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 1

GENERAL DYNAMICS CONVAIR DIVISION
KEARNY MESA PLANT
5001 KEARNY VILLA ROAD
SAN DIEGO, CALIFORNIA 92112

MAY 1975

TECHNICAL REPORT AFFDL-TR-75-44, VOLUME II
FINAL REPORT FOR PERIOD JULY 1972 – FEBRUARY 1975

Approved for public release; distribution unlimited

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

Best Available Copy

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

R. N. Mueller

R. N. MUELLER
Project Engineer
FBRB

FOR THE COMMANDER:

Gerald G. Leigh

GERALD G. LEIGH, Lt. Col., USAF
Chief, Structures Division
Air Force Flight Dynamics Laboratory

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

A

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFFDL-TR-75-44, Volume II, Part I	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) WEAPON SYSTEM COSTING METHODOLOGY FOR AIRCRAFT AIRFRAMES AND BASIC STRUCTURES. Volume II. Estimating Handbook and User's Manual, Part I.	5. TYPE OF REPORT & PERIOD COVERED Final Report July 1972 — February 1975
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. E. Kenyon	8. CONTRACT OR GRANT NUMBER(s) F33615-72-C-2083
9. PERFORMING ORGANIZATION NAME AND ADDRESS Convair Division of General Dynamics Kearny Mesa Plant, 5001 Kearny Villa Rd., San Diego, CA 92112	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 1368 136802
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Flight Dynamics Laboratory, Advanced Structures Division, Air Force System Command, Wright-Patterson AF Base, Ohio	12. REPORT DATE May 1975
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

parametric estimating
design to cost
aircraft structure cost estimating
trade study costing
airframe costs
airframe cost estimating
first unit cost
structural cost data

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This volume provides a detailed description of the function and use of two weapon system costing methodologies for aircraft airframes and basic structures developed for the Air Force Flight Dynamics Laboratory for use in conceptual and preliminary designs phases of weapon system development. The methods are a trade study costing method for detailed cost analysis of trades-off between weight, cost, type of construction and type of material and a system costing method for determining the pro-

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

147 ...

19. Key Words: (Continued) composite structure costs

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.

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

TABLE OF CONTENTS (Continued)

PART I

PART II

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (Continued)

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 I.

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

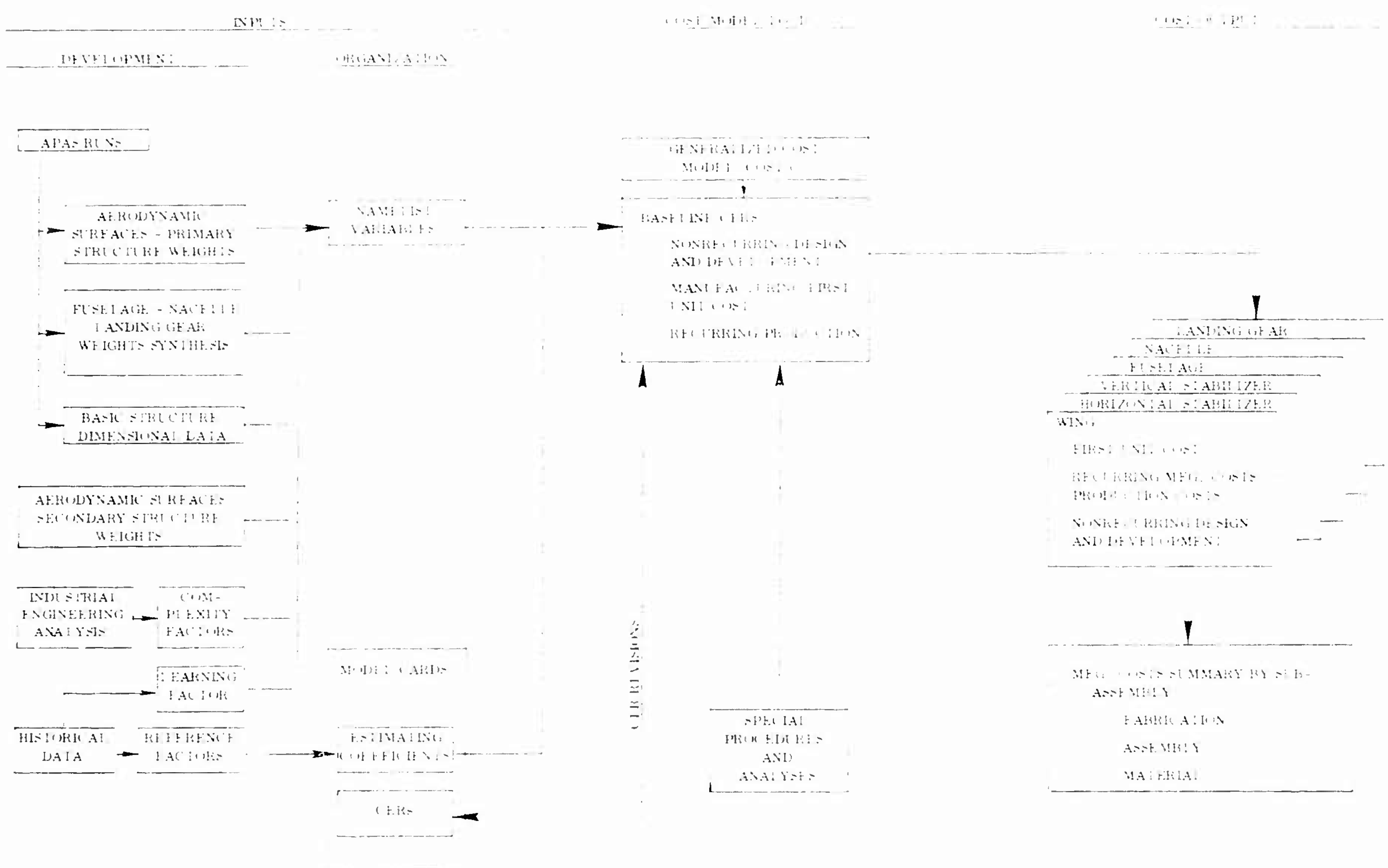


Figure 1. Trade Study Cost Estimating Method.

WING FIRST COST
(IF NO DECIMAL IMPLIED UNITS IN MILLIONS)

FIRST UNIT COST

WING

17.28.44. [illegible]

	DETAIL FAB HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	FINAL ASSY HOURS	MAJOR MATE HOURS	MATL COST $	TOTAL LABOR HOURS	TOTAL LABOR $	TOTAL $
STRUCTURAL BOX									
RIBS	[illegible]	[illegible]				[illegible]			
SPARS	[illegible]	[illegible]				[illegible]			
COVERS	[illegible]	[illegible]				[illegible]			
ASSEMBLY			40034			[illegible]			
STRUCTURAL BOX SUB-TOTALS	[illegible]	15144	40034			[illegible]			
LABOR COSTS ($)	[illegible]	[illegible]	251843						
SECONDARY STRUCTURE									
LEADING EDGE	[illegible]	[illegible]				[illegible]			
TRAILING EDGE	[illegible]	[illegible]				2145			
AILERONS	[illegible]	[illegible]				[illegible]			
FAIRINGS	[illegible]	7220				[illegible]			
TIPS	6719	[illegible]				[illegible]			
SPOILERS									
FLAPS + FLAPERONS									
ATTACHMENT STRUCTURE	1131	[illegible]				3338			
ACCESS + OTHER DOORS	1501	3273				[illegible]			
AIR INDUCTION									
HIGH-LIFT DUCTING									
SLATS									
HINGES, BRACKETS, SEALS									
PIVOTS + BOLTS									
CENTER SECTION									
OTHER	14914	3943				15403			
ASSEMBLY			29864			[illegible]			
SECONDARY STRUCTURE SUB-TOT	[illegible]	57737	[illegible]			[illegible]			
LABOR COSTS ($)	[illegible]	[illegible]	[illegible]						
WING SUBTOTAL	107744	[illegible]	[illegible]			[illegible]			
WING [illegible]	10774	[illegible]	[illegible]			[illegible]			
WING TOTAL	[illegible]	[illegible]	[illegible]	21975	10338	[illegible]			
LABOR COSTS ($)	[illegible]	[illegible]	[illegible]	133229	69114				
TOTALS							317663	1935203	22235 3

Figure 2. Wing First Unit Cost.

RDT&E COSTS 30

WING

17.28.46. 01/03/77

	TOTAL FAB HOURS	SUB ASSY HOURS	MAJOR ASSY HOURS	PRIME ASSY HOURS	MAJOR MATE HOURS	MATL COST $	TOTAL LABOR HOURS	TOTAL LABOR $	TOTAL $
STRUCTURAL BOX									
RIBS	42771	[illegible]				315769			
SPARS	52744	[illegible]				777473			
COVERS	103407	71017				1041437			
ASSEMBLY			372564			1701472			
STRUCTURAL BOX SUB-TOTALS	234202	140415	372564			[illegible]			
LABOR COSTS ($)	1477476	[illegible]	2343423						
SECONDARY STRUCTURE									
LEADING EDGE	45244	45127				176093			
TRAILING EDGE	27528	20193				54149			
AILERONS	306501	231404				371544			
FAIRINGS	74451	67105				247777			
TIPS	53734	47027				111464			
SPOILERS									
FLAPS & FLAPERONS									
ATTACHMENT STRUCTURE	11031	22240				33470			
ACCESS & OTHER DOORS	14130	30476				152540			
AIR INDUCTION									
HIGH LIFT DUCTING									
SLATS									
HINGES, BRACKETS, SEALS									
PIVOTS & FOLDS									
CENTER SECTION									
OTHER	133779	83267				395127			
ASSEMBLY			277881			855513			
SECONDARY STRUCTURE SUB-TOT	763934	547515	277881			2506365			
LABOR COSTS ($)	4305144	3443567	1747473						
WING SUBTOTAL	998136	688430	650445			6553116			
WING REWORK	49944	65143	65045			655312			
WING TOTAL	1098320	757277	715490	205713	102894	7208428			
LABOR COSTS ($)	6910344	4763745	4500431	1293970	645985				
TOTALS							2.8831	18.1156	25.3240

Figure 3. Wing RDT&E Costs.

AEROSPACE VEHICLE STRUCTURAL COSTS

RECURRING AIRFRAME PRODUCTION COSTS (SUMMARY)

17.25.46. 01/09/7[illegible]

	WING HOURS	HORIZ HOURS	VERT HOURS	FUSE HOURS	NACE HOURS	LDG GEAR HOURS	SUB-TOTAL HOURS	DOLLAR COSTS	PROD UNITS
RDT+E									
SUSTAINING ENGRG							1.366	[illegible]	70
SUSTAINING TOOLING							1[illegible]	11[illegible]	
MANUFACTURING									
DETAIL FAB	1.[illegible]		.1373	.7195	.5536	.0[illegible]	2.5[illegible]	15.741	
ASSEMBLY	1.4510		.2037	1.3250	.6810	.0147	3.[illegible]	23.147	
PRIMARY ASSY + MAJOR MATE							.742	4.[illegible]67	
QUAL CONTROL							.692	4.[illegible]	
MATERIAL + OTHER	7.2067		.8293	7.2450	2.3[illegible]	7.2335		[illegible]	
MAJOR MATE MATERIAL								3.[illegible]	
TOTALS							27.[illegible]	2[illegible]	
PROCUREMENT ARTICLES									
SUSTAINING ENGRG							.[illegible]	5.[illegible]	46
SUSTAINING TOOLING							10.2[illegible]	[illegible]	
MANUFACTURING									
DETAIL FAB	1.1920		.1452	.7340	.6032	.0225	2.727	17.153	
ASSEMBLY	1.5511		.2216	1.4438	.7421	.0215	4.[illegible]	25.223	
PRIMARY ASSY + MAJOR MATE							.[illegible]	5.[illegible]	
QUAL CONTROL							.755	5.[illegible]	
MATERIAL + OTHER	13.7568		2.1125	15.4543	6.0241	18.4378		63.355	
MAJOR MATE MATERIAL								[illegible]	
TOTALS							1[illegible].390	1[illegible].561	

Figure 4. Recurring Airframe Production Costs (Summary).

Aerospace Vehicle Structural Costs

Nonrecurring Design and Development Costs

17.28.46. 01/09/75

	Wing Hours	Hort Hours	Vert Hours	Fuse Hours	Nace Hours	Log Gear Hours	Sub-Total Hours	Dollar Costs
Basic Struc Design Engr	.152		.029	.201	.191	.079	.652	4.277
Configuration Design Engr							.750	4.919
Engineering Material								.492
Total Trade Study Engr							1.402	9.688
Basic Tool Mfg Hours	2.1		.17	2.08	.98		5.33	
Rate Tooling Mfg Hours							1.31	
Total Tool Mfg							6.64	41.57
Basic Tool Engrg Hours							2.132	
Rate Tool Engrg Hours							.1965	
Total Tool Engrg							2.33	13.34
Mfg Devel - Plant Engr							.13	.80
Total Matl - Other Dollars								6.64
Manufacturing Support Dollars								.402
Quality Control							.41	2.75
Totals							10.912	66.122

Figure 5. Nonrecurring Design and Development Costs.

Rib Detail Fabrication Hours

$$H_i = \frac{(W_i CF_i + W_i CF_i + W_i CF_i)(HF_i)(WT_i)^{E_i}}{WT_i}$$

where:

W_i	Weight of ribs of three alternative construction and material types represented by corresponding complexities.
CF_i	Complexity factor corresponding to rib type
WT_i	Sum of the rib weights
HF_i	Fabrication hours per pound for structural component for baseline configuration.
E_i	Weight-scaling exponent.

Rib Subassembly Hours

$$H_i = \frac{(W_i CM_i + W_i CM_i + W_i CM_i)(HF_i)(WT_i)^{E_i}}{WT_i}$$

where:

CM_i	Complexity factor for given material and construction technique.
HF_i	Subassembly hours per pound for baseline configuration.
E_i	Weight-scaling exponent.

Rib Structural Material Cost

$$M_i = W_i^G (RMC_i)(SF_i)$$

where:

RMC_i	Raw material cost per pound.
SF_i	Scrappage factor
G	Weight scaling exponent

Figure 6. CER 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 then 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

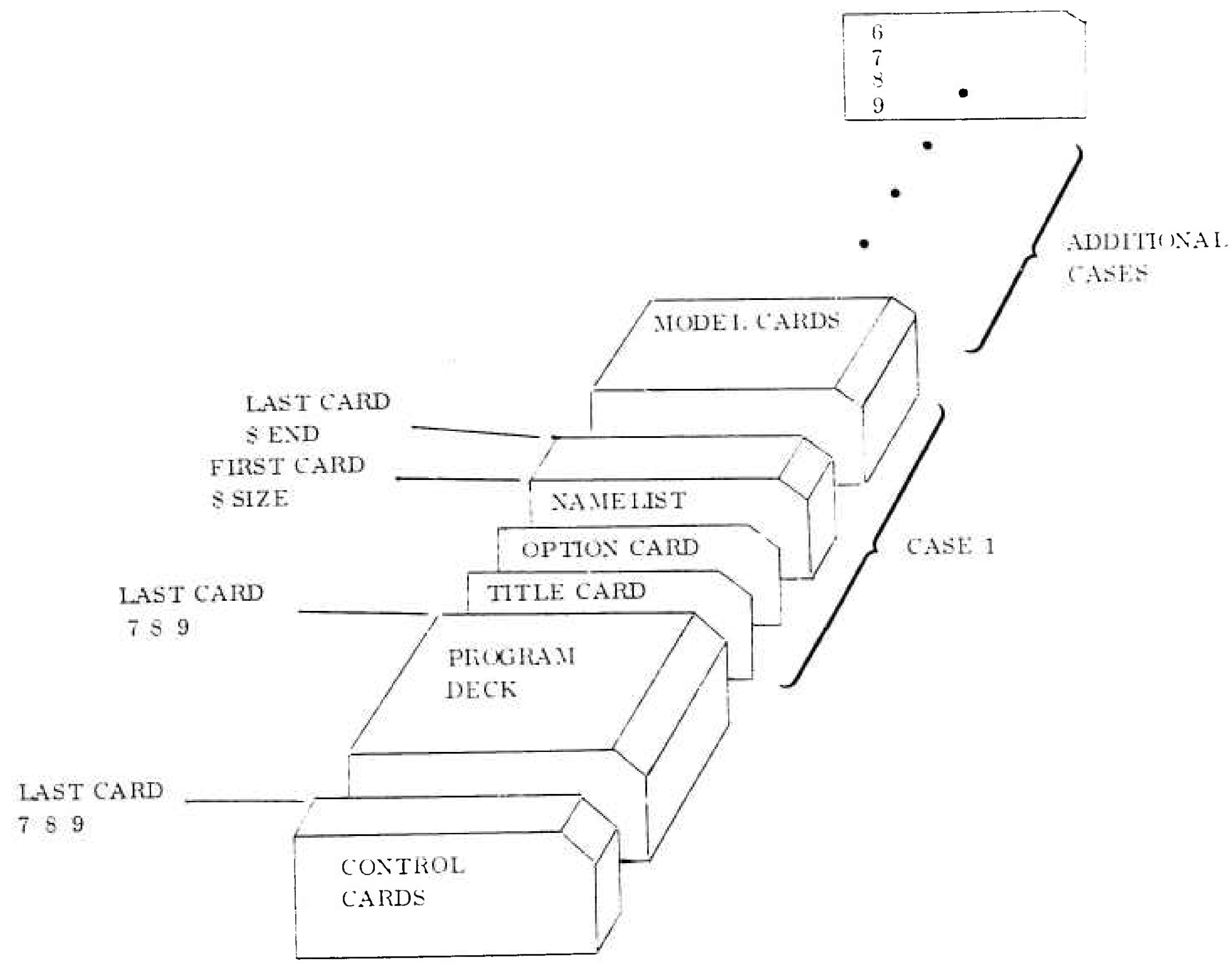


Figure 7. Computer Program Deck Set-Up.

```
   CARDS  350WNG  HTL  VTL  FLG  NAC  LDG
$SIZE
 W1=70.,CF1=.51,W2=270.,CF2=.88,W3=540.,CF3=1.,W4=1000.,CF4=.640,W5=693.,
 CF5=1.72,W6=250.,CF6=1.,W7=9114.,CF7=3.5,CM1=2.13,CM3=1.,CM4=3.34,CM6=1.,
 CM7=3.5,CN=60.,RN=5.,SNF=31.,SFF=30.,HF=50.,TS4=.1,FF1=1.3,FF2=2.,C31=1.75,
 WO1=348.7,CO1=2..CO2=4.,WO2=33.3,CO2=4.5,CO3=4.5,WO3=1135.2,CC3=4.75,CO4=2.7,
 WO4=797.7,CO4=2.5,CO5=2.5,WO5=265.3,CC5=2.7,CO5=3.,WO5=101.2,CC8=2.31,CO8=3.,
 WO9=275.9,CC3=3.,CB16=7.,WO16=956.,CO16=3.,WARP=44.3,CSO=1.,FSL=10.5,ERL=50.,
 RSL=21.,TS7=.2,FF3=2.5,CMB=3.,AS2=1890.,RMC1=16.,RMC2=16.,RMC3=16.,SF1=2.,
 SF2=5.3,SF3=2.,RMC4=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=18.,SF17=5.3,RMC18=50.,SF18=3.,RMC25=40.,
 SF25=2.,FM1=2.5,FM2=1.7,FH=540.,WAMPR=12156.,FCLF=6.56,TMF=7500.,TAM=3.,
 THC=6.26,TFC=5.34,TOC=6.,ROC=6.84,PN1=1.,PN2=30.,PN3=36.,RM=6.29,RT=6.26,
$
C             FIRST UNIT COST
C             WING
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  6    W1 WNG**.77 * RMC1 WNG * SF1 WNG + (12,3)
D          RIBS
F 32  1    (6,1) / (6,3. * 52.0 * (6,3)**.67
                           HF2            E2
F 32  2    (10,2) / (6,3) * 19.0 * (6,3)**.67
                            HF5            E5
F 32  6    W4 WNG**.77 * RMC4 WNG * SF4 WNG + (12,6)
D          SPARS
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  6    W7 WNG**.77 * RMC7 WNG * SF7 WNG + (12,9)
D          COVERS
```

Figure 5. Examples of Model Card Entries.

SIZE PARAMETER
APAS PROGRAM
SECONDARY STRUCTURE WT. EST.
OTHER WT. ESTIMATION

COMPLEXITY FACTOR
COMPLEXITY FACTOR TABLES

BASELINE EXPONENT
HISTORICAL DATA

$$H_i = \left[\frac{\left(W_i\ CF_i + W_i\ CF_i + W_i\ CF_i\right)\left(HF_i\right)\left(WT_i\right)}{WT_i}\right]^{E_i} \times (R)$$

LABOR RATE
OTHER INPUTS

BASELINE ESTIMATING COEFFICIENT
HISTORICAL DATA

Figure 9. Input and Input Source Examples.

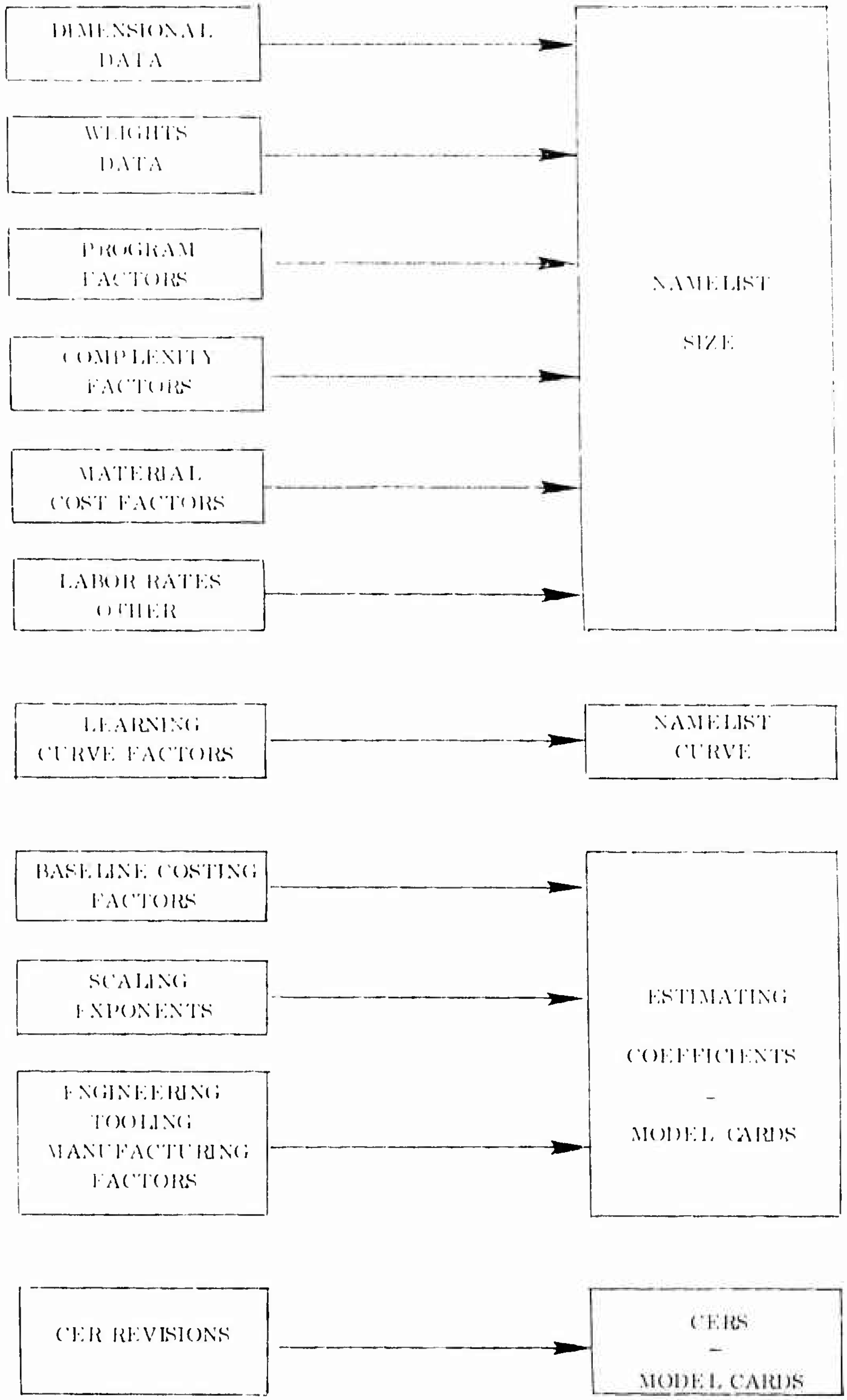


Figure 10. Cost Model Input Summary.

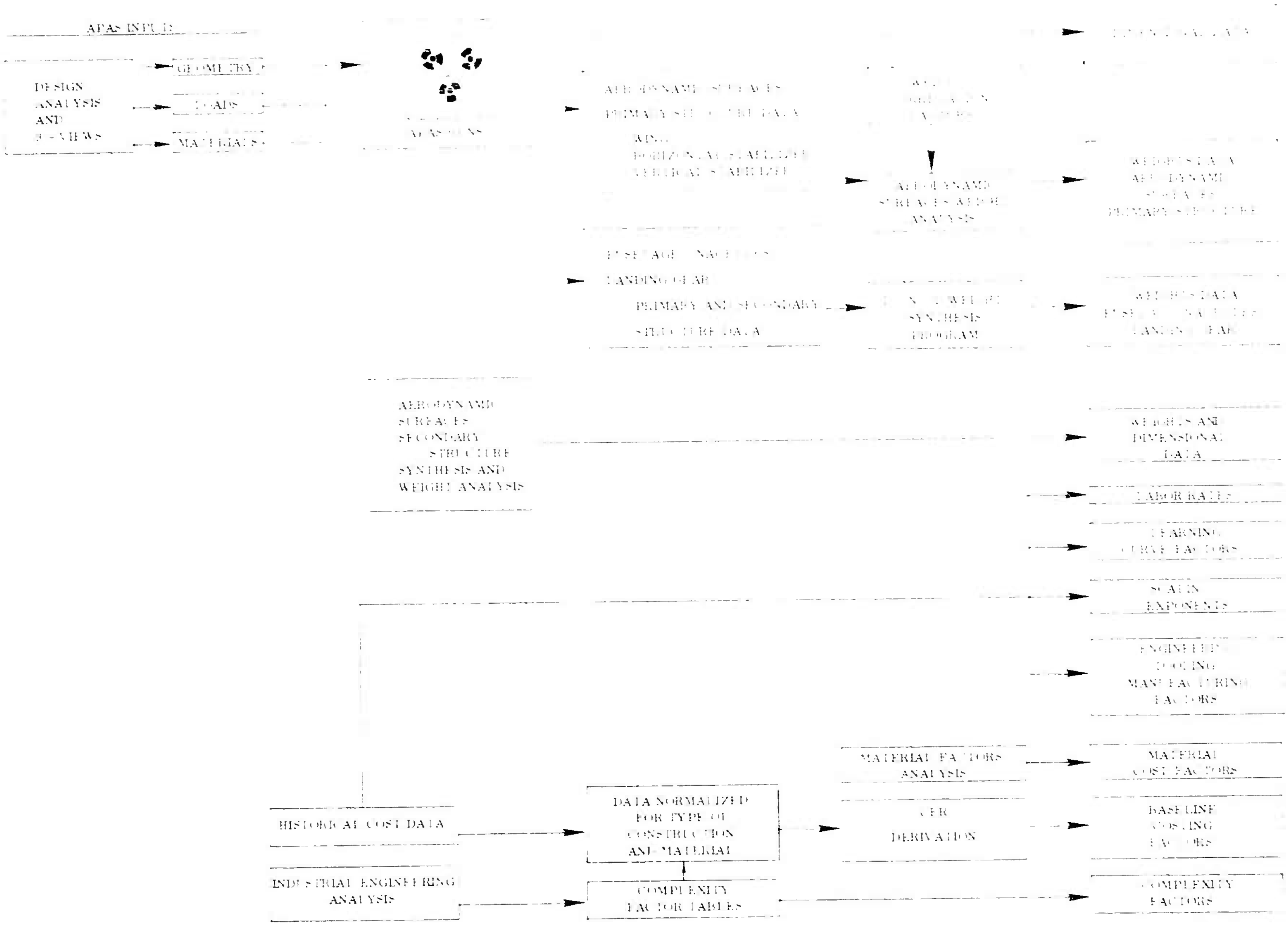


Figure 11. Input Development.

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.

BASIC SHELL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
COCKPIT PROVISIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NLG DOOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NLG CUTOUT / LOAD INTRODUCTION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WING REACTION [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TAIL PROVISIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WINDSHIELD AND CANOPY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FWD VERTICAL INERTIA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AFT VERTICAL INERTIA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FWD SIDE BENDING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AFT SIDE BENDING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FWD FUEL INERTIA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AFT FUEL INERTIA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AFT ENGINE BENDING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AFT HORIZ TAIL BENDING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FUEL PROVISIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARRESTING GEAR PROVISION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CATAPULT/HOLDBACK [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CATAPULT/HOLDBACK ALT TOW	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ENGINE PROVISIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DUCT PROVISIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MLG DOORS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MLG CUTOUT/LOAD INTRO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
EXTERNAL STORES PROV	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPEED BRAKES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BOMB/MISSLE BAY CUTOUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B/M BAY DOORS&MECH CONVENT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B/M BAY DOORS&MECH ROTARY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CABIN FLOOR [illegible] TRN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CABIN WINDOWS TRANSPORTS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PRESSURE [illegible] TRN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AIR EXTRACTION PROV TRN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CARGO LOADING [illegible] TRN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MLG EXTERNAL FAIRING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SIDE LOADING DOOR&MECH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CLAMSHELL DOOR&MECH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FLAT CARGO CLEARANCE DOORS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FUEL TANK FLOORING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SWING TAIL/NOSE PROVISIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
OVER WING FAIRING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WING SLOT SEAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WING GLOVE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WINDSHIELD FAIRING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BODY CONFIG PENALTIES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FUSELAGE MISC WEIGHT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL BODY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BODY ACTUAL WEIGHT	5174.0						
BODY PREDICTED WEIGHT	[illegible]						
EMPIRICAL WEIGHT FACTOR	[illegible]						
SEMI-ANALYTICAL FACTOR	[illegible]						

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 I. 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

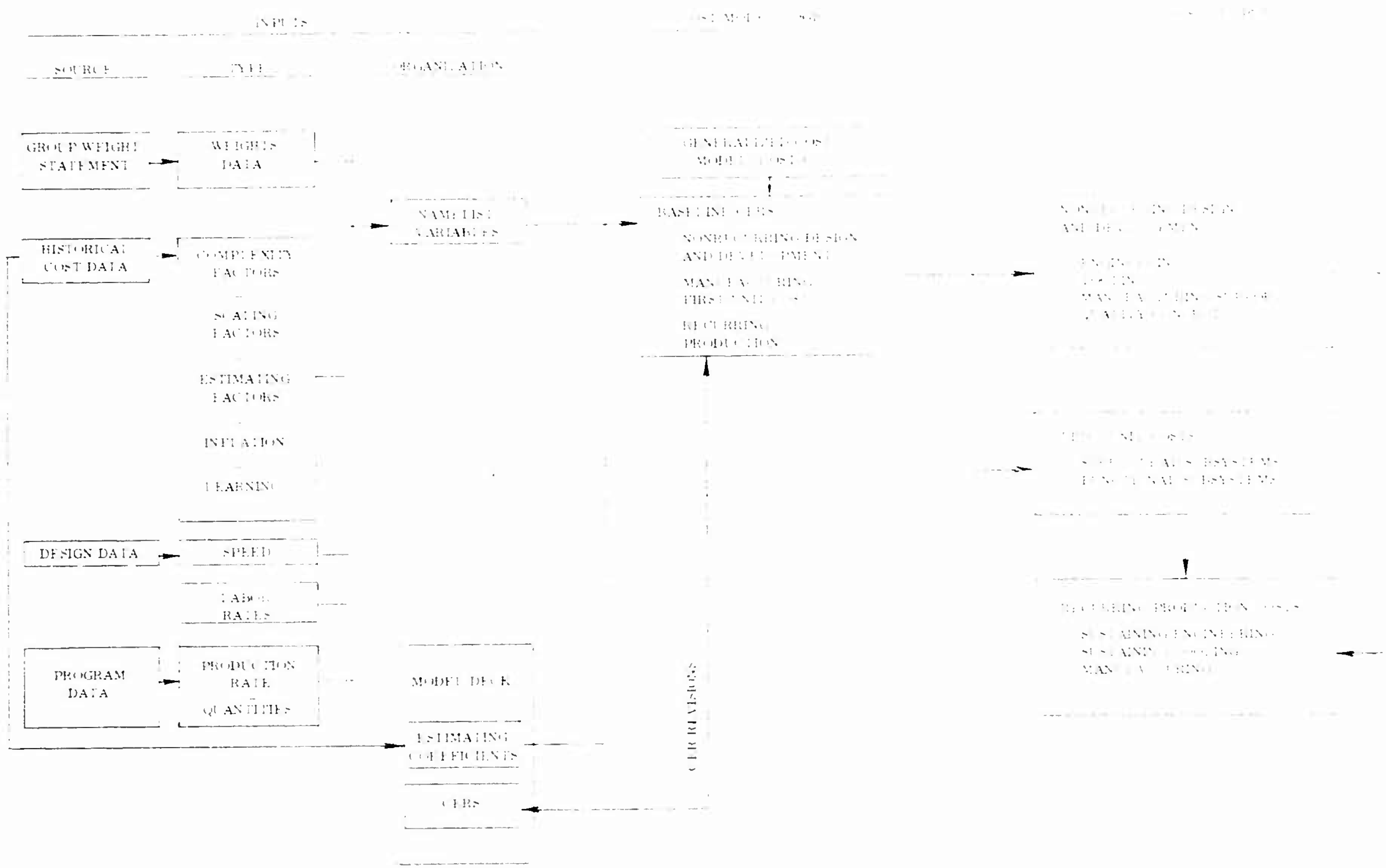


Figure 13. System Cost Estimating Method.

F-5A TEST CASE
USE OF DECIMAL I IES UNITS IN MILLIONS

AEROSPACE VEHICLE AIRFRAME SYSTEM COSTS

NONRECURRING DESIGN AND DEVELOPMENT COSTS

12.49.54. 01/03/75

	DIRECT LABOR HOURS	DIRECT LABOR COSTS	ENGRG MATL COSTS	LABOR +MATL COSTS
ENGINEERING				
BASIC STRUCTURE DESIGN ENGRG				
WING	.305			
HORIZONTAL STABILIZER				
VERTICAL STABILIZER	.047			
FUSELAGE	.421			
NACELLE	.782			
LANDING GEAR	.093			
CONFIGURATION DESIGN ENGRG	[illegible].223			
EQUIPMENT DESIGN				
SURFACE CONTROLS	.274			
ENVIRONMENTAL CONTROL SYS	.197			
HYDRAULICS/PNEUMATICS	.113			
ELECTRICAL	.293			
INSTRUMENTS	.091			
AUXILIARY POWER UNIT				
ARMAMENT PROVISIONS	.056			
ENGINE ASSOCIATED EQUIP	.047			
FUEL SYSTEM	.113			
AVIONICS PROVISION	.101			
FURNISHINGS + EQUIP	.133			
TOTAL ENGRG LABOR	4.689			
DOLLAR COSTS		30.761	6.152	36.913

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

Aerospace Vehicle Airframe System Costs

Nonrecurring Design and Development Costs

Basic Structure

12.40.54. 01/09/75

	Wing	Horiz Stab	Vert Stab	Fuse lage	Nac elle	Ldg Gear	Sub Sysm	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	.738	2.249	
Total Tool Mfg	3.748		.233	1.578	1.746	.271	3.743	11.413	74.867
Basic Tool Engrg D.L. Hrs	1.204		.075	.507	.561	.117	1.202	[illegible]	
Rate Tool Engrg D.L. Hrs	.111		.007	.047	.052	.010	.111	[illegible]	
Total Tool Engrg	1.315		.082	.554	.613	.127	1.313	4.0[illegible]4	23.784
Tool Material									21.375
Manufacturing Aids								1.093	11.125
Manufacturing Development								1.093	11.126
Total Tooling									106.579
Manufacturing Support									274.445
Quality Control								1.884	12.890

Figure 15. Nonrecurring Design and Development Costs Page 2.

AEROSPACE VEHICLE AIRFRAME SYSTEM COSTS

FIRST UNIT COSTS

12.49.54. 01/09/75

	DIRECT LABOR HOURS	DIRECT LABOR COSTS	MATL COSTS	LABOR +MATL ($)
BASIC STRUCTURE				
WING				6.199
HORIZONTAL STABILIZER				
VERTICAL STABILIZER				.570
FUSELAGE				5.995
NACELLE				1.413
LANDING GEAR				.683
SUBSYSTEMS				
SURFACE CONTROLS				2.452
ENVIRONMENTAL CONTROL SYS				.806
HYDRAULICS/PNEUMATICS				.309
ELECTRICAL				.409
INSTRUMENTS				1.034
AUXILIARY POWER UNIT				
ARMAMENT PROVISIONS				.196
ENGINE ASSOCIATED EQUIP				.258
FUEL SYSTEM				.792
AVIONICS PROVISIONS				.368
FURNISHINGS + EQUIPMENT				.557
SUBSYSTEMS SUBTOTAL				7.731
TOTAL FIRST UNIT COST				22.129

Figure 16. First Unit Costs.

AEROSPACE VEHICLE AIRFRAME SYSTEM COSTS

RECURRING AIRFRAME PRODUCTION COSTS

	PRT+E 7?		QUAN 86		QUAN	
	HOURS	$	HOURS	$	HOURS	$
SUSTAINING ENGINEERING	4.563	23.372	2.875	18.863		
SUSTAINING TOOLING	8.893	53.360	4.333	29.360		
MANUFACTURING						
WING		80.?33		119.575		
HORIZONTAL STABILIZER						
VERTICAL STABILIZER		7.?75		11.?19		
FUSELAGE		77.535		115.336		
NACELLE		13.?73		27.300		
LANDING GEAR		9.?63		15.361		
SURFACE CONTROLS		34.741		64.307		
ENVIRONMENTAL CONTROL SYS		10.740		22.061		
HYDRAULICS/PNEUMATICS		4.932		9.594		
ELECTRICAL		14.360		25.541		
INSTRUMENTS		16.379		29.361		
AUXILIARY POWER UNIT						
ARMAMENT PROVISIONS		3.032		5.439		
ENGINE ASSOCIATED EQUIP		4.???		7.256		
FUEL SYSTEM		1?.309		22.?42		
AVIONICS PROVISION		5.303		10.730		
FURNISHINGS + EQUIP		10.385		18.472		
TOTAL MANUFACTURING		315.721		507.743		

12.49.54 11/03/75

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 interrelated. 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, e, 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

3-58 TEST CASE
USE OF DECIMAL IMPLIES UNITS IN MILLIONS

FIRST UNIT COST

WING

17.28.44. [illegible]

	DETAIL FAB HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	PRIME ASSY HOURS	MAJOR MATE HOURS	MAT'L COST $	TOTAL LABOR HOURS	TOTAL LABOR $	TOTAL $
STRUCTURAL BOX									
RIBS	4539	1161				13529			
SPARS	8898	6757				24303			
COVERS	11778	7646				51651			
ASSEMBLY			40039			58266			
STRUCTURAL BOX SUB-TOTALS	25?45	15144	40039			1?1480			
LABOR COSTS ($)	179749	95?56	251343						
SECONDARY STRUCTURE									
LEADING EDGE	4352	4553				5447			
TRAILING EDGE	2421	2163				2168			
AILERONS	42612	24?71				14???			
FAIRINGS	5354	7222				3344			
TIPS	6719	5114				4419			
SPOILERS									
FLAPS + FLAPERONS									
ATTACHMENT STRUCTURE	1131	491				3338			
ACCESS + OTHER DOORS	1521	3273				10104			
AIR INDUCTION									
HIGH LIFT DUCTING									
SLATS									
HINGES, BRACKETS, SEALS									
PIVOTS + FOLDS									
CENTER SECTION									
OTHER	14814	9949				15403			
ASSEMBLY			29864			34216			
SECONDARY STRUCTURE SUB-TOT	62099	57737	29864			100242			
LABOR COSTS ($)	516473	363649	187642						
WING SUBTOTAL	107744	72481	69403			262?91			
WING REWORK	10774	7248	6990			26209			
WING TOTAL	118?78	74729	7?393	21976	10359	28?301			
LABOR COSTS ($)	742711	501494	4?7675	134229	59114				
TOTALS							307663	1935203	2223513

Figure 19. Wing First Unit Cost.

THIS PAGE INTENTIONALLY LEFT BLANK

(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.

FIRST UNIT COST

VERTICAL

17.28.46. [illegible]

	DTAIL FAB HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	PRIM-ASSY HOURS	MAJOR MATE HOURS	MAT'L COST $	TOTAL LABOR HOURS	TOTAL LABOR $	TOTAL $
STRUCTURAL BOX									
RIBS	504	172				616			
SPARS	1322	243				3629			
COVERS	2499	1635				4357			
ASSEMBLY			3261			5544			
STRUCTURAL BOX SUB-TOTALS	4325	2050	3261			14146			
LABOR COSTS ($)	[illegible]	[illegible]	[illegible]						
SECONDARY STRUCTURE									
LEADING EDGE	2226	2200				2195			
TRAILING EDGE									
FAIRING	543	513				512			
TIPS	730	593				354			
ATTACHMENT STRUCTURE	1272	352				1510			
ACCESS & OTHER DOORS	373	536				2010			
HINGES, BRACKETS, SEALS	404	172				583			
RUDDER	3363	5063				4136			
ASSEMBLY			3938			4504			
SECONDARY STRUCTURE SUB-TOTAL	8652	10707	3938			16015			
LABOR COSTS ($)	54420	67720	24773						
VERTICAL SUB-TOTAL	13076	12753	7200			30161			
VERTICAL REWORK	1308	1275	720			3016			
VERTICAL TOTAL	14384	14028	7920	2307	1453	33177			
LABOR COSTS ($)	90476	89237	49513	18262	9141				
TOTALS							40092	255950	289127

Figure 21. Vertical Stabilizer First Unit Cost.

FIRST UNIT COST

FUSELAGE

17.29.46. [illegible]

	DETAIL FAB HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	PRIM-ASSY HOURS	MAJOR MATE HOURS	MAT'L COST $	TOTAL LABOR HOURS	TOTAL LABOR $	TOTAL $
BASIC STRUCTURE									
FRAMES + BULKHEADS	22613	2407				25497			
LONGERONS	10934					20263			
SKINS + STRINGERS	14994	21677				55781			
ASSEMBLY			74904			127344			
BASIC STRUCTURE SUB-TOTALS	43452	24030	74905			223382			
LABOR COSTS ($)	304[illegible]	151150	471172						
SECONDARY STRUCTURE									
COCKPIT	6246	3543				3487			
NOSE LDG GEAR DOOR + BOX									
WING ATTACHMENT BOX									
TAIL ATTACHMENT									
WINDSHIELD + CANOPY	915	4925				5054			
MAIN LDG GEAR DOORS + BOX									
FUEL PROVISIONS									
ENGINE PROVISIONS									
DUCT PROVISIONS									
STORES PROVISIONS	1152	1169				2282			
SPEED BRAKES									
CABIN FLOORING + SUPPORTS	6414	4308				4646			
WINDOWS + WINDOW FRAMES	553	415				443			
DOORS + DOOR FRAMES	3965	4233				3399			
ASSEMBLY			12683			14651			
SECONDARY STRUCTURAL SUBTOT	22144	13394	12683			34582			
LABOR COSTS ($)	179234	115697	79775						
FUSELAGE SUBTOTAL	70615	42424	87591			263484			
FUSELAGE REWORK	7061	4242	8759			26348			
FUSELAGE TOTAL	77666	46666	96350	17655	8827	289832			
LABOR COSTS ($)	488519	293531	606242	111047	55524				
TOTALS							247164	1554662	1844494

Figure 22. Fuselage First Unit Cost.

FIRST UNIT COST

NACELLES

17.28.46. 01/09/75

	DTAIL FAB HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	PRIM-ASSY HOURS	MAJOR MATE HOURS	MAT'L COST $	TOTAL LABOR HOURS	TOTAL LABOR $	TOTAL $
COWLING	37960	13796				53308			
PYLON	16760	8136				26202			
MAIN LDG GEAR DOORS + REINFORC									
ASSEMBLY			36893						
NACELLES SUB-TOTALS	54370	27932	38893			56210			
LABOR COSTS ($)	341670	175595	244635						
NACELLES REWORK	5432	2797	3884			8601			
NACELLES TOTAL	59762	30725	42762	10661	5330	94511			
LABOR COSTS ($)	375640	193264	269044	67056	33528				
TOTALS							149251	939787	1033333

Figure 23. Nacelles First Unit Cost.

FIRST UNIT COST

LANDING GEAR

17.29.46. 01/04/77

	DETAIL FAB HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	PRIM-ASSY HOURS	MAJOR MATE HOURS	MAT'L COST $	TOTAL LABOR HOURS	TOTAL LABOR $	TOTAL $
BRAKES		157				43516			
BRAKE CONTROLS		[illegible]				10744			
WHEELS		36				32763			
TIRES						73255			
OLEOS		301				74276			
AXLES, TRUNNIONS + FITTINGS		44				42821			
DRAG BRACES	226	233				13599			
ASSEMBLY			962						
LANDING GEAR SUB-TOTALS	226	471	962			263245			
LABOR COSTS ($)	1422	6123	6052						
LANDING GEAR REWORK	23	97	96			26325			
LANDING GEAR TOTAL	249	1063	1058	190	95	289573			
LABOR COSTS ($)	1564	6719	6657	1195	595				
TOTALS							2660	15732	705314
AIRFRAME STRUCTURE TOTAL	273179	172217	225003	53363	26634	935494	430		
AIRFRAME LABOR RATE TOTAL	1699139	1053144	1415266	335410	167905			4701334	5443763

Figure 24. Landing Gear First Unit Cost.

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:

Column		
1-5	CLEAR	If this word is punched in this field, the variables are set to O 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.

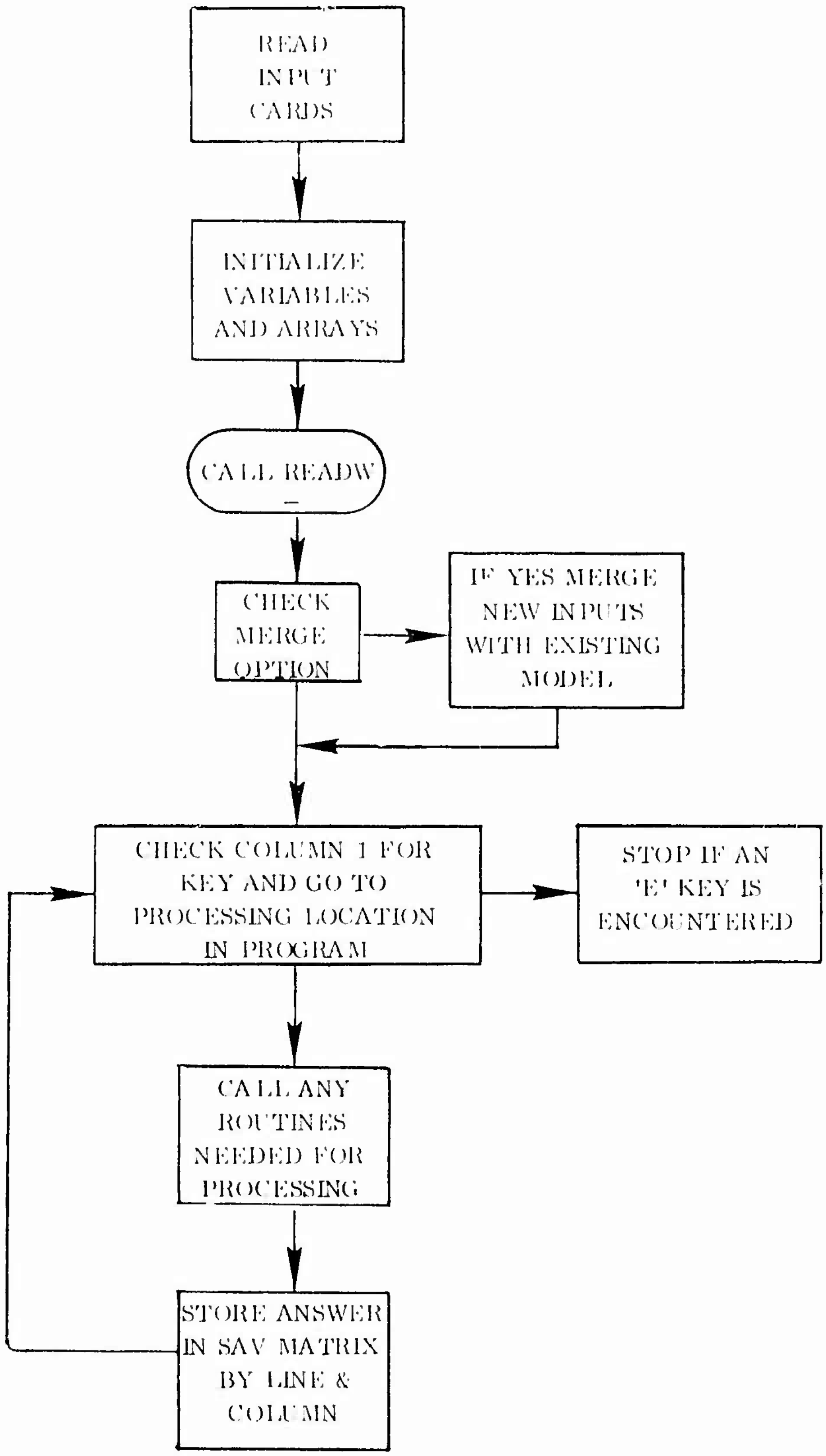


Figure 25. Cost Model General Flow Diagram.

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 <u>THE COSTC PROGRAM.</u> 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 s . aming 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 subtotaling 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
Spars	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 (15) F 58 6
Totals				Eq (20) F 59 4	Eq (21) F 59 5	

Table 4. Cost Output, CER Equation, and Model Card Cross Reference – Horizontal 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 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 108 1	F 108 2				F 108 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 4	F 124 5	

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 (10) is used for detail fabrication for all secondary structure hardware components, Equation (11) for secondary structure subassembly, and Equation (15) 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 House	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 222 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 1	F 311 2	F 311 3			F 311 6
Totals				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:

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

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 date 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	Weight of ribs or frames of Type A					NOT USED	NOT USED
CF1	Complexity factor for Type A (Rib or Frame						
W2	Weight of ribs or frames of Type B						
CF2	Complexity factor for Type B (Rib or Frame)						
W3	Weight of ribs or frames Type C						
CF3	Complexity factor for Type C (Rib or Frame)						
W4	Weight of spars or longerons of Type A						
CF4	Complexity factor for Type A (Spar or or longeron)						
W5	Weight of spars or longerons of Type B						
CF5	Complexity factor for Type B (Spar or longeron)						
W6	Weight of spars or longerons of Type C						
CF6	Complexity factor for Type C (Spar or longeron)						
W7	Weight of covers of Type A						
CF7	Complexity factor for Type A (Covers)						
W8	Weight of covers of Type B						
CF8	Complexity factor for Type B (Covers)						
W9	Weight of covers of Type C						
CF9	Complexity factor for Type C (Covers)						

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

WORKSHEET

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_i	Aluminum	1.00	0.76	0.52	0.51	0.99	0.96
	Titanium	1.31	0.95	0.59	0.57	[illegible]	[illegible]
	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 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
Frames & Bulkheads, Detail Fabrication CF1 CF2 CF3	Aluminum	Frame	1.0	[illegible]	[illegible]	[illegible]	1.0	0.97
		Bulkhead	2.5	-	-	-	.5	-
	Titanium	Frame	1.31	1.16	0.95	0.95	1.3[illegible]	[illegible]
		Bulkhead	3.3	-	-	-	3.3	-
	Low Carbon Steel	Frame	1.05	0.94	0.77	0.77	1.05	1.25
		Bulkhead	[illegible]	-	-	-	2.[illegible]	-
	Stainless Steel	Frame	1.5[illegible]	1.39	1.15	1.15	1.5[illegible]	1.56
		Bulkhead	.9	-	-	-	[illegible].9	-

*Range of values depending 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	[illegible]	[illegible]
	Titanium	1.21	1.05	0.68	0.67	5.22	3.72
	Low Carbon Steel	1.05	0.88	0.68	0.65	[illegible]	[illegible]
	Stainless Steel	1.34	1.22	0.68	0.70	4.42	[illegible]

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	2.07
	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	3.5	
	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	0.73	-	
	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

DETAIL FABRICATION LABOR	HF_i Code	Model Card Location	Model Card Value	Back-up Data Location
WING				
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
HORIZONTAL STABILIZER				
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
VERTICAL STABILIZER				
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
FUSELAGE				
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.

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

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

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

INPUT ELEMENTS - SUBASSEMBLY HOURS: AERODYNAMIC SURFACES STRUCTURAL BOX AND FUSELAGE BASIC STRUCTURE

Input Symbol	INPUT NAME	INPUT VALUE BY STRUCTURAL COMPONENT					
		Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
CM1	Complexity Factor for Type A (Rib or Frame)					NOT USED	NOT USED
CM2	Complexity Factor for Type B (Rib or Frame)						
CM3	Complexity Factor for Type C (Rib or Frame)						
CM4	Complexity Factor for Type A (Spar or Longeron)						
CM5	Complexity Factor for Type B (Spar or Longeron)						
CM6	Complexity Factor for Type C (Spar or Longeron						
CM7	Complexity Factor for Type A (Covers)						
CM8	Complexity Factor for Type B (Covers						
CM9	Complexity Factor for Type C (Covers)						

Figure 27. NAMELIST Inputs for Structural Box and Fuselage Basic Structure Subassembly Hours

WORKSHEET

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_i	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	3.84	0	0
	Titanium	1.72	1.52	0	5.40	0	0
	Low Cargon Steel	1.20	1.28	0	4.22	0	0
	Stainless Steel	2.31	1.77	0	6.75	0	0

Table 19. [illegible] Longerons [illegible] 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 Sub-assembly M_i	Aluminum	[illegible]	[illegible]	0	[illegible]	0	0
	Titanium	[illegible]	.5	0	5.4[illegible]	0	0
	Low Carbon Steel	1.20	[illegible]	0	4.2[illegible]	0	0
	Stainless Steel	2.31	1.77	0	6.75	0	0

Table 20. Aerodynamic Surface Cover 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	[illegible].99	0	0	0	3.5	
	Titanium	[illegible].24	0	0	0	–	
	Low Carbon Steel	[illegible].33	0	0	0	–	
	Stainless Steel	[illegible]	0	0	0	–	

Table 21. Fuselage Skin Panel Complexity Factors - 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	1.0[illegible]	0	0	0	3.5	
	Titanium	2.24	0	0	0	-	
	Low Carbon Steel	1.33	0	0	0	-	
	Stainless Steel	3.22	0	0	0	-	

Table 22. Cost Per Pound Factors (HF_i) Map

SUBASSEMBLY LABOR	HF_i Code	Model Card Location	Model Card Value	Back-up Data Location
WING				
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
HORIZONTAL STABILIZER				
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
VERTICAL STABILIZER				
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
FUSELAGE				
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
SNI		number of internal spars or longerons
Q		quantity scaling factor
2	-	operator for aerodynamic surfaces only

Panel Fit and Trim - Aerodynamic Surfaces

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

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

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

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

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

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

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

where

H_i hours for hole drilling (not doubled for fuselage)

HD = hours per foot for drilling

Finish Operations - Aero Surfaces or Fuselage

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

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

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

where

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

HFI 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

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

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 VALUE BY STRUCTURAL COMPONENT					
Input Symbol	INPUT NAME	Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
CN	Number of Cover Panels						
RN	Number of Ribs, Frames						
SNE	Number of External Spars, Longerons						
SNI	Number of Internal Spars, 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

WORKSHEET

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	
	Model Card Location	Value
Wing Box	F 16 6	.970
Horizontal Stab. Box	F 17 6	.970
Vertical Stab. Box	F 18 6	.970
Fuselage	F 22 8	.970

Back-Up Data Location

HSA1	-	F-13	HT	-	F-14	HD	-	F-14
HSA2	-	F-13	HL	-	F-14	HE	-	F-14
Q	-	F-13	R	-	F-13	HFI	-	F-14

Subassembly Hours

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

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 sealing 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 abritrary 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
	WING:			
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			
	HORIZONTAL STABILIZER:			
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			
	VERTICAL STABILIZER:			
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
	VERTICAL STABILIZER (Cont.):			
17	Rudder			
	FUSELAGE:			
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			
	NACELLES:			
1	Cowlings			
2	Pylon			
3	Main Landing Gear Door & Reinforcement			
	LANDING GEAR			
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, Cf_i

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

Table 25 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL						
	Aluminum	Fiber-Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium	Steel
FAIRINGS:							
Reference	1.0						
C-141 Horizontal	1.0						
Model 990 Wing to Fuselage (simple)	0.34	0.50	0.79				
C-5A Bullet Fairing Assy. (Complex)	1.17	1.73	2.23				
A-X Horizontal	0.93						
B-58 (Sandwich)		2.7					
TIPS:							
Reference Estimating Line	1.0						
C-141 Horizontal	1.0						
C-5A Horizontal	1.0						
A-X Horizontal	2.2						
A-X Wing	3.3						
VFX Horizontal	5.5						
B-58					2.5		
SPOILERS:							
Reference	1.0						
A(X) Wing	1.0						
Model 990 Type (simple)	0.71		1.68	2.04	0.87		
F-111 Type (simple)	0.43		1.01	1.25	0.53		
FLAPS:							
Reference	1.0						
A-X Wing	1.0						
Model 990 Outboard	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					4.70	3.60
C-141 Horizontal	0.67						
A(X) Horizontal	0.77						
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						
A(X) Wing	2.21				3.00		
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	1.0						
Built-up Aluminum	1.0		2.60	3.00			
Machined Aluminum	0.92						
HINGES, BRACKETS & SEALS:							
Reference	1.0						
C-141 Horizontal	0.3						
C-5A Horizontal	1.29						
A(X) Horizontal	1.8						
PIVOTS AND FOLDS:							
Reference	1.0						
C-5A Horizontal	0.9						
A (X) Horizontal	0.34						
C-141 Horizontal	1.54						
VFX Horizontal	2.50						
WING CENTER SECTION							
Reference	1.0						
A (X) (Estimated)	1.0						
C-141 Horizontal	0.54						
Model 880 (Estimated)	1.0						
Experimental Wing Carry-thru Box	0.86						
B-58 (Estimated)	1.58						
F-102/106 Type	3.30		3.70				

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	1.0						
B-58	5.0						
NACELLES-MLGD & REINFORCEMENTS							

Table 26. Secondary Structure Subassembly Complexity Factors, CC_i

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

Table 26 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL						
	Aluminum	Fiber-Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium	Steel
FAIRINGS:							
Reference	1.0						
A (X) Horizontal	1.0						
C-141 Horizontal	1.0						
C-5A Bullet Fairing	1.17	1.73	2.23				
B-58 (sandwich)		2.5					
TIPS:							
Reference	1.0						
C-141 Horizontal	1.0						
C-5A Horizontal	1.0						
A (X) Horizontal	2.18						
VFX Horizontal	5.7						
B-58					2.7		
SPOILERS:							
Reference	1.0						
A (X) Wing	3.9						
Model 990	0.7		1.7	2.0	0.9		
F-111	0.4		1.0	1.25	0.5		
FLAPS:							
Reference	1.0						
A (X) Wing	1.0						
Model 48	0.43		1.03	1.26	0.54		
Model 990 (Inboard)	0.72		1.65	2.00	0.90		
Model 990 (Outboard)	0.75		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	Steel
ATTACHMENT STRUCTURE:							
Reference	1.0						
C-141 Horizontal	0.7						
A (X) Horizontal	0.8						
C-5A Horizontal	1.62						
Machined Structure	2.31					4.72	3.94
ACCESS DOORS:							
Reference	1.0						
A (X) Horizontal	1.12						
C-141 Horizontal	0.89						
A (X) Wing	2.13						
Large Transport	1.06	1.62	2.86				
B-58					3.0		
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						1.0	
V/STOL Type (Welded Titanium)						1.0	
V/STOL Type (Formed Tubing)						1.79	1.13
SLATS:							
Reference	1.0						
Machined	0.92						
Build-up	1.0		2.6	3.0			

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	1.0						
A (X) Horizontal	1.95						
C-5A Horizontal	1.44						
C-141 Horizontal	0.33						
PIVOTS AND FOLDS							
Reference	1.0						
C-5A Horizontal	0.88						
C-141 Horizontal	1.52						
VFX Horizontal	2.5						
WING CENTER SECTION							
Reference	1.0						
A(X)	1.0						
Model 880	1.0						
C-141 Horizontal	0.52						
F-102/106 Type	3.16		3.52				
B-58	1.3						
OTHER:							
Reference	1.0						
A (X) Wing	0.58						
B-58	3.0						
ELEVATORS:							
Reference	1.0						
C-5A Horizontal	0.53	0.8	1.35				

Table 26 (Continued)

CONSTRUCTION INFORMATION	TYPE OF MATERIAL						
	Aluminum	Fiber-Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium	Steel
ELEVATORS: (Continued)							
C-141 Horizontal	0.73						
A (X) Horizontal	1.94						
Model 990 Type	0.7	1.0	1.8				
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	1.38	2.66				
B-58					3.5		
COCKPIT:							
Reference	1.0						
Model 880	1.0						
B-58	2.5						
NOSE LANDING GEAR DOOR:							
Reference	1.0						
T-2A	1.0						
Model 880	1.0						
A (X)	1.0						
B-58	3.08						

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 880	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 880	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	1.04						
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	1.0						
B-58	4.5						
NACELLES - MLGD & REINFORCEMENTS							

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

DETAIL FABRICATION LABOR	WC_i CODE	MODEL CARD 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

E_i follows the same map as WC_i with a constant value of 0.67

Table 27 (Continued)

DETAIL FABRICATION LABOR	WC_i CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
HORIZONTAL STABILIZER SECONDARY STRUCTURE				
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
VERTICAL STABILIZER SECONDARY STRUCTURE				
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
FUSELAGE SECONDARY STRUCTURE				
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	28.6	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
WING SECONDARY STRUCTURES				
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	21.0	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
Slats	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

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

Table 28 (Continued)

SUBASSEMBLY LABOR	WF_i CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
HORIZONTAL STABILIZER SECONDARY STRUCTURE				
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
VERTICAL STABILIZER SECONDARY STRUCTURE				
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	WF_i CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
FUSELAGE SECONDARY STRUCTURE				
Cockpit	WF1	F 208 2	35.0	F-77
Nose Landing Gear Door and Box	WF2	F 209 2	45.0	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	74.9	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 28 (Continued)

SUBASSEMBLY LABOR	WF_i CODE	MODEL CARD LOCATION	MODEL CARD VALUE	BACK-UP DATA LOCATION
NACELLES SECONDARY STRUCTURE				
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
LANDING GEAR SECONDARY STRUCTURE				
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

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

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

HEI = cost per unit length for assembly

CMB_i = complexity factor for assembly

Paint and Finish

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

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

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

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
	AERODYNAMIC SURFACES:						
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)				-	-	-
	FUSELAGE - NACELLE - LANDING GEAR:						
W	Weight of Element: Calculated by Computer Program						

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

WORKSHEET

Table 29. Factor Values and F-Card Location.

	WR		HEI		HS		RHP_i		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					
	F-58	Model 880	A (X)			
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.

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

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.

$$M_i = W_i^G (RMC_i)(SF_i) + W_i^G (RMC_i)(SF_i) + W_i^G (RMC_i)(SF_i) \qquad (16)$$

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:

$$M_i = WD_i^G \, (RMC_i) \, (SF_i) \qquad (17)$$

where

- M_i = material cost for secondary structure components
- WD_i = a series of weights for the secondary structure components being estimated
- G = 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					
		Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
RMC1	Raw Material Cost for Rib or Frame of Type A					NOT USED	NOT USED
RMC2	Raw Material Cost for Rib or Frame of Type B						
RMC3	Raw Material Cost for Rib or Frame of Type C						
SF1	Scrappage Factor for Rib or Frame of Type A						
SF2	Scrappage Factor for Rib or Frame of Type B						
SF3	Scrappage Factor for Rib or Frame of Type C						
RMC4	Raw Material Cost for Spar or Longeron of Type A						
RMC5	Raw Material Cost for Spar or Longeron of Type B						
RMC6	Raw Material Cost for Spar or Longeron of Type C						
SF4	Scrappage Factor for Spar or Longeron of Type A						
SF5	Scrappage Factor for Spar or Longeron of Type B						
SF6	Scrappage Factor for Spar or Longeron of Type C						
RMC7	Raw Material Cost for Covers of Type A						
RMC8	Raw Material Cost for Covers of Type B						
RMC9	Raw Material Cost for Covers of Type C						
SF7	Scrappage Factor for Covers of Type A						
SF8	Scrappage Factor for Covers of Type B						
SF9	Scrappage 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 H.

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, Longersons 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	Scrappage Factor SF_i
	WING		
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		
	HORIZONTAL STABILIZER		
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		
	VERTICAL STABILIZER		
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	Scrappage Factor SF_i
	VERTICAL STABILIZER (Cont)		
8	Attachment Structure		
9	Access & Other Doors		
13	Hinges, Brackets, Seals		
17	Rudder		
	FUSELAGE		
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		
	NACELLES		
1	Cowlings		
2	Pylons		
3	Main Landing Gear Door & Reinforcements		
	LANDING GEAR		
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

<u>BACK-UP DATA LOCATION</u>

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						NOT USED
FM2	Fastener Type Complexity Factor - Secondary Structure Assembly						

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:

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

Major Mate:

Major Mate Hours $= \left[\begin{array}{l}\text{Detailed Fabrication Hours + Subassembly Hours} \\ \text{+ Major Assembly Hours} \quad \times \text{ Factor}\end{array}\right]$ (24)

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

	Primary Assembly	Major Mate
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. Substautions 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 calculaton 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:

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

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 <u>NONRECURRING DESIGN AND DEVELOPMENT</u>. 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:

<u>BASIC STRUCTURE DESIGN ENGINEERING HOURS</u>

<u>CER Form</u>

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

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

Hardware Components	Detail Fabrication Hours	Subassembly Hours	[illegible] Assembly Hours	[illegible]	[illegible]	Material [illegible]
Structural Box						
Ribs	[illegible]	[illegible]				[illegible]
Spars	[illegible]	[illegible]				[illegible]
Covers	[illegible]	[illegible]				[illegible]
Assembly			[illegible]			[illegible]
Secondary Structure						
Leading Edge	[illegible]	[illegible]				[illegible]
Trailing Edge	[illegible]	[illegible]				[illegible]
Ailerons	F 343.1	[illegible]				[illegible]
Fairings	F 344.1	F 344.2				[illegible]
Tips	F 345.1	F 345.2				[illegible]
Spoilers	F 346.1	F 346.2				[illegible]
Flaps and Flaperons	F 347.1	F 347.2				[illegible]
Attachment Structure	F 348.1	F 348.2				[illegible]
Access and Other Doors	F 349.1	F 349.2				[illegible]
Air Induction	F 350.1	F 350.2				[illegible]
High Lift Ducting	F 351.1	F 351.2				[illegible]
Slats	F 352.1	F 352.2				[illegible]
Hinges, Brackets, Seals	F 353.1	F 353.2				[illegible]
Pivots and Folds	F 354.1	F 354.2				[illegible]
Center Section	F 355.1	F 355.2				[illegible]
Other	F 356.1	F 356.2				[illegible]
Assembly			F 357.[illegible]			[illegible]
Rework	F 361.1	F 361.2	F 361.[illegible]			[illegible]
Totals				F 362.[illegible]	F 362.[illegible]	

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

Hardware Components	Wing Hours	Horizontal Stabilizer Hours	Vertical Stabilizer Hours	Fuselage Hours	Nacelle Hours	Landing Gear Hours	Subtotal Hours	Dollars
Basic Structure Design Engineering Hours	Eq (26) F 615.1	Eq (26) F 615.2	Eq (26) F 615.3	Eq (26) F 615.4	[illegible] F 615.5	[illegible]	F 615.7	[illegible]
Configuration Design Engineering Hours							[illegible]	[illegible]
Engineering Material								[illegible]
Total Trade Study Engineering							[illegible]	[illegible]
Basic Tool Manufacturing Hours	Eq (28) F 619.1	Eq (28) F 619.2	Eq (28) F 619.3	Eq (28) F 619.4	[illegible]	[illegible]	F 619.7	
Rate Tool Manufacturing Hours							[illegible]	
Total Tool Manufacturing							[illegible]	[illegible]
Basic Tool Engineering Hours							[illegible]	
Rate Tool Engineering Hours							[illegible]	
Total Tool Engineering							[illegible]	[illegible]
Mfg. Development and Plant Engineering							[illegible]	[illegible]
Tooling Material and Other Dollars								[illegible]
Manufacturing Support Dollars								[illegible]
Quality Control Hours							[illegible]	[illegible]
Totals							[illegible]	[illegible]

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 emprirical 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

$$EMD = CDED \cdot F2 \qquad (27)$$

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

$$BTMH_i = TMF_i \, (WAMPR_i)^{ET} \qquad (28)$$

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

$$RTMH \quad (\sum BTMH_i) \; (TAM^{ER} - 1) \tag{29}$$

where

$\sum BTMH_i$ (619, 7) 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

$$TTMD = TTMH \cdot THC \tag{30}$$

where

TTMD = Total tool manufacturing dollar costs

TTMH = Total tool manufacturing hours

Table 40. Tool Manufacturing Hours CER Coefficients.

	Complexity	Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
TMF Value	Simple Design - Subsonic (.35)	455.	260.	210.	620. (.5)	435.	--
	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

$$BTEH = (\sum BTMH_i) F3 \qquad (31)$$

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

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

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 date. An average value is 20% based on taking one-half of F3.

TOTAL TOOL ENGINEERING DOLLAR COSTS

CER Form

TTED = TTEH × TEC (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 × F5 (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 × TDC (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

$$TMOD = TTMH \cdot F6 \qquad (36)$$

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

$$MSD = CDED \cdot F7 \qquad (37)$$

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
RDT&E 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	* Z 636 1	* Z 636 2	* Z 636 3	* Z 636 4	* Z 636 5	* Z 636 6		F 636 8
Primary Assy & Major Mate Material								Eq (45) F 637 8
Totals							F 638 7	F 638 8

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

AEROSPACE VEHICLE STRUCTURAL COST

RECURRING AIRFRAME PRODUCTION COSTS (SUMMARY)

17.29.55. [illegible]

	WING HOURS	HORZ HOURS	VERT HOURS	FUSE HOURS	NACL HOURS	L/G GEAR HOURS	SUBTOTAL HOURS	TOTAL COST	[illegible] UNIT
ROTAE									
SUSTAINING ENGRG							[illegible].366	[illegible]	[illegible]
SUSTAINING TOOLING							1[illegible]	1[illegible]	
MANUFACTURING									
DETAIL FAB	1.[illegible]		.1373	.7195	.5536	.[illegible]	[illegible]	1[illegible]	
ASSEMBLY	1.[illegible]		.2073	1.[illegible]	.[illegible]	.0147	[illegible]	[illegible]	
PRIMARY ASSY + MAJOR MATE							.[illegible]	[illegible]	
QUAL CONTROL							.[illegible]	[illegible]	
MATERIAL + OTHER	7.[illegible]		.8293	7.2453	2.3650	7.2335		[illegible]	
MAJOR MATE MATERIAL								[illegible]	
TOTALS							27.376	2[illegible]	
PROCUREMENT ARTICLES									
SUSTAINING ENGRG							.[illegible]	[illegible]	[illegible]
SUSTAINING TOOLING							10.[illegible]	64.[illegible]	
MANUFACTURING									
DETAIL FAB	1.[illegible]		.1452	.7340	.5032	.0125	2.727	17.[illegible]	
ASSEMBLY	1.[illegible]		.2215	1.4438	.7471	.0715	4.[illegible]	[illegible]	
PRIMARY ASSY + MAJOR MATE							.[illegible]	[illegible]	
QUAL CONTROL							.765	[illegible]	
MATERIAL + OTHER	13.3569		2.1175	15.4547	6.2241	15.4379		[illegible]	
MAJOR MATE MATERIAL								[illegible]	
TOTALS							19.330	1[illegible]	

Figure 34. Recurring Airframe Production Costs (Summary).

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 F638 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

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

where

SEH = Sustaining engineering hours

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

PN2 = RDT&E number of units

SUSTAINING TOOLING HOURS

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

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:

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

where

P1 First unit cost

P2 The number of RDT&E units

x $\dfrac{\ln P3}{\ln 2}$ 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

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

where

MMPCTL = Percentage factor (43)

QUALITY CONTROL HOURS

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

where

QCF   Q/C percentage factor

PRIMARY ASSEMBLY AND MAJOR MATE MATERIAL

MMM   (636, 8) × MMF   (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.

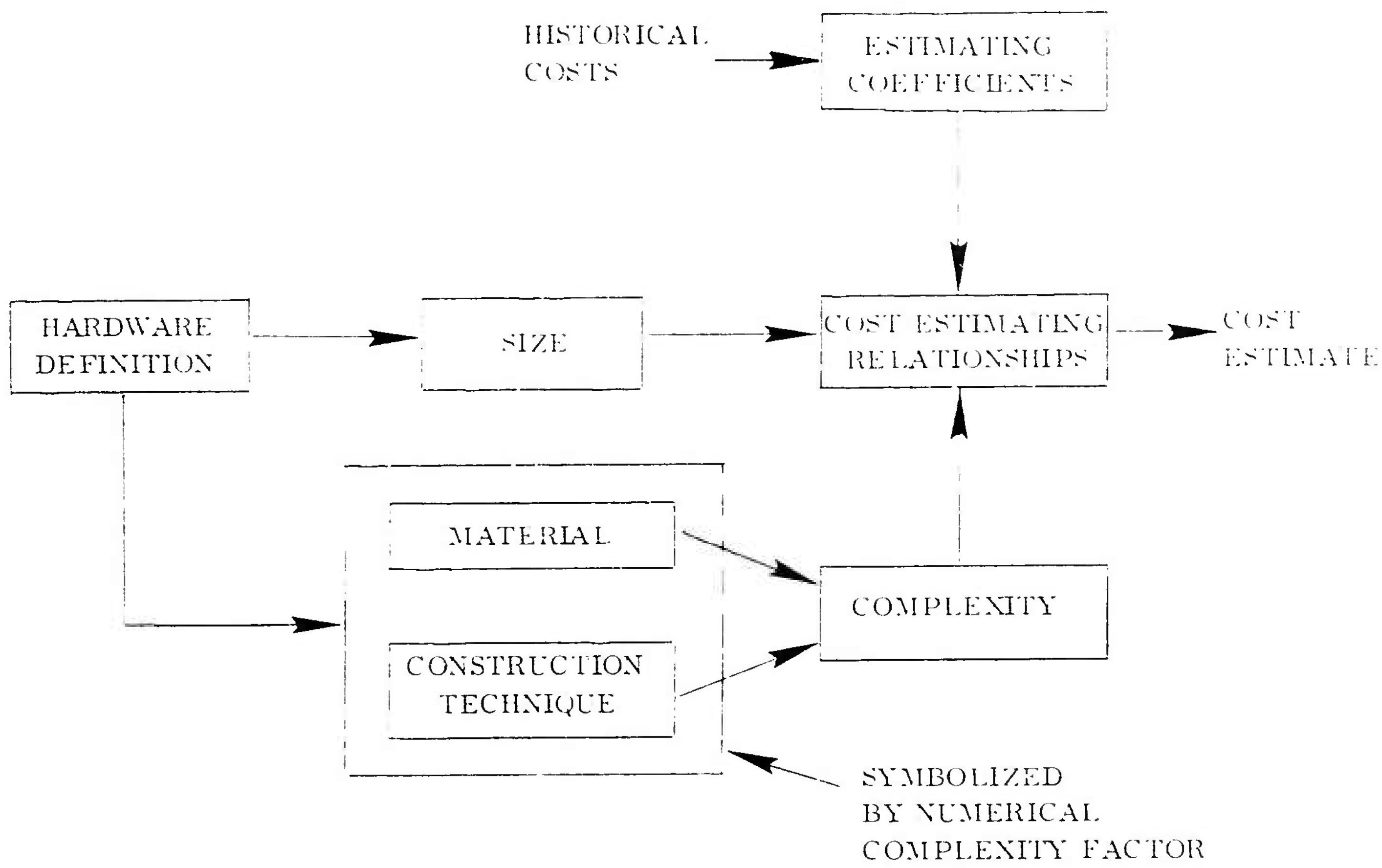


Figure 35. Costing Process.

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 <u>DERIVATION OF ESTIMATING COEFFICIENTS</u>. 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.

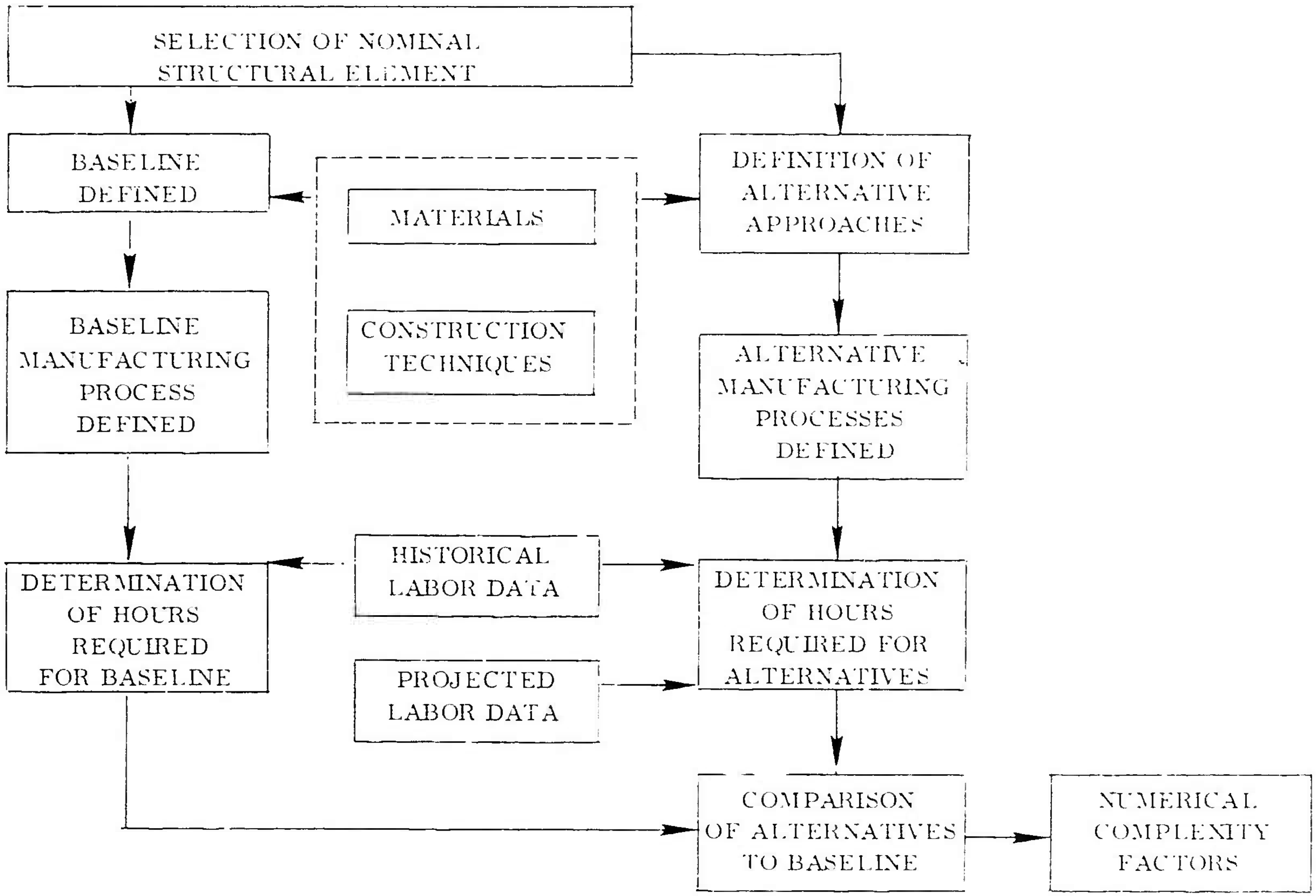
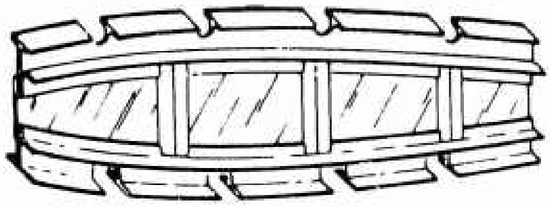


Figure 36. Development of Complexity Factors.



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

FIRST UNIT COST	DETAIL FABRICATION	SUBASSEMBLY
Structural Box		
Ribs	X	X
Spars	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.

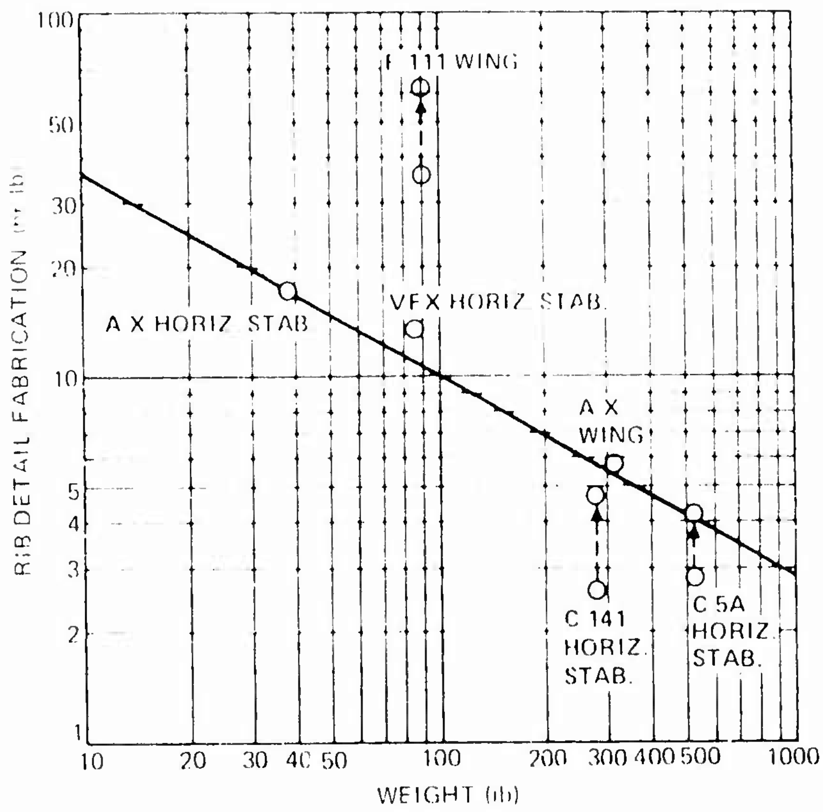


Figure 39. Detail Fabrication Hours Versus Weight for Ribs with Complexity Factor normalized.

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 <u>COMPUTER PROGRAM INTEGRATION</u>. 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.

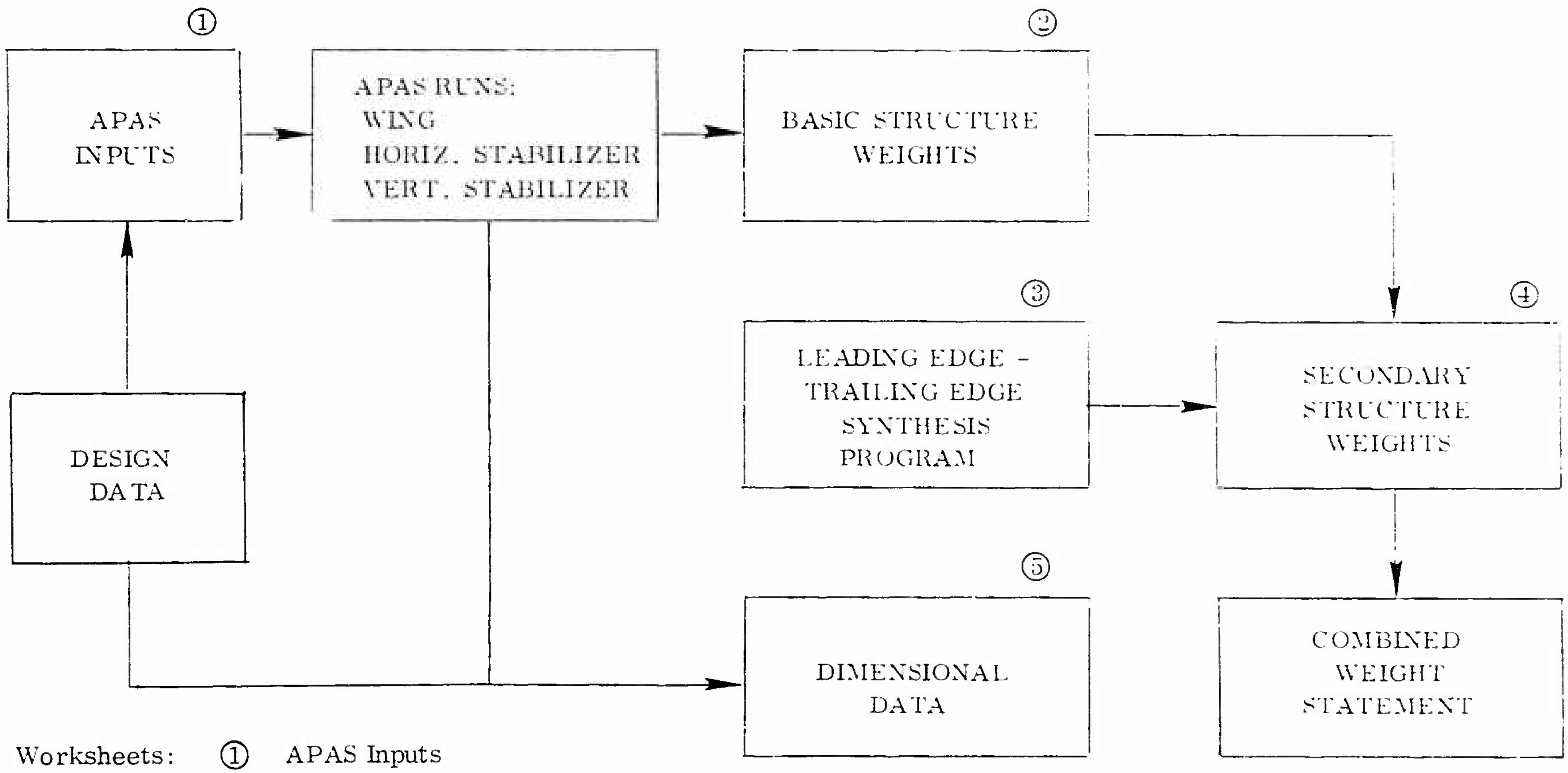
2.4.2 <u>OPERATION OF SUPPORTING PROGRAMS</u>. The sequence of operations for the programs involved in analyzing aerodynamic surfaces is shown in Figure 40. Also shown is the list of worksheets used in the transfer of data. An illustrative set of these worksheets is included and discussed in Appendix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

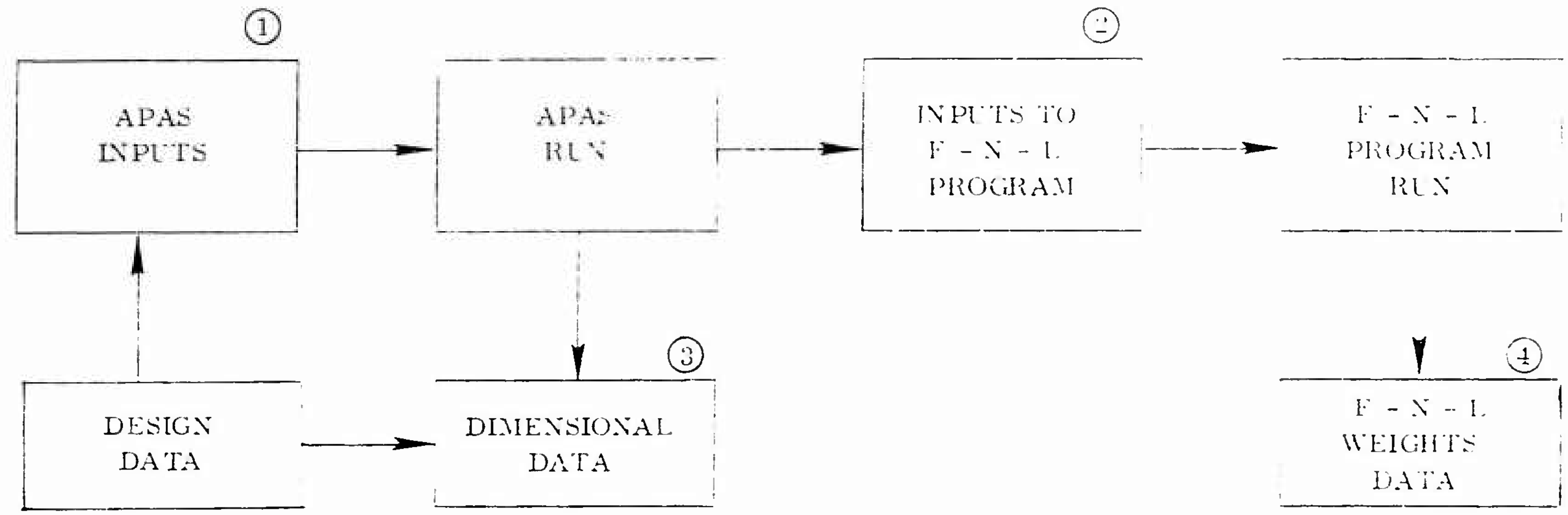
2.4.3 <u>TIME SHARING</u>. The use of Interactive Graphics was investigated as part of this study. From the results it appears that time-sharing using an INTERCOM type system offers significant advantages. A discussion of Interactive Graphics benefits and time-sharing using INTERCOM is provided in Volume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



Worksheets:
① APAS Inputs
② Basic Structure Weights
③ Inputs to LE-TE Program
④ Secondary Structure Weights from LE-TE Program
⑤ Dimensional Data

Figure 40. Supporting Synthesis Programs for Aerodynamic Surfaces.



Worksheets:

1. APAS Inputs
2. APAS Output to F-N-L Program
3. Dimensional Data
4. F-N-L Weights Data

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 } Other	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 printout, 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:

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

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

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

Hardware Components	Wing Hours	Horizontal Stabilizer Hours	Vertical Stabilizer Hours	Fuselage Hours	Nacelle Hours	Landing Gear Hours	Subsystem Hours	Total Hours	Total Dollars
Tooling									
Basic Tool Manufacturing	Eq (8) F 731.1	Eq (8) F 731.2	Eq (8) F 731.3	Eq (8) F 731.4	Eq (8) F 731.5	Eq (8) F 731.6	Eq (8) F 731.7	F 731.8	
Rate Tool Manufacturing	Eq (9) F 732.1	Eq (9) F 732.2	Eq (9) F 732.3	Eq (9) F 732.4	Eq (9) F 732.5	Eq (9) F 732.6	Eq (9) F 732.7	F 732.8	
Total Tool Manufacturing	F 733.1	F 733.2	F 733.3	F 733.4	F 733.5	F 733.6	F 733.7	F 733.8	F 733.9
Basic Tool Engineering	Eq (10) F 734.1	Eq (10) F 734.2	Eq (10) F 734.3	Eq (10) F 734.4	Eq (10) F 734.5	Eq (10) F 734.6	Eq (10) F 734.7	F 734.8	
Rate Tool Engineering	Eq (11) F 735.1	Eq (11) F 735.2	Eq (11) F 735.3	Eq (11) F 735.4	Eq (11) F 735.5	Eq (11) F 735.6	Eq (11) F 735.7	F 735.8	
Total Tool Engineering	F 736.1	F 736.2	F 736.3	F 736.4	F 736.5	F 736.6	F 736.7	F 736.8	F 736.9
Tool Material									Eq (12) F 737.9
Manufacturing Aids								Eq (13) F 738.8	F 738.9
Manufacturing Development								Eq (14) F 739.8	F 739.9
Total Tooling									F 740.9
Manufacturing Support									Eq (15) F 741.9
Quality Control								Eq (16) F 742.8	F 742.9

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:

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

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:

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

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_1 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:

$$TEL = \sum (701\ .\ .\ .\ 718,\ 1) \qquad (4)$$

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:

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

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:

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

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

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

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.

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

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 TF7, which must be derived as analogs from Figure L-13. Additionally, decisions on the choice of complexity factors for TF1 through TF5 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

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

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:

$$BTEH_i = BT_i \, (TEF_i) \qquad (10)$$

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

$$RTEH_i = RT_i \, (RTEF_i) \qquad (11)$$

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

$$TM = TTM\ (TMF2) \tag{12}$$

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

$$MAH = TTM\ (MAF) \tag{13}$$

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 aids 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

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

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 :

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

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

<u>Inputs</u>

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

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

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	[illegible] Material Dollars
Basic Structure				
Wing				Eq (17) I 751 4
Horizontal Stabilizer				Eq (17) I 752 4
Vertical Stabilizer				Eq (17) I 75[illegible] 4
Fuselage				Eq (17) I 754 4
Nacelle				Eq (17) I 755 4
Landing Gear				Eq (17) I 756 4
Subsystems				
Surface Controls				Eq (17) I 757 4
Environmental Control System				Eq (17) I 758 4
Hydraulics Pneumatics				Eq (17) I 759 4
Electrical				Eq (17) I 760 4
Instruments				Eq (17) I 761 4
Auxiliary Power Unit				Eq (17) I 762 4
Armament Provisions				Eq (17) I 763 4
Engine Associated Equipment				Eq (17) I 764 4
Fuel System				Eq (17) I 765 4
Avionics Provisions				Eq (17) I 766 4
Furnishing and Equipment				Eq (17) I 767 4
Subsystems Subtotal				I 769 4
Total First Unit Cost				I 770 4

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:

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

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-30. 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&E Hours	RDT&E Dollars	Production ( ) Hours	Production ( ) Dollars	Production ( ) Hours	Production ( ) Dollars
Sustaining Engineering	Eq (18) E 781 1	E 781 2	Eq (19) E 781 3	E 781 4	Eq (19) E 781 5	E 781 6
Sustaining Tooling	Eq (20) E 782 1	E 782 2	Eq (21) E 782 3	E 782 4	Eq (21) E 782 5	E 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

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

where

SEH = Sustaining engineering hours

TEL = Total engineering labor

QN2 = RDT&E quantity

ES = Scaling against quantity

The equation used for procurement quantities is

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

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

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

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

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

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,

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

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 printout 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.