminary design support, or specifically from the supporting design synthesis programs in the case of the trade study method.

The trade study estimating technique, in general, requires that the supporting design synthesis programs operate in an iterative manner, although, point design estimates can be made with the input data being developed manually. The number of inputs required initially to set up a run is quite extensive. Generally, however, only a few input variations are required for subsequent trade study alternatives.

A combined trade study-system method mode of operation may be selected. This is based on a modular estimating approach wherein both subsystem level CERs and detailed estimating routines are available for structural subsystems. This option is exercised by zeroing out one or the other method selectively by subsystem. Thus, a structural element of particular interest may be estimated in detail with the remaining elements being estimated at an aggregate level.

The following subsection of the introduction provides an overview of both estimating methods to answer the question: How to make an estimate? The organization of the handbook is then described. If the interest is in simply making an estimate, the reader may wish to begin study of the method with this volume rather than Volume 1.

1.1 HOW TO MAKE AN ESTIMATE

1.1.1 TRADE STUDY ESTIMATING METHOD. Figure 1 gives an outline of the trade study estimating method and the flow of information required in this process. In this description of the method, which is intended to provide an introduction only, the discussion will begin with the cost output and work backwards through the various phases of the program to the procedure for the development of input data.

The cost output is described and defined by the computer printout formats, samples of which are given in Figures 2 through 5. These represent a complete set of computer printouts except that two additional Recurring Production (Manufacturing) Cost printouts are provided for two alternative production quantities, and also that this series of printouts is provided for each of the structural elements: wing, horizontal stabilizer, vertical stabilizer, fuselage, nacelles and landing gear.

The Cost Model, comprising the cost estimating logic, consists of sets of CERs developed for each of the items of cost identified in the computer printouts. These CERs are described in Section 2.3. Their derivation is discussed in Volume 1. Figure 6 gives examples of manufacturing first unit CERs for labor and material. Many other forms are involved. Manufacturing First Unit Cost is an estimating convention based on using theoretical first unit cost as the basis for estimating manufacturing costs.

It is sometimes necessary to augment the standard procedure, as represented by the CERs, with special procedures and analyses. These require definition for each individual case and may or may not be of a nature to permit incorporation in the main body of CERs.

The estimating method makes use of an existing general cost program, designated as COSTC, that operates as a data manager program and handles the cost estimating logic as a program input. This provides a simple means of modifying cost estimating relationships. These are accomplished simply by changing an input model card and the corresponding input variable(s). This program is discussed further in Section 2.2.

The total set of CERs generates the variable input requirement entered in the program as NAMELIST variables. These, together with the model cards, constitute the input package. The model cards, which include the CER entries, constitute an input whenever they are to be revised. They may be revised for either of two reasons: (1) as previously mentioned, to change the form of a CER, or (2) to change an estimating coefficient. These coefficients appear as constants within the CERs, and

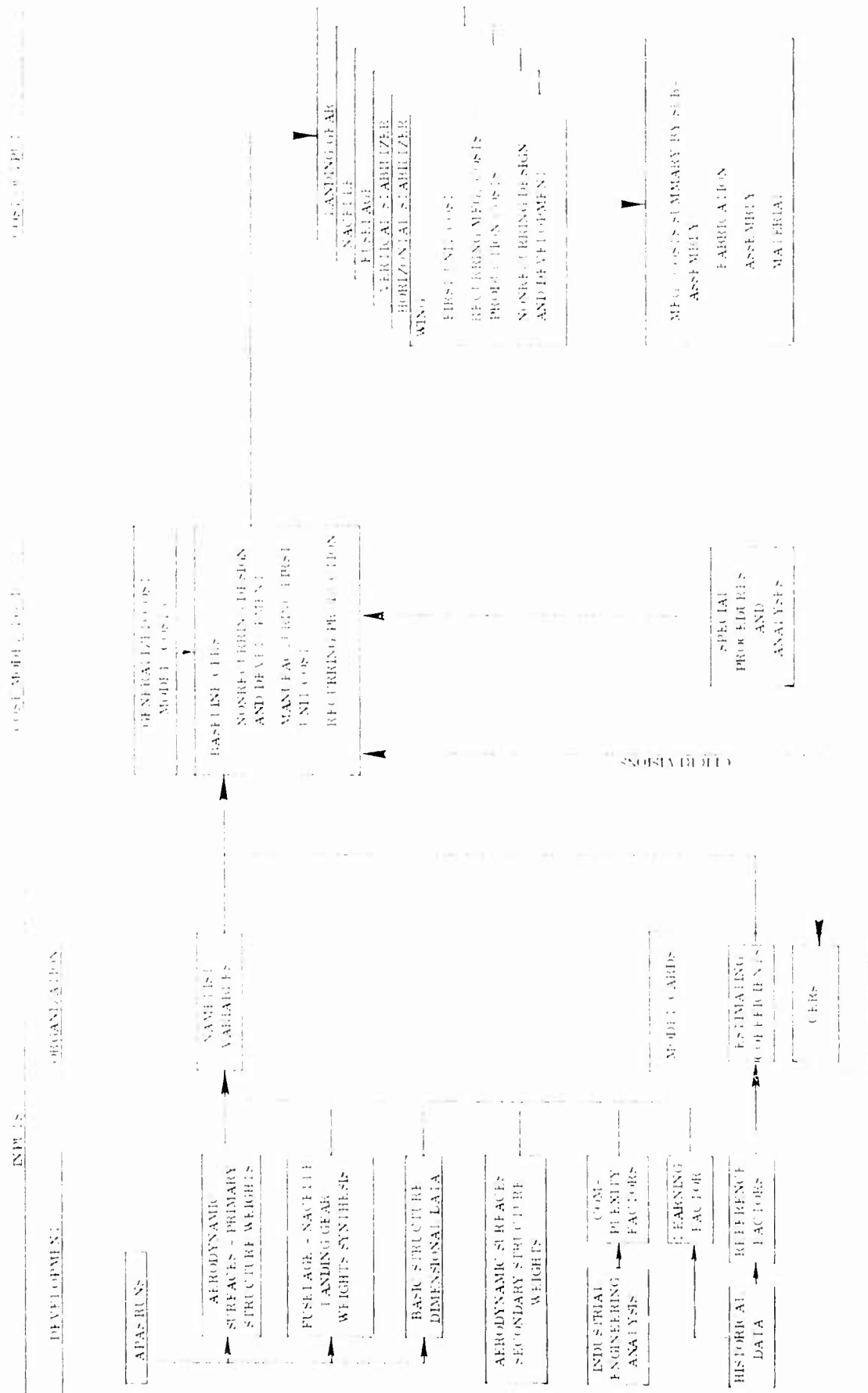


Figure 1. Trade Study Cost Estimating Method.

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Figure 4. Recurring Airframe Production Costs (Summary).

Aerospace Vehicle Structural Costs
Nonrecurring Design and Development Costs

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	Wing	Hort	Vert	Fuse	Nace	Log	Sub-	Dol
	Hours	Hours	Hours	Hours	Hours	Gear	Total	lar
	Hours	Hours	Hours	Hours	Hours	Hours	Hours	Costs
Basic Struc Design Engr	.152		.020	.201	.191	.079	.632	4.277
Configuration Design Engr							.750	4.919
Engineering Material								.492
Total Trade Study Engr							1.482	9.688
Basic Tool Mfg Hours	2.1		.17	2.08	.93		5.32	
Rate Tooling Mfg Hours							1.51	
Total Tool Mfg							6.64	41.57
Basic Tool Engrg Hours							2.132	
Rate Tool Engrg Hours							.1985	
Total Tool Engrg							2.33	13.84
Mfg Devel - Plant Engr							.13	.80
Total Plant - Other Dollars								6.04
Manufacturing Support Dollars								.492
Quality Control							.41	2.75
Totals							10.912	66.122

Figure 5. Nonrecurring Design and Development Costs.

Rib Detail Fabrication Hours

$$H_1 = \frac{W_1 CF_1 + W_1 CF_1 + W_1 CF_1 + H_1 + WT_1}{WT_1}$$

where: W_1 Weight of ribs of three alternative construction and material types represented by corresponding complexities.

CF_1 Complexity factor corresponding to rib type

WT_1 Sum of the rib weights

H_1 Fabrication hours per pound for structural component for baseline configuration.

E_1 Weight-scaling exponent.

Rib Subassembly Hours

$$H_1 = \frac{W_1 CM_1 + W_1 CM_1 + W_1 CM_1 + H_1 + WT_1}{WT_1}$$

where: CM_1 Complexity factor for given material and construction technique.

H_1 Subassembly hours per pound for baseline configuration.

E_1 Weight-scaling exponent.

Rib Structural Material Cost

$$M_1 = W_1^G (RMC_1) (SF_1)$$

where: RMC_1 Raw material cost per pound.

SF_1 Scrappage factor

G Weight scaling exponent

Figure 6. CFR Examples - Trade Study Estimating Method for Manufacturing First Unit Cost.

comprise such items as baseline costing factors, scaling factors, and other factors based on historical data. Input categories are determined with respect to the cost model computer program described in Section 2.2.

The computer program deck set-up is illustrated by Figure 7. The program deck consists of the COSTC general cost program. Inputs comprise NAMELIST SIZE, NAMELIST CURVE, and Model Card entries. Sample model card entries are illustrated in Figure 8. This is a very limited sample, the total Model Card Deck consisting, as it does, of approximately 650 entries. The functions of the model card are explained in Section 2.2. Figure 9 gives an example of the relationship between inputs (and input sources) and the CER. A general idea of the input organization is furnished by Figure 10. It should be noted that numerous additional CER forms and input relationships are involved as might be suspected from the number of model card entries involved. Section 2.2 provides a complete cost model computer program description, including COSTC program subroutines, model card listing, input listings, NAMELIST variables dictionary, and an estimating coefficients summary and locator. Section 2.3 identifies each of the CERs involved and relates them to the computer program.

Input development is illustrated by Figure 11. The option of CER revisions, shown in Figure 10, is excluded, however, since such changes, although literally handled as inputs, are best thought of in a separate category. Input development is then defined as being within the context of an existing set of CERs.

As shown by Figure 11, various synthesis program runs are required to support the development of inputs. These provide design information required in the estimating process. There are three such programs: (1) An Automated Program for Aerospace -- Vehicle Synthesis (APAS), (2) A Program for Development of Aircraft Fuselage, Nacelle and Landing Gear Weights, and (3) The Tip, Leading and Trailing Edge Analysis Program. The first of these in turn supports the second. The third program operates independently. A technical description of these programs is given in Section V of Volume I.

Each of these programs also has an input requirement. These input requirements, operating instructions for program runs, and output data transfer worksheets are covered in Section 2.4 of this Handbook.

The weight analysis for aerodynamic surfaces primary structure involves the use of correlation factors applied to the output of APAS. These factors are in turn based on weights research data from studies conducted concurrently with but separate from this study. A separate design synthesis and weight analysis procedure, the Tip, Leading and Trailing Edge Analysis Program, is used for aerodynamic surfaces secondary structure. These results, combined with those for primary structure, result in data such as shown in Table 1. Correlation factors are calculated as the ratio of

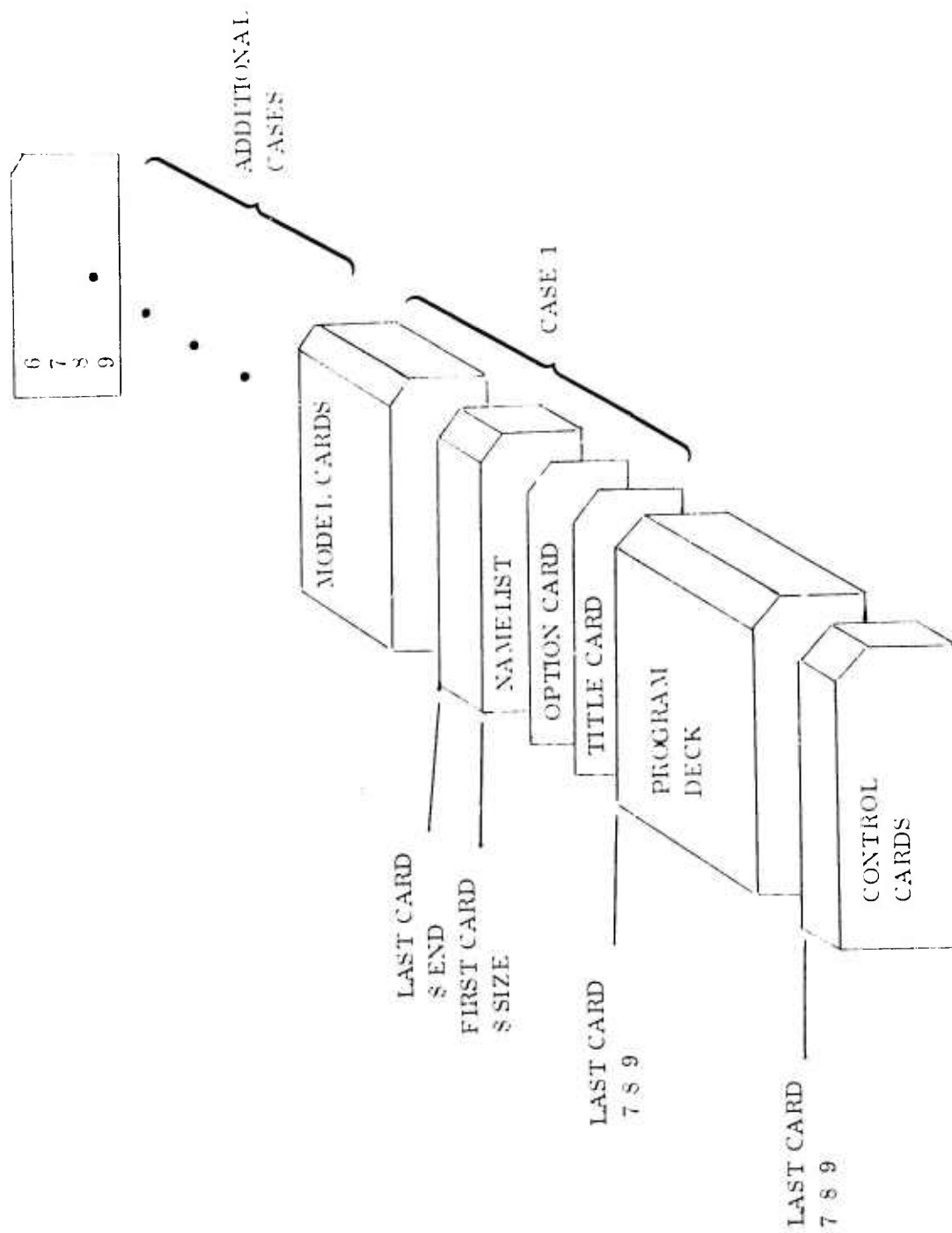


Figure 7. Computer Program Deck Set-up.

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CARDS 350WUG HTL VTL FLG NAG LDB
$SIZE
W1=70.,CF1=.51,X2=270.,CF2=.25,W3=540.,CF3=1.,W4=1000.,CF4=.540,W5=633.,
CF5=1.72,W6=250.,CF6=1.,W7=5114.,CF7=7.5,W8=1.,CF8=1.,CF9=1.,CF10=1.,
C47=3.5,CN=20.,RN=5.,SN=31.,SE=30.,PE=50.,PS4=1.,PF1=1.2,PF2=2.,CF1=1.75,
WQ1=343.7,CQ1=2.,CQ2=4.,WQ2=33.2,CQ3=4.5,CQ4=4.5,WQ3=1135.2,CQ5=4.75,CQ6=2.7,
WQ4=707.7,CQ4=2.5,CQ5=2.5,WQ5=265.3,CQ6=2.7,CQ7=3.,WQ6=101.2,CQ8=2.31,CQ9=3.,
WQ9=276.9,CQ9=3.,CQ10=7.,CQ11=950.,CQ12=3.,CQ13=1.,CQ14=10.5,CQ15=50.,
RSL=21.,TS7=.2,EF3=2.5,C43=3.,AS2=1890.,RMC1=10.,P12=10.,RMC2=10.,SF1=2.,
SF2=5.3,SF3=2.,WQ4=18.,RMC5=15.,RMC6=18.,SF4=3.,SF5=5.3,SF6=3.,RMC7=36.,
SF7=2.,RMC10=50.,SF10=1.2,RMC11=55.,SF11=1.2,RMC12=55.,SF12=1.2,RMC13=50.,
SF13=1.2,RMC14=50.,SF14=1.2,RMC17=10.,SF17=5.3,RMC18=50.,SF18=3.,RMC25=40.,
SF25=2.,F41=2.5,F42=1.7,F43=540.,W44=12156.,FCLF=5.56,TMF=7500.,TAM=3.,
THC=6.26,TFC=5.34,TCC=6.,RQC=5.54,P41=1.,P42=30.,PN3=30.,R4=5.23,RI=6.26,

```

```

S C FIRST UNIT COST
C WUG
N 9
T
C STRUCTURAL BOX
F 31 1 (5,1) / (5,3) * 51.0 * (5,3)**.67
HF1 E1
F 31 2 (9,2) / (5,3) * 14.5 * (5,3)**.67
HF4 E4
F 31 3 0.1 WUG**.77 * RMC1 WUG * SF1 WUG + (12,3)
RIBS
F 32 1 (0,1) / (0,3) * 52.0 * (0,3)**.67
HF2 E2
F 32 2 (10,2) / (6,3) * 19.0 * (6,3)**.67
HF5 E5
F 32 3 0.4 WUG**.77 * RMC4 WUG * SF4 WUG + (12,6)
SPANS
F 33 1 (7,1) / (7,3) * 11.0 * (7,3)**.67
HF3 E3
F 33 2 (11,2) / (7,3) * 7.2 * (7,3)**.67
HF6 E6
F 33 3 0.7 WUG**.77 * RMC7 WUG * SF7 WUG + (12,9)
COVERS

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Figure 3. Examples of Model Card Entries.

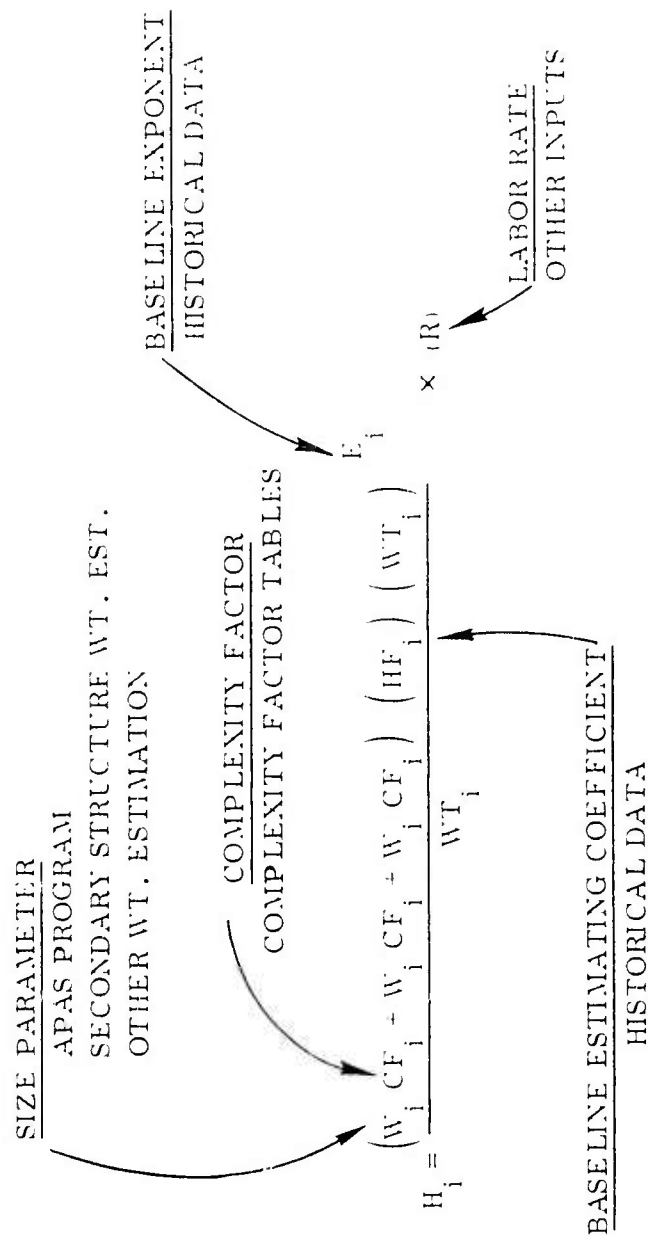


Figure 9. Input and Input Source Examples.

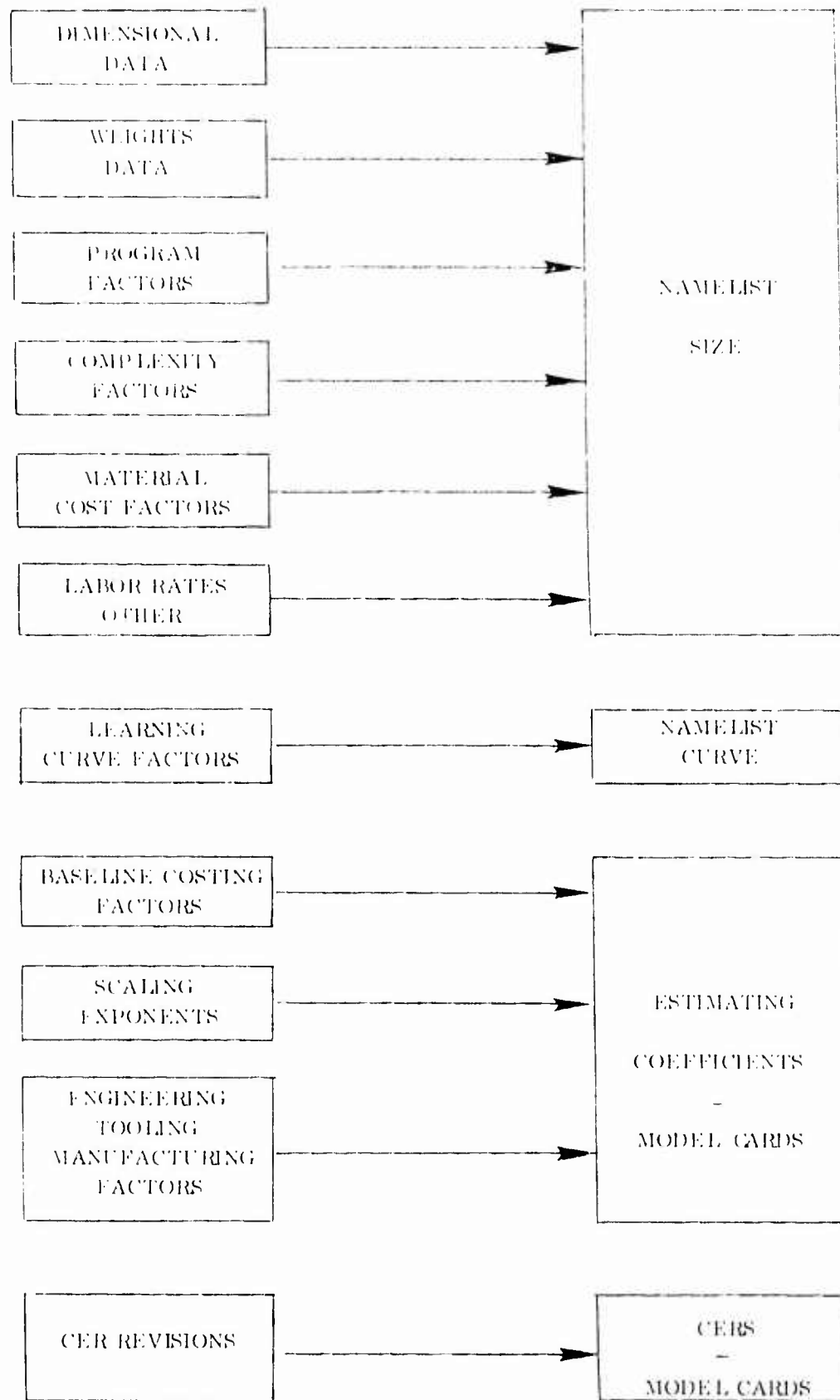


Figure 10. Cost Model Input Summary.



Table 1. Aerodynamic Surfaces Structural Weights

Part Definition	Actual Weight	Synthesis Weight	Correlation Factor
<u>A-X Wing</u>			
Inter-Spar Cover	750	672	1.12
Spars	410	286	1.43
Ribs	316	60	5.27
Leading Edge & Tip	125	166	0.75
Trailing Edge	52	92	0.56
Ailerons	49	24	1.87
Flaps & Foreflaps	359	281	1.28
Slats	278	198	1.40
Spoilers	83	134	0.67

Does Not Include:

1. Misc. Structure: 88 lbs
2. Aileron Balance Wts.: 45 lbs

actual weight to synthesis weight. They provide a measure of the credibility of the synthesized weight and can be used as analogs in estimating similar structural elements.

The weight analysis for fuselage structure, both primary and secondary, is handled by the Program for Development of Aircraft Fuselage, Nacelle and Landing Gear Weights driven by the APAS program. It provides weights data as shown in Figure 12.

Historical data is used to develop various factors: learning curve factors; scaling exponents; engineering, tooling, and manufacturing factors; and material cost factors. The tables summarizing these factors, the location in the Handbook of back-up data, and the model card deck location of the CERs in which these factors are used are given in Section 2.3.

The development of baseline costing factors and complexity factors is interrelated. Their development is fully explained in Volume I, Section II. Briefly, the following steps are involved:

- a. Development of complexity factors for primary structure by means of an industrial engineering analysis relating alternate types of construction and material to a baseline hardware element of known cost, thereby indicating cost ratios.
- b. The normalization of historical data by weight and by type of construction and material.

Figure 12. Fuselage-Nacelle-Landing Gear Structural Weights.

- c. The derivation of CERs from the normalized data, assuming that the significant cost related variables are weight, type of construction, and type of material, and further that a consistent scaling relationship is applicable.
- d. The continuing collection of historical cost data and update of the CER derivations.

The industrial engineering analysis investigates manufacturing operations associated with various categories of hardware construction and material types and determines a numerical relationship to a nominal element of hardware that utilizes a baseline type of construction and material. The individual manufacturing operations are evaluated by means of standard hours and a ratio of cost is established as a measure of complexity.

The original intent of this study was to deal only with primary structure. It was recognized early in the study, however, that the secondary structure was of equal significance from a cost standpoint, and the effort was redirected accordingly. Hardware elements making up secondary structure do not tend to fall into type of construction categories as conveniently as do those of primary structure. This complication is reflected in the complexity factor tables for secondary structure.

A provision is included in the method for applying learning curve factors at the detailed level shown in Figure 2. Development of the factors themselves was not included within the scope of the study. Values for these factors may be supplied by the user, however, according to available data.

Labor rates are inputs to the model. Economic escalation relating to labor may be handled through these inputs. Variations in labor costs, as for example differences between manufacturers, can thus be accounted for.

1.1.2 SYSTEM COST ESTIMATING METHOD. Figure 13 gives an outline of the system cost estimating method and the flow of information required in this process. The cost output is defined by the set of computer printouts shown as Figures 14 through 17. The Cost Model consists of sets of CERs developed for each of the items of cost identified in the computer printouts. These CERs are described in Section 3.3. Their derivation is discussed in Volume 1. Figure 18 gives examples of a few of the various types of CERs used.

The estimating method makes use of the same general cost program as the trade study method. The computer program module for the system costing model is described in Section 3.2. The conventions regarding NAMELIST variable inputs, model cards and model card changes is similar to the trade study method.

The computer program deck set-up for system costing is the same as for the trade study method illustrated in Figure 7. Variations occur in the use of control cards, title card, and option card. Inputs comprise NAMELIST CURVE, NAMELIST SUMMARY, and Model Card entries. Individual subsets of model cards are assigned to

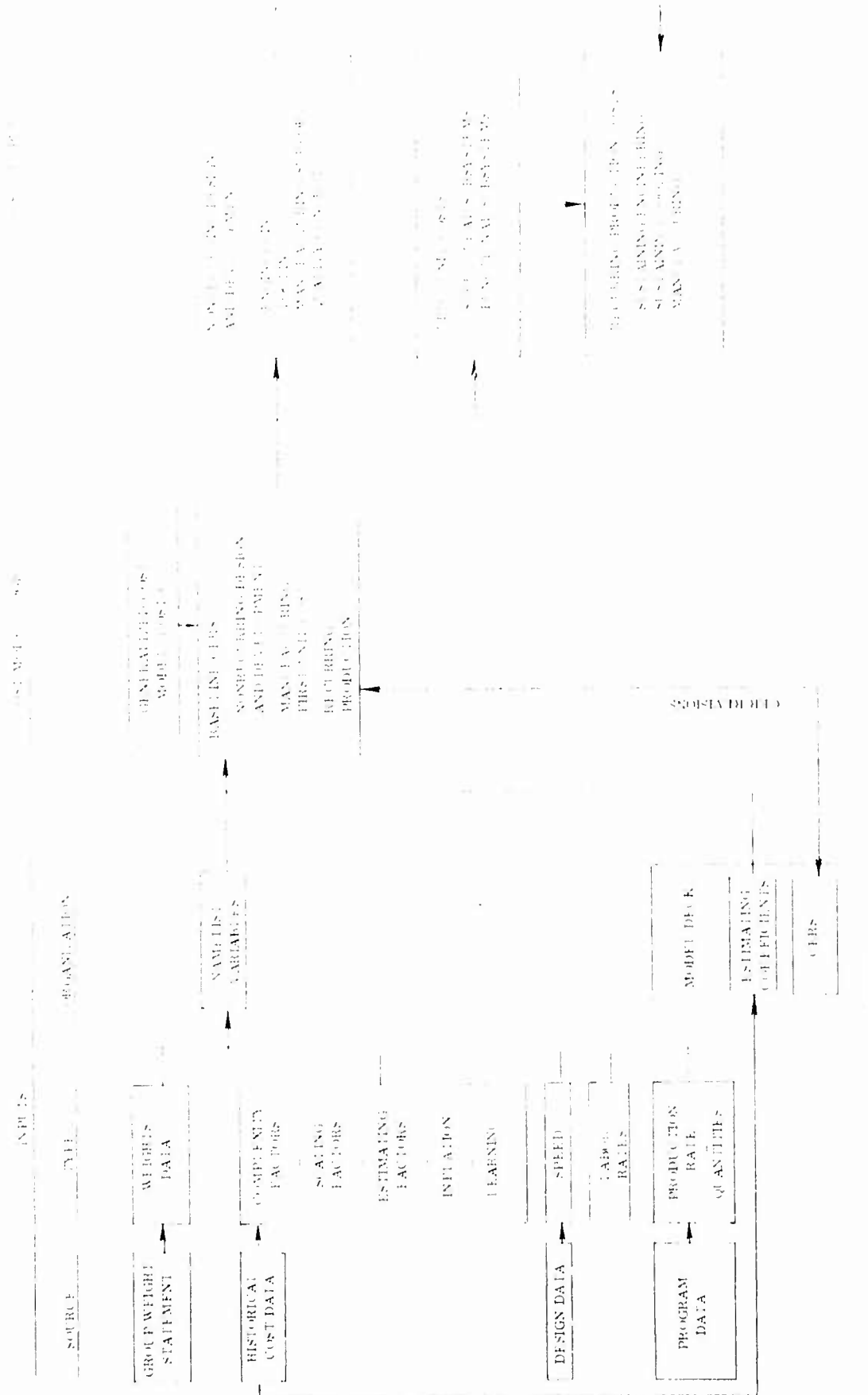


Figure 13. System Cost Estimating Method.

SUBJECT: [REDACTED]
[REDACTED] [REDACTED]
[REDACTED] [REDACTED]
[REDACTED] [REDACTED]

12.49.56.

34163175

1960	1960	1.00	1.00
1961	1961	1.00	2.00
1962	1962	1.00	3.00
1963	1963	1.00	4.00
1964	1964	1.00	5.00
1965	1965	1.00	6.00
1966	1966	1.00	7.00
1967	1967	1.00	8.00
1968	1968	1.00	9.00
1969	1969	1.00	10.00
1970	1970	1.00	11.00
1971	1971	1.00	12.00
1972	1972	1.00	13.00
1973	1973	1.00	14.00
1974	1974	1.00	15.00
1975	1975	1.00	16.00
1976	1976	1.00	17.00
1977	1977	1.00	18.00
1978	1978	1.00	19.00
1979	1979	1.00	20.00
1980	1980	1.00	21.00
1981	1981	1.00	22.00
1982	1982	1.00	23.00
1983	1983	1.00	24.00
1984	1984	1.00	25.00
1985	1985	1.00	26.00
1986	1986	1.00	27.00
1987	1987	1.00	28.00
1988	1988	1.00	29.00
1989	1989	1.00	30.00
1990	1990	1.00	31.00
1991	1991	1.00	32.00
1992	1992	1.00	33.00
1993	1993	1.00	34.00
1994	1994	1.00	35.00
1995	1995	1.00	36.00
1996	1996	1.00	37.00
1997	1997	1.00	38.00
1998	1998	1.00	39.00
1999	1999	1.00	40.00
2000	2000	1.00	41.00
2001	2001	1.00	42.00
2002	2002	1.00	43.00
2003	2003	1.00	44.00
2004	2004	1.00	45.00
2005	2005	1.00	46.00
2006	2006	1.00	47.00
2007	2007	1.00	48.00
2008	2008	1.00	49.00
2009	2009	1.00	50.00
2010	2010	1.00	51.00
2011	2011	1.00	52.00
2012	2012	1.00	53.00
2013	2013	1.00	54.00
2014	2014	1.00	55.00
2015	2015	1.00	56.00
2016	2016	1.00	57.00
2017	2017	1.00	58.00
2018	2018	1.00	59.00
2019	2019	1.00	60.00
2020	2020	1.00	61.00
2021	2021	1.00	62.00
2022	2022	1.00	63.00
2023	2023	1.00	64.00
2024	2024	1.00	65.00
2025	2025	1.00	66.00
2026	2026	1.00	67.00
2027	2027	1.00	68.00
2028	2028	1.00	69.00
2029	2029	1.00	70.00
2030	2030	1.00	71.00
2031	2031	1.00	72.00
2032	2032	1.00	73.00
2033	2033	1.00	74.00
2034	2034	1.00	75.00
2035	2035	1.00	76.00
2036	2036	1.00	77.00
2037	2037	1.00	78.00
2038	2038	1.00	79.00
2039	2039	1.00	80.00
2040	2040	1.00	81.00
2041	2041	1.00	82.00
2042	2042	1.00	83.00
2043	2043	1.00	84.00
2044	2044	1.00	85.00
2045	2045	1.00	86.00
2046	2046	1.00	87.00
2047	2047	1.00	88.00
2048	2048	1.00	89.00
2049	2049	1.00	90.00
2050	2050	1.00	91.00
2051	2051	1.00	92.00
2052	2052	1.00	93.00
2053	2053	1.00	94.00
2054	2054	1.00	95.00
2055	2055	1.00	96.00
2056	2056	1.00	97.00
2057	2057	1.00	98.00
2058	2058	1.00	99.00
2059	2059	1.00	100.00
2060	2060	1.00	101.00
2061	2061	1.00	102.00
2062	2062	1.00	103.00
2063	2063	1.00	104.00
2064	2064	1.00	105.00
2065	2065	1.00	106.00
2066	2066	1.00	107.00
2067	2067	1.00	108.00
2068	2068	1.00	109.00
2069	2069	1.00	110.00
2070	2070	1.00	111.00
2071	2071	1.00	112.00
2072	2072	1.00	113.00
2073	2073	1.00	114.00
2074	2074	1.00	115.00
2075	2075	1.00	116.00
2076	2076	1.00	117.00
2077	2077	1.00	118.00
2078	2078	1.00	119.00
2079	2079	1.00	120.00
2080	2080	1.00	121.00
2081	2081	1.00	122.00
2082	2082	1.00	123.00
2083	2083	1.00	124.00
2084	2084	1.00	125.00
2085	2085	1.00	126.00
2086	2086	1.00	127.00
2087	2087	1.00	128.00
2088	2088	1.00	129.00
2089	2089	1.00	130.00
2090	2090	1.00	131.00
2091	2091	1.00	132.00
2092	2092	1.00	133.00
2093	2093	1.00	134.00
2094	2094	1.00	135.00
2095	2095	1.00	136.00
2096	2096	1.00	137.00
2097	2097	1.00	138.00
2098	2098	1.00	139.00
2099	2099	1.00	140.00
2100	2100	1.00	141.00
2101	2101	1.00	142.00
2102	2102	1.00	143.00
2103	2103	1.00	144.00
2104	2104	1.00	145.00
2105	2105	1.00	146.00
2106	2106	1.00	147.00
2107	2107	1.00	148.00
2108	2108	1.00	149.00
2109	2109	1.00	150.00
2110	2110	1.00	151.00
2111	2111	1.00	152.00
2112	2112	1.00	153.00
2113	2113	1.00	154.00
2114	2114	1.00	155.00
2115	2115	1.00	156.00
2116	2116	1.00	157.00
2117	2117	1.00	158.00
2118	2118	1.00	159.00
2119	2119	1.00	160.00
2120	2120	1.00	161.00
2121	2121	1.00	162.00
2122	2122	1.00	163.00
2123	2123	1.00	164.00
2124	2124	1.00	165.00
2125	2125	1.00	166.00
2126	2126	1.00	167.00
2127	2127	1.00	168.00
2128	2128	1.00	169.00
2129	2129	1.00	170.00
2130	2130	1.00	171.00
2131	2131	1.00	172.00
2132	2132	1.00	173.00
2133	2133	1.00	174.00
2134	2134	1.00	175.00
2135	2135	1.00	176.00
2136	2136	1.00	177.00
2137	2137	1.00	178.00
2138	2138	1.00	179.00
2139	2139	1.00	180.00
2140	2140	1.00	181.00
2141	2141	1.00	182.00
2142	2142	1.00	183.00
2143	2143	1.00	184.00
2144	2144	1.00	185.00
2145	2145	1.00	186.00
2146	2146	1.00	187.00
2147	2147	1.00	188.00
2148	2148	1.00	189.00
2149	2149	1.00	190.00
2150	2150	1.00	191.00
2151	2151	1.00	192.00
2152	2152	1.00	193.00
2153	2153	1.00	194.00
2154	2154	1.00	195.00
2155	2155	1.00	196.00
2156	2156	1.00	197.00
2157	2157	1.00	198.00
2158	2158	1.00	199.00
2159	2159	1.00	200.00
2160	2160	1.00	201.00
2161	2161	1.00	202.00
2162	2162	1.00	203.00
2163	2163	1.00	204.00
2164	2164	1.00	205.00
2165	2165	1.00	206.00
2166	2166	1.00	207.00
2167	2167	1.00	208.00
2168	2168	1.00	209.00
2169	2169	1.00	210.00
2170	2170	1.00	211.00
2171	2171	1.00	212.00
2172	2172	1.00	213.00
2173	2173	1.00	214.00
2174	2174	1.00	215.00
2175	2175	1.00	216.00
2176	2176	1.00	217.00
2177	2177	1.00	218.00
2178	2178	1.00	219.00
2179	2179	1.00	220.00
2180	2180	1.00	221.00
2181	2181	1.00	222.00
2182	2182	1.00	223.00
2183	2183	1.00	224.00
2184	2184	1.00	225.00
2185	2185	1.00	226.00
2186	2186	1.00	227.00
2187	2187	1.00	228.00
2188	2188	1.00	229.00
2189	2189	1.00	230.00
2190	2190	1.00	231.00
2191	2191	1.00	232.00
2192	2192	1.00	233.00
2193	2193	1.00	234.00
2194	2194	1.00	235.00
2195	2195	1.00	236.00
2196	2196	1.00	237.00
2197	2197	1.00	238.00
2198	2198	1.00	239.00
2199	2199	1.00	240.00
2200	2200	1.00	241.00
2201	2201	1.00	242.00
2202	2202	1.00	243.00
2203	2203	1.00	244.00
2204	2204	1.00	245.00
2205	2205	1.00	246.00
2206	2206	1.00	247.00
2207	2207	1.00	248.00
2208	2208	1.00	249.00
2209	2209	1.00	250.00
2210	2210	1.00	251.00
2211	2211	1.00	252.00
2212	2212	1.00	253.00
2213	2213	1.00	254.00
2214	2214	1.00	255.00
2215	2215	1.00	256.00
2216	2216	1.00	257.00
2217	2217	1.00	258.00
2218	2218	1.00	259.00
2219	2219	1.00	260.00
2220	2220	1.00	261.00
2221	2221	1.00	262.00
2222	2222	1.00	263.00
2223	2223	1.00	264.00
2224	2224	1.00	265.00
2225	2225	1.00	266.00
2226	2226	1.00	267.00
2227	2227	1.00	268.00
2228	2228	1.00	269.00
2229	2229	1.00	270.00
2230	2230	1.00	271.00
2231	2231	1.00	272.00
2232	2232	1.00	273.00
2233	2233	1.00	274.00
2234	2234	1.00	275.00
2235	2235	1.00	276.00
2236	2236	1.00	277.00
2237	2237	1.00	278.00
2238	2238	1.00	279.00
2239	2239	1.00	280.00
2240	2240	1.00	281.00
2241	2241	1.00	282.00
2242	2242	1.00	283.00
2243	2243	1.00	284.00
2244	2244	1.00	285.00
2245	2245	1.00	286.00
2246	2246	1.00	287.00
2247	2247	1.00	288.00
2248	2248	1.00	289.00
2249	2249	1.00	290.00
2250	2250	1.00	291.00
2251	2251	1.00	292.00
2252	2252	1.00	293.00
2253	2253	1.00	294.00
2254	2254	1.00	295.00
2255	2255	1.00	296.00
2256	2256	1.00	297.00
2257	225		

Figure 14. Nonrecurring Design and Development Costs - Page 1.

Aerospace Vehicle Airframe System Costs

Nonrecurring Design and Development Costs

Basic Structure

12.49.54. 01/09 75

	Wing	Horiz Stab	Vert Stab	Fuse lage	Nac elle	Ldc Gear	Sub system	Total Hours	Total \$
Tooling									
Basic Tool Mfg D.L. Hrs	3.010		.187	1.267	1.402	.204	3.005	9.164	
Rate Tool Mfg. D.L. Hrs	.738		.046	.311	.344	.077	.708	2.249	
Total Tool Mfg	3.748		.233	1.578	1.746	.281	3.713	11.413	74.867
Basic Tool Engrg D.L. Hrs	1.204		.075	.507	.561	.117	1.292	3.659	
Rate Tool Engrg D.L. Hrs	.111		.007	.047	.052	.010	.111	.327	
Total Tool Engrg	1.315		.082	.554	.613	.127	1.403	4.086	23.754
Tool Material									21.375
Manufacturing Aids								1.003	11.123
Manufacturing Development								1.000	11.126
Total Tooling									108.570
Manufacturing Support								1.854	274.445
Quality Control									12.500

Figure 15. Nonrecurring Design and Development Costs Page 2.

AEROSPACE VEHICLE AIRFRAME SYSTEM COSTS

FIRST UNIT COSTS

12,49,54. 31/09/75

	RECT LABOR COSTS	RECT LABOR COSTS	WTL COSTS	LABOR +MATE (S)
BASIC STRUCTURE				5.199
FUS				
LONGITUDINAL STABILIZER				.570
VERTICAL STABILIZER				5.000
FUSELAGE				1.413
WHEELS				.642
LANDING GEAR				
SUBSYSTEMS				2.452
CONTROL CONTROLS				.806
ENVIRONMENTAL CONTROL SYS				.700
HYDRAULIC/POWER/HEATING				.400
ELECTRONIC				1.034
ELECTRIC POWER UNIT				.190
AVIATION PROVISIONS				.289
ENGINE ASSOCIATED EQUIP				.792
FUEL SYSTEM				.789
AVIONICS PROVISIONS				.657
AVIATION + EQUIPMENT				7.731
CONVERTING MATERIAL				27.120
TOTAL FIRST UNIT COST				

Figure 16. First Unit Costs.

APPROPRIATE AIRFRAME SYSTEM COSTS

RECURRING AIRFRAME MANUFACTURING COSTS

	ADJUST	2	ADJUST	3	ADJUST	3
SUSTAINING ENGINEERING	4,563	23,732	2,875	19,863		
ENGINEERING TOOLING	9,993	57,750	4,493	29,360		
MANUFACTURING						
COSTS		80,483		119,575		
CONSTRUCTION/REPAIRS						
STRUCTURAL COMPONENTS		7,075		11,119		
ELECTRICAL		77,635		115,932		
EQUIPMENT		19,772		27,700		
MATERIALS		9,069		15,761		
LABOR		34,741		64,937		
OVERHEADS		12,743		22,661		
ELECTRICAL/ELECTRONICS		4,840		9,594		
ELECTRICAL		14,765		25,541		
ELECTRONICS		16,819		29,661		
EQUIPMENT		3,000		5,449		
EQUIPMENT		1,000		7,288		
EQUIPMENT		10,000		20,000		
EQUIPMENT		5,000		10,000		
EQUIPMENT		10,000		19,472		
EQUIPMENT		715,701		507,743		
TOTAL MANUFACTURING						

17,49,54.

25/03/75

Figure 17. Recurring Airframe Production Cost.

Engineering Direct Labor Hours

$$\text{Engrg. DLH} = KR_1 (W_i)^E$$

where:

K = Complexity factor related to design category

R_1 = Statistical estimating coefficient

W_i = Estimated weight of the component being estimated

E = Scaling of hours to weight

Tool Manufacturing Direct Labor Hours

$$\text{Tool Mfg.} = KR_2 (W_i)^F$$

where:

K = Complexity factor related to tooling category

R_2 = Statistical estimating coefficient

W_i = Estimated weight of the component being estimated

F = Scaling of hours to weight

Manufacturing First Unit Cost

$$\text{Mfg. Cost} = K_a W_i^b$$

where:

K = Complexity factor related to category of manufacture

a = Statistical estimating coefficient

W_i = Estimated weight of the component being estimated

b = Scaling of cost to weight

Figure 18. Typical CERs — System Cost Estimating Method

each method. The relationship between inputs and CERs is similar to the Trade Study method. A general idea of the input organization is furnished by Figure 13. Section 3.2 provides a complete description of that portion of the cost model computer program comprising the system costing method.

Input development for the system costing method can be explained with reference to Figure 13. Weights data is obtained from a standard group weight statement. Complexity factors, scaling factors, estimating factors, and factors for inflation and learning are derived from historical cost data. The concept of complexity at this level of estimating is different than at the trade study level. Speed is used as a cost related variable in estimating one element of cost and is obtained from the design data. Labor rates are selected and input as appropriate. Production rates and quantities are obtained from program schedules.

The development of baseline costing factors and complexity factors is again inter-related. Their development is explained in Volume I, Section III.

In the system costing method, manufacturing costs are estimated in dollars by combining labor and materials. This introduces the need for considering economic escalation and the time reference for dollar values. In the trade study method, labor and material are separated and only material costs require an adjustment for inflation.

The two estimating methods can be used in a combined mode whereby a detailed first unit cost estimate from the trade study method can be substituted for the comparable estimate of the system costing method. This mode might be used, for example, when a detailed analysis is required for only one structural component while, at the same time, a total airframe system estimate is needed.

1.2 ORGANIZATION OF THE HANDBOOK

The remainder of the handbook provides complete instructions in the use of the methods briefly described above. The remainder of this section describes the Handbook organization.

Both estimating methods are described in detail: the Trade Study Method in Section II and the System Costing Method in Section III. Similar outlines are followed for each description. The complete set of computer printouts is described under Costs Estimated. The cost model computer program is completely described in Section 2.2. This description is supplemented by appendices that replicate pertinent portions of the program. Section 2.3 provides a type listing of all CERs used, gives input summaries organized by cost category and related to the CERs, cross references items of cost and the corresponding CER, identifies the location of the model card calling out a given calculation, summarizes the values used for estimating coefficients, and locates the relevant back-up data. Section 2.4 gives additional instructions covering the submittal of the program deck to the computer operation.

Section III provides a similar treatment for the system costing method, although modified by differences in the methods and by the simplification from the use of a common computer program. Section IV describes a demonstration case performed for three purposes:

- a. To illustrate the description of methods.
- b. To demonstrate the estimating capability.
- c. To provide a basis for testing the installation of the capability at AFFDL.

Included in the discussion of the demonstration cases in Section IV is a discussion of how the two methods can be used in a combined fashion.

SECTION II

TRADE STUDY COST ESTIMATING METHOD

This section describes the trade study cost estimating method and provides the user with the instructions necessary for making an estimate, including information relevant to the supporting design synthesis programs involved. The subject of methods research and development is covered either in Volume I or in previous reports, as referenced.

2.1 COSTS ESTIMATED

Costs are estimated in a variety of ways for each of the following hardware components:

Aerodynamic Surfaces:

Wing

Horizontal Stabilizer

Vertical Stabilizer

Fuselage

Nacelles

Landing Gears

The different types of cost outputs provided consist of:

- a. First Unit Manufacturing Costs
- b. RDT&E Units Manufacturing Costs
- c. Production Units Manufacturing Costs - Quantity 1
- d. Production Units Manufacturing Costs - Quantity 2
- e. Nonrecurring Design and Development Costs
- f. Recurring Production Costs - Summary

The combination of components and types of output produces 36 separate printouts for a given cost estimate. Shown in Section 1.1.1 was four types of output corresponding to a, b, c, and f above. Output types c and d are identical to type b except for the production quantity involved. The variation in output format by hardware component is illustrated by Figures 19 through 24, representing first unit cost for each component. The 36 printouts are summarized in Table 2. The hardware components

27

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(To provide for the Horizontal Stabilizer in the print-out sequence, since the test case aircraft (B-58) does not have this element.)

Figure 20. Horizontal Stabilizer First Unit Cost.

一、
 二、
 三、
 四、
 五、
 六、
 七、
 八、
 九、
 十、

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[illegible]

Figure 21. Vertical Stabilizer First Unit Cost.

FIRST UNIT COST

NACELLES

17.29.46. 01/03/75

	CTTL HOURS	SUB- ACTV HOURS	MAJOR ACTV HOURS	PRIM- ACTV HOURS	MAJOR ACTV HOURS	MATL COST \$	TOTAL LABOR HOURS	TOTAL LABOR COST \$	TOTAL COST \$
COILING	27340	19755				59205			
RYING	15750	8135				26202			
WELD L25 GEAR COORS + REINFORC ASSEMBLY			36893						
NACELLES SUB-TOTALS	54870	27890	23933			55010			
LABOR COSTS (\$)	341672	170595	244835						
NACELLES REMOVAL	5419	2787	1834			8601			
NACELLES TOTAL	59792	70765	42767	10661	5330	64611			
LABOR COSTS (\$)	375500	163064	260043	67056	13523		149251	338787	1033733
TOTALS									

Figure 23. Nacelles First Unit Cost.

15-00000

1929.29.26.

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[illegible]

Table 2. Summary of Cost Printouts for a Trade Study Estimate.

Hardware Component	Type of Cost Printout					
	First Unit Cost	RDT&E Units Cost	Production Units Quantity 1	Production Units Quantity 2	Nonrecurring Design & Development	Recurring Production Summary
Aerodynamic Surfaces:						
Wing	X	X	X	X	X	X
Horizontal Stabilizer	X	X	X	X	X	X
Vertical Stabilizer	X	X	X	X	X	X
Fuselage	X	X	X	X	X	X
Nacelles	X	X	X	X	X	X
Landing Gears	X	X	X	X	X	X

listed comprise the basic structure, or "airframe," when related to trade study methodology.

Production quantities are obtained by learning curve projections of the first unit costs for each item of cost broken out. This permits giving effect to different degrees of learning involved in different types of material and construction.

The relationship of the above subset of costs to a complete weapon system cost structure and to the CIR definitions of cost elements is covered in Volume I, Section 2.2.2-1.

2.2 COST MODEL COMPUTER PROGRAM

The computer program serves to organize the cost estimating task. The estimating process is accomplished in terms of going to the proper sources for the necessary input data, evaluating estimating coefficients in view of additional data acquisition and previous estimating results, and setting up the computer program deck. The cost estimating logic is also of immediate relevance, but its discussion has been deferred to Section 2.3 so that computer oriented terminology will have been covered.

The cost model computer program makes use of a general cost model program (designated as COSTC) taking advantage of certain features of that program. COSTC is a data manager program written in FORTRAN IV for the CDC CYBER 72. Features include treating the cost estimating logic as a program input, handling the cost output as an array (called the SAV matrix) in a manner whereby it is both addressable and displayable, and providing for a consistent pattern of costing in going from one hardware element to the next.

Treating the estimating logic as a program input provides a simple means of modifying cost estimating relationships. These are accomplished simply by changing an input model card and making an appropriate input variable change. Changes to estimating coefficients, which might, for example, result from additional analyses of historical cost data, can be accomplished simply by an input model card change; and if a time-sharing set-up is being used, this can be done on the card and graphically on a CRT display by means of a keyboard control.

Use of the SAV array printout provides for a display of intermediate computational results and permits the cost analyst to utilize computational results that are not typically available in a cost output format. Elements in this array may be used as terms in the cost estimating relationships.

The deck set-up for the complete cost program was shown in Figure 7. As can be seen, the major elements of the program are the control cards, the program deck, title and option cards, the variable input, i.e., NAMELIST, section of the input

section, and the model cards of this same section. The various elements of the program, including a NAMELIST variable dictionary and a summary of estimating coefficients, are described in the following sections.

2.2.1 CONTROL CARDS. The control cards entail an optional compiler usage. At Convair the program is compiled with the "RUN" compiler, but it may be compiled by either "RUN" or "FTN" compilers. The control cards for the use of a source deck with the "RUN" compiler are:

```
RUN.  
LGO.  
REWIND (TAPE 5)  
COPYSBF (TAPE 5, OUTPUT)  
EXIT.
```

The control cards for source decks under the "FTN" compiler are:

```
FTN.  
LGO.  
REWIND (TAPE 5)  
COPYSBF (TAPE 5, OUTPUT)  
EXIT.
```

The control cards for binary decks under either compiler are:

```
INPUT.  
REWIND (TAPE 5)  
COPYSBF (TAPE 5, OUTPUT)  
EXIT.
```

The control cards for updating a routine and executing the updated package with the "RUN" compiler are:

```
RUN (P)  
COPYBR (LGO, DISK)  
REWIND (LGO, DISK)  
COPYL (DISK, LGO, NPL)  
REWIND (NPL)  
NPL.  
REWIND (TAPE 5)
```

COPYSBF (TAPE 5, OUTPUT)

EXIT.

7 8 9

2.2.2 PROGRAM DECK. The program deck consists of the COSTC general cost program, plus subroutines and functions as follows:

Driver: Program COSTC

The driver initializes all variables, reads in the input cards, checks program options, and executes various subroutines as "KEY" input cards are recognized.

Subroutine: GETPAR

This routine determines what is contained in each field of ten characters of the 'Z' and 'R' cards and returns this information.

Subroutine: SEARCH

This routine searches the variable name array and returns the subscript that corresponds to the name requested.

Subroutine: EXPR

This routine evaluates the expression between parenthesis used by the 'F' card.

Subroutine: CHECK

This routine checks to see if the next card is a continuation card.

Subroutine: TITLE

This routine is used to print titles.

Function: PWORD

This function selects nonblank characters from variable names and left adjusts them in PWORD.

Function: NUMBER

This function gets an integer from any vector between given locations.

Function: MRGCRD

This function checks for several of the "KEY" denoters for the merge option.

Subroutine: RECORD

This subroutine interrogates input cards for a line location in the SAV array.

Function: ICHKLIN

This function checks lines in the array SAV for zero values.

Subroutine: FINDINT

This subroutine finds the single integer up to 99 from an input field.

Subroutine: TMERGE

This subroutine merges new input cards with the current cost model.

Function: ROUND

This function rounds a real number to two decimal places.

Function: VALUE

This function finds the value of a term, parameter, or a coefficient.

Subroutine: EQEVAL

This subroutine is the driver for the 'F' cards of the model cards.

Function: IPACK

This function packs characters of input fields for input to subroutine GETPAR.

Subroutine: UNPAK

This subroutine puts data into a predetermined number of separate words for output.

Function: TERM

This function computes terms involving parameters and coefficients. Coefficients are input as real numbers and parameters are variable inputs or recalled sums.

Subroutine: READW

This subroutine reads input variables from the namelists, SIZE, CURVE, and SUMMARY.

2.2.3 INPUT CARDS. The input cards consist of the following subsets:

TITLE CARD

OPTION CARD

NAMELIST INPUT CARDS

MODEL CARDS

A general flow diagram of the input sequence is shown in Figure 25. A printout of a complete set of input cards is shown in Appendix A.

The Title card uses 80 columns of alphanumeric data to be printed as the main title. The Option card is composed as follows:

<u>Column</u>		
1-5	CLEAR	If this word is punched in this field, the variables are set to 0 before reading the new variables.
	blank	If the field is blank, the variables used in the previous case are not cleared before reading new variables.
6-10	CARDS	If the model is going to be read from cards.
	TAPE2	If the model cards are either on Tape 2 for the first case only or the previous cost model information is to be reused.
	MERGE	If the model cards are either merged from card input and TAPE2 for the first case only or the previous model data is merged with revised cards thereafter.
11-15	Integer that specifies the maximum number of variables to be used by an element of the model.	
16-20	Name of Element 1, i.e., Wing	
21-25	Name of Element 2, i.e., Horizontal Stabilizer	
26-30	... etc. ...	

Columns 6-10 of the Option card control the form of the input data. TAPE 2 indicates that the model cards have been entered on tape by appropriate request. Entering the word MERGE provides for obtaining input from both TAPE and new input cards and is used for any change in input values or CERs for multicase runs.

When the MERGE option is being used, the program will assume that a baseline model has been previously stored on tape and that the cards contained in the Cost Model section of input are to be merged with the baseline model to produce and process an updated model. The following rules should be observed when merging:

- a. Z, R and F cards only can be merged.
- b. When replacing an element of the SAV matrix all the terms that make up that element should be replaced.

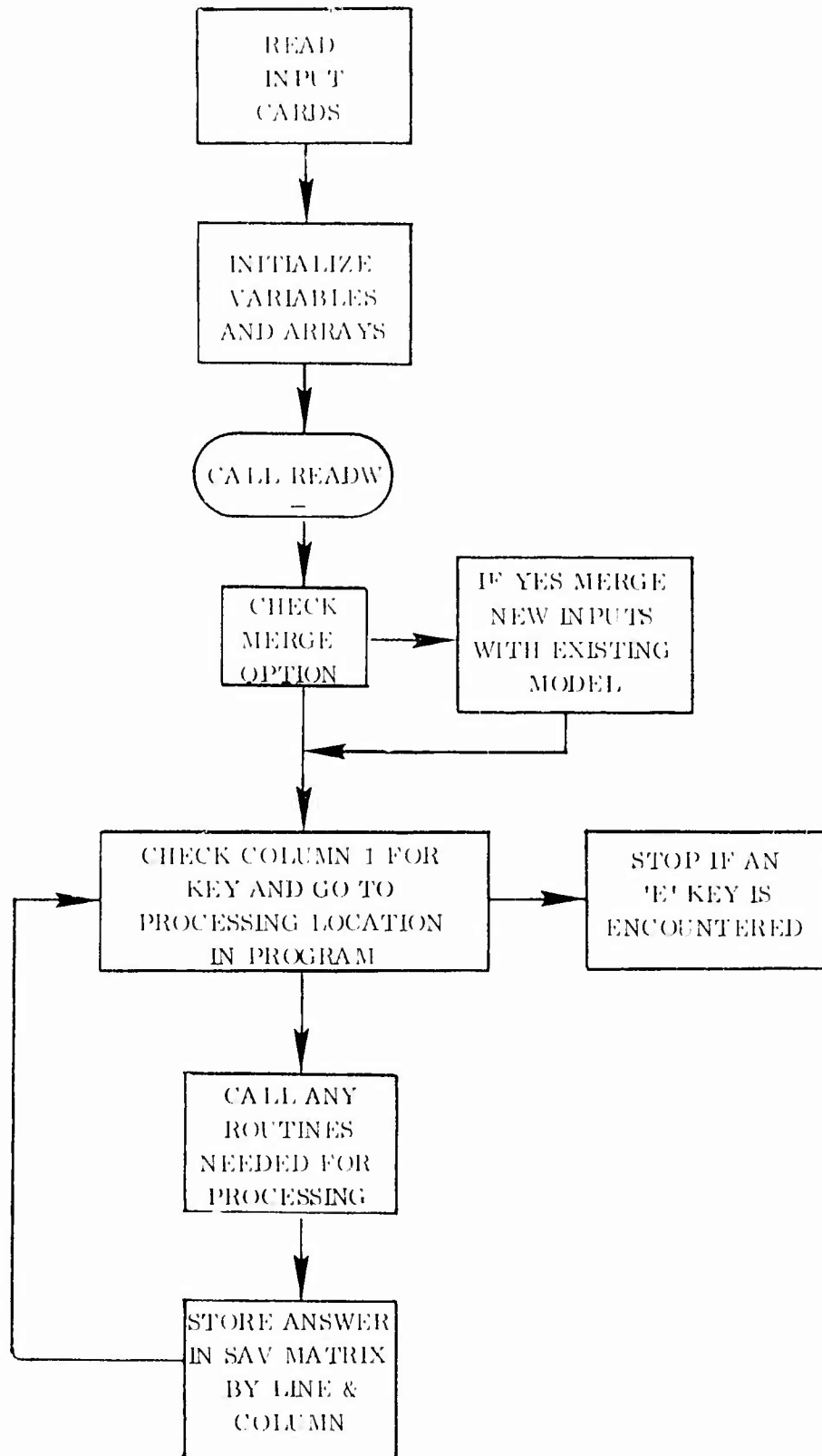


Figure 25. Cost Model General Flow Diagram.

- c. Merge cards should be ordered monotonically increasing by line and column number.
- d. New columns may be inserted to a defined line in the baseline model. New lines may not be inserted.
- e. A combination of Z-cards may replace an R-card. The converse is not valid.

NAMelist input cards record the input variables. The NAMelist identifiers are SIZE and CURVE. (NAMelist SUMMARY is part of the system costing method). One set of variables in a SIZE or CURVE block corresponds to an element of the model. As many blocks are read as are specified by the number of elements punched in the option card, and the inclusion or exclusion of an element is controlled by the option card. Sets of variables must then be furnished to correspond.

The first case should contain all the variables that are used by the model. For subsequent cases, only the variables that are to be changed are input. Variables are stored in a single dimensional array called PL. They are stored by elements and are printed out by element for each case run. A sample input element printout is shown in Appendix B.

The model cards consist of a series of different type cards that carry the costing logic. These cards perform different functions, and column one of each card is used as a "key" to determine the specific function of that card. The various types of cards and their function are described in Appendix A.

2.2.4 THE COSTC PROGRAM. The COSTC program is a general cost model that acts as a data manager. It provides a printed-out array of the results of the calculations directed by the model cards. This printout is called the SAV matrix, and a sample printout is shown in Appendix C. It is organized in lines and columns, which are numbered and which are addressable by the model cards. A value "stored" in any element of this matrix may be used as a term, and manipulated by certain types of model cards. The SAV matrix is dimensioned by the driver program, COSTC. The number of rows in the matrix corresponds to the number of lines containing cost values that are to be printed out. It is limited only by the dimension statement and, in turn, core capacity. The current program is dimensioned for 699 lines and 12 columns. A 13th column is used for summing a given line. The number of columns in the matrix corresponds to the number of columns that may be printed out. The program presets the SAV matrix to zeroes before the execution of a run. Terms are computed and added to a specific location in the matrix addressed by line and column number by the operative model cards. As an example of the operation of the matrix and the correspondence to the model cards, reference is made to Appendix A, a listing of the input deck, and Appendix C, a sample SAV matrix.

In Appendix A the first F-card entry appears as follows:

$$F 5 1 W1 WNG + CF1 WNG + W2 WNG + CF2 WNG + W3 WNG + CF3 WNG$$

This is an "F" card as noted by the F in the first column. The SAV matrix line is 5 and the column is 1. In Appendix C, the SAV Matrix, on the first line, line 5, in the first column will be found recorded the results of this calculation (the sum of rib type weights and complexity factor products).

As another example of the relationship, Appendix A shows

$$F 16 1 ((5,3) + (6,3) + (7,3)) + .20 + (15,8) + 2.0.$$

This translates as follows:

Enter on line 16, column 1, of the SAV matrix the sum of line 5, column 3, line 6, column 3, and line 7, column 3, multiplied by .20 and the value entered in line 15, column 8, multiplied by two. This program thus provides visibility of computations and provides a high degree of programming flexibility.

The functions of the various types of model cards are described in Appendix A, including the rules applicable to the use of each type of card. The cards are discussed in the order in which they appear in the printout in Appendix A, except that all of the input oriented cards are grouped together and discussed first. The complete list of card types in the order in which they appear in the model deck, is B-card; 1-card; 2-card; 3-card; F-card; blank-card; C-card; N-card; T-card; D-card; R-card; P-card; Z-card; L-card; and E-card. The input oriented cards are: F-card; R-card; Z-card.

2.2.5 INPUT ORGANIZATION. Figure 1 showed inputs organized as NAMELIST variables and Model Cards. As described above NAMELIST variables are recorded on the NAMELIST input cards. Model cards, in addition to providing the estimating logic in the form of CERs, contain what are called estimating coefficients, which were briefly mentioned in connection with Figure 9. These appear as constants on a given input card but are, however, subject to change. A discussion of these so-called F-card variables and how they might change in value (giving them the effect of an input variable) is needed to completely describe the organization of inputs. NAMELIST variables are subject to change with each study case, whereas the F-card variables do not usually change from case to case and usually change only as the result of additional cost research.

Revisions can be made in the above categorization, if need dictates, simply by changing the F-card to indicate the variable name rather than a constant and by including the variable in NAMELIST. It can be seen from this comment that the distinction is partially one of convenience describing the type of input card manipulation required

for a new input. The nature of the F-card variable will become clear from the discussion in Section 2.3. A dictionary of NAMELIST variables is provided in Appendix D. A summary of estimating coefficients, or F-card variables, is provided in Appendix E. Section 2.3 provides a complete discussion of CERs, the resulting input requirements and input sources, and a referencing of back-up data.

2.3 COST ESTIMATING RELATIONSHIPS AND INPUT DESCRIPTION

The step by step development of input data includes providing NAMELIST variable inputs and determining the suitability of estimating coefficients called out by the CERs and recorded as model card coefficients. Tables are provided for the purpose of cross referencing individual costs as given in the various computer printouts, the pertinent CER equation number to be described and the model card location within the computer program.

2.3.1 FIRST UNIT COST. Theoretical first unit cost is used as a means of estimating recurring manufacturing costs. Manufacturing costs for the production quantities for which estimates are desired are obtained by learning curve projections against this theoretical first unit cost. First unit costs are estimated by a series of general CERs that are used in a specified sequence to estimate major structural components: wing, horizontal stabilizer, vertical stabilizer, fuselage, nacelle, and landing gear. The computer program controls the repetitive use of the CERs with the input data serving as the key to the structural elements and categories of cost that are estimated. Tables 3, 4, 5, 6, 7 and 8 cross reference the cost printout, CERs and model cards for the above structural elements. Operations such as subtotalling and the conversion of labor hours to dollars are handled within the program model deck.

The general CERs that provide these estimates and the input requirement that is generated by their repetitive use, matched to the output shown, are discussed below. The discussion of inputs will provide a transition from the estimating output to the CER structure and a means of identifying the computational indices applicable to the general CERs.

Detail fabrication and subassembly hours and material costs are estimated for each item listed, if the structural component occurs on the aircraft being estimated. The CER structure provides for the simultaneous evaluation of up to three different types of ribs, spars, and covers with respect to these cost categories. The structural box major assembly hours subtotal is estimated by means of a series of CERs as described.

Structural material costs are considered in two general classes: the cost of raw material for the fabrication of structural components and the cost of assembly hardware, which includes fasteners, seals, bearings, paint, preservatives and other

Table 3. Cost Output, CER Equation, and Model Card
Cross Reference - Wing First Unit Cost.

Hardware Components	Detail Fabrication Hours	Subassembly Hours	Major Assembly Hours	Primary Assembly Hours	Major Mate Hours	Material Cost
Structural Box						
Ribs	Eq (1) F 31 1	Eq (2) F 31 2				Eq (16) F 31 6
Spurs	Eq (1) F 32 1	Eq (2) F 32 2				Eq (16) F 32 6
Covers	Eq (1) F 33 1	Eq (2) F 33 2				Eq (16) F 33 6
Assembly			Eq (3-9) F 34 3			Eq (18) F 34 6
Secondary Structure						
Leading Edge	Eq (10) F 38 1	Eq (11) F 38 2				Eq (17) F 38 6
Trailing Edge	Eq (10) F 39 1	Eq (11) F 39 2				Eq (17) F 39 6
Ailerons	Eq (10) F 40 1	Eq (11) F 40 2				Eq (17) F 40 6
Fairings	Eq (10) F 41 1	Eq (11) F 41 2				Eq (17) F 41 6
Tips	Eq (10) F 42 1	Eq (11) F 42 2				Eq (17) F 42 6
Spoilers	Eq (10) F 43 1	Eq (11) F 43 2				Eq (17) F 43 6
Flaps and Flaperons	Eq (10) F 44 1	Eq (11) F 44 2				Eq (17) F 44 6
Attachment Structure	Eq (10) F 45 1	Eq (11) F 45 2				Eq (17) F 45 6
Access and Other Doors	Eq (10) F 46 1	Eq (11) F 46 2				Eq (17) F 46 6
Air Induction	Eq (10) F 47 1	Eq (11) F 47 2				Eq (17) F 47 6
High Lift Ducting	Eq (10) F 48 1	Eq (11) F 48 2				Eq (17) F 48 6
Slats	Eq (10) F 49 1	Eq (11) F 49 2				Eq (17) F 49 6
Hinges, Brackets, Seals	Eq (10) F 50 1	Eq (11) F 50 2				Eq (17) F 50 6
Pivots and Folds	Eq (10) F 51 1	Eq (11) F 51 2				Eq (17) F 51 6
Center Section	Eq (10) F 52 1	Eq (11) F 52 2				Eq (17) F 52 6
Other	Eq (10) F 53 1	Eq (11) F 53 2				Eq (17) F 53 6
Assembly			Eq (12-13) F 54 3			Eq (19) F 54 6
Rework	Eq (15) F 58 1	Eq (15) F 58 2	Eq (15) F 58 3	Eq (20) F 59 4	Eq (21) F 59 5	Eq (15) F 58 6
Totals						

Table 4. Cost output, CER Equation, and Model Card Cross Reference -
Horizontal Stabilizer First Unit Cost.

Hardware Components		Detail		Subassembly		Major Assembly		Primary Assembly		Major Mate		Material Cost	
		Fabrication		Hours		Hours		Hours		Hours			
Structural Box													
Ribs		F 101 1		F 101 2								F 101 6	
Spars		F 102 1		F 102 2								F 102 6	
Covers		F 103 1		F 103 2								F 103 6	
Assembly						F 104 3						F 104 6	
Secondary Structure													
Leading Edge		F 105 1		F 105 2								F 105 6	
Trailing Edge		F 109 1		F 109 2								F 109 6	
Fairings		F 110 1		F 110 2								F 110 6	
Tips		F 111 1		F 111 2								F 111 6	
Attachment Structure		F 112 1		F 112 2								F 112 6	
Access & Other Doors		F 113 1		F 113 2								F 113 6	
Hinges, Brackets, Seals		F 114 1		F 114 2								F 114 6	
Pivots & Folds		F 115 1		F 115 2								F 115 6	
Center Section		F 116 1		F 116 2								F 116 6	
Elevators		F 117 1		F 117 2								F 117 6	
Balance Weights		F 118 1		F 118 2								F 118 6	
Assembly						F 119 3						F 119 6	
Rework		F 123 1		F 123 2		F 123 3						F 123 6	
Totals								F 124 1		F 124 5			

Equation numbers are exactly the same as shown for Wing First Unit Cost, Table 3. Equation (10) is used for detail fabrication for all secondary structure hardware components, Equation (11) for subassembly, and Equation (17) for production material. Model card addresses are shown below:

Table 5. Cost Output, CER Equation, and Model Card Cross Reference – Vertical Stabilizer First Unit Cost

Equation numbers are exactly the same as shown for Wing First Unit Cost, Table 3. Equation (10) is used for detail fabrication for all secondary structure hardware components, Equation (11) for subassembly, and Equation (17) for production material. Model card addresses are shown below:						
Hardware Components	Detail Fabrication Hours	Subassembly Hours	Major Assembly Hours	Primary Assembly Hours	Major Mate Hours	Material Cost
Structural Box						
Ribs	F 151 1	F 151 2				F 151 6
Spars	F 152 1	F 152 2				F 152 6
Covers	F 153 1	F 153 2				F 153 6
Assembly			F 154 3			F 154 6
Secondary Structure						
Leading Edge	F 158 1	F 158 2				F 158 6
Trailing Edge	F 159 1	F 159 2				F 159 6
Fairing	F 160 1	F 160 2				F 160 6
Tips	F 161 1	F 161 2				F 161 6
Attachment Structure	F 162 1	F 162 2				F 162 6
Access and Other Doors	F 163 1	F 163 2				F 163 6
Hinges, Brackets, Seals	F 164 1	F 164 2				F 164 6
Rudder	F 165 1	F 165 2				F 165 6
Assembly			F 166 3			F 166 6
Rework	F 170 1	F 170 2	F 170 3			F 170 6
Totals				F 171 4	F 171 5	

Table 6. Cost Output, CER Equation, and Model Card
Cross Reference – Fuselage First Unit Cost.

Equation numbers are exactly the same as shown for Wing First Unit Cost, Table 3, except that Equation (14) is used in place of Equation (12) and Equation (13) is divided by 2 for Secondary Structure Assembly. Equation (16) is used for detail fabrication for all secondary structure hardware components, Equation (14) for secondary structure subassembly, and Equation (17) for secondary structure production materials. Ribs, spars, and covers correspond, respectively, to the Basic Structure component listed below. Model card addresses are shown below:

Hardware Components	Detail Fabrication Hours	Subassembly Hours	Major Assembly Hours	Primary Assembly Hours	Major Mate Hours	Material Cost
Basic Structure						
Frames and Bulkheads	F 201.1	F 201.2				F 201.6
Longerons	F 202.1	F 202.2				F 202.6
Skins and Stringers	F 203.1	F 203.2				F 203.6
Assembly			F 204.3			F 204.6
Secondary Structure						
Cockpit	F 208.1	F 208.2				F 208.6
Nose Landing Gear Door & Box	F 209.1	F 209.2				F 209.6
Wing Reaction Box	F 210.1	F 210.2				F 210.6
Tail Attachment	F 211.1	F 211.2				F 211.6
Windshield & Canopy	F 212.1	F 212.2				F 212.6
Main Landing Gear Door & Box	F 213.1	F 213.2				F 213.6
Fuel Provisions	F 214.1	F 214.2				F 214.6
Engine Provisions	F 215.1	F 215.2				F 215.6
Duct Provisions	F 216.1	F 216.2				F 216.6
Stores Provisions	F 217.1	F 217.2				F 217.6
Speed Brakes	F 218.1	F 218.2				F 218.6
Cabin Flooring & Supports	F 219.1	F 219.2				F 219.6
Window & Window Frames	F 220.1	F 220.2				F 220.6
Doors & Door Frames	F 221.1	F 221.2				F 220.6
Assembly			F 222.3			F 221.6
Rework	F 226.1	F 226.2	F 226.3			F 226.6
Totals				F 227.4	F 227.5	

Table 7. Cost Output, CER Equation, and Model Card Cross Reference - Nacelle First Unit Cost

Equation numbers are exactly the same as the modified structure described for the fuselage, except that there are no Basic Structure components.						
Hardware Components	Detail Fabrication Hours	Subassembly Hours	Major Assembly Hours	Primary Assembly Hours	Major Mate Hours	Material Cost
Secondary Structure						
Cowling	Eq (10) F 271 1	Eq (11) F 271 2				Eq (17) F 271 6
Pylon	Eq (10) F 272 1	Eq (11) F 272 2				Eq (17) F 272 6
Main Landing Gear Doors	Eq (10) F 273 1	Eq (11) F 273 2				Eq (17) F 273 6
Assembly			Eq (14-13) F 274 3			Eq (19) F 274 6
Rework	Eq (15) F 277 1	Eq (15) F 277 2	Eq (15) F 277 3			Eq (15) F 277 6
Totals				Eq (20) F 278 4	Eq (21) F 278 5	

Table 8. Cost Output, CER Equation, and Model Card Cross Reference — Landing Gear First Unit Cost

Equation numbers are exactly the same as outlined for Nacelle First Unit Cost, Table 7. Model card addresses only are shown below:						
Hardware Components	Detail Fabrication Hours	Subassembly Hours	Major Assembly Hours	Primary Assembly Hours	Major Mate Hours	Material Cost
Secondary Structure						
Brakes	F 301 1	F 301 2				F 301 6
Brake Controls	F 302 1	F 302 2				F 302 6
Wheels	F 303 1	F 303 2				F 303 6
Tires	F 304 1	F 304 2				F 304 6
Oleos	F 305 1	F 305 2				F 305 6
Axles, Trunnions & Fittings	F 306 1	F 306 2				F 306 6
Drag Braces	F 307 1	F 307 2				F 307 6
Assembly			F 308 3			F 308 6
Rework			F 311 3			F 311 6
Totals	F 311 1	F 311 2		F 312 4	F 312 5	

special hardware or supplies used in the course of completing the structure assembly. The detailed breakdown of material costs follows the breakdown used for manufacturing labor hours. CER forms, the resulting input requirements, the organization of these inputs and their respective back-up data is the subject of the discussion that follows.

DETAIL FABRICATION HOURS FOR RIBS, FRAMES, SPARS, LONGERONS AND COVERS

CER Form

A CER of the following form is used for estimating detail fabrication hours:

$$H_i \left[\frac{W_i CF_i + W_i CF_i + W_i CF_i}{WT_i} \right] (HF_i) (WT_i)^{E_i} \quad (1)$$

where

H_i = fabrication hours for ribs, frames, spars, longerons and covers corresponding to element inputs

W_i = a series of weights for the components estimated: ribs, frames, spars, longerons, and covers

CF_i = a series of complexity factors corresponding to component type related to fabrication

WT_i = computer summation of the weights:

$WT =$ Sum of rib weights

$WT1 =$ Sum of spar weights

$WT2 =$ Sum of cover weights

HF_i = a series of reference cost per pound values for ribs, frames, spars, longerons, & covers related to fabrication labor

E_i = a series of weight scaling exponents for ribs, frames, spars, longerons, and covers related to fabrication labor

H_i values are stored by the computer program and aggregated by structural component.

Inputs

This CER uses three types of variables:

- (1) Weights data
- (2) Complexity factors

- (3) Cost estimating coefficients - cost per pound and other factors and scaling exponents

The first two are handled as NAMELIST variables and vary with the aircraft design. The third is handled through the model card convention with values used based on analyses as described in Volume I.

Weights data and complexity factors for estimating detail fabrication hours for ribs, spars and covers for wings, horizontal stabilizers and vertical stabilizers and frames, longerons and covers for fuselages are input as shown in Figure 26. As mentioned above, the estimating method provides for the simultaneous evaluation of three different types of ribs, frames, spars, longerons or covers. Ribs and frames may be, alternatively, bulkheads. These components may appear in various combinations limited to the maximum of three types. The nacelle and landing gear involves secondary structure only. They are included in Figure 26 only to denote the overall computational sequence.

The remaining two inputs, reference cost per pound, HF_i , and the weight scaling exponent, E_i , are entered on model cards. They may be changed in the program simply by changing the appropriate F card as discussed in Section 2.2.3. They are subject to change if the subsequent acquisition and analysis of historical data indicates a more appropriate value. Hence they are not necessarily variables within the context of a given estimating problem. Currently available back-up data for reference cost per pound values appears in Appendix F.

Input Data Sources

The discussion in this section provides a map for locating the required program inputs. With reference to Figure 26, weights data are obtained from the APAS program and the secondary structure weight estimating routines by a process to be described in Section 2.4.2. Complexity factors are obtained from an appropriate complexity factor table. For primary structure detail fabrication labor, these are Tables 9, 10, 11, 12, 13 and 14. Back-up data for complexity factors is given in Appendix G. Also located there is data that can be used to develop a multiplier for application to complexity factors for construction types involving machining with differing tolerance requirements.

The derivation of reference cost per pound and weight scaling exponents is described in Volume I, Section 2. The values developed are summarized in Table 15. This table also serves to summarize the model cards where Equation 1 is used.

E_i follows the same map as HF_i . A consistent finding of the cost research has been that the scaling of hours to weight is very nearly a constant with a value of approximately 0.67. E_i values are thus not listed in Table 15. This finding is discussed more fully in Volume I.

INPUT ELEMENTS - SUBASSEMBLY HOURS:		AERODYNAMIC SURFACES STRUCTURAL BOX AND FUSELAGE BASIC STRUCTURE					
		INPUT VALUE BY STRUCTURAL COMPONENT					
Input Symbol	INPUT NAME	Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
W1 CF1	Weight of ribs or frames of Type A Complexity factor for Type A (Rib or Frame)						
W2 CF2	Weight of ribs or frames of Type B Complexity factor for Type B (Rib or Frame)						
W3 CF3	Weight of ribs or frames Type C Complexity factor for Type C (Rib or Frame)						
W4 CF4	Weight of spars or longerons of Type A Complexity factor for Type A (Spar or longeron)						
W5 CF5	Weight of spars or longerons of Type B Complexity factor for Type B (Spar or longeron)						
W6 CF6	Weight of spars or longerons of Type C Complexity factor for Type C (Spar or longeron)						
W7 CF7	Weight of covers of Type A Complexity factor for Type A (Covers)						
W8 CF8	Weight of covers of Type B Complexity factor for Type B (Covers)						
W9 CF9	Weight of covers of Type C Complexity factor for Type C (Covers)						
						NOT USED	NOT USED

Figure 26. NAMELIST Inputs for Structural Box and Fuselage Basic Structure
Detail Fabrication Hours.

Table 9. Aerodynamic Surfaces Rib Complexity Factors
- Detail Fabrication

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Web Stiffener	Build-Up Truss	Sheet Web	Corrugated Web	Integral Web Stiffener	Integral Truss
Ribs, Detail Fabrication CF ₁	Aluminum	1.00	0.70	0.52	0.51	0.99	0.90
	Titanium	1.31	0.95	0.59	0.57	1.52	1.50
	Low Carbon Steel	1.05	0.77	0.54	0.53	1.21	1.14
	Stainless Steel	1.56	1.15	0.64	0.62	2.48	2.54

Table 10. Fuselage Frame and Bulkhead Complexities Factors
- Detail Fabrication

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Web Stiffener	Built-Up Truss	Sheet Web (Roll Formed)	Corrugated Web	Integral Web Stiffener	Integral Truss
Frames & Bulkheads, Detail Fabrication CF1 CF2 CF3	Aluminum	1.3 2.5	0.5	0.5 -	0.5 -	1.0 1.5	0.97 -
	Titanium	1.31 3.3	0.16 -	0.95 -	0.95 -	1.37 3.3	1.57 -
	Low Carbon Steel	1.05 4.0	0.94 -	0.77 -	0.77 -	1.05 2.0	1.25 -
	Stainless Steel	1.50 1.9	1.39 -	1.15 -	1.15 -	1.50 0.9	1.56 -

* Range of values determined on tolerances.

Table 11. Aerodynamic surfaces Spars Complexity Factors,
- Detail Fabrication

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Web Stiffener	Built-Up Truss	Sheet Web	Corrugated Web	Integral Web Stiffener	Integral Truss
Spars, Detail Fabrication CF _i	Aluminum	1.00	0.83	0.68	0.64	0.72	0.88
	Titanium	1.21	1.05	0.68	0.67	0.92	0.72
	Low Carbon Steel	1.05	0.88	0.68	0.65	0.72	0.78
	Stainless Steel	1.34	1.22	0.68	0.70	0.49	0.70

Table 12. Fuselage Longeron Complexity Factors
- Detail Fabrication

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Web Stiffener	Built-Up Truss	Sheet Web (Roll Formed)	Corrugated Web	Integral Web Stiffener	Integral Truss
Longerons, Detail Fabrication CF4 CF5 CF6	Aluminum	1.03	0.9	0.7	-	1.5	1.55
	Titanium	1.25	1.14	0.7	-	2.8	3.07
	Low Carbon Steel	1.08	0.95	0.7	-	1.85	1.97
	Stainless Steel	1.38	1.32	0.7	-	3.85	4.29

*Range of values depends upon tolerances

Table 13. Aerodynamic Surfaces Covers Complexity Factors -
- Detail Fabrication

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Skin Stringer	Integral Skin Stringer	Machined Plate	Sheet	Sandwich Bonded & Beaded	
Covers, Detail Fabrication CF7 CF8 CF9	Aluminum	1.00	2.72	2.40	0.75	0.5	
	Titanium	1.10	5.20	4.50	0.80	-	
	Low Carbon Steel	1.03	3.38	2.92	0.76	-	
	Stainless Steel	1.19	7.22	6.23	0.84	-	

Table 14. Fuselage Cover Complexity Factors, Detailed Fabrication

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE				
		Built-Up Skin Stringer	Integral Skin Stringer	Machined Plate	Sheet	Sandwich Bonded and Beaded
Covers, Detail Fabrication CF 7 CF 8 CF 9	Aluminum	1.0	2.72	2.4	0.75	3.5
	Titanium	1.1	5.	4.5	0.8	-
	Low Carbon Steel	1.03	3.38	2.92	0.78	-
	Stainless Steel	1.19	7.22	6.23	0.84	-

Multiplier for Type of Contour:

(Applicable only to built-up stringer and sheet)

Drape Formed: 1.0

Compound Contoured: 3.0

Machine Tapered: 6.5

Table 15. Cost Per Pound Factors
(HF_i) Map

<u>DETAIL FABRICATION LABOR</u>		HF _i Code	Model Card		Model Card Value	Back-up Data Location
<u>WING</u>			Location			
Rib		HF1	F 31 1		51.0	F-1
Spar		HF2	F 32 1		52.0	F-2
Cover		HF3	F 33 1		11.0	F-3
<u>HORIZONTAL STABILIZER</u>						
Rib		HF1	F 100 1		51.0	F-1
Spar		HF2	F 101 1		52.0	F-2
Cover		HF3	F 102 1		11.0	F-3
<u>VERTICAL STABILIZER</u>						
Rib		HF1	F 151 1		51.0	F-1
Spar		HF2	F 152 1		52.0	F-2
Cover		HF3	F 153 1		11.0	F-3
<u>FUSELAGE</u>						
Frames		HF1	F 201 1		100.0	F-4
Longerons		HF2	F 202 1		75.0	F-5
Covers		HF3	F 203 1		32.0	F-6

SUBASSEMBLY HOURS FOR RIBS, FRAMES, SPARS, LONGERONS AND COVERS

CER Form

This CER is of the same general form as that used for detail fabrication.

$$H_i = \left[\frac{W_i CM_i + W_i CM_i + W_i CM_i}{WT_i} \right] (HF_i) (WT_i)^{E_i} \quad (2)$$

where

- H_i = subassembly hours for ribs, frames, spars, longerons and covers corresponding to variable inputs
- W_i = weights used for detail fabrication
- CM_i = a series of complexity factors corresponding to component type related to subassembly
- WT_i = computer summation of weights
- HF_i = a series of reference cost per pound values for ribs, frames, spars, longerons, and covers related to subassembly labor
- E_i = a series of weight scaling exponents for ribs, frames, spars, longerons, and covers related to subassembly labor

Inputs

The same types of inputs are involved for subassembly as for fabrication. The weights data is unchanged. The additional NAMELIST inputs required consist of complexity factors as shown in Figure 27. These are obtained from Tables 16, 17, 18, 19, 20, and 21. Reference cost per pound and weight scaling exponents are summarized in Table 22. Backup data appears in Appendix F, Pages F-7 thru F-12. The points of usage of Equation (2) are also represented by Table 22.

STRUCTURE BOX OR BASIC STRUCTURE MAJOR ASSEMBLY LABOR

CER Form

A series of CERs of the following general form are used for the aerodynamic surfaces and fuselage for major assembly labor.

Transporting and Positioning - Aero Surfaces or Fuselage

$$H_i = \left[(WT_i) (HSA1) + (HSA2) (CN + RN + SNE + SNI)^Q \right] \times 2 \quad (3)$$

Table 16. Aerodynamic Surfaces Rib Complexity Factors - Subassembly

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Web Stiffener	Built-Up Truss	Sheet Web	Corrugated Web	Integral Web Stiffener	Integral Truss
Ribs, Sub- Assembly CM ₁	Aluminum	1.00	0.89	0	2.08	0	0
	Titanium	1.75	1.57	0	2.58	0	0
	Low Carbon Steel	1.19	1.07	0	2.22	0	0
	Stainless Steel	2.33	2.10	0	2.98	0	0

Table 17. Fuselage Frame & Bulkhead Complexity Factors - Subassembly

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Web Stiffener	Built-Up Truss	Sheet Web	Corrugated Web	Integral Web Stiffener	Integral Truss
Frames Sub- Assembly CM _i	Aluminum	1.0	0.89	0	2.08	0	0
	Titanium	1.75	1.57	0	2.58	0	0
	Low Carbon Steel	1.19	1.07	0	2.22	0	0
	Stainless Steel	2.33	2.10	0	2.98	0	0

Table 18. Aerodynamic Surfaces Spars Complexity Factors, Subassembly

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Web Stiffener	Built-Up Truss	Sheet Web	Corrugated Web	Integral Web Stiffener	Integral Truss
Spars, Sub - assembly CM _i	Aluminum	1.00	1.20	0	3.34	0	0
	Titanium	1.72	1.52	0	5.40	0	0
	Low Carbon Steel	1.20	1.28	0	4.22	0	0
	Stainless Steel	2.31	1.77	0	6.75	0	0

Table 19. Subassembly Factors - Subassembly

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Web Stiffener	Built-Up Truss	Sheet Web	Corrugated Web	Integral Web Stiffener	Integral Truss
Longerons Subassembly M _i	Aluminum	1.00	1.00	0	5.34	0	0
	Titanium	1.5	1.5	0	5.40	0	0
	Low Carbon Steel	1.00	1.0	0	4.22	0	0
	Stainless Steel	2.31	1.07	0	6.75	0	0

Table 20. Aerodynamic Surface Covering Level Factor - Subassembly

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE					
		Built-Up Skin Stringer	Integral Skin Stringer	Machined Plate	Sheet	Sandwich	
Covers, Subassembly CM _i	Aluminum	1.00	0	0	0	0.5	
	Titanium	0.04	0	0	0	-	
	Low Carbon Steel	1.30	0	0	0	-	
	Stainless Steel	0.01	0	0	0	-	

Table 21. Fuselage Skin Panel Complexity Factor - Subassembly

Structural Element CER Input Symbol	Material Type	CONSTRUCTION TYPE				
		Built-Up Skin Stringer	Integral Skin Stringer	Machined Plate	Sheet	Sandwich
Covers, Subassembly CM _i	Aluminum	1.00	0	0	0	3.5
	Titanium	2.24	0	0	0	-
	Low Carbon Steel	3.33	0	0	0	-
	Stainless Steel	3.22	0	0	0	-

Table 22. Cost Per Pound Factors
(HF_i) Map

<u>SUBASSEMBLY LABOR</u>			HF _i Code	Model Card		Model Card Value	Back-up Data	
<u>WING</u>				Location			Location	
	Rib		HF4	F 31 2		14.5	F-7	
	Spar		HF5	F 32 2		19.0	F-8	
	Cover		HF6	F 33 2		7.2	F-9	
<u>HORIZONTAL STABILIZER</u>								
	Rib		HF4	F 100 2		14.5	F-7	
	Spar		HF5	F 101 2		19.0	F-8	
	Cover		HF6	F 102 2		7.2	F-9	
<u>VERTICAL STABILIZER</u>								
	Rib		HF4	F 151 2		14.5	F-7	
	Spar		HF5	F 152 2		19.0	F-8	
	Cover		HF6	F 153 2		7.2	F-9	
<u>FUSELAGE</u>								
	Frames		HF4	F 201 2		65.0	F-10	
	Longerons		HF5	F 202 2		40.0	F-11	
	Covers		HF6	F 203 2		47.0	F-12	

where

- H_i = primary structure major assembly hours for aerodynamic surfaces
structural boxes and fuselage basic structure.
- WT_i = weights used for detail fabrication
- HSA1 = assembly hours per unit weight for transporting and positioning
- HSA2 = assembly hours per subassembly for transporting and positioning
- CN = number of cover panels
- RN = number of ribs or frames
- SNE = number of external spars
- SN1 = number of internal spars or longerons
- Q = quantity scaling factor
- 2 = operator for aerodynamic surfaces only

Panel Fit and Trim - Aerodynamic Surfaces

$$H_i = 2 (SPE + RP) (HT) (TJ4) \quad (4)$$

where

- H_i = hours for panel fit and trim
- SPE = average spar perimeter in feet
- RP = average rib perimeter in feet
- HT = hours per lineal feet for fit and trim
- TJ4 = joint thickness ratio: $2 TS/0.04$
- TS = average skin thickness

Panel Fit and Trim - Fuselage

$$H_i = (SPE + RP) (HT) (TJ4) \quad (5)$$

where

- H_i = hours for panel fit and trim
- SPE = average fuselage length
- RP = Average frame circumference
- HT = hours per lineal feet for fit and trim
(differing from aero surfaces value)

Assembly Clamp And Layout - Aero Surfaces Or Fuselage

$$H_i = 2 \left[(RP)^R (RN)^Q + (SPE)^R (SNE+SNI)^Q \right] HL \quad (6)$$

where

H_i = hours for assembly clamp and layout

R = size scaling exponent

HL = assembly hours per unit length for clamp and layout

Note: Definitional differences between aerodynamic surfaces and fuselage indicated above for the terms RN, SNI, SPE, and RP apply. For the fuselage, the computer program neglects the doubling of value indicated above.

Hole Drilling - Aero Surfaces or Fuselage

$$H_i = 2 \left[(RP)^R (RN)^Q + (SPE)^R (SNE+SNI)^Q \right] (HD) (TJ4) \quad (7)$$

where

H_i = hours for hole drilling (not doubled for fuselage)

HD = hours per foot for drilling

Finish Operations - Aero Surfaces or Fuselage

$$H_i = 2 \left[(RP)^R (RH)^Q + (SPE)^R (SNE+SNI)^Q \right] (HE) (TJ4) (FF1) \quad (8)$$

where

H_i = hours for finishing operations (not doubled for fuselage)

HE = hours per unit length for finishing

$FF1$ = factor for fastener selection

Fastener Installation - Aero Surfaces or Fuselage

$$H_i = 2 \left[(RP)^R (RN)^Q + (SPE)^R (SNE+SNI)^Q \right] (HFI) (TJ4) (FF2) \quad (9)$$

where

H_i = hours for fastener installation (not doubled for fuselage)

- HF1 hours per foot for fastener installation
- FF2 factor for fastener selection

Inputs

The categories of inputs used to estimate major assembly are:

- (1) the previously used weights data
- (2) additional dimensional data and factors
- (3) Reference cost per pound data and scaling exponents.

The data for Item (2) is required as shown in Figure 28. All of these data, except the two factors for fastener selection, are obtained from the APAS program. Fastener selection factors are obtained from Table 23. Reference cost per pound data and scaling exponents are summarized in Table 24, with back-up data in Appendix F.

DETAIL FABRICATION AND SUBASSEMBLY HOURS FOR SECONDARY STRUCTURE

CER Forms

Both detail fabrication and subassembly hours estimating relationships for secondary structure are covered in this section, conforming to the computer program organization of input elements. The basic equation forms are:

Detail Fabrication Hours

$$H_i = CB_i (WC_i) (WD_i)^{E_i} \quad (10)$$

where

- H_i detail fabrication hours, secondary structure
- CB_i a series of complexity factors corresponding to component type related to fabrication
- WC_i a series of reference cost per pound values for secondary structure components related to fabrication labor
- WD_i a series of weights for the secondary structure components being estimated
- E_i a series of weight scaling exponents for secondary structure components related to fabrication labor.

INPUT ELEMENTS - SUBASSEMBLY HOURS:		AERODYNAMIC SURFACES STRUCTURAL BOX AND FUSELAGE BASIC STRUCTURE				
Input Symbol	INPUT NAME	INPUT VALUE BY STRUCTURAL COMPONENT				Landing Gear
		Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle
CN	Number of Cover Panels					
RN	Number of Ribs, Frames					
SNE	Number of External Spar., Longerons					
SN1	Number of Internal Spar., Longerons					
SPE	Average Spar Perimeter in Feet					
RP	Average Rib Perimeter in Feet					
TS4	Average Skin Thickness in Inches					
FF1	Factor for Fastener Selection - Finish Operation					
FF2	Factor for Fastener Selection - Fastener Installation					

Figure 28. NAMELIST Inputs for Structural Box and Fuselage Basic Structure
Major Assembly Hours

Table 23. Fastener Type Installation Factor.

TYPE FASTENER	ALUMINUM	TITANIUM OR STEEL
INTERNAL RIVETS	1.0	1.0
INTERNAL BOLTS	1.5	.86
INTERFERENCE FIT INTERNAL BOLTS	2.8	1.6
EXTERNAL RIVETS	1.2	1.2
EXTERNAL BOLTS	1.6	.92
EXTERNAL BOLTS AND NUT PLATES	1.9	1.08
INTERFERENCE FIT EXTERNAL BOLTS	3.2	1.83
FF1 appears in equation (8) FF2 appears in equation (9) FF3 appears in equation (12)		

Table 24. Structural Box and Basic Structure Major Assembly Factors -
Map and Factor Values.

	HSA1		HSA2		Q		HT	
	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value
Wing Box	F 16 1	.2	F 15 8	2.0	F 15 8	.95	F 16 2	1.216
Horizontal Stab. Box	F 17 1	.2	F 15 9	2.0	F 15 9	.95	F 17 2	1.216
Vertical Stab. Box	F 18 1	.2	F 15 10	2.0	F 15 10	.95	F 18 2	1.216
Fuselage	F 22 3	.2	F 22 2	2.0	F 22 2	.95	F 22 4	1.216

	HL		R		HD		HE	
	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value
Wing Box	F 16 3	1.238	F 15 1	.95	F 16 4	.557	F 16 5	.810
Horizontal Stab. Box	F 17 3	1.238	F 15 4	.95	F 17 4	.557	F 17 5	.810
Vertical Stab. Box	F 18 3	1.238	F 15 7	.95	F 18 4	.557	F 18 5	.810
Fuselage	F 22 5	1.238	F 22 1	.95	F 22 6	.557	F 22 7	.810

	HFI		Back-Up Data Location			
	Model Card Location	Value	HSA1	F-13	HT	F-14
Wing Box	F 16 6	.970	-	-	-	-
Horizontal Stab. Box	F 17 6	.970	HSA2	-	HL	-
Vertical Stab. Box	F 18 6	.970	Q	-	R	-
Fuselage	F 22 8	.970		-	F-13	HFI
						F-14

Subassembly Hours

$$H_i = CC_i (WF_i) (WD_i)^{F_i} \quad (11)$$

where

H_i	subassembly hours, secondary structure
CC_i	a series of complexity factors corresponding to component type related to subassembly
WF_i	a series of reference cost per pound values for secondary structure components related to fabrication labor
WD_i	the same series of weights as for detail fabrication
F_i	a series of weight scaling exponents for secondary structure components related to subassembly labor

Inputs

The inputs for these CERs follow the pattern established above:

- (1) Weights data obtained from a supporting computer program, the secondary structure weight analysis program.
- (2) Complexity factors obtained from complexity factor tables.
- (3) Reference cost per pound data and weight- scaling exponents.

Separate input data are required for each structural element since the list of secondary structure components (and consequently the series index) differs with each element. Input data requirements are shown in Figure 29. The applicable complexity factors are obtained from Tables 25 and 26, with back-up data in Appendix G.

The computer program provides for seventeen lines for secondary structure items for each of the six computational elements. Since the cost estimating relationships are general in nature, the listing of components is arbitrary and governed only by a need for correspondence between the component index and the input data.

The reference cost per pound and weight scaling exponent values are shown in Tables 27 and 28 with their model card and back-up data location.

COMPONENT MAJOR ASSEMBLY (SECONDARY STRUCTURE) LABOR

This task involves separate estimating approaches for aerodynamic surfaces and fuselage - nacelles - landing gear.

INPUT ELEMENTS — DETAIL FABRICATION & SUBASSEMBLY HOURS FOR SECONDARY STRUCTURE, ALL ELEMENTS				
INDEX	SECONDARY STRUCTURE COMPONENT	INPUT VALUE		
		CB _i	WD _i	CC _i
		Fab Complexity	Weights	Assy Complexity
	<u>WING:</u>			
1	Leading Edge			
2	Trailing Edge			
3	Ailerons			
4	Fairings			
5	Tips			
6	Spoilers			
7	Flaps & Flaperons			
8	Attachment Structure			
9	Access & Other Doors			
10	Air Induction			
11	High Lift Ducting			
12	Slats			
13	Hinges, Brackets, Seals			
14	Pivots & Folds			
15	Center Section			
16	Other			
	<u>HORIZONTAL STABILIZER:</u>			
1	Leading Edge			
2	Trailing Edge			
4	Fairings			
5	Tips			
8	Attachment Structure			
9	Access & Other Doors			
13	Hinges, Brackets, Seals			
14	Pivots & Folds			
15	Center Section			
16	Elevators			
17	Balance Weights			
	<u>VERTICAL STABILIZER:</u>			
1	Leading Edge			
2	Trailing Edge			
4	Fairings			
5	Tips			
8	Attachment Structure			
9	Access & Other Doors			
13	Hinges, Brackets, Seals			

Figure 29. NAMELIST Inputs for Secondary Structure Detail
Fabrication and Subassembly Hours.

WORKSHEET

INDEX	SECONDARY STRUCTURE COMPONENT	INPUT VALUE		
		Fabrication Complexity CB_i	Component Weight WD_i	Subassembly Complexity CC_i
17	<u>VERTICAL STABILIZER</u> (Cont.): Rudder			
	<u>FUSELAGE:</u>			
1	Cockpit			
2	Nose Landing Gear Door & Box			
3	Wing Reaction (carry-thru) Box			
4	Tail Attachment			
5	Windshield & Canopy			
6	Main Landing Gear Doors & Box			
7	Fuel Provisions			
8	Engine Provisions			
9	Duct Provisions			
10	Stores Provisions			
11	Speed Brakes			
12	Cabin Flooring & Supports			
13	Windows & Window Frames			
14	Doors & Door Frames			
	<u>NACELLES:</u>			
1	Cowlings			
2	Pylon			
3	Main Landing Gear Door & Reinforcement			
	<u>LANDING GEAR</u>			
1	Brakes			
2	Brake Controls			
3	Wheels			
4	Tires			
5	Oleos			
6	Axles, Trunnions & Fittings			
7	Drag Braces			

Figure 29. NAMELIST Inputs for Secondary Structure Detail
Fabrication and Subassembly Hours (Continued)

Table 25. Secondary Structure Detail Fabrication Complexity Factors, C₁

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber-Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium
LEADING EDGE: Reference A-X Horizontal Stabilizer Model 880 Type (simple) Model 990 Type (complex) VFX Horizontal (supersonic) A-X Wing C-141 Horizontal B-58	1.0					
	1.0					
	0.76	1.0	1.8			
	0.87	1.5	2.2			
	1.25					
	1.70					
	1.47				1.75	
TRAILING EDGE: Reference Model 880 Type (simple) Model 990 Type (complex) VFX Horizontal C-5A Horizontal C-141 Horizontal B-58 (Honeycomb)	1.0					
	1.4					
	1.6	2.8	3.5	5.0	1.93	
	2.1					
	1.4					
	0.75					
AILERONS (ELEVONS): Reference A-X Wing Model 990 Type (complex) B-58 (Honeycomb)	1.0					
	1.0					
	1.0		2.24	2.6	1.2	
						4.0
						4.5

Table 25 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
FAIRINGS: Reference C-141 Horizontal Model 990 Wing to Fuselage (simple) C-5A Bullet Fairing Assy. (Complex) A-X Horizontal B-58 (Sandwich)	1.0					
	1.0					
	0.34	0.50	0.79			
	1.17	1.73	2.23			
	0.93	2.7				
TIPS: Reference Estimating Line C-141 Horizontal C-5A Horizontal A-X Horizontal A-X Wing VFX Horizontal B-58	1.0					
	1.0					
	1.0					
	2.2					
	3.3					
SPOILERS: Reference A(X) Wing Model 990 Type (simple) F-111 Type (simple)	5.5				2.5	
	1.0					
	1.0					
	0.71		1.68	2.04	0.87	
	0.43		1.01	1.25	0.53	
FLAPS: Reference A-X Wing Model 990 Outboard	1.0					
	1.0					
	0.81		1.77	2.12	0.97	

Table 25 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
FLAPS: (Continued)						
Model 990 Inboard	0.75		1.70	2.06	0.93	
Model 48	0.45		1.05	1.30	0.56	
ATTACHMENT STRUCTURE:						
Reference	1.0					
Machined Structures	2.30					
C-141 Horizontal	0.67					4.70
A(X) Horizontal	0.77					3.60
C-5A Horizontal	1.57					
B-58 Machined	3.00					
ACCESS DOORS:						
Reference	1.0					
Commercial Transport	1.0	1.49	3.62			
C-5A Horizontal	0.27					
C-141 Horizontal	0.87					
A(X) Horizontal	1.17				3.00	
A(X) Wing	2.21					
WING MOUNTED AIR INDUCTION:						
Reference	1.0					
Similar to 990 Pod (single)	1.0		2.42			1.48
Similar to F-111 (complex)	3.5	5.10				3.40
HIGH LIFT DUCTING:						
Reference						1.0
Wing Mounted Air Ducts						1.0
High Lift Ducting						1.11
						0.71

Table 25 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
SLATS: Reference Built-up Aluminum Machined Aluminum:	1.0		2.60	3.00		
	1.0					
	0.92					
HINGES, BRACKETS & SEALS: Reference C-141 Horizontal C-5A Horizontal A(X) Horizontal	1.0					
	0.3					
	1.29					
	1.8					
PIVOTS AND FOLDS: Reference C-5A Horizontal A (X) Horizontal C-141 Horizontal VFX Horizontal	1.0					
	0.9					
	0.34					
	1.54					
	2.50					
WING CENTER SECTION Reference A (X) (Estimated) C-141 Horizontal Model 880 (Estimated) Experimental Wing Carry-thru Box B-58 (Estimated) F-102/100 Type	1.0		3.70			
	1.0					
	0.54					
	1.0					
	0.86					
	1.58					
	3.30					

Table 25 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber-Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
OTHER:						
Reference	1.0					
A-X Wing	0.75					
B-58	3.00					
ELEVATORS:						
Reference	1.0					
C-5A Horizontal	1.0					
C-141 Horizontal	1.6					
AX Horizontal	4.0					
BALANCE WEIGHTS:						
Reference	1.0					
C-5A Horizontal	0.42					
C-141 Horizontal	0.66					
A-X Horizontal	1.85					
RUDDER:						
Reference	1.0					
C-5A Type: Aluminum	0.8					
Fiberglass	0.65					
Boron Aluminum	1.25					
B-58					3.5	
COCKPIT:						
Reference	1.0					
Model 880	1.0					
A-X	1.0					
B-58	2.5					

Table 25 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
WING REACTION BOX (Same as Wing Center Section)						
TAIL ATTACHMENT (Same as Attachment Structure)						
WINDSHIELD & CANOPY:						
Reference	1.0					
T-2A	0.92					
A (X)	1.0					
Model 880	1.09					
A-5A	1.13					
B-58	2.20					
MAIN LANDING GEAR DOOR:						
Reference	1.0					
A-5A	1.0					
Model 880	1.0					
A (X)	1.23					
FUEL PROVISIONS						
Reference	1.0					
ENGINE PROVISIONS						
Reference	1.0					
DUCT PROVISIONS						
Reference	1.0					

Table 25 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber-Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
STORES PROVISIONS						
Reference	1.0					
A (X)	1.0					
B-58	2.00					
SPEED BRAKES						
Reference	1.0					
A (X)	1.0					
T-2A	0.33					
Model 880	1.08					
CABIN FLOORING & SUPPORTS						
Reference	1.0					
Model 880	1.6					
B-58	3.0					
WINDOWS & WINDOW FRAMES						
Reference	1.0					
Model 880	1.0					
B-58	2.0					
DOORS & DOOR FRAMES						
Reference	1.0					
Model 880	1.0					
B-58	1.92					
NACELLES - STRUCTURE						
Reference	1.0					
B-58	5.0					

Table 25 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
NACELLES - PYLONS Reference B-58 NACELLES-MIGD & REINFORCEMENTS	1.0 5.0					

Table 26. Secondary Structure Subassembly Complexity Factors, CC_1

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
LEADING EDGE: Reference AN Horizontal Stabilizer Model 880 Type (simple) Model 990 Type (complex) VFX Horizontal C-141 Horizontal A (X) Wing C-5A Horizontal B-58	1.0					
	1.0					
	0.71	0.96	1.7			
	0.83	1.48	2.12			
	1.36					
	1.5					
	1.71					
	0.3				2.0	
TRAILING EDGE: Reference Model 880 Type (simple) Model 990 Type (complex) VFX Horizontal C-5A Horizontal C-141 Horizontal B-58 (Honeycomb) AILERONS (ELEVONS) Reference A (X) Wing Model 990 Type (complex) B-58 (Honeycomb)	1.0					
	1.33					
	1.52					
	1.97	2.75	3.45	5.02	1.87	
	1.29					
	0.69					4.5
	1.0					
	1.0					
	1.0		2.26	2.62	1.20	4.75

Table 26 (Continued),

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
FAIRINGS: Reference A (X) Horizontal C-141 Horizontal C-5A Bullet Fairing B-58 (sandwich)	1.0					
	1.0					
	1.0					
	1.17	1.73	2.23			
		2.5				
TIPS: Reference C-141 Horizontal C-5A Horizontal A (X) Horizontal VFX Horizontal B-58	1.0					
	1.0					
	1.0					
	2.18					
	5.7				2.7	
SPOILERS: Reference A (X) Wing Model 990 F-111	1.0					
	3.9					
	0.7		1.7	2.0	0.9	
	0.4		1.0	1.25	0.5	
FLAPS: Reference A (X) Wing Model 48 Model 990 (Inboard) Model 990 (Outboard)	1.0					
	1.0					
	0.43		1.03	1.26	0.54	
	0.72		1.65	2.00	0.90	
	6.75		1.72	2.07	0.93	

Table 26 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber-Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium
ATTACHMENT STRUCTURE:						
Reference	1.0					
C-141 Horizontal	0.7					
A (X) Horizontal	0.8					
C-5A Horizontal	1.62					
Machined Structure	2.31					3.94
ACCESS DOORS:						
Reference	1.0					
A (X) Horizontal	1.12					
C-141 Horizontal	0.89					
A (X) Wing	2.13					
Large Transport		1.62	2.86		3.0	
B-58	1.06					
WING MOUNTED AIR INDUCTION:						
Reference	1.0					
Model 990 Pod (simple-heavy)	1.0		2.42			1.50
F-111 (complex)	3.58		5.14			3.96
HIGH LIFT DUCTING:						
Reference						
V/STOL Type (Welded Titanium)						1.0
V/STOL Type (Formed Tubing)						1.0
						1.79
SLATS:						
Reference	1.0					
Machined	0.92					
Build-up	1.0		2.6	5.0		1.13

TABLE 26 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
HINGES, BRACKETS AND SEALS: Reference A (N) Horizontal C-5A Horizontal C-141 Horizontal	1.0					
	1.95					
	1.44					
	0.33					
PIVOTS AND FOLDS Reference C-5A Horizontal C-141 Horizontal VFN Horizontal	1.0					
	0.88					
	1.52					
	2.5					
WING CENTER SECTION Reference A(N) Model 880 C-141 Horizontal F-102/106 Type B-55	1.0					
	1.0					
	1.0					
	0.52					
	3.16		3.52			
	1.3					
OTHER: Reference A (N) Wing B-55	1.0					
	0.58					
	3.0					
ELEVATORS: Reference C-5A Horizontal	1.0					
	0.53	0.5	1.35			

Table 26 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
ELEVATOR(S): (Continued)						
C-141 Horizontal	0.73					
A (X) Horizontal	1.94					
Model 990 Type	0.7	1.0	1.5			
BALANCE WEIGHTS:						
Reference	1.0					
C-5A Horizontal	0.42					
C-141 Horizontal	0.68					
A (X) Horizontal	1.86					
RUDDER:						
Reference	1.0					
C-5A Type	1.0	1.35	2.66		3.5	
B-55						
COCKPIT:						
Reference	1.0					
Model 880	1.0					
B-55	2.5					
NOSE LANDING GEAR DOOR:						
Reference	1.0					
T-2A	1.0					
Model 880	1.0					
A (X)	1.0					
B-55	3.05					

Table 26 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
WING REACTION BOS (Same as Wing Center Section)						
TAIL ATTACHMENT (Same as Attachment Structure)						
WINDSHIELD AND CANOPY						
Reference	1.0					
Model SS0	1.04					
T-2A	1.61					
A-5A	1.52					
B-58	2.13					
MAIN LANDING GEAR DOOR						
Reference	1.0					
A (X)	1.0					
Model SS0	1.08					
A-5A	1.69					
FUEL PROVISIONS						
Reference	1.0					
ENGINE PROVISIONS						
Reference	1.0					
DUCT PROVISIONS						
Reference	1.0					
STORES PROVISIONS						
Reference	1.0					

Table 26 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
STORES PROVISIONS (Continued)						
A (X)	1.0					
B-58	2.03					
SPEED BRAKES						
Reference	1.6					
A (X)	0.71					
T-2A	1.64					
Model 880	1.06					
CABIN FLOORING AND SUPPORT						
Reference	1.0					
Model 880	1.1					
B-58	3.0					
WINDOWS & WINDOW FRAMES:						
Reference	1.0					
Model 880	1.0					
B-58	2.0					
DOORS AND DOOR FRAMES:						
Reference	1.0					
Model 880	1.0					
B-58	2.05					
NACELLES - STRUCTURES						
Reference	1.0					
B-58	4.5					

Table 26 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
NACELLES - PYLONS Reference B-58	1.0 4.5					
NACELLES - MLGD & REINFORCEMENTS						

Table 27. Cost Per Pound Factors - (WC_i) Map

DETAIL FABRICATION LABOR	WC _i CODE	MODEL CARP LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
<u>WING SECONDARY STRUCTURE</u>				
Leading Edge	WC1	F 38 1	55.0	F-15
Trailing Edge	WC2	F 39 1	29.0	F-16
Ailerons	WC3	F 40 1	0.0	F-17
Fairings	WC4	F 41 1	0.0	F-18
Tips	WC5	F 42 1	21.5	F-19
Spoilers	WC6	F 43 1	25.0	F-20
Flaps and Flaperons	WC7	F 44 1	46.0	F-21
Attachment Structure	WC8	F 45 1	0.0	F-22
Access and Other Doors	WC9	F 47 1	0.0	F-23
Air Induction	WC10	F 47 1	0.0	F-24
High Lift Ducting	WC11	F 48 1	0.0	F-25
Slats	WC12	F 49 1	0.0	F-26
Hinges, Brackets, Seals	WC13	F 50 1	0.0	F-27
Pivots and Folds	WC14	F 51 1	0.0	F-28
Center Section	WC15	F 52 1	0.0	F-29
Other	WC16	F 53 1	50.0	F-30
<u>E_i follows the same map as WC_i with a constant value of 0.67</u>				

Table 27 (Continued)

DETAIL FABRICATION LABOR	WC _i CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
<u>HORIZONTAL STABILIZER SECONDARY STRUCTURE</u>				
Leading Edge	WC1	F 108 1	55.0	F-15
Trailing Edge	WC2	F 109 1	29.0	F-16
Fairings	WC4	F 110 1	36.0	F-18
Tips	WC5	F 111 1	60.0	F-19
Attachment Structure	WC8	F 112 1	18.0	F-22
Access and Other Doors	WC9	F 113 1	13.0	F-23
Hinges, Brackets, Seals	WC13	F 114 1	25.0	F-27
Pivots and Folds	WC14	F 115 1	10.0	F-28
Center Section	WC15	F 116 1	0.0	F-29
Elevators	WC16	F 117 1	67.0	F-31
Balance Weights	WC17	F 118 1	5.5	F-32
<u>VERTICAL STABILIZER SECONDARY STRUCTURE</u>				
Leading Edge	WC1	F 158 1	55.0	F-15
Trailing Edge	WC2	F 159 1	9.0	F-16
Fairings	WC4	F 160 1	0.0	F-18
Tips	WC5	F 161 1	60.0	F-19
Attachment Structure	WC8	F 162 1	0.0	F-22
Access and Other Doors	WC9	F 163 1	0.0	F-23
Hinges, Brackets, Seals	WC13	F 164 1	0.0	F-27
Rudder	WC17	F 165 1	22.2	F-33

Table 27 (Continued)

DETAIL FABRICATION LABOR	WC _i CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
<u>FUSELAGE SECONDARY STRUCTURE</u>				
Cockpit	WC1	F 208 1	60.0	F-34
Nose Landing Gear Door and Box	WC2	F 209 1	43.0	F-35
Wing Reaction (Carry-thru) Box	WC3	F 210 1	60.0	F-36
Tail Attachment	WC4	F 211 1	60.0	F-37
Windshield and Canopy	WC5	F 212 1	30.0	F-38
Main Landing Gear Doors and Box	WC6	F 213 1	28.0	F-39
Fuel Provisions	WC7	F 214 1	20.0	F-40
Engine Provisions	WC8	F 215 1	20.0	F-41
Duct Provisions	WC9	F 216 1	20.0	F-42
Stores Provisions	WC10	F 217 1	20.0	F-43
Speed Brakes	WC11	F 218 1	16.0	F-44
Cabin Flooring and Support	WC12	F 219 1	40.0	F-45
Window and Window Frames	WC13	F 220 1	40.0	F-46
Doors and Door Frames	WC14	F 221 1	45.0	F-47

Table 27 (Continued)

DETAIL FABRICATION LABOR	WC _i CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
<u>NACELLES SECONDARY STRUCTURE</u>				
Cowlings	WC1	F 271 1	70.0	F-48
Pylons	WC2	F 272 1	12.0	F-49
Main Landing Gear Door and Reinforcement	WC3	F 273 1	60.0	F-50
<u>LANDING GEAR SECONDARY STRUCTURE</u>				
Brakes	WC1	F 301 1	15.0	F-51
Brake Controls	WC2	F 302 1	12.0	F-52
Wheels	WC3	F 303 1	5.0	F-53
Tires	WC4	F 304 1	4.0	F-54
Oleos	WC5	F 305 1	18.0	F-55
Axles, Trunnions and Fittings	WC6	F 306 1	20.0	F-56
Drag Braces	WC7	F 307 1	15.0	F-57

Table 28. Cost Per Pound Factors - (WF_i) Map

SUBASSEMBLY LABOR	WF _i CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
<u>WING SECONDARY STRUCTURES</u>				
Leading Edge	WF1	F 38 2	48.0	F-58
Trailing Edge	WF2	F 39 2	23.0	F-59
Ailerons	WF3	F 40 2	0.0	F-60
Fairings	WF4	F 41 2	0.0	F-61
Tips	WF5	F 42 2	24.0	F-62
Spoilers	WF6	F 43 2	34.0	F-63
Flaps and Flaperons	WF7	F 44 2	42.0	F-64
Attachment Structure	WF8	F 45 2	0.0	F-65
Access and Other Doors	WF9	F 46 2	0.0	F-66
Air Induction	WF10	F 47 2	0.0	F-67
High Lift Ducting	WF11	F 48 2	0.0	F-68
Slat	WF12	F 49 2	0.0	F-69
Hinges, Brackets, Seals	WF13	F 50 2	0.0	F-70
Pivots and Folds	WF14	F 51 2	0.0	F-71
Center Section	WF15	F 52 2	0.0	F-72
Other	WF16	F 53 2	30.0	F-73

WF_i follows the same map as WF_i and has constant value of 0.67.

Table 25 (Continued)

SUBASSEMBLY LABOR	WF CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
<u>HORIZONTAL STABILIZER SECONDARY STRUCTURE</u>				
Leading Edge	WF1	F 108 2	48.0	F-58
Trailing Edge	WF2	F 109 2	23.0	F-59
Fairings	WF4	F 110 2	34.0	F-61
Tips	WF5	F 111 2	45.0	F-62
Attachment Structure	WF8	F 112 2	17.5	F-65
Access and Other Doors	WF9	F 113 2	28.0	F-66
Hinges, Brackets, Seals	WF13	F 114 2	21.0	F-70
Pivots and Folds	WF14	F 115 2	10.0	F-71
Center Section	WF15	F 116 2	0.0	F-72
Elevators	WF16	F 117 2	67.0	F-74
Balance Weights	WF17	F 118 2	5.5	F-75
<u>VERTICAL STABILIZER SECONDARY STRUCTURE</u>				
Leading Edge	WF1	F 158 2	48.0	F-58
Trailing Edge	WF2	F 159 2	0.0	F-59
Fairings	WF4	F 160 2	0.0	F-61
Tips	WF5	F 161 2	45.0	F-62
Attachment Structure	WF8	F 162 2	0.0	F-65
Access and Other Doors	WF9	F 163 2	0.0	F-66
Hinges, Brackets, Seals	WF13	F 164 2	0.0	F-70
Rudder	WF17	F 165 2	40.0	F-76

Table 28 (Continued)

SUBASSEMBLY LABOR	WT. CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
<u>FUSELAGE SECONDARY STRUCTURE</u>				
Cockpit	WF1	F 208 2	35.0	F-77
Nose Landing Gear Door and Box	WF2	F 209 2	43.0	F-78
Wing Reaction (Carry-thru) Box	WF3	F 210 2	40.0	F-79
Tail Attachment	WF4	F 211 2	40.0	F-80
Windshield and Canopy	WF5	F 212 2	56.0	F-81
Main Landing Gear Doors and Box	WF6	F 213 2	32.0	F-82
Fuel Provision	WF7	F 214 2	30.0	F-83
Engine Provisions	WF8	F 215 2	30.0	F-84
Duct Provisions	WF9	F 216 2	30.0	F-85
Stores Provisions	WF10	F 217 2	30.0	F-86
Speed Brakes	WF11	F 218 2	37.3	F-87
Cabin Flooring and Supports	WF12	F 219 2	74.0	F-88
Window and Window Frames	WF13	F 220 2	55.0	F-89
Doors and Door Frames	WF14	F 221 2	60.0	F-90

Table 25 (Continued)

SUBASSEMBLY LABOR	WF CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
<u>NACELLES SECONDARY STRUCTURE</u>				
Cowlings	WF1	F 271 2	9.0	F-91
Pylons	WF2	F 272 2	9.0	F-92
Main Landing Gear Door and Reinforcement	WF3	F 273 2	10.0	F-93
<u>LANDING GEAR SECONDARY STRUCTURE</u>				
Brakes	WF1	F 301 2	13.0	F-94
Brake Controls	WF2	F 302 2	12.0	F-95
Wheels	WF3	F 303 2	3.0	F-96
Tires	WF4	F 304 2	2.0	F-97
Oleos	WF5	F 305 2	15.0	F-98
Axles, Trunnions and Fittings	WF6	F 306 2	20.0	F-99
Drag Braces	WF7	F 307 2	15.0	F-100

Aerodynamic Surfaces

CER Form

Two CERs are involved:

Assembly Task

$$H_i = \left[(WRRP) (CSO) + 2(FSL) + 2(ERL) + 2(RSL) \right]^{WR} \cdot (TJ7) (FF3) (HE1) (CMB_i) \quad (12)$$

where

H_i = component major assembly hours for aerodynamic surfaces

WRRP = root rib length in feet

CSO = center section operator: 1 without; 2 with

FSL = front spar length in feet

ERL = end rib length in feet

RSL = rear spar length in feet

WR = size scaling parameter

TJ7 = joint thickness ratio: $2TS7/0.04$

TS7 = average skin thickness

FF3 = factor for fastener selection

HE1 = cost per unit length for assembly

CMB_i = complexity factor for assembly

Paint and Finish

$$H_i = (AS2_i) (HS) (2) \quad (13)$$

where

H_i = hours for paint and finish

$AS2_i$ = surface area, ft^2

HS = hours per square foot for paint and finish

Fuselage - Nacelle - Landing Gear

CER Form

Two CERs are involved:

Assembly Task

$$H_i = CMB_i (RHP_i) (W_i)^{E_i} \quad (14)$$

where

- H_i component major assembly hours for fuselage, nacelle, landing gear
- CMB_i a series of complexity factors related to the component estimated
- RHP_i a series of reference hours per pound related to the component estimated
- W_i total weight of the component estimated
- E_i a series of weight scaling exponents

Paint and Finish (Excluding Landing Gear)

Same as Aerodynamic Surfaces except not multiplied by 2.

Inputs

The values for WRRP, CSO, FSL, ERL, RSL, TJ7, AS2 and W are obtained from the APAS program. These input requirements are as shown in Figure 30. FF3 is obtained from Table 23. The size scaling parameter, WR, the cost per unit length for assembly HEI, hours per square foot for paint and finish, HS, and RHP are summarized in Table 29 with the source table location identified. The complexity factor, CMB, is obtained from Table 30.

Rework

Provision is made for the addition of a rework factor to consider rework in a given cost study.

CER Form

A factor is applied to each of the labor cost subtotals according to the following:

INPUT ELEMENTS - COMPONENT MAJOR ASSEMBLY HOURS, SECONDARY STRUCTURE							
Input Symbol	INPUT NAME	INPUT VALUE BY STRUCTURAL COMPONENT					
		Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
	<u>AERODYNAMIC SURFACES:</u>						
WRRP	Root Rib Length, (feet)				-	-	-
CSO	Center Section Operator: 1 without; 2 with				-	-	-
FSL	Front Spar Length, (feet)				-	-	-
ERL	End Rib Length, (feet)				-	-	-
RSL	Rear Spar Length, (feet)				-	-	-
TS7	Average Skin Thickness, (inches)				-	-	-
FF3	Factor for Fastener Selection				-	-	-
CMB	Complexity Factor for Assembly				-	-	-
AS2	Surface Area, (ft ²)				-	-	-
	<u>FUSELAGE - NACELLE - LANDING GEAR:</u>						
W	Weight of Element: Calculated by Computer Program						

Figure 30. NAMELIST Inputs for Secondary Structure Component Major Assembly Hours.

Table 29. Factor Values and F-Card Location.

	WR		HEI		HS		RHP		E _i	
	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value
Wing	F 53 8	0.95	F 53 7	2.48	F 53 9	0.07	-	-	-	-
Horizontal Stabilizer	F 118 8	0.67	F 118 7	2.48	F 118 10	0.07	-	-	-	-
Vertical Stabilizer	F 165 8	0.95	F 165 7	2.48	F 165 10	0.07	-	-	-	-
Fuselage	-	-	-	-	F 222 3	0.07	F 222 3	20.0	F 222 3	0.67
Nacelle	-	-	-	-	F 274 3	0.07	F 274 3	30.0	F 274 3	0.67
Landing Gear	-	-	-	-	-	-	F 308 3	20.0	F 308 3	0.67

BACK-UP DATA LOCATION

WR F-13
 HEI F-14
 HS F-14
 RHP_i F-13
 E_i (See Table 7)

Table 30. Component Major Assembly Complexity Factor (CMB)

	Aircraft			
	P-58	Model 880	A (N)	
Aerodynamic Surfaces:				
Wing	3	1	1	
Horizontal Stabilizer	-	1	1	
Vertical Stabilizer	2	1	1	
Other Basic Structure:				
Fuselage	3	1	2	
Nacelle	4.5	1	2	
Landing Gear	2	1	2	

NOTE: The factor, CMB, is used in two equations: Equation (12) for Aerodynamic Surfaces assembly task and Equation (14) for Fuselage-Nacelle-Landing Gear assembly task. The assembly task involved is based on an abstraction of assembly tasks, and therefore, this factor is itself an abstraction. The Model 880 is the baseline, reference, analog. It represents an aluminum technology and a commercial transport. Other factors are based on judgment based on review of the structural complexities actually involved. This table is set up to record additional points as further analyses are made.

$$\text{Rework Labor} = \text{Labor Subtotal} \cdot U \quad (15)$$

where

U = rework factor

Inputs

The value to be used as a rework factor is entered on the appropriate F card, by element. The factor is to be based on the analyst's judgment. This factor is used at F-card locations as follows:

Wing: F 58 (1, 2, 3 and 6)

Horizontal Stabilizer: F 121 (1, 2, 3 and 6)

Vertical Stabilizer: F 170 (1, 2, 3 and 6)

Fuselage: F 226 (1, 2, 3 and 6)

Nacelles: F 291 (1, 2, 3 and 6)

Landing Gear: F 328 (1, 2, 3 and 6)

STRUCTURAL MATERIAL COST FOR RIBS, FRAMES, SPARS, LONGERONS AND COVERS

CER Form

A CER of the following form is used for estimating structural material cost for the components of the aerodynamic surfaces structural box and the fuselage basis structure.

$$M_i = W_i^{G_i} (RMC_i) (SF_i) \cdot W_i^{G_i} (RMC_i) (SF_i) \cdot W_i^{G_i} (RMC_i) (SF_i) \quad (16)$$

where

M_i = material cost for ribs, frames, spars, longerons and covers corresponding to inputs

W_i = a series of weights for the components estimated: ribs, frames, spars, longerons, and covers. (Weight of finished structure)

G = a series of weights scaling exponents

RMC_i = a series of raw material costs per pound for each type of component estimated

SF_i = a series of scrappage factors related to the material and component estimated

M_i values are stored by the computer program and aggregated by structural component.

Inputs

Weights data is the same as was shown in Figure 26. Raw material cost per pound and scrappage factors are input as shown in Figure 31 and are categorized as NAMELIST variables. Raw material costs and scrappage factors are obtained, respectively, from Tables 31 and 32. A value of 0.77 is used for G_i and is entered as an F-card coefficient. See Appendix H, Page H-1 for back-up data.

Raw material costs and scrappage factors are categorized as NAMELIST variables because they were felt to be more subject to change than the estimating coefficients for labor, which were treated as model card variables. In line with this distinction their back-up data is given in a separate appendix, Appendix H.

STRUCTURAL MATERIAL COST FOR SECONDARY STRUCTURE

CER Form

A CER of the following form is used:

$$M_i = WD_i^{G_i} (RMC_i) (SF_i) \quad (17)$$

where

- M_i = material cost for secondary structure components
- WD_i = a series of weights for the secondary structure components being estimated
- G_i = a series of weight scaling exponents
- RMC_i = a series of raw material costs per pound for each type of component estimated
- SF_i = a series of scrappage factors related to the material and component estimated

This CER is of the same form as that for basic structure material costs as a simplifying convenience. It should be noted, though, that the terms RMC_i and SF_i take on different meanings in this case. In the case of basic structure, the scrappage factor was defined in relation to type of construction. RMC values are derived from available data, and the term SF is available for future development as a complexity factor.

INPUT ELEMENTS - DETAIL FABRICATION HOURS:		AERODYNAMIC SURFACES STRUCTURAL BOX AND FUSELAGE BASIC STRUCTURE					
Input Symbol	INPUT NAME	INPUT VALUE BY STRUCTURAL ELEMENT					Landing Gear
		Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	
RM11	Raw Material Cost for Rib or Frame of Type A						
RM12	Raw Material Cost for Rib or Frame of Type B						
RM13	Raw Material Cost for Rib or Frame of Type C						
SF1	Scrapage Factor for Rib or Frame of Type A						
SF2	Scrapage Factor for Rib or Frame of Type B						
SF3	Scrapage Factor for Rib or Frame of Type C						
RM14	Raw Material Cost for Spar or Longeron of Type A						
RM15	Raw Material Cost for Spar or Longeron of Type B						
RM16	Raw Material Cost for Spar or Longeron of Type C						
SF4	Scrapage Factor for Spar or Longeron of Type A						
SF5	Scrapage Factor for Spar or Longeron of Type B						
SF6	Scrapage Factor for Spar or Longeron of Type C						
RM17	Raw Material Cost for Covers of Type A						
RM18	Raw Material Cost for Covers of Type B						
RM19	Raw Material Cost for Covers of Type C						
SF7	Scrapage Factor for Covers of Type A						
SF8	Scrapage Factor for Covers of Type B						
SF9	Scrapage Factor for Covers of Type C						

Figure 31. NAMELIST Inputs for Structural Box and Fuselage
Basic Structure Material.

WORKSHEET

Table 31. Primary Structure Raw Material Cost Factor (RMC)

	Aluminum	Steel	Titanium	Aluminum and Steel
Ribs, Frames, Spars, Longeron, and Covers — Production Material	18.0	22.0	28.0	

Back-up data appears in Appendix II.

Table 32. Primary Structure Material Scrappage Factor (SF)

Structure Type	Material Type	Built-up Web Stiffener	Built-up Truss	Sheet Web	Corrugated Web	Integral Web Stiffener	Integral Truss
Ribs, Frames SF1, SF2, SF3	Aluminum	2.0	2.0	2.0	2.0	5.3	5.3
	Titanium	3.5	3.5	3.5	3.5	5.3	5.3
	Steel						
Spars, Longerons SF4, SF5, SF6	Aluminum	3.0	3.0	3.0	3.0	5.3	5.3
	Titanium	3.0	3.0	3.0	3.0	5.3	5.3
	Steel						

Structure Type	Material Type	Built-up Skin Structure	Integral Skin Stringer	Machined Plate	Sheet
Covers SF7, SF8, SF9	Aluminum	2.0	5.3	4.5	1.0
	Titanium	3.5	5.3	4.5	1.0
	Steel				1.0

Inputs

Weights data is the same as entered in Figure 28. Cost per pound and scrappage factors are input as shown in Figure 32 to be recorded as NAMELIST variables. Input values for RMC are obtained from Table 33. SF is given the value of 1 pending further development of this estimating concept and Table 34 is reserved for this development.

BASIC STRUCTURE ASSEMBLY MATERIAL COST

CER Form

A CER of the following form is used for each of the structural components except nacelles and landing gears:

$$M_i \left[\text{Primary Structure Assembly Labor} \right] \cdot (AMF1_i)(FM1_i) \quad (18)$$

where

- M_i cost of material for primary structure assembly
- $AMF1_i$ a series of assembly material cost per labor hour factors related to the structural component being estimated
- $FM1_i$ a series of complexity factors related to fastener type used

Inputs

Primary structure assembly labor hours are obtained by using the sum of the structural box and basic structure major assembly labor CERs, equations 3 through 9. AMF1 values are obtained through Table 35. FM1 values are required as shown in Figure 33, which are in turn obtained from Table 36. The location of back-up data is indicated in each table.

COMPONENT ASSEMBLY MATERIAL COST

CER Form

A CER of the following form is used for each of the structural components:

$$M_i \left[\text{Component Assembly Labor} \right] \cdot (AMF2_i)(FM2_i) \quad (19)$$

INDEX	INPUT ELEMENTS — SECONDARY STRUCTURE STRUCTURAL MATERIAL COST		
	SECONDARY STRUCTURE COMPONENTS	INPUT VALUE	
		Raw Material Cost RMC_i	Scrapage Factor SF_i
	<u>WING</u>		
1	Leading Edge		
2	Trailing Edge		
3	Ailerons		
4	Fairings		
5	Tips		
6	Spoilers		
7	Flaps & Flaperons		
8	Attachment Structure		
9	Access & Other Doors		
10	Air Induction		
11	High Lift Ducting		
12	Slats		
13	Hinges, Brackets, Seals		
14	Pivots and Folds		
15	Center Section		
16	Other		
	<u>HORIZONTAL STABILIZER</u>		
1	Leading Edge		
2	Trailing Edge		
4	Fairings		
5	Tips		
8	Attachment Structure		
9	Access & Other Doors		
13	Hinges, Brackets, Seals		
14	Pivots & Folds		
15	Center Section		
16	Elevators		
17	Balance Weights		
	<u>VERTICAL STABILIZER</u>		
1	Leading Edge		
2	Trailing Edge		
4	Fairings		
5	Tips		

Figure 32. NAMELIST Inputs for Secondary Structure Structural Material Cost.

INDEX	SECONDARY STRUCTURE COMPONENT	INPUT VALUE	
		Raw Material Cost RMC_i	Scrapage Factor SF_i
	<u>VERTICAL STABILIZER</u> (Cont)		
8	Attachment Structure		
9	Access & Other Doors		
13	Hinges, Brackets, Seals		
17	Rudder		
	<u>FUSELAGE</u>		
1	Cockpit		
2	Nose Landing Gear Door & Box		
3	Wing Reaction (carry-thru) Box		
4	Tail Attachment		
5	Windshield & Canopy		
6	Main Landing Gear Doors & Box		
7	Final Provisions		
8	Engine Provisions		
9	Duct Provisions		
10	Stores Provisions		
11	Speed Brakes		
12	Cabin Flooring & Supports		
13	Windows & Window Frames		
14	Doors & Door Frames		
	<u>NACELLES</u>		
1	Cowings		
2	Pylons		
3	Main Landing Gear Door & Reinforcements		
	<u>LANDING GEAR</u>		
1	Brakes		
2	Brake Controls		
3	Wheels		
4	Tires		
5	Oleos		
6	Axles, Trunnions & Fittings		
7	Drag Braces		

Figure 32. NAMELIST Inputs for Secondary Structure
Structural Material Cost (Continued).

Table 33. Secondary Structure Raw Material Cost Factor (RMC)

	Aluminum	Steel	Titanium	Aluminum and Steel
Secondary and Other Structure Basic Material	40.0	55.0	70.0	50.0*

* Use when aluminum secondary structure includes a steel pivot.

Back-up data appears in Appendix II.

Table 34. Secondary Structure Material Scrappage Factor (SF)

(This table is reserved for future development of factors indicated, and will be of the following form.)

Type of Construction	Material			
	Aluminum	Steel	Titanium	Fibreglass
Leading Edge:				
Typical Construction:				
-				
-				
-				
-				
Trailing Edge:				
Typical Construction				
-				
-				
-				
-				
-				
Etc.:				

Table 35. Assembly Material Cost Map and Factor Values

	Primary Structure Assembly Material AMF1		Component Assembly Material AMF2	
	Model Card Location	Value	Model Card Location	Value
Wing	F 16 7	0.34	F 53 11	0.68
Horizontal Stabilizer	F 17 7	0.34	F 118 9	0.68
Vertical Stabilizer	F 18 7	0.34	F 165 9	0.68
Fuselage	—	—	F 22	0.68
Nacelles	—	—	F 274 6	0.68
Landing Gear	—	—	F 308 6	0.68

BACK-UP DATA LOCATION

AMF1 - Appendix II

AMF2 - Appendix II

INPUT ELEMENTS - ASSEMBLY MATERIAL FOR BASIC STRUCTURE AND MAJOR COMPONENT ASSEMBLY							
Input Symbol	INPUT NAME	INPUT VALUE BY STRUCTURAL COMPONENT					
		Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
FM1	Fastener Type Complexity Factor - Primary Structure Assembly						
FM2	Fastener Type Complexity Factor - Secondary Structure Assembly					NOT USED	

Figure 33. NAMELIST Inputs for Assembly Material Costs

WORKSHEET

Table 36. Fastener Type Complexity Factor
Related to Assembly, FM

	TYPE OF FASTENER			
	Aluminum (Subsonic)	Aluminum (Supersonic)	Steel and Composite	Titanium
FM1	1.0	2.5	3.0	3.50
FM2	1.0	1.7	1.7	2.90

where

M_i = cost of material for component assembly

$AMF2_i$ = a series of assembly material cost per labor hour factors
related to the structural component being estimated

$FM2_i$ = a series of complexity factors related to fastener type used.

Inputs

Component assembly labor hours are obtained by using the sum of equations 12 and 13 for aerodynamic surfaces and equations 13 and 14 for fuselage, nacelles, and landing gear. FM_i values are required as shown in Figure 33, and are obtained from Table 36.

PRIMARY ASSEMBLY AND MAJOR MATE. Manufacturing labor for these items is estimated as follows:

Primary Assembly:

$$\text{Primary Assembly Hours} = \left[\begin{array}{l} \text{Detailed Fabrication Hours} + \text{Subassembly} \\ \text{Hours} + \text{Major Assembly Hours} \times \% \text{ Factor} \end{array} \right] \quad (20)$$

Major Mate:

$$\text{Major Mate Hours} = \left[\text{Detailed Fabrication Hours} + \text{Subassembly Hours} \right] + \text{Major Assembly Hours} \times F \text{ Factor} \quad (21)$$

F-Card locations where equations are used are as follows:

	<u>Primary Assembly</u>	<u>Major Mate</u>
Wing:	F 59 4	F 59 5
Horizontal Stabilizer:	F 122 4	F 122 5
Vertical Stabilizer:	F 171 4	F 171 5
Fuselage:	F 227 4	F 227 5
Nacelles:	F 260 4	F 260 5
Landing Gear:	F 292 4	F 292 5

2.3.2 RECURRING PRODUCTION COSTS BY STRUCTURAL ELEMENT. Recurring production costs are estimated for three alternate production quantities: the RDT&E, or flight test quantities, and two alternate full scale production quantities. Figure 17, a printout of RDT&E production costs, illustrates the output format, which is the same for all quantities.

The calculation of production costs is a simple process of projecting first unit costs by means of an appropriate learning curve and applying labor rates to convert to dollars. The detailed first unit cost level of detail is used for this projection in order to provide adequate trade study insight. Substitutions of types of material or construction can be evaluated from the standpoint of effect on learning and resultant quantity costs. The explanation of the method which follows is based on the computer program with only one additional equational form being added.

The Z-card option is used for learning curve projections. (See Appendix A for a discussion of model card functions.) F-cards are used for conversion of hours to dollars, for cost-on-cost calculations and for totaling. RDT&E costs and the remaining recurring production costs are handled in the same way.

To illustrate the Z-card option, the model card entry at (335, 1) will be used. This is the calculation for recurring production costs for the Wing, Structural Box, Ribs, Detailed Fabrication hours and appears as:

Z335 1 29 31 1 PN2 WNG PN4 WNG PC11 WNG

The Z in the first column indicates use of the Z-card convention. The numbers 335 1 indicate the SAV matrix address at which the calculation results are entered. The

number 29 signifies the use of TERM 29 as an equational form. The numbers 31 1, which constitute an entry in the first subfield for entry of parameters, is the SAV matrix address where the previously calculated first unit cost of wing rib detailed fabrication labor is stored. The remaining entries are three additional parameters used in the calculation:

PN2 WNG	The starting quantity for the calculation
PN4 WNG	The ending quantity for the calculation
PC11 WNG	The relevant learning curve factor

The meaning of these parameters is determined by the equational form specified, TERM 29 in this case. TERM 29 is of the following form:

$$\text{Cost estimated} = P1 \sum_{P2}^{P3} i^x \quad (22)$$

where

P1	First unit cost
P2	The beginning point of the projection
P3	The ending point of the projection
i	The series of production units covered
x	$\frac{\ln P4}{\ln 2}$ where
P4	The relevant learning curve factor expressed as a decimal fraction.

The computerized calculation procedure is embodied in the COSTC program.

An example of a cost-on-cost relationship is

F 340 1 (339, 1) * RM WNG,

which translates as

F 340 1	Labor cost in dollars of the structural box detail fabrication hours
(339, 1)	The structural box detail fabrication hours subtotal from the SAV matrix address.
RM WNG	Manufacturing labor rate.

The entry (339,1) is produced by an R-card operation from the model card

R339 1 6 3 4 335 1.

The R-card function is discussed in Appendix A. Table 37 serves to summarize the above discussion by giving the cross reference between the cost output and model cards for Wing Recurring Production Costs (86 units in the demonstration case). RDT&E and Recurring Production Costs for the five other hardware elements follow similar patterns that can be readily identified within the model card structure.

2.3.3 NONRECURRING DESIGN AND DEVELOPMENT. Nonrecurring design and development costs are estimated by a series of CERs covering the following categories of cost:

- a. Basic Structure Design Engineering Hours
- b. Configuration Design Engineering Hours
- c. Configuration Design Engineering Dollar Cost
- d. Engineering Material Dollar Cost
- e. Total Trade Study Engineering
- f. Basic Tool Manufacturing Hours
- g. Rate Tooling Manufacturing Hours
- h. Total Tool Manufacturing Hours
- i. Total Tool Manufacturing Dollar Costs
- j. Basic Tool Engineering Hours
- k. Rate Tool Engineering Hours
- l. Total Tool Engineering Hours
- m. Total Tool Engineering Dollar Costs
- n. Manufacturing Development and Plant Engineering Hours
- o. Manufacturing Development and Plant Engineering Dollar Costs
- p. Tooling Material and Other Dollar Costs
- q. Manufacturing Support Dollar Costs
- r. Quality Control Hours
- s. Quality Control Dollar Costs

Table 38 shows the interrelationship between CERs by equation number, the cost printout, and the controlling model card. Two of the above categories, Basic Structure Design Engineering Hours and Basic Tool Manufacturing Hours, are estimated by structural element. The remainder are estimated at an aggregate level. The CERs to provide the estimates are as follows:

BASIC STRUCTURE DESIGN ENGINEERING HOURS

CER Form

$$DEH_i = EH_i (WAMPR_i)^{EE} \quad (23)$$

Table 37. Cost Output and Model Card Cross Reference -
Wing Recurring Production Costs.

Hardware Components	Part Number	Quantity	Material Cost	Assembly Cost	Overhead Cost	Model Card Cost
Structural Box						
Ribs	F 351 1	1 351 2				
Spars	F 351 1	1 351 2				
Covers	F 351 1	1 351 2				
Assembly						
Secondary Structure						
Loading edge	F 351 1	1 351 2				
Trailing edge	F 351 1	1 351 2				
Ailerons	F 351 1	1 351 2				
Fairings	F 351 1	1 351 2				
Tips	F 351 1	1 351 2				
Spoilers	F 351 1	1 351 2				
Flaps and Flaprons	F 351 1	1 351 2				
Attachment Structure	F 351 1	1 351 2				
Access and Fair Doors	F 351 1	1 351 2				
Air Induction	F 351 1	1 351 2				
High Lift Ducting	F 351 1	1 351 2				
Slats	F 351 1	1 351 2				
Hinges, Brackets, Seals	F 351 1	1 351 2				
Pivots and Folds	F 351 1	1 351 2				
Center Section	F 351 1	1 351 2				
Other	F 351 1	1 351 2				
Assembly						
Rework	F 351 1	1 351 2				
Totals						

Table 38. Cost Output, CER Equation Number, and Model Card Cross Reference -
Nonrecurring Design and Development Costs.

Hardware Components	Wing		Horizontal Stabilizer		Vertical Stabilizer		Fuselage		Nacelle		Landing Gear		Sustent		Totals
	Hours	Eq	Hours	Eq	Hours	Eq	Hours	Eq	Hours	Eq	Hours	Eq	Hours	Eq	
Basic Structure Design Engineering Hours	1 615 1	1 9 620	1 615 2	1 9 620	1 615 3	1 9 620	1 615 4	1 9 620	1 615 5	1 9 620	1 615 6	1 9 620	1 615 7	1 9 620	1 6 614
Configuration Design Engineering Hours															1 6 615
Engineering Material															1 6 616
Total Trade Study Engineering															1 6 617
Basic Tool Manufacturing Hours	1 616 1	1 9 621	1 616 2	1 9 621	1 616 3	1 9 621	1 616 4	1 9 621	1 616 5	1 9 621	1 616 6	1 9 621	1 616 7	1 9 621	1 6 618
Rate Tool Manufacturing Hours															1 6 619
Total Tool Manufacturing															1 6 620
Basic Tool Engineering Hours															1 6 621
Rate Tool Engineering Hours															1 6 622
Total Tool Engineering															1 6 623
Mfg. Development and Plant Engineering															1 6 624
Tooling Material and Other Dollars															1 6 625
Manufacturing Support Dollars															1 6 626
Quality Control Hours															1 6 627
Totals															1 6 628

where

DEH_i		Design Engineering Hours
EH_i	=	Empirical estimating coefficient by structural component
$WAMPR_i$		AMPR weight of the structural component being estimated
EE		Scaling exponent of engineering hours to weight

Inputs

This CER entails two types of inputs:

- (1) Weights data input from the weights analysis program.
- (2) Estimating coefficients: the empirical coefficients, EH, and the scaling exponent, EE, are based on historical data. EH is a NAMELIST variable and EE is a model card input at locations F 615 1 thru 6.

BASIC STRUCTURE DESIGN ENGINEERING DOLLAR COST

CER Form

$$DED = DEH \times ECLR \quad (24)$$

where

DED	=	Basic structure design engineering dollars
ECLR		Engineering composite labor rate

Inputs

ECLR is input as a NAMELIST VARIABLE. It is subject to variation due to time, manufacturer and the nature of the engineering task and is to be provided by the cost analyst according to the problem at hand.

Input Data Sources

The derivation of the above estimating coefficients is described in Volume I. Values for EH and EE are summarized in Table 39. Back-up data is given in Appendix I. EH is a NAMELIST variable, EE is a model card entry.

Table 39. Engineering Labor CER Coefficients

Coefficient	Structural Subsystem					
	Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
EE_i , scaling exponent	0.60	0.60	0.60	0.60	0.60	0.60
EH_i , estimating coefficient	540	428	400	1200	1200	560

The trade study and system costing method use common factors in estimating non-recurring design and development costs.

CONFIGURATION DESIGN ENGINEERING HOURS

CER Form

$$CDEH = DEH \times F1 \quad (25)$$

where

$CDEH$ = Configuration Design Engineering Hours

$F1$ = Factor for Configuration Design Engineering Hours

Inputs

The factor, $F1$, is a percentage factor increasing basic structure design engineering hours to add configuration design engineering. $F1$ is a model card input at F 616 7, and its value, based on an historical average derived in Appendix I, is 1.15 for a complete airframe and 0.67 for basic structure or an individual structural subsystem.

CONFIGURATION DESIGN ENGINEERING DOLLAR COST

CER Form

$$CDED = CDEH \times ECLR \quad (26)$$

where

CDED Configuration Design Engineering Dollar Costs

ECLR Engineering Composite Labor Rate

Inputs

No additional inputs are required.

ENGINEERING MATERIAL

CER Form

$$\text{EMD} = \text{CDED} \cdot \text{F2} \quad (27)$$

where

EMD Engineering Material Dollar Cost

F2 A Percentage Factor Applied to configuration
design engineering dollar cost

Inputs

The value of F2 is input as a model card term at (F 617 8). A value of 0.15, based on available cost histories is programmed into the present model. Variations are to be provided by the cost analyst.

TOTAL TRADE STUDY ENGINEERING

This is a summing operation, Configuration Design Engineering Dollar Cost plus Engineering Material Dollar Cost, performed by F-Card F 618 8.

BASIC TOOL MANUFACTURING HOURS

CER Form

$$\text{BTMH}_i = \text{TMF}_i (\text{WAMPR}_i)^{\text{ET}} \quad (28)$$

where

BTMH_i Basic Tool manufacturing hours

TMF_i Empirical estimating coefficient by structural component

ET Scaling exponent, tool manufacturing hours to weight

Inputs

Two additional inputs are required. TMF is a NAMELIST variable obtained from Table 40. ET is a model card input appearing at (F 619 1, . . . 6). Its value has been derived as 0.75. Back-up data is contained in Appendix I.

RATE TOOL MANUFACTURING HOURS

CER Form

$$RTMH = \left(\sum BTMH_i \right) (TAM^{ER} - 1) \quad (29)$$

where

$$\sum BTMH_i \quad (619, 7) \text{ SAV Matrix summation}$$

RTMH = Rate tool manufacturing hours

TAM = Monthly production rate

ER = Exponent for scaling of rate tooling to production rate

Inputs

TAM is a NAMELIST variable and is obtained from programmatic data. ER is a model card input appearing at (F 620 7) and (F 621 7). Its value has been determined by current manufacturing experience.

TOTAL TOOL MANUFACTURING DOLLAR COSTS

CER Form

$$TTMD = TTMH \times THC \quad (30)$$

where

TTMD = Total tool manufacturing dollar costs

TTMH = Total tool manufacturing hours

Table 40. Tool Manufacturing Hours CER Coefficients.

TMF Value	Complexity	Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
	Simple Design - Subsonic (.35)	455.	260.	210.	620. (.5)	485.	--
	Regular Subsonic (.50)	650.	375.	300.	745. (.6)	620.	--
	Complex Subsonic (.65)	845.	490.	390.	930. (.75)	810.	--
	Simplified Design - Supersonic (.85)	1105.	640.	510.	1120. (.9)	1054.	--
	Regular Supersonic (1.0)	1300.	750.	600.	1240.	1240.	--
	Complex Supersonic (1.4)	1820.	1050.	840.	3470. (2.8)	1740.	--

$$RTMH = \sum BTMH_i \quad (621, 7)$$

THC Tool manufacturing labor cost per hour

Inputs

THC is a NAMELIST variable. Its value is based on labor rate information.

BASIC TOOL ENGINEERING HOURS

CER Form

$$BTEH = \left(\sum BTMH_i \right) F3 \quad (31)$$

where

BTEH Basic tool engineering hours

F3 Decimal percentage: ratio of basic tool engineering to basic tool manufacturing hours.

Inputs

The additional input is the factor F3, appearing at (F 622 7). This is a model card input whose value is based on historical data. See Appendix I.

RATE TOOL ENGINEERING HOURS

CER Form

$$RTEH = (RTMH) F4 \quad (32)$$

where

RTEH Rate tool engineering hours

F4 Decimal percentage: ratio of rate tool engineering hours to rate tool manufacturing hours.

Inputs

F4 is a model card input appearing at (F 623 7). Its value is based on historical data. An average value is 20% based on taking one-half of F3.

TOTAL TOOL ENGINEERING DOLLAR COSTS

CER Form

$$TTED = TTEH \times TEC \quad (33)$$

where

TTED Total tool engineering dollar costs

TTEH Total tool engineering hours:

$$BTEH + RTEH$$

TEC Tool engineering labor rate

Inputs

TEC is a NAMELIST variable. Its value is based on labor rate information.

MANUFACTURING DEVELOPMENT AND PLANT ENGINEERING HOURS

CER Form

$$MDPEH = TTMH \times F5 \quad (34)$$

where

MDPEH Manufacturing Development and Plant Engineering Hours

F5 Decimal percentage: ratio of MDPEH to total tool manufacturing hours.

Inputs

F5 is a model card input at (F 625 7). Its value is based on historical data, and an average value is 2%.

MANUFACTURING DEVELOPMENT AND PLANT ENGINEERING DOLLARS

CER Form

$$MDPED = MDPEH \times TDC \quad (35)$$

where

MDPED Manufacturing Development and Plant Engineering Dollars

TDC Composite labor rate

Inputs

TDC is a NAMELIST variable. Its value is based on labor rate information.

TOOLING MATERIAL AND OTHER DOLLAR COSTS

CER Form

$$\text{TMOD} = \text{TTMH} \cdot \text{F6} \quad (36)$$

where

TMOD Tooling material and other dollar costs

F6 Per hour allowance for tooling material and other costs (\$/hr)

Inputs

The factor F6 is a model card input at (F 626 8). Its value is based on historical data. An average value is \$1.00 per tool manufacturing hour based on F-106, F-102, B-58 and F-111 experience.

MANUFACTURING SUPPORT DOLLAR COSTS

CER Form

$$\text{MSD} = \text{CDED} \cdot \text{F7} \quad (37)$$

where

MSD Manufacturing support dollars

F7 Decimal percentage: ratio of MSD to configuration design engineering dollars

Inputs

F7 is a model card input at (F 627 8). Its value is based on manufacturing experience.

QUALITY CONTROL HOURS

CER Form

$$QCH = (CDEH \cdot F8) + (TTMH \cdot F9) \quad (38)$$

where

QCH Quality Control hours

F8 Decimal fraction: ratio of QCH to configuration design engineering

F9 Decimal fraction: ratio of QCH to total tool manufacturing hours

Inputs

F8 and F9 are model card inputs at (F 628 7). Their values, based on manufacturing experience, are respectively, 1% and 6%.

QUALITY CONTROL DOLLAR COSTS

CER Form

$$QCD = QCH \cdot RQC \quad (39)$$

RQC Quality Control labor rate

Inputs

RQC is a NAMELIST variable. Its values is based on labor rate information.

2.3.4 RECURRING AIRFRAME PRODUCTION COSTS (SUMMARY). A summary format for recurring airframe production costs is also furnished as part of the cost breakdown and computer output. Table 41 provides the cross-reference between cost output and model card. Figure 34 is a sample computer printout for the summary. As was the case for recurring airframe production costs by structural elements, the description of calculations that follows is oriented to the computer program.

The items of cost that are summarized consist of:

Sustaining Engineering Hours and Dollars

Table 41. Cost Output and Model Card Cross Reference -
Recurring Production Costs (Summary).

Hardware Components	Wing Hours	Horizontal Stabilizer Hours	Vertical Stabilizer Hours	Fuselage Hours	Nacelle Hours	Landing Gear Hours	Subtotal Hours	Dollars
RDTE Units								
Sustaining Engineering							Eq (40) F 630 7	F 630 8
Sustaining Tooling							Eq (41) F 631 7	F 631 8
Manufacturing:								
Detail Fabrication	Z 632 1	Z 632 2	Z 632 3	Z 632 4	Z 632 5	Z 632 6	F 632 7	F 632 8
Assembly	Z 633 1	Z 633 2	Z 633 3	Z 633 4	Z 633 5	Z 633 6	F 633 7	F 633 8
Primary Assembly & Major Mate							Eq (43) F 634 7	F 634 8
Quality Control							Eq (44) F 635 7	F 635 8
Material and Other								
Primary Assy & Major Mate	Z 636 1	Z 636 2	Z 636 3	Z 636 4	Z 636 5	Z 636 6		F 636 8
Material								Eq (45) F 637 8
Totals							F 638 7	F 638 8

* Equation (42) is used at each of these points.

MASSAGE VEHICLE STRUCTURAL COSTS
RECURRING AIRFRAME PRODUCTION COSTS (Summary)

17,290.00 11/ 30/ 77

DATE	Q177	Q277	Q377	Q477	Q577	Q677	Q777	Q877	Q977	Q078	Q178	Q278	Q378	Q478	Q578	Q678	Q778	Q878	Q978	Q079	Q179	Q279	Q379	Q479	Q579	Q679	Q779	Q879	Q979	Q080	Q180	Q280	Q380	Q480	Q580	Q680	Q780	Q880	Q980	Q081	Q181	Q281	Q381	Q481	Q581	Q681	Q781	Q881	Q981	Q082	Q182	Q282	Q382	Q482	Q582	Q682	Q782	Q882	Q982	Q083	Q183	Q283	Q383	Q483	Q583	Q683	Q783	Q883	Q983	Q084	Q184	Q284	Q384	Q484	Q584	Q684	Q784	Q884	Q984	Q085	Q185	Q285	Q385	Q485	Q585	Q685	Q785	Q885	Q985	Q086	Q186	Q286	Q386	Q486	Q586	Q686	Q786	Q886	Q986	Q087	Q187	Q287	Q387	Q487	Q587	Q687	Q787	Q887	Q987	Q088	Q188	Q288	Q388	Q488	Q588	Q688	Q788	Q888	Q988	Q089	Q189	Q289	Q389	Q489	Q589	Q689	Q789	Q889	Q989	Q090	Q190	Q290	Q390	Q490	Q590	Q690	Q790	Q890	Q990	Q091	Q191	Q291	Q391	Q491	Q591	Q691	Q791	Q891	Q991	Q092	Q192	Q292	Q392	Q492	Q592	Q692	Q792	Q892	Q992	Q093	Q193	Q293	Q393	Q493	Q593	Q693	Q793	Q893	Q993	Q094	Q194	Q294	Q394	Q494	Q594	Q694	Q794	Q894	Q994	Q095	Q195	Q295	Q395	Q495	Q595	Q695	Q795	Q895	Q995	Q096	Q196	Q296	Q396	Q496	Q596	Q696	Q796	Q896	Q996	Q097	Q197	Q297	Q397	Q497	Q597	Q697	Q797	Q897	Q997	Q098	Q198	Q298	Q398	Q498	Q598	Q698	Q798	Q898	Q998	Q099	Q199	Q299	Q399	Q499	Q599	Q699	Q799	Q899	Q999	Q1000	Q1001	Q1002	Q1003	Q1004	Q1005	Q1006	Q1007	Q1008	Q1009	Q1010	Q1011	Q1012	Q1013	Q1014	Q1015	Q1016	Q1017	Q1018	Q1019	Q1020	Q1021	Q1022	Q1023	Q1024	Q1025	Q1026	Q1027	Q1028	Q1029	Q1030	Q1031	Q1032	Q1033	Q1034	Q1035	Q1036	Q1037	Q1038	Q1039	Q1040	Q1041	Q1042	Q1043	Q1044	Q1045	Q1046	Q1047	Q1048	Q1049	Q1050	Q1051	Q1052	Q1053	Q1054	Q1055	Q1056	Q1057	Q1058	Q1059	Q1060	Q1061	Q1062	Q1063	Q1064	Q1065	Q1066	Q1067	Q1068	Q1069	Q1070	Q1071	Q1072	Q1073	Q1074	Q1075	Q1076	Q1077	Q1078	Q1079	Q1080	Q1081	Q1082	Q1083	Q1084	Q1085	Q1086	Q1087	Q1088	Q1089	Q1090	Q1091	Q1092	Q1093	Q1094	Q1095	Q1096	Q1097	Q1098	Q1099	Q1100	Q1101	Q1102	Q1103	Q1104	Q1105	Q1106	Q1107	Q1108	Q1109	Q1110	Q1111	Q1112	Q1113	Q1114	Q1115	Q1116	Q1117	Q1118	Q1119	Q1120	Q1121	Q1122	Q1123	Q1124	Q1125	Q1126	Q1127	Q1128	Q1129	Q1130	Q1131	Q1132	Q1133	Q1134	Q1135	Q1136	Q1137	Q1138	Q1139	Q1140	Q1141	Q1142	Q1143	Q1144	Q1145	Q1146	Q1147	Q1148	Q1149	Q1150	Q1151	Q1152	Q1153	Q1154	Q1155	Q1156	Q1157	Q1158	Q1159	Q1160	Q1161	Q1162	Q1163	Q1164	Q1165	Q1166	Q1167	Q1168	Q1169	Q1170	Q1171	Q1172	Q1173	Q1174	Q1175	Q1176	Q1177	Q1178	Q1179	Q1180	Q1181	Q1182	Q1183	Q1184	Q1185	Q1186	Q1187	Q1188	Q1189	Q1190	Q1191	Q1192	Q1193	Q1194	Q1195	Q1196	Q1197	Q1198	Q1199	Q1200	Q1201	Q1202	Q1203	Q1204	Q1205	Q1206	Q1207	Q1208	Q1209	Q1210	Q1211	Q1212	Q1213	Q1214	Q1215	Q1216	Q1217	Q1218	Q1219	Q1220	Q1221	Q1222	Q1223	Q1224	Q1225	Q1226	Q1227	Q1228	Q1229	Q1230	Q1231	Q1232	Q1233	Q1234	Q1235	Q1236	Q1237	Q1238	Q1239	Q1240	Q1241	Q1242	Q1243	Q1244	Q1245	Q1246	Q1247	Q1248	Q1249	Q1250	Q1251	Q1252	Q1253	Q1254	Q1255	Q1256	Q1257	Q1258	Q1259	Q1260	Q1261	Q1262	Q1263	Q1264	Q1265	Q1266	Q1267	Q1268	Q1269	Q1270	Q1271	Q1272	Q1273	Q1274	Q1275	Q1276	Q1277	Q1278	Q1279	Q1280	Q1281	Q1282	Q1283	Q1284	Q1285	Q1286	Q1287	Q1288	Q1289	Q1290	Q1291	Q1292	Q1293	Q1294	Q1295	Q1296	Q1297	Q1298	Q1299	Q1300	Q1301	Q1302	Q1303	Q1304	Q1305	Q1306	Q1307	Q1308	Q1309	Q1310	Q1311	Q1312	Q1313	Q1314	Q1315	Q1316	Q1317	Q1318	Q1319	Q1320	Q1321	Q1322	Q1323	Q1324	Q1325	Q1326	Q1327	Q1328	Q1329	Q1330	Q1331	Q1332	Q1333	Q1334	Q1335	Q1336	Q1337	Q1338	Q1339	Q1340	Q1341	Q1342	Q1343	Q1344	Q1345	Q1346	Q1347	Q1348	Q1349	Q1350	Q1351	Q1352	Q1353	Q1354	Q1355	Q1356	Q1357	Q1358	Q1359	Q1360	Q1361	Q1362	Q1363	Q1364	Q1365	Q1366	Q1367	Q1368	Q1369	Q1370	Q1371	Q1372	Q1373	Q1374	Q1375	Q1376	Q1377	Q1378	Q1379	Q1380	Q1381	Q1382	Q1383	Q1384	Q1385	Q1386	Q1387	Q1388	Q1389	Q1390	Q1391	Q1392	Q1393	Q1394	Q1395	Q1396	Q1397	Q1398	Q1399	Q1400	Q1401	Q1402	Q1403	Q1404	Q1405	Q1406	Q1407	Q1408	Q1409	Q1410	Q1411	Q1412	Q1413	Q1414	Q1415	Q1416	Q1417	Q1418	Q1419	Q1420	Q1421	Q1422	Q1423	Q1424	Q1425	Q1426	Q1427	Q1428	Q1429	Q1430	Q1431	Q1432	Q1433	Q1434	Q1435	Q1436	Q1437	Q1438	Q1439	Q1440	Q1441	Q1442	Q1443	Q1444	Q1445	Q1446	Q1447	Q1448	Q1449	Q1450	Q1451	Q1452	Q1453	Q1454	Q1455	Q1456	Q1457	Q1458	Q1459	Q1460	Q1461	Q1462	Q1463	Q1464	Q1465	Q1466	Q1467	Q1468	Q1469	Q1470	Q1471	Q1472	Q1473	Q1474	Q1475	Q1476	Q1477	Q1478	Q1479	Q1480	Q1481	Q1482	Q1483	Q1484	Q1485	Q1486	Q1487	Q1488	Q1489	Q1490	Q1491	Q1492	Q1493	Q1494	Q1495	Q1496	Q1497	Q1498	Q1499	Q1500	Q1501	Q1502	Q1503	Q1504	Q1505	Q1506	Q1507	Q1508	Q1509	Q1510	Q1511	Q1512	Q1513	Q1514	Q1515	Q1516	Q1517	Q1518	Q1519	Q1520	Q1521	Q1522	Q1523	Q1524	Q1525	Q1526	Q1527	Q1528	Q1529	Q1530	Q1531	Q1532	Q1533	Q1534	Q1535	Q1536	Q1537	Q1538	Q1539	Q1540	Q1541	Q1542	Q1543	Q1544	Q1545	Q1546	Q1547	Q1548	Q1549	Q1550	Q1551	Q1552	Q1553	Q1554	Q1555	Q1556	Q1557	Q1558	Q1559	Q1560	Q1561	Q1562	Q1563	Q1564	Q1565	Q1566	Q1567	Q1568	Q1569	Q1570	Q1571	Q1572	Q1573	Q1574	Q1575	Q1576	Q1577	Q1578	Q1579	Q1580	Q1581	Q1582	Q1583	Q1584	Q1585	Q1586	Q1587	Q1588	Q1589	Q1590	Q1591	Q1592	Q1593	Q1594	Q1595	Q1596	Q1597	Q1598	Q1599	Q1600	Q1601	Q1602	Q1603	Q1604	Q1605	Q1606	Q1607	Q1608	Q1609	Q1610	Q1611	Q1612	Q1613	Q1614	Q1615	Q1616	Q1617	Q1618	Q1619	Q1620	Q1621	Q1622	Q1623	Q1624	Q1625	Q1626	Q1627	Q1628	Q1629	Q1630	Q1631	Q1632	Q1633	Q1634	Q1635	Q1636	Q1637	Q1638	Q1639	Q1640	Q1641	Q1642	Q1643	Q1644	Q1645	Q1646	Q1647	Q1648	Q1649	Q1650	Q1651	Q1652	Q1653	Q1654	Q1655	Q1656	Q1657	Q1658	Q1659	Q1660	Q1661	Q1662	Q1663	Q1664	Q1665	Q1666	Q1667	Q1668	Q1669	Q1670	Q1671	Q1672	Q1673	Q1674	Q1675	Q1676	Q1677	Q1678	Q1679	Q1680	Q1681	Q1682	Q1683	Q1684	Q1685	Q1686	Q1687	Q1688	Q1689	Q1690	Q1691	Q1692	Q1693	Q1694	Q1695	Q1696	Q1697	Q1698	Q1699	Q1700	Q1701	Q1702	Q1703	Q1704	Q1705	Q1706	Q1707	Q1708	Q1709	Q1710	Q1711	Q1712	Q1713	Q1714	Q1715	Q1716	Q1717	Q1718	Q1719	Q1720	Q1721	Q1722	Q1723	Q1724	Q1725	Q1726	Q1727	Q1728	Q1729	Q1730	Q1731	Q1732	Q1733	Q1734	Q1735	Q1736	Q1737	Q1738	Q1739	Q1740	Q1741	Q1742	Q1743	Q1744	Q1745	Q1746	Q1747	Q1748	Q1749	Q1750	Q1751	Q1752	Q1753	Q1754	Q1755	Q1756	Q1757	Q1758	Q1759	Q1760	Q1761	Q1762	Q1763	Q1764	Q1765	Q1766	Q1767	Q1768	Q1769	Q1770	Q1771	Q1772	Q1773	Q1774	Q1775	Q1776	Q1777	Q1778	Q1779	Q1780	Q1781	Q1782	Q1783	Q1784	Q1785	Q1786	Q1787	Q1788	Q1789	Q1790	Q1791	Q1792	Q1793	Q1794	Q1795	Q1796	Q1797	Q1798	Q1799	Q1800	Q1801	Q1802	Q1803	Q1804	Q1805	Q1806	Q1807	Q1808	Q1809	Q1810	Q1811	Q1812	Q1813	Q1814	Q1815	Q1816	Q1817	Q1818	Q1819	Q1820	Q1821	Q1822	Q1823	Q1824	Q1825	Q1826	Q1827	Q1828	Q1829	Q1830	Q1831	Q1832	Q1833	Q1834	Q1835	Q1836	Q1837	Q1838	Q1839	Q1840	Q1841	Q1842	Q1843	Q1844	Q1845	Q1846	Q1847	Q1848	Q1849	Q1850	Q1851	Q1852	Q1853	Q1854	Q1855	Q1856	Q1857	Q1858	Q1859	Q1860	Q1861	Q1862	Q1863	Q1864	Q1865	Q1866	Q1867	Q1868	Q1869	Q1870	Q1871	Q1872	Q1873	Q1874	Q1875	Q1876	Q1877	Q1878	Q1879	Q1880	Q1881	Q1882	Q1883	Q1884	Q1885	Q1886	Q1887	Q1888	Q1889	Q1890	Q1891	Q1892	Q1893	Q1894	Q1895	Q1896	Q1897	Q1898	Q1899	Q1900	Q1901	Q1902	Q1903	Q1904	Q1905	Q1906	Q1907	Q1908	Q1909	Q1910	Q1911	Q1912	Q1913	Q1914	Q1915	Q1916	Q1917	Q1918	Q1919	Q1920	Q1921	Q1922	Q1923	Q1924	Q1925	Q1926	Q1927	Q1928	Q1929	Q1930	Q1931	Q1932	Q1933	Q1934	Q1935	Q1936	Q1937	Q1938	Q1939	Q1940	Q1941	Q1942	Q1943	Q1944	Q1945	Q1946	Q1947	Q1948	Q1949	Q1950	Q1951	Q1952	Q1953	Q1954	Q1955	Q1956	Q1957	Q1958	Q1959	Q1960	Q1961	Q1962	Q1963	Q1964	Q1965	Q1966	Q1967	Q1968	Q1969	Q1970	Q1971	Q1972	Q1973	Q1974	Q1975	Q1976	Q1977	Q1978	Q1979	Q1980	Q1981	Q1982	Q1983	Q1984	Q1985	Q1986	Q1987	Q1988	Q1989	Q1990	Q1991	Q1992	Q1993	Q1994	Q1995	Q1996	Q1997	Q1998	Q1999	Q2000	Q2001	Q2002	Q2003	Q2004	Q2005	Q2006	Q2007	Q2008	Q2009	Q2010	Q2011	Q2012	Q2013	Q2014	Q2015	Q2016
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Sustaining Tooling Hours and Dollars

Manufacturing: Detailed Fabrication Hours and Dollars
Subassembly and Assembly Hours and Dollars
Primary Assembly and Major Mate Hours and Dollars
Quality Control Hours and Dollars
Material by Structural Element
Primary Assembly and Major Mate Material

These items are repeated for RDT&E production units and for each of the alternate production quantities. The discussion that follows, and Table 41, applies only to RDT&E units. Procurement articles follow similar patterns that can be readily discerned within the model card structure. To illustrate, the sequence of model card calculations for the RDT&E summary that runs from F 630 7 to F 638 8 is repeated for the first quantity of procurement articles in the sequence of model cards from F 640 7 to F 648 8.

The conversion of hours to dollars is a repetitive process that follows the procedures already described above. These calculations occur at (630, 8), (631, 8), (632, 8), (633, 8), (634, 8), and (635, 8).

SUSTAINING ENGINEERING HOURS

$$SEH = (DEH + CDEH) (PN2)^{0.2 - 1} \quad (40)$$

where

SEH Sustaining engineering hours

DEH and CDEH: See Equations (23) and (25)

PN2 RDT&E number of units

SUSTAINING TOOLING HOURS

$$STH = (TTMH + TTEH + MDPEH) (PN2)^{0.14 - 1} \quad (41)$$

where

STH Sustaining tooling hours

TTMH	Total tool manufacturing hours
TTEH	Total tool engineering hours
MDPEH	Mfg. development and plant engineering hours

MANUFACTURING: DETAILED FABRICATION, SUBASSEMBLY AND ASSEMBLY AND MATERIAL COSTS

These three items of costs are handled in exactly the same way as described for the progress curve projection procedure for recurring production costs for structural elements, except that in using the Z-card convention, TERM 24 is used (for RDT&E units). TERM 24 is of the following form:

$$\text{Cost estimated} = P1 \sum_{i=1}^{P2} i^x \quad (42)$$

where

P1	First unit cost
P2	The number of RDT&E units
x	$\frac{\ln P3}{\ln 2}$ where
P3	The relevant learning curve factor expressed as a decimal fraction.

For the projection of costs for procurement articles, TERM 29 is again used in the manner described in Section 2.3.2.

PRIMARY ASSEMBLY AND MAJOR MATE HOURS

$$MML = [(632, 7) + (633, 7)] \quad (MMPCTL)$$

where

$$MMPCTL = \text{Percentage factor} \quad (43)$$

QUALITY CONTROL HOURS

$$QCH = [(632, 7) + (633, 7) + MML] \quad QCF \quad (44)$$

where

QCF Q/C percentage factor

PRIMARY ASSEMBLY AND MAJOR MATE MATERIAL

$$MMM = (636, 8) \times MMF \quad (45)$$

where

(636, 8) Summation of material costs for structural elements

MMF Major mate material percentage factor

2.3.5 COMPLEXITY FACTORS. The development of first unit costs as described above makes extensive use of complexity factors. These are also used to a lesser degree in the development of nonrecurring design and development costs.

Complexity factors are used in the current methodology as a segment of an overall costing process. The costing process, as illustrated in Figure 35, can be thought of as having basically three inputs: historical costs through the mechanism of estimating coefficients, hardware definition translated as size/weight, and hardware definition translated as complexity. These inputs interact within the costing relationships to produce the cost estimate. Definition of the hardware has the element of size and complexity. Defining these two elements is sufficient to provide a suitably unambiguous specification of the hardware. The complexity of any piece of structure is reflected in the material and the type of construction used. The complexity associated with a given material and construction technique can be symbolized by a numerical complexity factor.

The numerical complexity factors are developed from a detailed analysis of the candidate structures and materials. The first step in this process is the selection of a nominal structural element that provides a model of the manufacturing approaches for that structure. This defines a baseline, which is assigned a reference complexity of one.

Other structural approaches using different materials and construction techniques are defined. The manufacturing processes for both the baseline and alternate structures are then identified and listed. From both historical and projected labor data, hours can then be assigned to the various manufacturing processes. This results in a number of hours being associated with each specific type of material and construction technique as a variation of the nominal structural element.

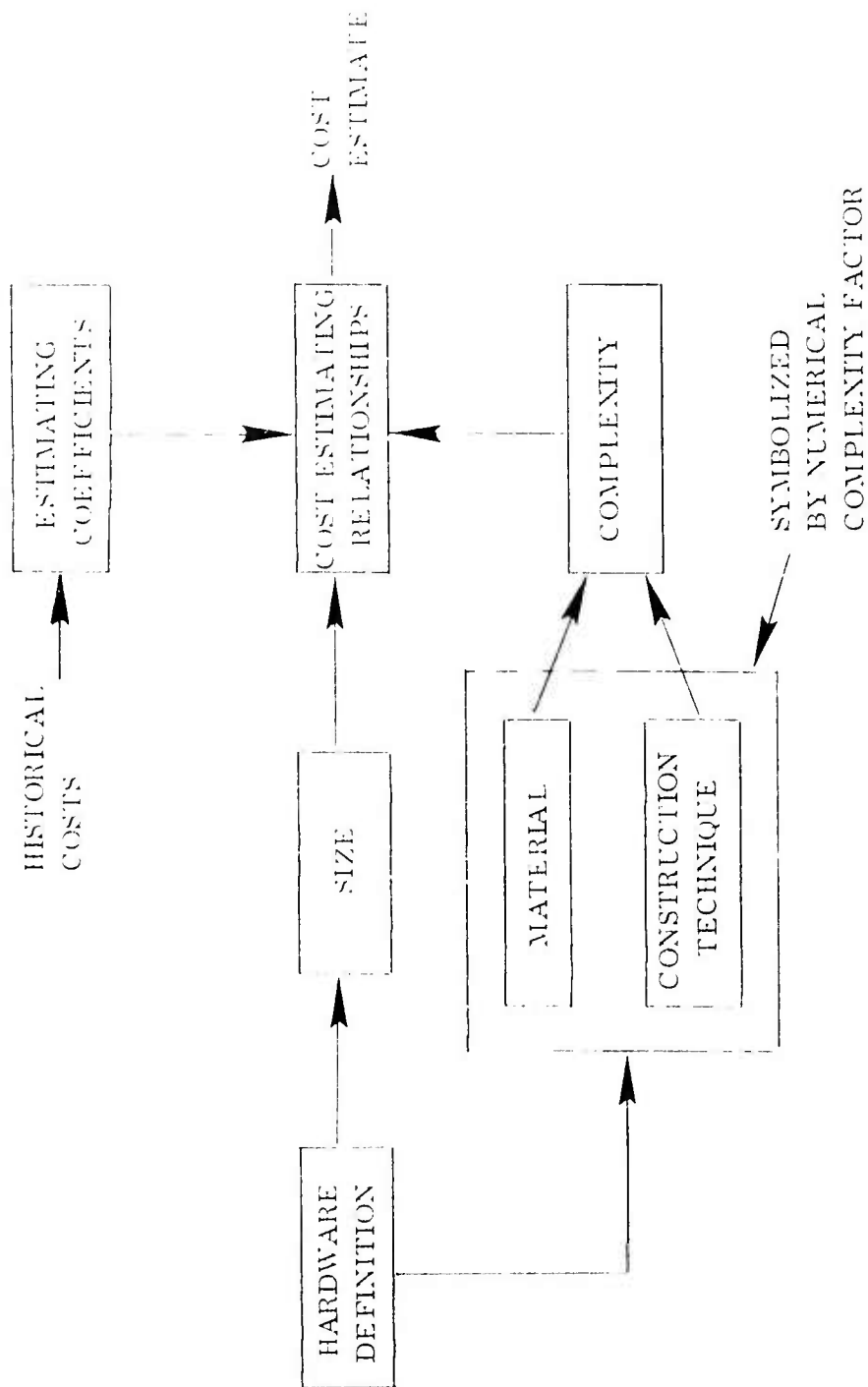


Figure 35. Costing Process.

By dividing the number of hours for each material construction technique combination by the number of hours required for the baseline, we arrive at a complexity factor for each box of the material-construction technique matrix. The flow of this process is shown in Figure 36. An example of a completed material-construction technique matrix for rib detail fabrication was shown in Table 9. A sample of the detailed estimates used to generate hour requirements for the different types of construction and material appears in Figure 37. The complete set of complexity factor tables was shown in Section 2.3, and these are backed up by projected cost data included in Appendix G.

For each type of construction, a sketch defines the specifics, such as number of rails, web parts, number of machined surfaces, number of stiffeners, etc. A nominal size was defined to make the different design approaches to ribs, spars, and covers comparable on a complexity factor basis. For each piece of detail structure, the manufacturing operations were identified that are required to manufacture each piece. These included such operations as those shown in Figure 37: saw set up, edge burring, router set up, routing of cutouts, processing to specifications, identifying and inspecting, etc. Where assembly was required, these operations were identified and included clamping in place, hole drilling riveting, welding, identifying and inspecting, etc.

Complexity factors for secondary structure are less well defined because distinctions in type of construction are not as well defined. For secondary structure, complexity factors have been developed by analogy from historical data and by industrial engineering studies that evaluate the impact and relative cost effect of selected design alternatives. The secondary structure complexity factors are contained in Tables 25 and 26. Use of these tables requires selection of a suitable analog or analogs as a point of reference for selection of a suitable complexity factor.

The use of complexity factors in the estimating process at the level of detail depicted above provides a great deal of flexibility. New types of structure can be analyzed from the standpoint of impact on manufacturing processes and the resultant impact on cost determined. Some anomalies occur, however, since the historical data does not always confirm presupposed patterns of cost. The detailed study as to the reasons for such ambiguity is beyond the scope of this study.

2.3.6 DERIVATION OF ESTIMATING COEFFICIENTS. A summary of cost elements for which baseline coefficients were developed is shown in Figure 38. Historical cost data was collected for each of the cost elements of the matrix. This basic cost data was normalized, where appropriate, by making use of the complexity factors. The construction and material type for each of the cost elements was identified and the appropriate complexity factor divided into the baseline cost. The effect of this procedure is to reduce all the data points to a common basis to which a complexity factor of one can be applied.

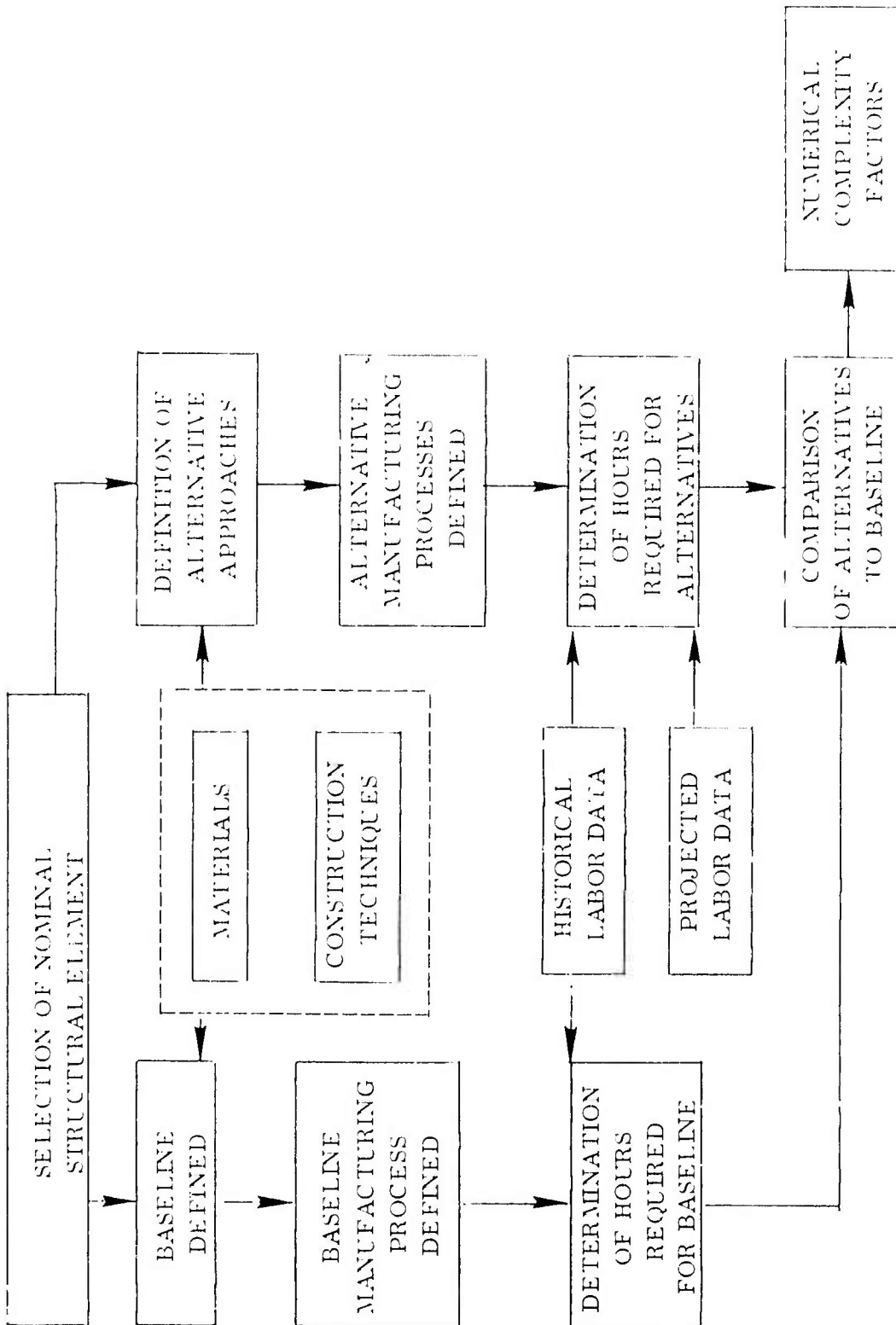
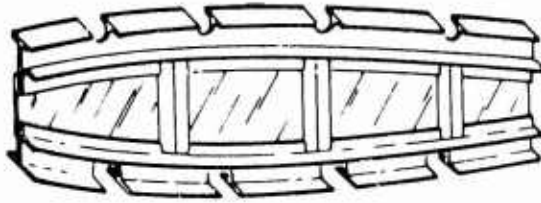


Figure 36. Development of Complexity Factors.



RIB BUILT-UP
WEB STIFFENER

	Low-C Non-Hard. Steel	Ti	SS	Al	1
Rib size 48 x 12 x 2 in.					
Detail parts are rails (2), web (1), stiffeners (2) & intercostals (3)					
Fabrication of rails (2)					
Setup saw	0.50	0.50	0.50	0.5	
Saw extrusion to length (2)		0.75	1.11	0.3	
Burr edges	0.42	0.75	1.11	0.3	
Setup router	0.50	0.50	0.50	0.5	
Route stringer cutouts	0.98	1.75	2.59	0.7	
Burr	0.42	0.75	1.11	0.3	
Set up rolls	0.50	0.50	0.50	0.5	
Roll form to contour	0.30	0.30	0.30	0.3	
Prime surfaces	0.50	0.50	0.50	0.5	
Identify & inspect	0.50	0.50	0.50	0.5	
Fabrication of web (1)					
Setup shear	0.50	0.50	0.50	0.5	
Shear part to width & length (12 in x 48 in.)	0.30	0.30	0.30	0.3	
Burr	0.50	0.50	0.50	0.5	
Route web to shear	0.70	1.25	1.85	0.5	
Burr	0.28	0.50	1.74	0.2	
Prime surfaces	0.50	0.50	0.50	0.5	
Identify & inspect fabrication of stiffeners (2)					
Setup saw	0.50	0.50	0.50	0.5	
Saw extrusion (2)	0.42	0.75	1.11	0.3	
Burr	0.28	0.50	0.74	0.6	
Setup rolls	0.50	0.50	0.50	0.5	
Roll form to contour	0.50	0.50	0.50	0.5	
Prime surfaces	0.50	0.50	0.50	0.5	
Identify & inspect	0.50	0.50	0.50	0.5	
Fabrication of intercostals (3)					
Setup saw	0.50	0.50	0.50	0.5	
Saw extrusion (3)	0.42	0.75	1.11	0.3	
Burr	0.42	0.75	1.11	0.3	
Process to spec. (alodine)	4.00	4.00	4.00	4.0	
Prime surfaces	0.50	0.50	0.50	0.5	
Identify & inspect	0.50	0.50	0.50	0.5	
Total detail Fabrication	17.21	21.40	25.48	16.3	

Figure 37. Detailed Industrial Engineering Estimates for Complexity
Factor Derivation

<u>FIRST UNIT COST</u>	<u>DETAIL FABRICATION</u>	<u>SUBASSEMBLY</u>
Structural Box		
Ribs	X	X
Spurs	X	X
Covers	X	X
Secondary Structure		
Leading Edge	X	X
Trailing Edge	X	X
Ailerons	X	X
Fairings	X	X
Tips	X	X
Spoilers	X	X
Flaps + Flaperons	X	X
Attachment Structure	X	X
Access + Other Doors	X	X
Air Induction	X	X
High Lift Ducting	X	X
Slats	X	X
Hinges, Brackets, Seals	X	X
Pivots + Folds	X	X
Center Section	X	X
Elevators	X	X
Balance Weights	X	X
Rudder	X	X
Other	X	X

Figure 38. Summary of CER Coefficients.

Once the normalized data for the cost elements has been plotted on log-log paper, the problem becomes one of simply determining the line that can best represent the adjusted data. The two basic parameters define the CER line: the slope of the line and the intercept of the y axis where the value of the x axis (weight) is one pound. Based on a composite plot of all cost data and the results of previous research, in particular References 1, 2, and 3, a constant exponential scaling relationship was used. With the slope of the curves specified, each y intercept was determined by fitting the fixed slope line to the data available for each cost element. A cost plot showing the technique for the rib detail fabrication is shown in Figure 39. Back-up data charts for each of the CERs appear in Appendix F. The curve fit line is not plotted on these charts since they are expected to change with the addition of new data. Values used were determined by plots on work sheets.

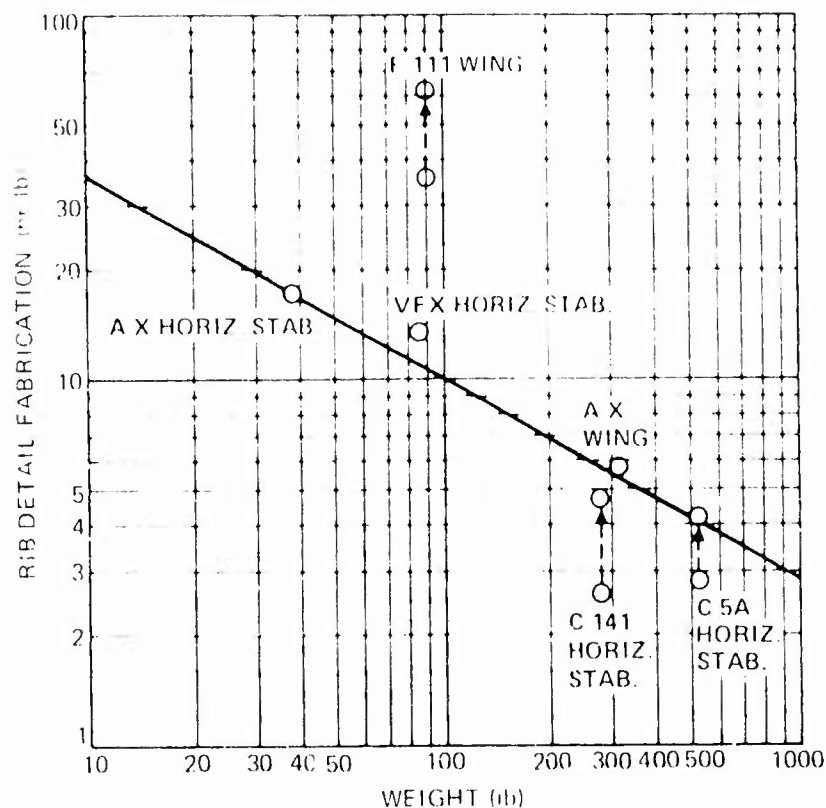


Figure 39. Detail Fabrication Hours Versus Weight for Ribs with Complexity Factor normalized.

2.4 PROGRAM OPERATION AND INSTRUCTIONS

This section discusses additional considerations involved in the full set of trade study cost estimating computer programs. As the method is currently structured each of the programs depicted in Figure 1 operate independently, and data is transferred manually between them.

2.4.1 COMPUTER PROGRAM INTEGRATION. The elements of the estimating method have been designed to operate in a modular mode, as opposed to being hard-wired, for two reasons: (1) Each of the elements is in a state of development and changes in input/output are to be expected and (2) It was desired to have the capability of operating the costing program independent of the structural synthesis program, limited, of course, to those cases where the necessary input data could be provided manually.

In the modular mode then, coordination of the programs is accomplished by means of a set of instructions covering input development, the preparation of input cards, and the set-up of the computer deck for the desired operation. Section 2.3 provided the general instructions for input development and identified input sources. Specific instructions for operation of the supporting programs and the transfer of relevant input data are given next.

2.4.2 OPERATION OF SUPPORTING PROGRAMS. The sequence of operations for the programs involved in analyzing aerodynamic surfaces is shown in Figure 40. Also shown is the list of worksheets used in the transfer of data. An illustrative set of these worksheets is included and discussed in Appendix J.

Worksheets 2, 4, and 5 are the final output of the aerodynamic surfaces supporting programs. (The combined weight statement appears as Table 1.) These data are entered as NAMELIST variables. They are identified by means of the coding on the NAMELIST Variable Dictionary in Appendix D, which also identifies the worksheet location of the input.

The sequence of operations for the programs involved in analyzing the fuselage, nacelles and landing gear is shown in Figure 41. Also shown is the list of worksheets used in the transfer of data. The situation parallels that of the aerodynamic surfaces. In this case worksheets 3 and 4 are the final output of the supporting programs. Further material is included in Appendix D.

2.4.3 TIME SHARING. The use of Interactive Graphics was investigated as part of this study. From the results it appears that time-sharing using an INTERCOM type system offers significant advantages. A discussion of Interactive Graphics benefits and time-sharing using INTERCOM is provided in Volume I.

INTERCOM is being used as part of the installation at AFFDL. It provides a simplified procedure for making NAMELIST and model card changes. These are made at a deskside terminal that displays a card and provides for a change in the card as a keyboard operation. This capability is especially significant for maintaining currency in estimating coefficients as new data indicates a need for revision and for changes in the CERs themselves.

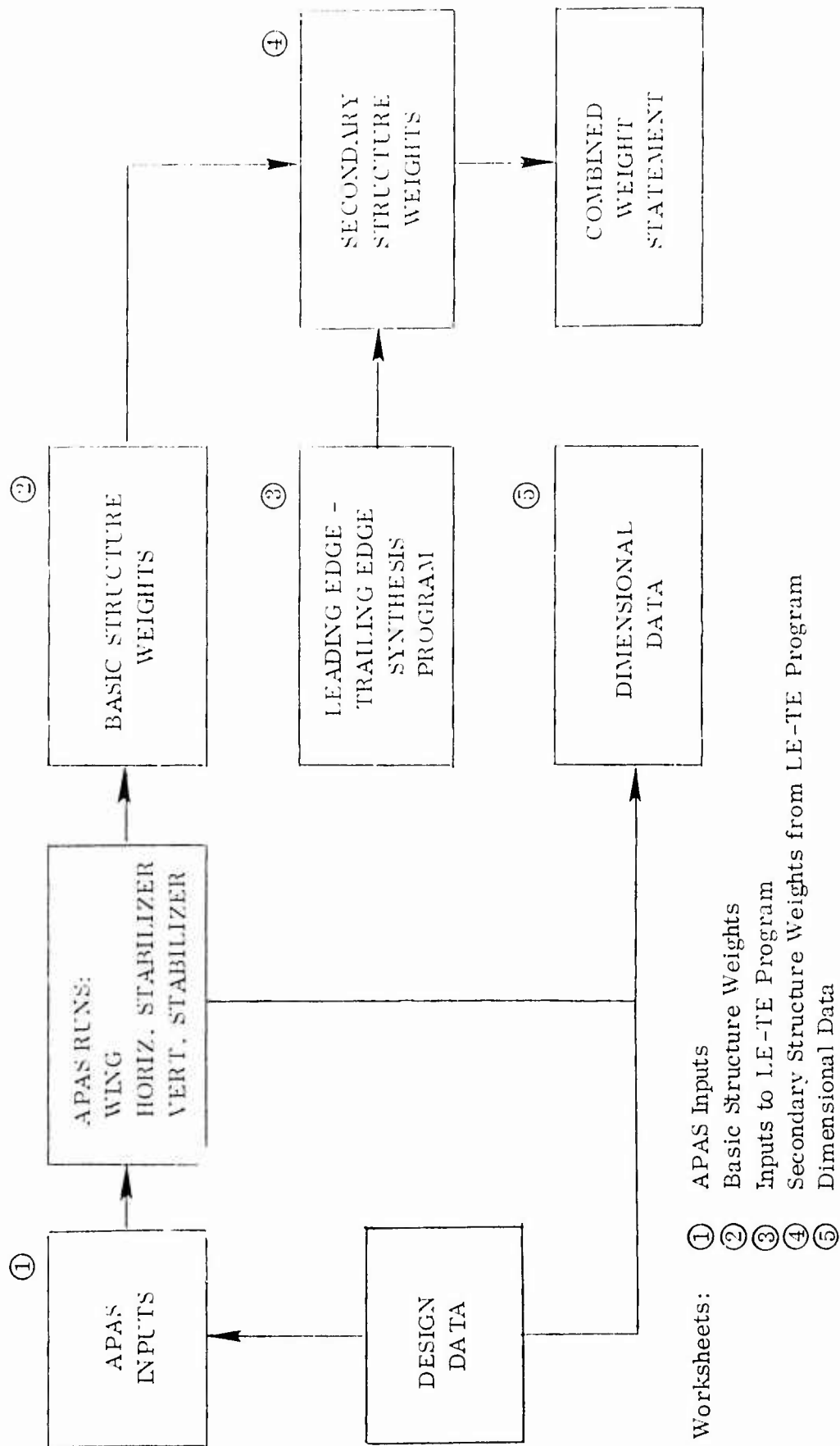


Figure 40. Supporting Synthesis Programs for Aerodynamic Surfaces.

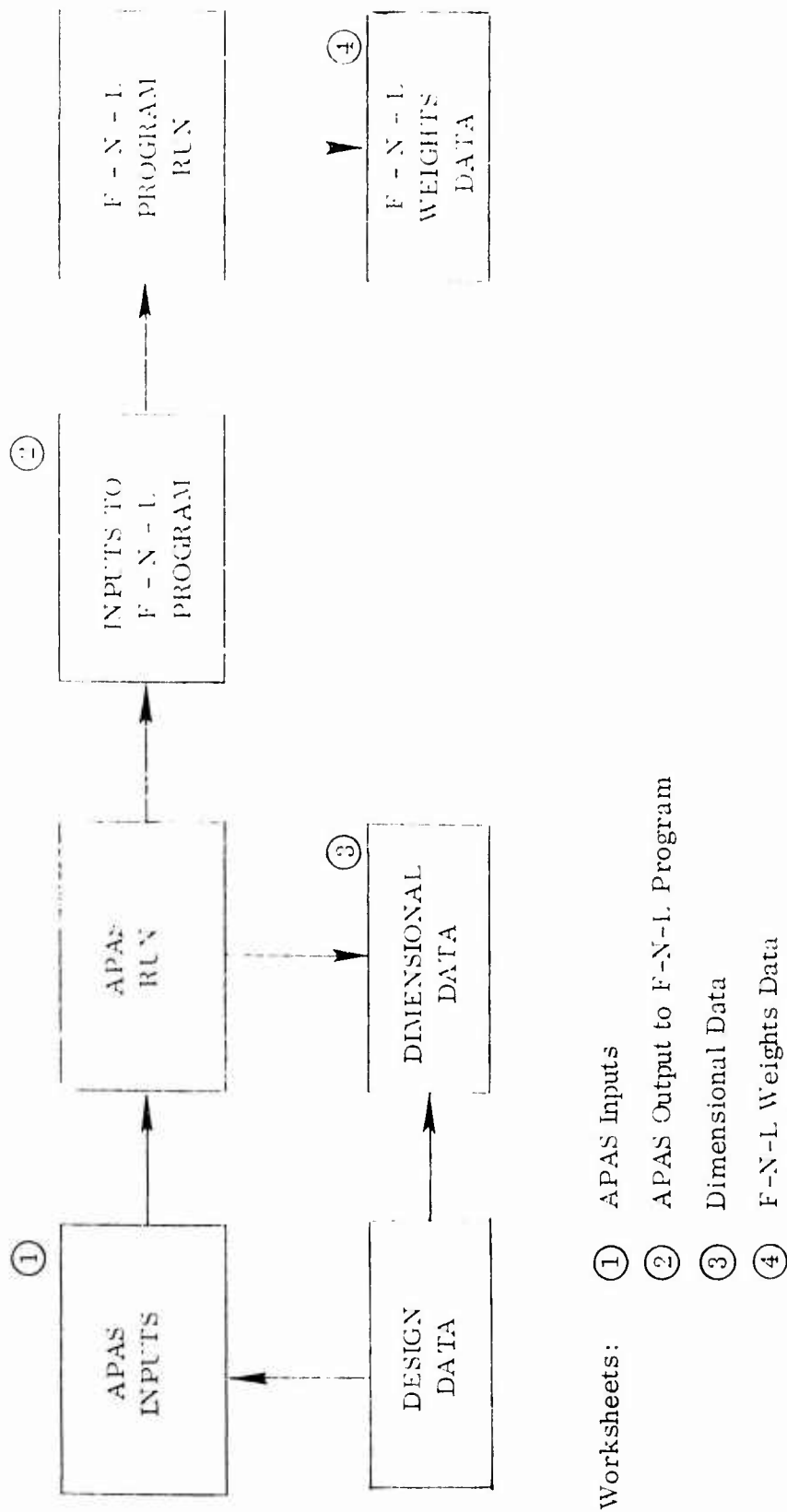


Figure 41. Supporting Synthesis Programs for Fuselage, Nacelles, Landing Gears.

SECTION III

AIRFRAME SYSTEM COST ESTIMATING METHOD

The system cost estimating method is described in this section. User instructions for making an estimate are provided. The system method does not require the use of the previously described, supporting structural synthesis programs. A group weight statement and design information are the principal sources of input information. The research leading to the development of the method is covered either in Volume I, or in previous reports as referenced.

3.1 COSTS ESTIMATED

Costs are estimated for each of the airframe subsystems as shown in Figure 42.

	Engineering Direct Labor	Tool Mfg. Direct Labor	Manufacturing First Unit Cost
Structural Subsystems			
Wing	x	x	x
Horizontal Stabilizer	x	x	x
Vertical Stabilizer	x	x	x
Fuselage	x	x	x
Nacelles	x	x	x
Landing Gear	x		x
Functional Subsystems			
Surface Controls	x		x
Environmental Control System	x		x
Hydraulics/Pneumatics	x		x
Electrical/Electronics	x		x
Instruments	x	x	x
Auxiliary Power	x		x
Armament Provisions	x		x
Engine Associated Equipment	x		x
Fuel System	x		x
Avionics Provisions	x		x
Furnishings and Equipment	x		x
Support Engineering	x		

Figure 42. Airframe System Cost Estimating Structure

The different categories of cost outputs provided consist of:

- a. Nonrecurring Design and Development Costs
- b. First Unit Manufacturing Costs
- c. Recurring Airframe Production Costs

Shown in Section 1.1.2, Figures 14 through 17, are computer printout examples of each of these types of cost output. The hardware components listed comprise the "airframe" when related to system costing methodology. The capability for alternate production quantities is the same as for the trade study method. Production quantities are again obtained by learning curve projections of first unit costs.

The system cost formats are laid out and programmed for later expansion in the case of first unit cost. Under the present approach the subsystems are estimated by a combined labor and material CER. With the acquisition of additional data it should become possible to make separate labor and material estimates, as illustrated by the format in Figure 16.

3.2 COST MODEL COMPUTER PROGRAM MODULE

The computer program for the system cost estimating method is a module of the trade study program, as stated previously. This module uses SAV matrix lines 700 through 799. The number of lines used is kept to a minimum for computer efficiency and may be increased by a simple change in the DIMENSION statement in the COSTC program. The details of the computer program remain unchanged for system costing operation except that only a subset of the model card deck is used: that pertaining to the cards corresponding to the section described above. Input organization is simplified and is described in connection with the discussion of cost estimating relationships.

Additional material describing the system costing computer program module is covered in Appendix K. This consists of a computer listing of input elements, the program module listing of model cards, a NAMELIST variables dictionary, and a summary of estimating coefficients, back-up data for which are given in Appendices I and L. The NAMELIST variable dictionary serves as an input summary table in lieu of the individual input summary tables by cost category used for the trade study method.

3.3 COST ESTIMATING RELATIONSHIPS AND INPUT DESCRIPTION

A summary of the system cost estimating approach is given in the following sections for each of the major categories of cost. A complete description of CERs, the resulting input requirements, input sources, and references to back-up data are provided. Tables are provided for cross referencing cost items as given in the output formats, the CER equations, and the model card locations. The step-by-step development of

input data consists of providing NAMELIST variable inputs and determining the suitability of estimating coefficients called out by the CERs and recorded as model card constants.

3.3.1 NONRECURRING DESIGN AND DEVELOPMENT. Nonrecurring design and development costs are estimated by a series of CERs, each of the same general form, for each of the costs in Figures 14 and 15. Table 42 cross references the cost print-out, CERs, and model cards for each. The CER forms and the input requirement that is generated by their use are discussed below. Equations are numbered separately from the trade study method.

ENGINEERING:

BASIC STRUCTURE DESIGN ENGINEERING

Definition

Basic Structure Design Engineering comprises the detailed design of the elements of basic structure, plus such supporting activities as lines and lofting, checking, stress, weights and value engineering, as they relate to the elements of basic structure.

CER Form

A CER of the following form is used for estimating basic structure design engineering for each of the elements of basic structure:

$$DE_i = F_i (EC_i)^{E_i} (WE_i) \quad (1)$$

where

DE_i = Design engineering hours for each structural element estimated

F_i = Complexity factor

EC_i = Estimating coefficient

WE_i = Weight of the structural element estimated

E_i = Cost/weight scaling exponent

i = Index numbers, 1 through 6 for basic structure

Inputs

The categorization of inputs used in the system costing method can be best explained by reference to the model cards of the computer program. As an example, we have, F701 1 F1 WNG * 540.0 * WW WNG ** E1 WNG taken from the

Table 42. Cost Output, CER Equation, and Model Card Cross Reference -
System Nonrecurring Design and Development Cost.

Hardware Components	Direct Labor Hours	Direct Labor Costs	Engineering Material Costs	Labor and Material Costs
Engineering				
Basic Structure Design Engineering				
Wing	Eq (1)	F 701 1		
Horizontal Stabilizer	Eq (1)	F 702 1		
Vertical Stabilizer	Eq (1)	F 703 1		
Fuselage	Eq (1)	F 704 1		
Nacelle	Eq (1)	F 705 1		
Landing Gear	Eq (1)	F 706 1		
Configuration Design Engineering	Eq (2)	F 707 1		
Surface Controls	Eq (3)	F 711 1		
Environmental Control System	Eq (3)	F 712 1		
Hydraulics-Pneumatics	Eq (3)	F 713 1		
Electrical	Eq (3)	F 714 1		
Instruments	Eq (3)	F 715 1		
Auxiliary Power Unit	Eq (3)	F 716 1		
Armament Provisions	Eq (3)	F 717 1		
Engine Associated Equipment	Eq (3)	F 718 1		
Fuel System	Eq (3)	F 719 1		
Avionics Provision	Eq (3)	F 720 1		
Furnishings and Equipment	Eq (3)	F 721 1		
Total Engineering Labor	Eq (4)	R 722 1		
Dollar Costs		Eq (5) F 723 2	Eq (6) F 723 3	Eq (7) F 723 4

model card listing in Appendix K. The conventions are the same as applied in the trade study method. This model card is of the F-card type. Calculated values of DE_i are entered in the SAV matrix, in this case at the address (701, 1); and the following equivalencies and categorization apply:

F_i	F1 WNG	(NAMELIST variable)
EC_i	540.0	(Model card coefficient)
WE_i	WW WNG	(NAMELIST variable)
E_i	E1 WNG	(NAMELIST variable)

Input organization is simple enough so as to obviate the need for individual input summary tables by cost category as was used for the trade study. NAMELIST variables are entered on the NAMELIST SUMMARY input cards, one for each structural element in the following sequence:

WNG = Wing
 HTL = Horizontal Stabilizer
 VTL = Vertical Stabilizer
 FLG = Fuselage
 NAC = Nacelle
 LGD = Landing Gear

It can be seen that the sample F-card above represents a calculation for the wing.

Input values to be entered for F_i are obtained from the historical cost data supplied as back-up data in Appendix I. (The same data is used in this case for both trade and system costing.) The complexity factor is obtained by analogy to historical references displayed in the Figures I-1 through I-6, or through other comparable data.

Values for EC_i are already entered on the appropriate model card and can be seen on the listing in Appendix K. These values are developed from an analysis of the data on the above referenced figures.

The estimated weight of the structural element being estimated, WE_i , is obtained from an appropriate weight statement. In the system costing method, this input source is not definitely established.

The scaling exponent, E , is obtained from the previously mentioned historical data in Appendix I. Independent research has shown this scaling to be a constant value, as indicated by Figures I-1 through I-6.

In examining the NAMELIST variables as shown in the model card listing, a convention of the COSTC program should be recalled: An input element remains the same for the entire sequence of elements to be estimated unless a change is entered in a subsequent NAMELIST variable input card. Thus, E1 VTL will equal E1 HTL will equal E1 WNG if only the original entry under WNG is made. This is not true of F1 WNG and F2 HTL, since F1 and F2 are defined to be different variables.

CONFIGURATION DESIGN ENGINEERING

Definition

Configuration design engineering includes support engineering consisting of preliminary design, aerodynamics, dynamics, and thermodynamics activity related to structure.

CER Form

A CER of the following form is used for estimating configuration design engineering:

$$CDE = F7 (EC) (WAMP)^{E2} \quad (2)$$

where

CDE = Configuration design engineering hours

F7 = Complexity factor

EC = Estimating coefficient = 1840

WAMP = AMPR weight of the total basic structure

E2 = Cost/weight scaling exponent

Inputs

F7, WAMP and E2 are NAMELIST variable inputs. EC is an estimating coefficient entered on the model card.

Input values to be entered for F7 are obtained from the historical cost data shown as Figure L-1, or through comparable data. A value for EC is entered at line 707 of the model card list, being derived from the same historical data. WAMP, the AMPR weight of basic structure is obtained from a suitable weight statement. E2, the scaling exponent, is the same value as E1 above and is obtained from the same data base.

EQUIPMENT DESIGN ENGINEERING

Definition

Equipment design relates to the design and development of aircraft functional subsystems.

CER Form

A general CER of the following form is used:

$$EDE_i = F_i (EC_i) (WE_i)^{E_i} \quad (3)$$

where

EDE_i = Equipment design engineering hours for each functional subsystem

and F_i , EC_i , WE_i and E_i are as defined before. The index, i , runs from 8 through 18, inclusive, corresponding to the functional subsystems as listed in Figure 42.

Inputs

Categorizations are the same as before. Input values for F_i are obtained by reference to Figures L-2 through L-12. Values for EC_i , derived from these same data, are given in model cards for lines 711 through 721. WE_i values are obtained from a weight statement, as before. The scaling exponent, E_i remains 0.6 based on data in the above figures.

TOTAL ENGINEERING LABOR

Total engineering labor is the summation of the previous estimates accomplished by an R-card, line 722. The formula appears as follows:

$$TEL = \sum (701 \dots 718, 1) \quad (4)$$

where

TEL = Total engineering labor,

and the summation is of the series of estimates recorded in the SAV matrix from line 701 through 721.

ENGINEERING DOLLAR COSTS

Engineering dollar costs are obtained by applying a composite engineering labor rate by means of an F-card at line 723, 2. The formula is:

$$EDC = TEL (ECLR1) \quad (5)$$

where

EDC = Engineering dollar costs

ECLR1 = Composite engineering labor rate

ENGINEERING MATERIAL COSTS

Definition

This cost covers miscellaneous costs associated with engineering design such as engineering materials and supplies, travel and per diem and computer costs. Material for developmental hardware is excluded here and included under development support.

CER Form

A CER of the following form is used:

$$EM = EDC (FM) \quad (6)$$

where

EM = Engineering Material cost

EDC = Engineering dollar cost taken from the SAV matrix at (723,2)

FM = A percentage factor

Inputs

The NAMELIST input FM is based on the contractor's experience and is currently entered as 0.2.

TOTAL LABOR AND MATERIAL COST

This cost is calculated by an F-card at line (723,4) and is represented by

$$TLM = EDC + EM \quad (7)$$

TOOLING:

BASIC TOOL MANUFACTURING HOURS

Definition

Basic tool manufacturing provides a complete set of manufacturing tools assumed to be capable of supporting a manufacturing rate of approximately one aircraft per month.

CER Form

A CER of the following form is used for estimating basic tool manufacturing hours for each of the elements of basic structure.

$$BT_i = TF_i (EC_i) (WE_i)^{T_i} \quad (8)$$

where

BT_i = Basic tool manufacturing hours by hardware element

TF_i = Complexity factor for tooling

EC_i = Estimating coefficient

WE_i = Weight of the structural element estimated

T_i = Cost/weight scaling exponent

i = Index numbers 1 through 7 for tooling elements

This CER is essentially the same as Equation 28 of the trade study method except that here the complexity factor is treated explicitly whereas in the trade study method it is built into Table 46.

Inputs

Input values for TF_i are obtained from Table 40 except for TF_7 , which must be derived as analogs from Figure L-13. Additionally, decisions on the choice of complexity factors for TF_1 through TF_5 may be based on analogy from the data in Figures I-7 through I-11, the same data used in the trade study method. Data is not available for the landing gear. Values for EC_i are entered on model cards F731, 1 through 7, based on the above data. Weights are the same as for engineering. The scaling exponent, T_i , based on these data has been taken as a value of 0.75.

A summation of hours is provided by F631-8.

RATE TOOL MANUFACTURING HOURS

Definition

Rate tooling is defined as the tool provisioning required to increase production capability to a required rate from that provided by basic tooling.

CER Form

The CER used is

$$RT_i = BT_i (R^{TR} - 1) \quad (9)$$

where

RT_i Rate tool manufacturing hours by hardware element

R Production rate

TR Scaling with production rate increase

This calculation is applied to each of the hardware elements.

Inputs

The inputs R and TR are NAMELIST variables entered in NAMELIST SUMMARY. The production rate is obtained from program plan data and will normally be the same for all hardware elements, although provision is made for the application of separate rates. The value for TR is 0.3 based on manufacturing experience.

A summation of hours is again provided, F732-8.

TOTAL TOOL MANUFACTURING

Basic and Rate Tool Manufacturing Hours are summed by column for each hardware element, for other subsystems and for the subtotals. The calculation by F-card at line 733, column 9, converts tool manufacturing labor to dollars using the NAMELIST variable, TMLR.

BASIC TOOL ENGINEERING

Definition

The design of tools and preparation of production planning to accomplish production at the initial rate of production.

CER Form

The CER used applies a factor to basic tool manufacturing labor:

$$BTEH_i = BT_i (TEF_i) \quad (10)$$

where

$BTEH_i$ = Basic tool engineering hours by hardware element

TEF_i = Tool engineering factor; a ratio of tool engineering to tool manufacturing

Inputs

TEF is based on data shown in Table I-2 and is entered as a NAMELIST variable.

RATE TOOL ENGINEERING HOURS

Definition

The design of tools and preparation of production planning to accompany an increase in production from an initial rate.

CER Form

The CER used is

$$RTEH_i = RT_i (RTEF_i) \quad (11)$$

where

$RTEH_i$ = Rate tool engineering hours by hardware element

$RTEF_i$ = Rate tool engineering factor

Inputs

RTEF is based on manufacturing experience and is entered as a NAMELIST variable.

TOTAL TOOL ENGINEERING

Basic and Rate Tool Engineering Hours are summed in the same way as Tool Manufacturing. Tool engineering labor is converted to dollars by an F-card calculation at line 736, column 9, using the NAMELIST variable, TELR.

TOOL MATERIAL COST

Definition

This item covers miscellaneous costs associated with tool design, manufacturing, and production planning including materials for tool manufacture and procured tools.

CER Form

$$TM = TTM (TMF2) \quad (12)$$

where

TM = Tooling material cost

TTM = Total tool manufacturing hours

TMF2 = Tooling material factor: a ratio of tooling material to tool manufacturing

MANUFACTURING AIDS COSTS

Definition

This covers the plant engineering function associated with the design, manufacture, and maintenance of special noncapital manufacturing aids such as holding cradles, work platforms, slings, load bars, transportation trailers, handling dollies, and access stands.

CER Form

$$MAH = TTM (MAF) \quad (13)$$

where

MAH = Manufacturing aids hours

MAF = Manufacturing aids factor

Inputs

The manufacturing aids factor is entered as a NAMELIST variable. Experience indicates that on past aircraft programs these hours have ranged from 8 to 15 percent of tool manufacturing hours. An average value of 0.12 is used.

Manufacturing and labor is converted to dollars by an F-card calculation at line 738, column 9, using as input the NAMELIST variable, MALR. This is a composite rate that includes an allowance for required materials.

MANUFACTURING DEVELOPMENT COSTS

Definition

This consists of the development of manufacturing method associated with a given program, including processes, standards and procedures.

CER Form

$$MDH = TTM (MDF) \quad (14)$$

where

MDH = Manufacturing development hours

MDF = Manufacturing development factor

Inputs

The manufacturing development factor is entered as a NAMELIST variable. Manufacturing experience indicates a value of 0.15.

MANUFACTURING SUPPORT:

Definition

Manufacturing support hours represent the effort undertaken to support engineering during the development phase of an aircraft program. It includes manufacturing labor and material for such items as development test parts, test fixtures, mockups and models, and other support activities. It also includes manufacturing material and other costs made up primarily of vendor costs for development, test and production startup.

CER Form

The CER form used is based on Rand studies, Reference 4 :

$$MS = 0.008325 (WAMP)^{.873} (S)^{1.89} (QD)^{.346} (INF) \quad (15)$$

where

MS = Manufacturing support cost in 1974 dollars.

- S Maximum speed (kts) at best altitude
- QD Development quantity (number of flight test airframes)
- INF A term to adjust the dollar base from 1970 to 1974 and to provide for subsequent adjustments as follows:
- $$INF = \left[1.273 \times (1 - RI)^{(Y - 1974)} \right] \text{ and}$$
- RI Rate of inflation
- Y Year in which dollars are stated

Inputs

All of the variables are entered as NAMELIST variables. WAMP, the AMPR weight of the airframe, is obtained from a suitable group weight statement. Speed (S) is obtained from design characteristics data. Quantity (QD) is obtained from program data. The rate of inflation is estimated, and Y is self-evident.

QUALITY CONTROL

Definition

The establishment of quality control procedures and requirements and set-up for production.

CER Form

$$QCH = TEL (QCF1) + TTM (QCF2) \quad (16)$$

where

QCH = Quality control hours

QCF1 = Factor applied to engineering labor

QCF2 = Factor applied to tool manufacturing labor

Inputs

The Quality Control factors are entered as NAMELIST variables. Based on contractor experience, QCF1 is 0.01 and QCF2 is 0.06.

3.3.2 FIRST UNIT COSTS. First unit costs, defined as before, are estimated by a series of CERs, each of the same general form, for each of the costs in Figure 16. Table 43 cross references the cost printout, CERs, and model cards for each. The CER form and the input requirements that are generated by its use are discussed below.

Table 43. Cost Output, CER Equation Number, and Model Card
Address Cross Reference - System First Unit Cost.

Hardware Components	Direct Labor Hours	Direct Labor Costs	Material Costs
Basic Structure			
Wing			\$1,070 + 700 +
Horizontal Stabilizer			\$1,070 + 700 +
Vertical Stabilizer			\$1,070 + 700 +
Fuselage			\$1,070 + 700 +
Nacelle			\$1,070 + 700 +
Landing Gear			\$1,070 + 700 +
Subsystems			
Surface Controls			\$1,070 + 700 +
Environmental Control System			\$1,070 + 700 +
Hydraulics Pneumatics			\$1,070 + 700 +
Electrical			\$1,070 + 700 +
Instruments			\$1,070 + 700 +
Auxiliary Power Unit			\$1,070 + 700 +
Armament Provisions			\$1,070 + 700 +
Engine Associated Equipment			\$1,070 + 700 +
Fuel System			\$1,070 + 700 +
Avionics Provisions			\$1,070 + 700 +
Furnishing and Equipment			\$1,070 + 700 +
Subsystems Subtotal			\$1,070 + 700 +
Total First Unit Cost			\$1,070 + 700 +

BASIC STRUCTURE FIRST UNIT COST

CER Form

A CER of the following form is used for estimating first unit cost (labor and material combined) for each of the elements of basic structure:

$$CFU_i = UF_i (EC_i) (WE_i)^{E_i} (INF) + (SAV_i) \quad (17)$$

where

CFU_i = Cost of the first unit of the element estimated

UF_i = Complexity factor

EC_i = Estimating coefficient

WE_i = Weight of the structural element being estimated

E_i = Cost/weight scaling exponent

INF = Adjustment of 1970 data base to 1974 base as shown in Equation (15)

SAV_i = SAV matrix address for pick-up of trade study method estimate

Inputs

The complexity factors and the weights are handled as NAMELIST variables. The estimating coefficients and the scaling exponents are entered as model card constants at the model card locations shown in Table 43. Back-up data for the complexity factors, estimating coefficients, and scaling exponent are provided in Appendix L, Figures L-14 through L-39. Figure L-16 is blank (with the page reserved for later data), since for the present, the horizontal and vertical stabilizer are combined as the empennage.

Inflation is treated as shown for Manufacturing Support, although for programming convenience a separate F-card is used for this calculation.

The term SAV_i refers to the series of SAV matrix addresses called out on lines F751 through F756. These represent the corresponding first unit cost estimates made by the trade study method. It is necessary to make certain that one or the other method is zeroed out. Use of the combined method is discussed further in Section 4.3.

3.3.3 RECURRING PRODUCTION COSTS. Recurring production costs for the system costing method are handled in a manner similar to that for the Recurring Production Cost Summary for the trade study costing method. Figure 17 gave a sample of the computer printout involved. Table 44 provides the cross-reference between cost output and model cards. These cost items consist of the following:

Table 44. Cost Output, CER Equation Number, and Model Card Address
Cross Reference - System Recurring Production Cost.

Hardware Components	RDT&I		Production (C)		Production (C)	
	Hours	Dollars	Hours	Dollars	Hours	Dollars
Sustaining Engineering	Eq (18)		Eq (19)		Eq (19)	
	F 781.1	F 781.2	F 781.3	F 781.4	F 781.5	F 781.6
Sustaining Tooling	Eq (20)		Eq (21)		Eq (21)	
	F 782.1	F 782.2	F 782.3	F 782.4	F 782.5	F 782.6
Manufacturing						
Wing		*		*		*
		Z 783.2		Z 783.4		Z 783.6
Horizontal Stabilizer		*		*		*
		Z 784.2		Z 784.4		Z 784.6
Vertical Stabilizer		*		*		*
		Z 785.2		Z 785.4		Z 785.6
Fuselage		*		*		*
		Z 786.2		Z 786.4		Z 786.6
Nacelle		*		*		*
		Z 787.2		Z 787.4		Z 787.6
Landing Gear		*		*		*
		Z 788.2		Z 788.4		Z 788.6
Surface Controls		*		*		*
		Z 789.2		Z 789.4		Z 789.6
Environmental Control System		*		*		*
		Z 790.2		Z 790.4		Z 790.6
Hydraulics/Pneumatics		*		*		*
		Z 791.2		Z 791.4		Z 791.6
Electrical		*		*		*
		Z 792.2		Z 792.4		Z 792.6
Instruments		*		*		*
		Z 793.2		Z 793.4		Z 793.6
Auxiliary Power Unit		*		*		*
		Z 794.2		Z 794.4		Z 794.6
Armament Provisions		*		*		*
		Z 795.2		Z 795.4		Z 795.6
Engine Associated Equipment		*		*		*
		Z 796.2		Z 796.4		Z 796.6
Fuel System		*		*		*
		Z 797.2		Z 797.4		Z 797.6
Avionics Provision		*		*		*
		Z 798.2		Z 798.4		Z 798.6
Furnishing and Equipment		*		*		*
		Z 799.2		Z 799.4		Z 799.6
Total Manufacturing		R 800.2		R 800.4		R 800.6

* Equation 22 is used at each of these points.

Sustaining Engineering
 Sustaining Tooling
 Manufacturing (Including Quality Control) for
 Wing
 Horizontal Stabilizer
 Vertical Stabilizer
 Fuselage
 Nacelles
 Landing Gear
 Subsystems

Estimates are provided for three alternative quantities: The RDT&E quantity and two alternative production quantities. Quantity inputs are the NAMELIST variables QN2, QN3, and QN5.

In the system costing method manufacturing costs are estimated in dollars. Conversion of engineering and tooling hours to dollars is the same process previously described. These calculations occur at (781, 2), (781, 4), (781, 6), (782, 2), (782, 4).

SUSTAINING ENGINEERING HOURS

CER Form

The equation used for the RDT&E quantity is

$$SEH = TEL (QN2^{ES} - 1) \quad (18)$$

where

SEH = Sustaining engineering hours

TEL = Total engineering labor

QN2 = RDT&E quantity

ES = Scaling against quantity

The equation used for procurement quantities is

$$SEH = TEL (QN4^{ES} - QN2^{ES}), \quad (19)$$

or $(QN6^{ES} - QN2^{ES})$ for the second procurement quantity, where

$$QN4 = QN2 + QN3$$

$$QN6 = QN2 + QN5$$

Inputs

QN2 and ES are NAMELIST SUMMARY inputs. QN2 is obtained from program plan data. ES has a value of 0.2 as previously discussed. QN3 and QN5 are alternative production quantities.

SUSTAINING TOOLING HOURS

CER Form

The equation used for the RDT&E quantity is

$$STH = (TTM + TTE) (QN2^{TU} - 1) \quad (20)$$

where

STH = Sustaining tooling hours

TTM = Total tool manufacturing hours

TTE = Total tool engineering hours

TU = Scaling against quantity

The equation used for procurement quantities is

$$STH = (TTM + TTE) (QN4^{TU} - QN2^{TU}), \quad (21)$$

or $(QN6^{TU} - QN2^{TU})$ for the second procurement quantity.

Inputs

TU has a value of 0.14 as previously discussed.

MANUFACTURING RECURRING COSTS

Based on first unit manufacturing costs, recurring manufacturing costs are projected on a dollar basis. Exactly the same procedure is used as was used for the trade study recurring production costs by structural element, described in Section 2.3.2. A

Z-card calculation based on TERM 29 is used. This has the equational form,

$$\text{Cost Estimated} = P1 \sum_{P2}^{P3} i^X \quad (22)$$

with the same definitions as in Section 2.3.2. The calculation is performed for each of the aircraft subsystems.

Quality Control costs are included in the first unit cost estimate since they were included in the original data base.

3.4 PROGRAM OPERATION AND INSTRUCTION

This discussion covers the same topics considered in connection with the trade study method. Computer program integration is not applicable, however, since for system costing, supporting programs are not described. Input data is developed from a group weight statement, certain design and program data, and historical cost data, requiring an appropriate pre-design activity. Time sharing is applicable in a manner similar to that described in Section 2.4.3.

NAMelist CURVE and NAMelist SUMMARY input cards are prepared according to the NAMelist variables dictionary (Appendix K). A computer printout of the required input cards is given in Appendix K as a guide.

SECTION IV

DEMONSTRATION RUNS

Test case estimates have been performed for each of the two estimating methods using the cost model computer program and the results from runs of the supporting synthesis programs, in the case of the trade study method. Printouts from these runs have been used to illustrate the methods in the previous sections. This section describes the steps taken and the information gathered in setting up the demonstration runs. An evaluation from the standpoint of estimating results is provided in the Technical Volume. Results of the demonstration runs are given in Appendix M.

The B-58 aircraft program was selected as the test case for both the trade study and the system cost estimating methods. Other candidates were considered but were not selected for various reasons:

The selection had to be limited to a Convair program since data collection experience indicated that access to data was a problem otherwise. Choice of the B-58 was supported by the availability of results from a NASA-funded cost data study, Reference 5. The F-111A was a candidate, but the cost of collecting comparative actual data was beyond the budgetary limits of the study.

Data for the B-58 program were obtained from four general sources: (1) B-58 Cost Data Study Report, Reference 5; (2) B-58 Cost History; (3) Actual Weight and Balance Report for B-58A (Bomber Airplane), FZW-4-038, Reference 6; and (4) other internal company data sources. The B-58 Cost History is a specific internal document prepared as part of the company's ongoing cost research.

The results of the trade study and system runs cannot be directly compared since they are set up in different time frames: the trade study method estimates historical costs using a composite, then year labor rate, whereas the system cost estimate is made in 1974 dollars. The trade study method estimates labor and material separately, so that by applying the appropriate labor rate and material cost factor, economic escalation is taken into account. Some ambiguity occurs in the case of material cost, however, since the historical data typically intermingles production material associated with structure and purchased parts associated with the functional subsystems.

The system cost estimating factors were developed from a data base that had been adjusted to 1970 dollars. An inflation adjustment was applied to these results to convert to 1974 dollars. Going back to the 1970 data base, or any intervening year, requires only a simple series of F-card changes. However, moving back to any earlier period would require a more comprehensive adjustment to the data base.

For the usual estimating situation, estimates will be made in the current time frame, and comparisons of the results from the methods can be made. Making a comparison in the case of the B-58 would be time consuming and still not conclusive due to the difficulties in determining precise escalation adjustment factors.

The demonstration case as presently set up does provide a comprehensive test of both methods. An analysis of estimates and a comparison to actuals, both from the B-58 aircraft and other aircraft, at subsystem and detailed levels, has been accomplished and is reported in the Technical Volume. Verification of the estimating logic and debugging of the computer program have been largely accomplished. The demonstration case also served as a vehicle to coordinate the installation of the system at AFFDL.

4.1 TRADE STUDY ESTIMATING DEMONSTRATION RUN

The steps used in making this run are described below. They differ from the nominal procedure inasmuch as actual design and weights data were available eliminating the need for synthesis data and resulting in deemphasis on the demonstration of the design synthesis computer programs.

First Unit Cost Estimate

- a. Obtained detailed weights data by review of the detailed weight statement contained in Reference 6.
- b. Determined type of construction and material used for the basic structure from a review of Reference 5 and determined approximate weight breakdown.
- c. Determined complexity factor by reference to complexity factor tables for detail fabrication and subassembly.
- d. Prepared an input data summary similar to Figure 26 for aerodynamic surfaces and fuselage hardware elements for detail fabrication hours and similar to Figure 27 for subassembly hours.
- e. Developed design data required by Figure 28 from Reference 5.
- f. Entered detailed weights data for secondary structure in a Figure 29-type summary sheet.
- g. Analyzed secondary structure descriptions contained in Reference 5, determined type of construction and material, determined complexity factor by analogy to data contained in Tables 25 and 26, and entered fabrication and subassembly complexity factors in a Figure 29-type summary sheet.
- h. Developed design data required by Figure 30 from Reference 5.
- i. Obtained material factors required by Figure 31 from Tables 31 and 32 for primary structure.

- j. Obtained material factors required by Figure 32 from Tables 33 and 34 for secondary structure.
- k. Determined fastener complexity for entries required by Figure 33. Data is obtained from Table 36.

Recurring Production Cost Estimate

- l. Determined quantities to be estimated based on original program plan.
- m. Analyzed historical cost data to determine manufacturing and tool manufacturing labor rates to be used to represent historical B-58 costs.
- n. Input values for the matrix of learning curve factors: hardware elements by category of cost, i.e., detail fabrication labor, assembly labor, and material. These factors are based on general experience. Analysis of learning curves at this level of detail is considered to be beyond the scope of this contract. Appendix D shows the extent of the learning curve breakout.

Nonrecurring Design and Development Costs

- o. Determined AMPR weight values from Reference 6.
- p. Input estimating coefficients obtained from Appendix I for engineering direct labor (EH) and total manufacturing labor (TMF).
- q. Determined maximum production rate from historical data.
- r. Analyzed historical cost data to determine other labor rates: engineering, tool manufacturing, tool engineering, composite rate for manufacturing development and plant engineering, and quality control.
- s. Input values for composite learning curves for fabrication, assembly, and material costs.

Appendix B gives a sample printout of the input elements. This sample was taken from the B-58 demonstration run and may be referred to for the input values used for this test case. Appendix M provides the additional estimating results, in computer printout form, which, when taken in conjunction with the other printout shown for illustrative purposes throughout this Handbook, constitutes a complete set of printouts. Table M-1 gives the location of the output set.

4.2 SYSTEM COST ESTIMATING DEMONSTRATION RUN

The steps used in making this run are described below. In the case of the system costing test case, sources for the required input data are not precisely determined so that the procedures described represent a typical case. Reference is made to Appendix K, which contains a printout of the input elements as used for the test case and a

NAMELIST variables dictionary. The latter serves as a summary table for the required inputs and will be referred to in the discussion below.

Nonrecurring Design and Development Cost Estimate

- a. Obtained weights data for basic structure by review of the detailed weight statement contained in Reference 6.
- b. Entered value for cost-weight scaling based on data contained in Figures I-1 through I-6, and L-1 through L-12.
- c. Developed complexity factor values by judgment based on a comparison of characteristics between the B-58 component estimated and a suitable analog. Input value is the ratio of the analog to the best fit curve suitably factored. See pages 150 and 152 of this volume and page 93 forward in Volume 1.
- d. Determined AMPR weight for basic structure from Reference 6.
- e. Obtained weights data for secondary structure by review of the detailed weight statement contained in Reference 6.
- f. Entered an estimated value for a composite engineering labor rate (i. e. , to cover the various types of engineering involved) and the values for FM and TI obtained from the NAMELIST variables dictionary.
- g. Entered tooling complexity factors as obtained from Table 40.
- h. Entered complexity factor TF7 as the ratio of the B-58 actual cost to the comparable point on a best fit curve.
- i. Determined production rate from historical data.
- j. Entered value for TR, scaling with production rate increase, from NAMELIST variables dictionary. Value is based on manufacturing experience.
- k. Estimated tool manufacturing and tool engineering labor rates based on historical data or obtained from trade study data.
- l. Determined ratio of tool engineering to tool manufacturing from historical data. See Table I-2.
- m. Obtained rate tool engineering factor, ratio of tooling material to tool manufacturing, manufacturing aids factor, manufacturing development factor, ratio of quality control to engineering labor, and ratio of Q/C to tool manufacturing labor from NAMELIST variables dictionary. Values are based on manufacturing experience.
- n. Determined manufacturing aids, manufacturing development, and quality control labor rates from historical data.
- o. Obtained speed from design data.
- p. Determined development quantity from historical data.

First Unit Cost Estimate

- q. Determined complexity factor values, UF1 through UF17, from Figures L-14 through L-30 either by taking the ratio of the B-58 actual cost to a comparable point on a best fit curve or by judgment based on a comparison of characteristics between the B-58 component and the average represented by a best fit curve.

Recurring Airframe Production Costs

- r. Determined quantities to be estimated based on original program plan.
- s. Entered sustaining engineering and sustaining tooling exponents from the NAMELIST variables dictionary.
- t. Determined composite tool manufacturing-tool engineering labor rate.
- u. Input values for the matrix of learning curve factors: hardware subsystem by quantity block.

Appendix K gives a sample printout of the input elements. This sample was taken from the B-58 demonstration run and may be referred to for the input values used for the test case. The printouts shown in Figures 14 through 17 give the estimating results of these inputs.

4.3 COMBINED METHODS OPERATION

The combined methods operation is limited to the substitution of basic structure first unit costs from the trade study costing method in the system costing results. The combined mode thus involves basically the system cost estimating logic as augmented by the substitution of certain trade study calculations: those occurring from F-cards F751,4 through F756,4. The series of terms (61,9), (124,9), (173,9), (229,9), (280,9), and (314,9) serve to interconnect the two methods. If the combined mode is to be used, then the first part of the respective equations, i. e., the part in front of the plus sign, must be zeroed out by an appropriate entry and the calculations producing these terms must be activated from the trade study model card deck. Each of these terms is traced back through the calculations, the necessary model cards are activated by insertion in the input deck, the relevant NAMELIST variables are input, and the case can then be run as before. The terms involved are defined as follows:

(61,9)	=	Wing first unit labor and material dollar cost
(124,9)	=	Horizontal stabilizer first unit labor and material dollar cost
(173,9)	=	Vertical " " " " " " "
(229,9)	=	Fuselage " " " " " " "
(280,9)	=	Nacelles " " " " " " "
(314,9)	=	Landing Gear " " " " " " "

If these terms are substituted, then the recurring airframe production costs automatically reflect the substitution. The system costing method then provides a detailed analysis of basic structure costs, and detailed costs are provided either as a partial print-out of the trade study format or from the SAV matrix.

4.4 ABBREVIATED RUNS

Abbreviated or partial runs can be made in the case of the trade study cost estimating method. This is exemplified in the B-58 test case in two ways: (1) Since the B-58 aircraft does not have a horizontal stabilizer, one of the six hardware elements modeled is omitted and (2) One production quantity, instead of two, is evaluated.

The elimination of the horizontal stabilizer is accomplished by removing the appropriate model cards:

- a. Cards F-100 through F-150, the eight cards immediately preceeding, and the two cards immediately following.
- b. Cards F-365 through F-390 and the two cards immediately preceeding and immediately following.
- c. Cards F-507 through F-532 and the two cards immediately preceeding and immediately following.

The elimination of the second production quantity is accomplished by removing the following cards:

- a. Cards F-475 through F-613, the immediately preceeding two cards and the following one card.
- b. Cards F-650 through F-658, the immediately preceeding six cards and the following card.

The elimination from consideration of other hardware elements is accomplished by removing comparable sets of cards.

4.5 ESTIMATING ACCURACY

The demonstration runs give evidence of a fully operational cost model. A full assessment of estimating accuracy has not been attempted, however, in view of the fact that only one test case has been identified and completed. Based on this case, a limited evaluation of estimating results is discussed in Volume I, Section 6. In addition, however, a few qualitative statements can be made regarding the estimating accuracy that can be expected from the use of a model of this type.

The initial decision regarding the level of detail at which to pursue the development and the concomitant acceptance of the state of data availability described as unlimited data (the idea that the expected future availability of data would be reflected in the level of detail estimated) limited the use of statistical estimating approaches. In the form of the model that resulted, input development is an important key to estimating accuracy. The experience of the user, the availability of expert judgment, the relevance of available analogs, the performance of experiments, and the results of special studies all are channels for improving input development, which in turn improves the estimating results.

Again with regard to input, the accuracy of the output of the supporting design synthesis and weight estimating programs is of great import. The overall accuracy of the methodology must be judged on the basis of the entire set of programs used.

In using a model of this type, and in fact, in any estimating process, accuracy is dependent upon the degree of product definition and the extent to which the product incorporates advanced technology. In some respects these amount to the same thing: the application of advanced technology tends to make product definition more difficult, but product definition can lag for other reasons also. In this model improved product definition enhances accuracy by facilitating the choice of better complexity factor, providing more accurate definition of materials and construction categories, and insuring a more representative choice of analogs. Dealing with advanced technologies reduces the accuracy of estimates because of data base limitations. This will always be true, but the use of a detailed estimating procedures permits a more precise focusing on the problem.

The current model provides credible estimates. It is felt, however, that development of the full potential of the model involves: (1) additional user experience; (2) additions to the cost data base; (3) continuing improvements in the supporting synthesis and weight analysis programs; and (4) development and incorporation of specific additional features in the cost model logic. The additional user experience will also, undoubtedly, provide feedback for model improvements and steps to augment the data base.