DEVELOPMENT COST ESTIMATING SURVEY

Prepared For

DIRECTOR OF DEFENSE RESEARCH & ENGINEERING
OFFICE OF THE SECRETARY OF DEFENSE

Under

TASK 3 of CONTRACT SD-142

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Task 3

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Section I

SUMMARY

A. Objectives

This report was prepared in fulfillment of OSD/ODDR&E Contract SD-142, Task 3. The primary objective of Task 3 was to provide data and techniques which will permit ODDR&E to better appraise development cost estimates on future weapon systems. The initial scope of the contract, as stated in the task statement, Appendix 6, was defined in three parts:

- A survey and evaluation of cost estimating techniques already developed and sources of pertinent historical data;
- Collection and analysis of past data; development of parametric estimating relationships;
- A plan for enhancing future ODDR&E capability through data collection and iterative revision.

The scope of the task was changed, however, in January 1963, as the result of discussions with Dr. Harold Asher, Deputy Assistant Secretary of Defense (Comptroller) for Programming. A newly established staff under Dr. Asher plans to conduct in-house studies on both production and development cost estimating. It was agreed to reorient the work under Contract SD-142 to supplement Dr. Asher's efforts and therefore limit the scope of Task 3 to the survey described in Part One of the Task Statement.

Accordingly, this report documents a survey of development cost estimating techniques and sources of pertinent data on past weapon systems. It catalogues and codifies most of the available information on this subject and outlines the sources of appropriate historical data. In addition, the survey provides a basis for defining the analytical and data collection program to follow. The material presented here is intended to be preliminary to that program, and in itself does not constitute a set of useful procedures. Because many of the cost estimating relationships abstracted and referenced in this report are presented out of context, they must be highly qualified and are included solely for illustrative purposes.

B. Results

The survey resulted in identification of the following information by categories of cost and weapon system:

- Types and sources of historical data (costs, performance/design and program characteristics) necessary to develop estimating techniques for selected weapon systems. Table IV-1 summarizes this information.

- The more significant cost estimating relationships in use or under development, including a tabulation of estimating parameters used for each major cost. Tables IV-2 through IV-6 summarize this information.

The specific estimating relationships referenced in Tables IV-3 to IV-5 are listed with comments in Appendix 4. These relationships do not necessarily represent current working material, but rather a sample of pertinent reports on the subject. Little quantitative evaluation was possible, and the qualifications are numerous. The relationships serve only to illustrate typical dependent and independent cost estimating variables and the forms of empirical relationships employed.

Preparations were made to obtain pertinent data on a sample of weapon systems from each of the three services so as to better define the availability and usefulness of past data obtained through service records. Formats for this purpose are included in Appendix 5. This effort, initially within the scope of the survey, was curtailed following the establishment of Dr. Asher's staff.

The information obtained during the survey reflects both a limited level of effort and the restrictions imposed by privileged information. Somewhat less than six man-months were applied to the survey itself, from September through December, 1962, and much of this effort was constrained by the natural reluctance of defense contractors to discuss specific cost estimating relationships which reveal proprietary information.

Section II

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of the survey indicate the following conclusions:

- A useful collection of development cost data on past weapon systems can be acquired through the services. The required effort will be considerable but not prohibitive if the data obtained is limited in detail. Such data, with a clear identification of the items encompassed by each cost element, is basic to the development or evaluation of any estimating methodology.

- The RAND data bank, while far from the complete answer to ODDR&E's data needs, would represent a valuable initial contribution to a central OSD data source.

- Any conclusions regarding the future promise to ODDR&E of statistically based estimating techniques are premature. The evidence obtained in the survey does suggest, however, that specific areas of useful applications can be defined for Engineering and Operational Systems Development where the techniques are used to audit rather than supplant source estimates. A thorough analytical study of the historical data to be obtained is warranted.

- While a number of applications of parametric cost estimates have been revealed, the total material obtained in the survey does not provide ODDR&E with adequate estimating relationships for considering:

  - a broad range of weapon systems and configurations;

- all of the significant cost elements within each program; and

- the unique performance/design features and technology <u>increment</u> associated with a particular development.

The parameters commonly employed in the cost estimating relationships (e.g., weight, thrust) do not adequately express many of the major cost generating variables in a development program. The inclusion of such factors as type of contract, time schedules, reliability specifications, technological advance rating, unique performance or design characteristics, etc., as quantitative expressions in the estimating relationships appears feasible and should be evaluated further.

<u>Recommendations</u>

It is recommended that:

- a data collection program be initiated within the three services and OSD for those weapon systems and types of data tentatively identified by the formats in Appendix 5.

- efforts be made to avail ODDR&E of appropriate portions of the RAND data.

- the data collected be used to:

    - evaluate selected estimating relationships summarized in this survey (see Appendix 4);

    - establish additional and more comprehensive groups of cost dependent parameters; and

- derive and evaluate cost estimating relationships for these parameters, using appropriate statistical techniques.

Section III

BACKGROUND

The need for more accurate weapon development cost estimates and improved estimating processes is highlighted by the importance of ODDR&E decisions which these estimates influence. These decisions include:

- selection of weapon systems and components for development; and
- the funding, scheduling, and technical characteristics of the items selected for development.

These decisions, in turn, affect annual RDT&E appropriations and five-year force structure and financial plans. In addition to development cost estimates, the decisions require other information inputs such as production and operating cost estimates, effectiveness measures, time phasing of RDT&E expenditures, alternate investment opportunities, and resource constraints. A more accurate total development cost estimate at program inception is not a singular requirement, but it would be a significant contribution to the decision-making process.

The goals of this study are best expressed in terms of achieving a <u>relative</u> improvement. Currently, actual costs over 200 percent in excess of original estimates are not uncommon. Even without changing the environment, i.e., the competitive pressures and uncertainties which can promote this situation, it is apparent that there is a large area for improvement.

As indicated in the task statement, the research emphasis was placed on developing "parametric" techniques. The natural predisposition toward statistical methods stems from the gross quality of predictive data that is available for use when cost projections are to be made. The magnitude of the programs and the insufficiency of cost generating detail in early program stages necessarily ruled out traditional cost synthesis methods for ODDR&E use. In addition to these considerations, however, statistical forecasting techniques applied at the proper levels of detail to a complex weapon development program should increase estimating accuracy, particularly if used in conjunction with synthesis estimates.

Even without the development of parametric estimating relationships it was apparent that the availability of carefully defined cost and technical data on selected past weapon systems would provide a basis for comparison and thus enhance ODDR&E's ability to appraise future development cost estimates. A logical first step in this task would be to survey the already existing useful knowledge on parametric techniques and to determine the availability of appropriate historical data. It was intended that this survey would result in recommendations for future data collection and analysis.

It was recognized that a complete survey of data sources was not practical. Data, therefore, became a secondary objective to the survey of cost estimating techniques. It was planned to collect actual data on nine weapon systems within the three services and to ascertain the level of detail available on many others. The purpose of this effort would be to better define the availability and usefulness of past data obtained through service records. The selected nine systems from which various contracting and administrative arrangements were to be sampled are as follows:

Army: Chinook
Hawk
Sergeant

Navy: NTDS
Sparrow III
Tartar

Air Force: F-106
465L
Titan II

The above specific weapon systems were selected because they were relevant to <u>future</u> weapon systems development and were significant in dollar cost. Only missiles, aircraft, and large-scale electronic systems were considered. Formats for the desired data are included in Appendix 5. This effort was curtailed upon the establishment of Dr. Asher's staff.

Prior to initiation of the survey, the following criteria were established to define more precisely the scope of the problem being addressed:

. The subjects to be estimated will be weapon systems which represent major dollar value and cost uncertainty; e.g., aircraft, missiles, and electronic systems. Spacecraft are not included.

. Consideration will be limited to the categories defined in DOD Instruction 3200.6 as Engineering Development and Operational Systems Development.

. The <u>cost</u> to be estimated will be <u>total development</u> cost from program initiation through completion of test operations on the final test article.

. The <u>time</u> at which the estimate is made will be just prior to program initiation, and information input to the estimate will be limited to that which is typically available at that point in time.

. A consistent definition of what constitutes the "beginning" of development is not relevant to the problem of estimating development cost of a specific program. The costs will be defined by whatever lies within the scope of that particular program. As such, varying degrees of prior development may be available to a proposed system, thereby significantly varying the technology increment to be spanned within the project. Accounting for these variable starting points in each project will be interpreted as part of the forecasting problem.

. The uncertainty of a predicted configuration (design characteristics) to meet specified mission requirements (performance characteristics) would be a legitimate concern of the forecast, but the uncertainty of mission requirements would not be considered. A revised estimate would be held accountable for revised job scope, not the original estimate.

. Where appropriate, major subsystems (i.e., airframe propulsion, guidance, etc.) or major components will be individually estimated in arriving at a total weapon system cost.

. Request for data on past programs would be confined initially to the three services and the Department of Defense; i.e., data would not be solicited directly from contractors.

Section IV

DISCUSSION

A. General

A major limiting factor in this study was realized to be the quantity, value, and level of detail of historical development cost data. Parametric techniques can be developed for any level of cost detail, but the accuracy of the total program cost estimate may suffer if the cost breakdown is too gross or too detailed. Excessive detail in cost definition increases the risk of omission as well as the difficulty of expressing the correlations which will exist among cost elements and is subject to a greater percent error in the independent variables (inputs). Excessive aggregation will lump together independent cost elements and may obscure significant causal relationships.

The categories used in this section for classifying applications of estimating relationships represent a meaningful breakdown for purposes of this study and probably a maximum practical level of detail.

Many cost elements within a development program may represent the procurement of subsystems or components already developed. In this sense the cost of such subsystems to the program would be more in the nature of production rather than development. Further, the fabrication of articles for system test incurs production type costs, which may in some instances comprise over 50 percent of total development costs. For this reason some technqiues applicable to these costs are included in the survey. Because of the similarities of certain development hardware cost elements with production costs and the frequent continuity or overlap between development and production, the joint derivation of both types of cost estimating relationships would be desirable.

A bibliography of the literature surveyed during this study is included as Appendix 1. Selected reports are abstracted in Appendix 2, and key cost estimating relationships are summarized in Appendix 4. A list of sources contacted is also included as Appendix 3.

B. Historical Data Sources

The degree of difficulty in locating usable development cost data varies greatly from one weapon system to another, depending on such factors as the program's age, the concentration of program responsibility, the proportion of in-house development, and the extent of data consolidation already performed. Once having collected the information, one still has to deal with the divergent ways of defining and allocating costs.

Since a clear determination of the data collection problem within the services was not completed, any statements on this aspect of the survey are inconclusive. Apparently, total development cost and, in some cases, major subsystem costs can be obtained with reasonable effort from system project offices or program managers. The effort required to obtain costs in much further detail may be prohibitive in many cases.

Tabulated in Table IV-1 are the primary sources of historical weapon system development cost data encountered in this survey. The list can be regarded only as a starting point, as is evident from the source descriptions which follow the table.

Central contract files maintained by the services have not been mentioned as a first source, because the files are not useful until contract numbers for each system's development program have been identified. The one instance encountered in which development contracts had been tabulated by individual weapon system was the listing provided by the Army Missile Command (see below).

Table IV-1 - A PARTIAL LISTING OF HISTORICAL DATA SOURCES

Sources & Where Available	Development Data							
	Total Obl. Auth.	Actual Cost: By Total System	Actual Cost: By Sub-system	Actual Cost: By Con-tract	Design & Perf. Data	Program Char-acter-istics	Listing of Contract #'s: Par-tial	Listing of Contract #'s: Com-plete
Weapon Dictionary, Parts I, II, and III OSD/Comptroller's Office	AEM*				AEM	AEM		
R&D Project Cards (DD-613) and/or		AEM	AEM		AEM	AEM	AEM	
Technical Development Plans (TDP) Dep.Dir.(Admin. & Mgment) ODDR&E		AEM*	AEM*		AEM	AEM	AEM	
Army: Army Missile Command, Proc. & Prod. Directorate, Redstone Arsenal		M		M				M
Navy: Bur. of Naval Weapons PFM (A/C R&D Data)		A*	A*		A			
Office, Ass't Chief for Prog. Management Program Manager's Office		AEM*	AEM*	AEM	AEM	AEM		AEM
Air Force: System Program Package (Available OSD/Compt. Files)		AEM*	AEM*		AEM	AEM		
System Program Offices (SPO's) (Contractor Cost Studies)		AEM*	AEM*	AEM	AEM	AEM		AEM
RAND Corporation - Data Bank		AEM	AEM		AEM	AEM		
Stanford Research Institute		M*		M		M		M
Grad. School of Bus.Admin., Harvard Source Data for Wpn Acq. Study		AM				AM		

Key: A = Aircraft M = Missiles
E = Electronics * = Available by Fiscal Year

Comments on each data source follow.

Weapon Dictionary

The funding information in the Weapon Dictionary is useful only as an indication of R&D dollar volume and as a convenient summary of systems extant among the services.

DD-613 and TDP's

The Project Cards (DD-613) and Technical Development Plans (TDP's) are helpful in that they indicate funding by fiscal year and, in some cases, by subsystem. Some contract numbers are given. The TDP's have only been in existence for about two and a half years.

Army Missile Command

The Army Missile Command has punched card records of R&D contract numbers by weapon system. Difficulties will be encountered, however, in isolating costs of in-house development, which have been substantial in such programs as Jupiter and Pershing.

Navy

The Office of the Program Manager in the Navy's Bureau of Weapons is a logical source for Navy development cost data on aircraft and missile systems. Problems of data continuity are to be expected for the older programs because of organization changes, notably the merger of BuAer and BuOrd in 1959. BuWeps (Code PFM) has aircraft development cost figures summarized by subsystem, by fiscal year. The aircraft data is extensive and well organized, both in its summary of technical characteristics and in its breakdown of subsystem costs. It is considered a useful data source for estimating aircraft development costs.

Air Force

The Air Force System Package Programs (SPP's), on file in OSD/Comptroller's office, contain subsystem development costs by fiscal year. However, the best source within the Air Force for Development costs in depth is the System Program Office (SPO), where more detailed information (such as Contractor Cost Studies) is available.

RAND Corporation

Discussions with the RAND Corporation indicate that RAND possesses the most useful collection of historical development cost data of any source encountered during the survey. This conclusion is, however, the result of discussion rather than examination of the data. Efforts by OSD to obtain this data have so far been impeded by:

- RAND's acquisition of some data considered proprietary by the contractor source; and
- the form in which the data exists (unsummarized) which does not lend itself to a transfer without considerable effort and extensive qualifications.

This data collection would provide a valuable initial input to an OSD data bank. A partial list of systems known to be included follows:

By Subsystem	By System		
Atlas	F-84	F-105	GAM-72
Titan I	F-84F	F-106	GAM-73
Titan II	F-86A	B-47	GAM-77
Minuteman	F-86D	B-52	GAM-87
Thor	F-89	B-57	Bomarc
C-141	F-100	B-58	GAR-8
Some L-Systems	F-101	Snark	Falcon
B-58	F-102	Navaho	Q-2
Others	F-103	GAM-63	Q-4
	F-104	GAM-67	Others

Stanford Research Institute

Stanford Research Institute has completed cost studies for a number of Army and Navy weapon systems. For example, Hawk, Nike-Hercules, Nike-Zeus, and Redeye are some Army systems studied; Navy systems studies include Terrier, Tartar, and Talos. Characteristically, these studies provide total system development costs by fiscal year or by development contract and fiscal year.

Harvard University

Harvard Business School collected total development costs on selected weapon systems as source material for their study, "The Weapons Acquisition Process". Systems included are:

Atlas	Bomarc
Jupiter	Sparrow III
Polaris	Nike-Zeus
Talos	B-58
Nike-Ajax	F-105
Nike-Hercules	F4H

Costs were not gathered by subsystem, and the method of derivation probably limits the data's usefulness for this study. The working data is not generally available. It is understood, however, that individual studies on three systems, Sparrow III, Atlas, and Nike-Ajax, are being prepared for release.

C. Cost Estimating Techniques

In this survey, those sources were contacted who employ cost estimating techniques (particularly parametric techniques) which might prove useful to ODDR&E. Parametric technique implies calculating gross costs from a few statistically correlated design/performance and program parameters. In practically every instance where parametric estimating by a development contractor was encountered, its purpose was to audit rather than supplant his conventional estimate.

In most cases (RAND and GE-TEMPO excluded), the historical data used for development of the parametric relationship was internal and was considered by the source to be proprietary information. For this reason, very little beyond an identification of dependent and independent variables used (not their relationships) was obtained from contractors. Most of the cost estimating relationships (CER's) summarized in the appendix were extracted from a few key RAND and GE-TEMPO reports. A discussion of their usefulness and limitations follows in Section IV-D.

Table IV-2 summarizes the parametric cost estimating applications noted in this survey. The list is not all-inclusive, but rather serves to indicate the apparent state-of-the-art. Entries in the table indicate that cost estimating relationships exist; however, in some cases (e.g., Lockheed-California, Douglas, Boeing, and North American Aviation), the nature of the relationships was indicated in discussions but not specifically identified.

An entry in Table IV-2 does not imply usefulness or availability, but only that CER's have been or are being developed for one or more cost element within the category listed. A brief comment on each source is given below. Reference numbers refer to bibliography accession number in Appendix 1.

RAND Corporation

RAND has achieved an extensive development of CER's for both development and production cost estimates. The primary areas of concentration to date have been aircraft airframes, and missile airframes and propulsion systems (see References 29, 47, 60). While further developments in all applications are continuing, the major current efforts apply to missile guidance and control systems, aircraft electronics, and spacecraft (not included in this survey).

Table IV-2

SOURCE	APPLICATIONS OF COST ESTIMATING RELATIONSHIPS										
	Aircraft			Missiles/Boosters				Electronic Systems			
	Air-frame	Pro-pul-sion	Elec-tron-ics	Air-frame	Pro-pul-sion	Gui-dance & Con-trol	GSE	Data Acq. & Sur-veill.	Data Pro-ces-sing	Com-mu-nica-tions	Pres-enta-tion/Dis-play
RAND	D P	D P	D P	D P	D P	D P	D P				
GE-TEMPO	P	P	P	P	P						
Boeing	D P			D P	D P						
IBM									D		
Lockheed-California	D										
Douglas	D P			D P							
Planning Res. Corp.			D			D					
AFSC	P								P		
NAA	D P										

Key: D = Design, development and test applications
P = Procurement or production applications

Note: Entries within the above table do not necessarily imply completeness or usefulness.

Both development and production costs are being considered. Further development is also planned for cost estimates on missile ground support equipment.

The RAND estimating relationships are comprehensive and are the most useful of any obtained. In many cases, the data base for their derivation is, of necessity, quite limited. Some of the required input parameters (e.g., component fabrication weights and GSE weights) may not be available to ODDR&E at the time an estimate is prepared.

GE-TEMPO

While most of the TEMPO relationships apply to production (i.e., manufacturing costs), these are included for possible applicability to test vehicle fabrication costs for an R&D program. The large production quantities on which many of the relationships are based make modifications necessary for estimating prototype costs. References 44 and 73 were the sources of these CER's.

TEMPO has developed and used many parametric relationships for production costs of missiles, aircraft, and electronic components which are not formally documented. The data base for these CER's and their usefulness were not determined. The development of relationships for radar and communications equipment procurement cost has been initiated, but has provided no useful results to date.

Boeing Airplane Company

Boeing apparently has developed a number of CER's for both development and production costs of aircraft and missiles. However, only cursory information is available. The pertinent references (References 16, 19, and 67) in fact use Congressional appropriation hearing cost estimates for data on space boosters and launch costs.

IBM Corporation

The "life cycle" approach to development cost estimating derives from the observation that development effort is expended in characteristic cycles over the life of a program, e.g., Planning, Design, Prototype, Release. The assumption is that if a program's cycle characteristics are known, total program engineering costs can be forecast based on:

- an estimate of the peak rate of manpower usage; and
- when the peak is expected to occur.

A study under sponsorship of the Institute of Management Sciences was conducted by SCARDE (Study Committee for the Analysis of Research, Development, and Engineering) on the historical data of some 45 R&D projects from 5 or 6 contributing companies. These projects, representing widely varying applications, exhibited similar cycle patterns and were the basis for deriving the cycle formula described in Appendix 4.

This technique has been pilot tested successfully on a number of IBM development programs for computer systems. The factors which will determine the usefulness of this approach are:

- determination of that portion (if any) of a total program (i.e., subsystem or components design) which can be represented by characteristic manpower cycles and the relative stability of these cycles; and
- the accuracy with which key parameters of the cycles can be estimated at program inception.

Lockheed-California

The parametric estimates described in this survey apply only to development engineering (Lockheed in-house) man-hours for aircraft. The data base consists of 18 Lockheed aircraft of all descriptions used jointly in the same sample. The several independent variables employed in each equation include various schedule "mileposts", speed, acceleration, range, and weight specifications. Current efforts are being applied to spacecraft.

The computer programs used for deriving (using multiple regression) estimating relationships consider up to 50 independent variables at a time and over 100 possible functions of these variables.

Douglas Aircraft

Many CER's have been developed for both development and production costs of aircraft and missile airframes. Data source is limited to Douglas programs. No material was made available to the survey.

Planning Research Corporation

PRC was not visited during the survey, but References 10, 11, 31, and 42 indicate significant work on development cost estimating techniques. Reference 31 is the only case where parametric estimates of automatic flight control system development costs were noted during the survey. Both the selection of design parameters and their treatment appear to be very useful. Development time, as well as cost, is estimated in Reference 31.

The techniques are currently being applied to inertial guidance systems.

North American Aviation

Although NAA did not make documented information available, it is known that parametric techniques for estimating aircraft engineering and production costs are being used. One relationship for estimating engineering hours is contained in Reference 71, ASD Cost Estimating Manual. The performance parameter is not defined.

Air Force Systems Command

An Air Force CER program was initiated in 1962. It entails a 3 to 5 man-year level of effort in each division (ASD, BMD, ESD, and SSD) to collect historical cost data and develop cost estimating relationships. Published results available at the time of this survey were limited (see Reference 74).

D. Cost Estimating Relationships

In Tables IV-3, IV-4, and IV-5 the pertinent equations extracted from each referenced report are categorized by element of cost and weapon subsystem. Only the statistically estimated cost elements themselves are indicated, i.e., no entries are given for cost categories which are obtained by an aggregation of more detailed cost estimates. The numbers contained in each table are reference numbers (identical to the bibliography accession numbers) which refer the reader to a tabulation of actual equations in Appendix 4. This tabulation lists by ascending reference number all of the equations extracted from each referenced document. Comments on these relationships and a list of terminology (adopted for the sake of consistency in this report) are also included in Appendix 4.

The equations in Appendix 4 are representative of the estimating relationships encountered during the survey. A rigorous analysis of their value is beyond the scope of the survey. Furthermore, there is insufficient data available for testing the predictive accuracy of most equations, with the possible exception of aircraft. In

Table IV-3

TABLES OF ESTIMATING RELATIONSHIPS BY APPLICATION AND SOURCE

Missiles and Space Boosters

COST ELEMENT	SUBSYSTEM				
	Air-frame	Pro-pul-sion	Gui-dance/Con-trol	GSE	TOTAL
Subsystem Development	47	19,44,47		47	
1. Engineering	47	47		47	
2. Hardware Fab.	47	47			
3. Facilities, Test Equipment, etc.		29,47			
System Test					
1. Test Vehicle Fab.	29,44,60	8,29,44,60	60		70
Labor	29,44				
Materials	29,44				
Tooling	29				
Engineering					
Other	44				
2. Test Operations					29,47,60
3. Test Facilities, TGSE, etc.					29,47
System Engineering and Management					47
TOTAL					

Note: Table entry numbers (identical to bibliography accession numbers, Appendix 1) refer reader to a tabulation of equations & comments in Appendix 4.

Table IV-4

TABLE OF ESTIMATING RELATIONSHIPS BY APPLICATION AND SOURCE

Aircraft

COST ELEMENT	SUBSYSTEM			
	Air-frame	Propul-sion	Elec-tronics	TOTAL
Subsystem Development			31	
1. Engineering	55,71	55	55	13,80
2. Hardware Fab.				
3. Facilities, TGSE, etc.				
System Test				
1. Test Vehicle Fab.		72,73		70
Labor	71,72, 73			
Materials	71,72, 73			
Tooling / Engineering	73			
GFAE			73	
2. Test Operations				
3. Test Facilities, TGSE, etc.				
System Engineering and Management				
TOTAL				

Note: Table entry numbers (identical to bibliography accession numbers, Appendix 1) refer reader to a tabulation of equations and comments in Appendix 4.

Table IV-5

TABLES OF ESTIMATING RELATIONSHIPS BY
APPLICATION AND SOURCE

Electronic Systems

COST ELEMENT	SUBSYSTEM				
	Acq. Sur-veil-lance	Data Pro-ces-sing	Pre-senta-tion Dis-play	Com-mu-nica-tions	TOTAL
Subsystem Development 1. Engineering 2. Hardware Fab. 3. Facilities, etc.	55	55	55	55	
System Test 1. Test Article Fab. 2. Test Operations 3. Test Facilities		74		64	
System Engineering and Management					
TOTAL					

Note: Table entry numbers (identical to bibliography accession numbers, Appendix 1) refer reader to a tabulation of equations and comments in Appendix 4.

only one instance (see Reference 31) were analyses of actual forecast errors observed during the survey to substantiate the relationships used. This may be attributed to a use of all available historical data to derive the relationship itself, particularly since data samples were usually limited in size, or simply that error analyses were not available to the survey.

Apparent duplication and deficiencies in the applications for which CER's were obtained can be observed in Tables IV-3, IV-4, and IV-5. The multiple reference numbers in a single cost category usually treat different cost elements within that category. The overlap in coverage is more apparent than real. Where identical costs are forecast, the input (independent) variables are usually so different that meaningful sensitivity comparisons cannot be made without related data for the uncommon parameters. In addition, clear definitions of the cost (dependent) variable were not always provided, further compounding the problem. For these reasons, no comparisons of estimating relationships have been attempted. The anticipated collection of data on past programs will, however, provide a basis for some useful comparisons and evaluations.

The categories which are most noticeably lacking in CER's are guidance and electronic systems. The few equations listed in these areas have limited coverage and use, with the possible exception of "life cycle" methods for estimating engineering hours, which in theory is not unique to the end item being developed. Practically speaking, however, its usefulness will be limited by certain development characteristics not yet determined.

In total, the equations summarized do not provide a comprehensive estimating technique for ODDR&E. The qualifications surrounding them, such as uniqueness of data and cost definitions, restrict their direct use. In some cases the input parameters required will not be available to ODDR&E at the time of its estimate. The major value of the CER's tabulated in this study is their indication of the typical variables and empirical relationships employed.

The forms of relationships employed can be characterized generally as follows:

$$y = \sum_i \alpha_i x_i^{\theta_i}$$

$$y = \prod_i x_i^{\theta_i}$$

where

y = dependent cost variable

x = independent variable, i.e., parameter

α, θ = empirical constants

Table IV-6 lists for each major cost (dependent variable) the parameters (independent variables) which have been used, either individually or in combination, for calculation of the cost estimate. Table IV-6 is not limited to the specific equations in Appendix 4, but is a general summary for all information obtained in the survey.

Table IV-6

SUMMARY OF DEPENDENT AND INDEPENDENT COST ESTIMATING VARIABLES

Dependent Variable	Independent Variables
1. Aircraft airframe manufacturing cost	1. Airframe AMPR weight 2. Maximum velocity 3. Number of units 4. Learning curve constants
2. Aircraft engine production cost	1. Engine weight 2. Thrust 3. Velocity 4. No. engines/aircraft 5. Number of aircraft
3. Aircraft GFAE	1. Aircraft weight 2. Velocity
4. Aircraft automatic flight control system development cost	1. Maximum velocity 2. Maximum altitude 3. Weight of electronics 4. Complexity factors 5. Calendar year
5. Aircraft development engineering man-hours	1. Weights 2. Maximum velocity 3. Maximum altitude 4. Rate of climb 5. Technical difficulty factor 6. Density factor 7.*Schedule "mileposts" 8.*Acceleration specifications 9.*Range specifications 10.*Number of places in aircraft 11.*Number of aircraft for which design is intended

*/ Lockheed-California Company only.

Table IV-6, Continued

Dependent Variable	Independent Variables
6. Liquid Propellant missile airframe development cost	1. Airframe weight 2. Propellant weight ratio 3. Propellant factor 4. Thrust 5. Engineering cost/man-hour 6. Number of hardware equivalents 7. Cost of first production unit 8. Propellant factor 9. Number engines/stage
7. Liquid rocket engine development cost	1. Thrust 2. Number of hardware equivalents 3. Cost of 1st production unit 4. Design factor 5. Engineering cost/man-hour
8. Liquid & solid rocket engine development instrumentation cost	1. Number of engine hardware equivalents 2. Cost of 1st production unit 3. Number of chambers/stage and per vehicle 4. Thrust 5. Scaling factor 6. Basic equipment cost for in-plant tests
9. Liquid & solid missile test operations (captive and flight) costs	1. Propellant volume 2. Propellant weight (solid motor) 3. Propellant cost 4. Various cost factors 5. Number of flight test units 6. Number of captive test units 7. Number of stages 8. Number of engines/vehicle 9. Number of nozzles & segments/stage 10. Vehicle length

Table IV-6, Continued

Dependent Variable	Independent Variables
10. Missile GSE development cost	1. Liquid propellant volume 2. Propellant factor 3. Engineering cost/hour 4. Total stage weight (solid propellant)
11. Missile GSE costs for test program	1. Various weights 2. Number consoles/blockhouse 3. Number blockhouses/complex 4. Number of continuous data channels, etc. 5. Number of launchers/site 6. Various cost factors
12. Missile test data reduction costs	1. Number of flight test vehicles 2. Number of engines/vehicle 3. Engine development instrumentation cost
13. Solid propellant motor development cost	1. Total impulse 2. Motor diameter 3. Propellant weight ratio 4. Total weight 5. Number of test motors 6. Cost/engineering man-hour 7. Cost of first production motor
14. Solid propellant missile interstage and skirt structure	1. Number of dissimilar interfaces 2. Weight 3. Cost/engineering man-hour
15. Solid propellant manufacturing facility cost	1. Ten year production capacity 2. Proportion of facility allocable to development program

Table IV-6, Continued

Dependent Variable	Independent Variables
16. System engineering and management cost	1. Total subsystem development and system test costs
17. Preliminary design cost	1. Total subsystem development costs
18. Liquid propellant missile airframe manufacturing cost	1. Weight 2. Number of units 3. Learning curve constants 4. Scaling factor 5. Costs/pound for labor, material and tooling 6. Monthly production rate 7. Complexity factor
19. Liquid and solid rocket engine manufacturing cost	1. Weights 2. Thrust 3. Number of units 4. Learning curve constants 5. Scaling factors 6. Costs/pound for labor, materials and tooling 7. Monthly production rate
20. Development program engineering man-hours	1. Time of peak manpower utilization within cycle 2. Rate of peak manpower utilization within cycle 3. Ratios of development cycle elapsed times and total man-hours
21. Aircraft and missile debiasing coefficient for contractor production cost estimate	1. Length of development period 2. Degree of technological advance 3. Fraction of development period elapsed 4. Program starting calendar year

Table IV-6, Continued

Dependent Variable	Independent Variables
22. Military radio communications equipment production cost	1. Power output
23. Digital computer core storage acquisition cost	1. Storage capacity
24. Magnetic tape unit acquisition cost	1. Data transfer rate

E. Approach to Future Data Analysis

The following material describes in more detail the recommended approaches for analysis of data if the general recommendations of Section II are followed.

The exact scope of the data collection effort will be defined after further exploration with each of the three services. It should, however, involve the system project or program manager's office as a data source in most cases.

The formats in Appendix 5 suggest types of data and weapon systems to be included. The recommended sources for each category of data are shown in the following table:

Data Category	Source
Development Costs	Army, Navy, Air Force, RAND
Program Characteristics	ODDR&E and Services
Performance/ Design Data	ODDR&E

The nature of analytical development will naturally be limited by the level of cost detail obtained. The following table indicates the general approaches to be evaluated versus available cost detail:

General Cost Estimating Approach	Development Cost Detail				
	Total System			Total Sub-system	Type of Re-source[1] within Sub-system
	Total RDT&E	Labor Mat'l G&A, etc.	Type of Re-source[1] within System		
1. Parametric relationship for estimating <u>total</u> program R&D cost	X	X	X	X	X
2. Individual parametric relationships for <u>subsystem</u> R&D and system test				X[2]	X[2]
3. "Life cycle" method for estimating engineering costs		X[3]	X[3]		X[3]

The distinction between Approach 1, a total system estimate and Approach 2, estimates by subsystem, is not in the detail of independent program and performance/design characteristics considered, but the number of cost elements individually estimated to obtain the total. Approach 1, therefore, would involve only one or a few equations for

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1/ For example, engineering, hardware fabrication, facilities, and equipment.
2/ RAND techniques apply.
3/ If available in discrete time periods through program.

the entire system (because of having obtained only total development costs on past systems), but it would include a greater number of independent variables than any single subsystem estimating relationship. For a given sample size, the increase in number of independent variables per relationship decreases the number of statistical degrees of freedom, thus decreasing the reliability of the regression. Another disadvantage of Approach 1, in appraising other estimates, is the inability to better identify sources of discrepancy. However, even with these limitations, as an only alternate for the near future, this approach may provide useful relationships.

Approaches 1 and 3 could provide some short term results following a minimum data collection effort. The only initial data required for evaluation of the "life cycle" method are engineering hours by quarter (or fiscal year) on several programs.

Data permitting, all three approaches should be evaluated. The level of detail indicated by Approach 2 offers the best potential return, assuming a feasible data collection effort.

The recommended development of parametric relationships should include a comprehensive treatment of:

- program characteristics such as:
  - type of contract;
  - key schedule milestones;
  - estimate of peak man-hour rate;
  - estimated production quantities;

- performance/design characteristics, such as:
  - technological advance required at program start: weightings given for unique design features, number of components to be developed, type construction, package density, mission characteristics, environment, etc.;
  - reliability specifications;
  - accuracy specifications;
  - reaction time.

The characteristics analyzed for each subsystem or component, particularly the factors and weighting which constitute technological advance, should be closely coordinated with knowledgeable engineers (within ODDR&E where possible) in each technical area.

Based upon the work by Planning Research Corporation, RAND (Summers and Glennan), and Harvard (Peck and Scherer) encountered during the survey, it appears desirable to use a formal method of accounting for the presence or absence of certain performance or design features of given classes of weapon systems, and to derive a single numerical factor from weights ascribed to each feature. This factor, a technological advance rating, would be a measure not only of the end item complexity, but also of the technological increment spanned by a particular development program; i.e., it would be sensitive to the contribution of prior developments. Such a rating would constitute one of the independent variables of a cost estimating relationship.

The obvious importance of a comprehensive selection of independent parameters to be analyzed for each cost element is stressed. This selection along with the consistency and accuracy with which historical data has been defined are critical to the analysis.

The analytical effort will be facilitated by the availability of several versatile multiple regression programs for high speed computers, which make practical an extensive analysis of:

- many forms of analytical relationships
- various data sample compositions;
- various dependent-independent variable groupings;
- forecast errors on data not used in the regression itself;
- statistical correlations and confidence intervals for the degrees of freedom allowed.

Appendix 1

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Appendix 2

SELECTED REPORT ABSTRACTS

This appendix contains selected report abstracts. The abstracts are referenced by bibliography accession number as listed in Appendix 1.

Reference 8

This report provides information on methods used in developing cost estimates for large solid rocket motor programs. It treats engineering cost as a function of the "design complexity" and "technical challenge" involved, and includes provision for test hardware costs. The writer does not, however, offer a means for defining and quantifying the complexity and challenge factors. Engineering cost, in the example given, was derived from "experience with similar programs such as Minuteman and reference to generally accepted industrial practices."

The methods discussed will have somewhat limited application in state-of-the-art programs because of their dependence on production-type data.

Reference 10

R&D costs are defined and a formal procedures is described for preparing an RDT&E estimate. Basically, the procedure consists of:

1. List known equipment requirements.

2. Make order of magnitude dollar estimates of total RDT&E costs by comparing with similar past projects.

3. Estimate engineering effort required on total program as a function of meaningful design parameters.

4. Estimate engineering effort for each <u>subsystem</u> by comparisons with similar past projects.

5. Reconcile 3 with the sum of each subsystem estimate in 4 .

6. Reconcile 5 + 1 with 2.

A typical form of parametric estimating relationship for engineering hours is suggested and approximations are given for its use where the historical data sample is small and regression constants are not available.

<u>Reference 11</u>

A rather complete discussion of progress (or learning) curves is given along with procedures for their application to manufacturing labor, materials, tooling, and engineering costs. A variety of examples are shown with particular reference to RDT&E activities. Formulas are summarized with sample computations, and typical learning curve slopes are given.

<u>Reference 13</u>

This paper summarizes very briefly the methods and approaches that a Price Analyst employs at the Air Force Plant Representative Office, Northrop Aviation, in analyzing and estimating factory labor hours for engineering, tooling, and production on an airframe program. A parametric relationship is given for estimating total engineering hours for aircraft up to test.

Reference 16

This report tabulates current cost per launch of Air Force and NASA Launch Vehicles. Vehicle and operational costs associated with each launch, excluding payload and launch facility costs, are included.

Data sources are varied and of questionable value. The systems included are: Atlas Agena, Atlas Agena B, Atlas Booster, Atlas Centaur, Saturn, Scout, Thor Agena B, and Thor Delta.

Reference 18A

This report describes briefly a technique for placing an "absolute value" on what a total aircraft development and production program should cost. No particularly useful cost-estimating relationships are given.

Reference 19

This document contains tabulations of RDT&E cost estimates for the Saturn C-1 and Centaur space boosters by fiscal year. Cost breakouts by subsystem and activity (i.e., development engineering, ground testing, etc.) are included. The sources for this data are NASA appropriation hearings, which indicate estimates rather than actual costs.

Included with this data (separately attached) are three curves of liquid rocket engine and airframe development cost versus thrust for various combinations of engine configuration and thrust.

A miscellaneous curve plotting solid booster development cost versus stage diameter for MINUTEMAN (all three stages) and Polaris first stage was also attached. No data source was revealed.

The nature of data sources and definitions given do not provide reliable cost correlations. This material should be considered cursory.

Reference 20

This report contains an excellent discussion of the major sources of uncertainty in cost analysis; specifically; (a) requirements uncertainty (i.e., cost variations due to configuration changes); and (b) cost uncertainty (i.e., cost variations for a constant and known configuration).

It discusses Eugene Brussell's and R. W. Summer's work in developing multipliers or factors for unbiasing early cost estimates. Cost sensitivity analysis is suggested as one of the best currently available techniques for helping to deal with the uncertainty problem.

Reference 24

This report was written by the Bell Telephone Laboratories for internal use by personnel concerned with preparation of cost estimates for government contracts. It sets forth the Armed Services Procurement Regulations (ASPR) in general, and relates them to Bell Telephone Laboratories -- Western Electric cost estimating procedures.

Reference 31

The results of a preliminary study (November 1961 through July 1962) to investigate and formulate techniques for predicting the development time and development cost of automatic flight control systems are reported. The automatic flight control systems included in this study are employed in aerodynamically supported vehicles -- both manned and unmanned.

Implemented with relevant historical data, a predictive methodology is evolved using a statistical estimation procedure. Simple algebraic equations are derived to evaluate development cost and development time estimates. The principal elements which constitute the basis of prediction are automatic flight control system characteristics, performance characteristics of the parent vehicle, and the calendar date of the development program. These elements are assumed to be known during the preliminary design stage of a proposed control system.

This report is intended to be used in control system optimization studies.

Reference 33

This report represents an initial effort to define a generalized cost structure for electronic systems and to describe some of the problems involved in establishing such a structure. The cost structure has both an empirical and a theoretical basis. Numerous cost studies completed by the MITRE Economic Factors Department provide the empirical frame of reference, and a set of cost-classifying criteria set forth in MITRE TM-3050, "Criteria for Cost Categorization," provides the general theoretical basis. The paper draws heavily upon system cost methodology developed by the RAND Corporation.

Reference 38

This paper presents a general discussion of various problems which arise in predicting the cost, duration and success of development projects. Intentional and unintentional biasing of estimates and the effects of technological evolution are discussed in considerable detail.

Reference 41

This paper describes a revised WSPACS reprogramming model for forecasting final program airframe cost by simulating conventional estimating and pricing techniques. The model is designed to indicate the dollar amount by which the face value of a contract will be changed if a given reprogramming action is taken. Estimates are not based upon performance and design characteristics of the contract end items.

Reference 44

This report contains a collection of papers dealing with a heterogeneous set of cost problems. One paper, "Rocket Vehicle Cost Elements," examines the suitability of various factors which have been chosen for parametrically estimating costs of rocket motors. It presents a compilation of data and generalized first approximation expressions for use in rocket vehicle costing.

Reference 47

The material in this report was prepared for a course in cost estimating techniques and concepts at the Air Force Institute of Technology. It identifies and defines the R&D cost elements for which estimating relationships are developed. The report offers specific relationships relevant to a ground-launched liquid propellant ballistic missile. They include estimates for:

- Preliminary design
- Airframe development
- GSE development
- Propulsion development
- Subsystem development instrumentation
- Captive test operations
- Flight test site operations
- Launcher electrical and electronics equipment/complex
- Launcher mechanical and structural equipment/complex
- Non-basic test instrumentation associated with propulsion
- Data reduction and analysis
- System management and technical direction

Also included are sample format sheets for collecting data required by the estimating equations and a brief treatment of the R&D expenditure time distributions. A problem-and-solution supplement contains some R&D estimating relationships for a solid propellant missile stage. Individual equations are given for:

- Propulsion system development engineering
- Propulsion system development hardware
- Interstage and skirt structure development engineering and hardware
- Ground equipment development engineering and hardware
- Development instrumentation, special tooling and test equipment
- Solid propellant manufacturing facilities to support R&D plus operational program.

Reference 48

Techniques for applying learning curves to cost-quantity relationship are described.

Reference 49

This paper suggests that R&D projects consist of problem-solving tasks that have a characteristic structure, plus administrative and support activities which are comparatively unstructured. It argues that the nature of the technical work determines a preferable size of the unit tasks, and that the regularities required for prediction and planning seem to appear only when projects are divided into tasks of the "right" size. Some suggestions are presented for approaching this ideal size in practice.

Reference 50

This paper discusses the "Life-Cycle Approach" to estimating manpower requirements for applied research and engineering development programs. Life'Cycle is concerned with manpower utilization curves which tend to be universally characteristic of these programs. The forms of the curves given are in many cases "mathematically" deduced with certain assumptions about human learning and problem solving.

Reference 55

This report describes a method for making a Life-Cycle analysis. The report defines Life-Cycle as "a model describing the way in which people work". Broadly, it says that the amount of work which a group accomplishes in any given month depends upon how long they have been working and on the amount of work left to be done. A Life-Cycle analysis is described as "the use of this model to interpret a project's past history and current status and to project its probable future". No extensive mathematical training is required to learn the techniques discussed.

Four cycles are identified as typical for many development projects in describing the overall utilization of engineering manpower. They are:

- Planning
- Design
- Prototype
- Release

Reference 64

This report describes the development of approximate empirical design-cost relationships based on the characteristics of some existing and developmental military radio communications equipment. Use of such relationships in construction of performance-cost trade-offs is illustrated.

Reference 67

This paper offers an approach for combining cost estimates of the elements of missile booster systems (simple, recoverable, and building block) and applying learning curves to obtain an estimate of total system costs. No estimating relationships are given for development cost and first-unit fabrication cost, both of which are included in the equations.

Reference 70

The author statistically analyzes the errors in cost estimates for producing major hardware items in twenty-two weapon systems. He notes that a large portion of the estimating errors arose because the quantity of hardware produced differed from the quantity on which the estimates were based. Beyond this significant source of error, the writer suggests that the margin of estimate error can be substantially reduced by "debiasing" estimates, on the basis of information known about errors in estimating similar programs in the past. The paper presents an approach for obtaining the debiasing factor for a given program, taking into account the following program characteristics which have had identifiable effect on the margins of estimating error in the past:

- How far along in the development program the estimate is made
- The magnitude of technological advance entailed
- Length of development period
- Calendar date
- Missiles versus aircraft
- Quantity of units
- Estimator and/or contractor
- What has been achieved in the development program at the time the estimate is made.

Reference 71

This guide for evaluating the validity of program estimates lists the cost elements to be examined, along with the procedures for checking each. Some parametric relationships (mostly from NAA) are described for aircraft airframes.

Reference 73

This report presents a statistical approach to estimating aircraft procurement cost. The approach relates cost to various aircraft physical and performance characteristics so that optimization techniques can be applied to identify preferred combinations of variables for specific levels of capability.

Reference 74 (August)

This memorandum presents a parametric estimating relationship for the acquisition cost of a magnetic core storage unit. This relationship is derived from past data (contained in the report) on more than 30 different storage units.

Reference 74 (September)

This memorandum presents a parametric estimating relationship for purchase cost and monthly rental cost of magnetic tape handling units. This relationship is derived from past data (contained in the report) on more than 20 different units.

Reference 75

A general theory of research and development is formulated, which includes the relationships between the characteristics of the R&D end product, the firm, the customer, and the organization required by the nature of

Reference 75 (Continued)

the work. An Industrial Dynamics model of this process is developed, and extensive computer simulation experiments on the model elements are reported and analyzed. Three basic product-related factors are found to be important influences on the outcome of R&D projects: (1) job size; (2) product value; and (3) the state of the product technology.

Reference 76

The comprehensive nature of this book is implicit in the title. It provides useful background information on the environment in which the cost estimating process takes place. For the twelve weapon systems studied (see Section IV), significant statistical correlations were found between the ratio of actual to estimated development cost and a state-of-the-art exploitation index plus importance of time index. The book concludes, not surprisingly, that the most significant causes of cost overruns are:

- unexpected difficulties due to "pure" technical uncertainties;
- "competitive" optimism in original estimates;
- lack of urgency leading to a schedule slippage.

This book is pertinent to the cost estimating problem in its identification of program characteristics which significantly affect development costs.

Appendix 3

SOURCES CONTACTED SEPTEMBER 27 - DECEMBER 14, 1962

	Date	Company and Name of Person
1.	9/27/62	RAND Corporation, Bethesda, Maryland Dr. Robert Grosse
2.	10/3/62	Air Force Electronic Systems Division, Hanscom Field, Bedford, Massachusetts Mr. Walter Schiazza
3.	10/3/62	MITRE Corporation, Bedford, Massachusetts Dr. W. Marcuse
4.	10/5/62	Graduate School of Business Administration, Harvard University, Cambridge, Massachusetts Dr. Paul Cherington Mr. Frederic Scherer
5.	10/9/62	Air Force Systems Command Headquarters (Cost Analysis Directorate), Andrews Air Force Base, Washington 25, D. C. Mr. John Connor Col. C. J. Ellis
6.	10/10/62	Operations Evaluation Group, Arlington, Virginia Mr. W. H. Meckling
7.	10/26/62	Bureau of Naval Weapons, Department of the Navy, Washington 25, D. C. Mr. J. A. Rexroth Mr. David Pepper
8.	11/5/62	Boeing Airplane Company, Seattle, Washington Mr. Alfred C. Ettel Mr. Joe Lindsley Mr. Russ Winslow

	Date	Company and Name of Person
9.	11/6-7/62	North American Aviation, Los Angeles, California Mr. John P. Lathrop Mr. F. W. Schmitt
10.	11/6-7/62	Hughes Aircraft Company, Los Angeles, California Mr. Ronald Haine Mr. Ray Kenny
11.	11/7/62	Aerospace Corporation, Los Angeles, California Mr. Frank Eliel Dr. J. C. Grimberg
12.	11/8-9/62	RAND Corporation, Santa Monica, California Mr. Milton Margolis Mr. Joseph Noah
13.	11/9/62	Douglas Aircraft Company, Santa Monica, California Mrs. June Fischer
14.	11/9/62	Nortronics Division, Northrop Aviation, Hawthorne, California Mr. S. J. Worth
15.	11/10/62	Lockheed-California Company, Burbank, California Mr. Verne Myers
16.	11/12/62	TEMPO, General Electric Company, Santa Barbara, California Mr. Donald Clegg
17.	11/13/62	Lockheed Missile Systems Company, Sunnyvale, California Mr. R. H. Miner

	Date	Company and Name of Person
18.	12/3/62	IBM Corporation, Poughkeepsie, New York Dr. P. V. Norden Mr. F. J. O'Reilly
19.	12/11/62	Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio Mr. Saul Hoch
20.	12/13/62	Bell Telephone Laboratories, Whippany, New Jersey Mr. G. H. Baker
21.	12/14/62	Signal Corps Development Laboratory, Fort Monmouth, New Jersey Mr. Tucci

Appendix 4

SUMMARY OF COST ESTIMATING RELATIONSHIPS

This section contains a summary of selected equations extracted from each referenced report. The reference numbers are identical to the bibliography accession numbers in Appendix 1.

All relationships have been given a common set of terminology and converted from graphical to analytical form where necessary.

Comments on the relationships are included.

Reference 8

COMPLETE SOLID ROCKET MOTOR PRODUCTION COST

$$\log C_{s2} = 8.61 - 0.15 \log N_s - 2.93 \log W_{s2} + 0.28 (\log W_{s2})^2$$

$100 \leq N_s \leq 1,000$ $W_{s2} \leq 150,000$; assumed 90% learning

TERMINOLOGY

N_s = Number of motors produced

C_{s2} = Total production cost/lb., solid motor

W_{s2} = Total weight of solid motor (pounds)

COMMENTS

This equation was developed primarily from Minuteman cost data and industry proposals for larger size motors. The costs calculated include labor, burden, manufacturing, engineering, tooling, and other manufacturing costs.

Validity outside the limits given is undetermined, although uses for $N_s < 100$ and W_{s2} up to 400,000 pounds were discussed as being "reasonable".

In testing applicability to other data samples, it was found that double base propellant motors could not be included with composite propellants.

Reference 13

TOTAL ENGINEERING HOURS FOR AIRCRAFT UP TO TEST

$$H_{aE} = 126(p)^{.90}$$

$$H_{aE} = 126(0.1W_{at} + 10v_{am} + 0.1A_m + A' + 100D_F)^{.90}$$

$$10{,}000 \leq p \leq 40{,}000$$

TERMINOLOGY

A' = Rate of climb (feet/min.) at sea level

A_m = Maximum altitude (feet)

D_F = Aircraft density factor (lbs./cubic foot)

H_{aE} = Total engineering man-hours expended for aircraft development, exclusive of tests

p = Performance factor

v_{am} = Maximum aircraft speed (miles/hour)

W_{at} = Total aircraft takeoff weight (pounds)

COMMENTS

This relationship was developed from statistics of other airframe manufacturers as well as Norair. It is represented as having merit for gauging order of magnitude proposals. Nine data points are shown on the regression plot.

Use of this estimate as a point on an engineering progress curve is recommended for estimating sustaining engineering during fabrication of later prototype and production units.

Reference 19

SOLID & LIQUID PROPELLANT BALLISTIC MISSILES

Liquid Rocket Engine Development Cost

$$D_{\ell 2} = 59F^{2} - 24F + 135$$

defined for $200{,}000 \leq F \leq 1{,}500{,}000$
from J-2, M-1, and F-1 engine estimates

Liquid Propellant Airframe Development Cost

$$D_{\ell 1} = 141F^{.19}$$

defined for $30{,}000 \leq F \leq 1{,}500{,}000$
from three points: Saturn C-1 -- 1st stage
-- 2nd stage
Centaur -- 2nd stage

Solid Propellant Engine Development Cost

$$D_{s2} = .137d^{2}$$

defined for $38'' \leq d \leq 65''$
from four points: Minuteman -- 1st stage
-- 2nd stage
-- 3rd stage
Polaris -- 2nd stage

Reference 19 (Continued)

TERMINOLOGY

d = Solid propellant stage diameter (inches)

$D_{\ell 1}$ = Liquid rocket vehicle airframe development cost for single tank stage ($millions)

$D_{\ell 2}$ = Liquid rocket engine development cost ($millions)

D_{s2} = Solid propellant motor development cost ($millions)

F = Thrust (million pounds)

COMMENTS

These equations are of limited value because of 1) the data sources, i.e., Congressional appropriation hearing estimates, various publications, etc., and 2) the lack of definition for what is included in a "development cost".

Sample data used in deriving these relationships are indicated with the equations.

Reference 31

TOTAL DEVELOPMENT COST OF AUTOMATIC FLIGHT CONTROL SYSTEM

$$C_{AFC} = 10^3 \left\{ -31 - 94 \frac{M_m A_m}{10^4 (Y-1950)} + 151 \frac{W_z}{(Y-1950)} + 33 f_{17} \right\}$$

TERMINOLOGY

A_m = Maximum altitude capability (thousands of feet)

C_{AFC} = Total development cost ($)

f_{17} = Complexity factor for automatic flight control system

M_m = Maximum vehicle Mach number

W_z = Weight of electronic units (pounds)

Y = Calendar year of program start

COMMENTS

The discussion in the report indicates that it is feasible to predict the development cost and development time of automatic flight control systems (developed for aerodynamically supported vehicles) using a statistical estimation procedures supplemented by fairly detailed design data. The prediction equations derived in this study are based on a sample size of 11, consisting mostly of fighters and drones whose development programs commenced in the early 1950's. The relationships were tested against three additional systems, with excellent results. The prediction equations are based on development programs characterized by modest extensions of state-of-the-art technology. Extreme care must be exercised in applying these equations to programs that require basic research or specialized component development.

Reference 44

Production Cost for Bell-Nozzle Rocket Engines

(Sample data are actual costs for 2 points, F = 75,000 lbs. and F = 150,000 lbs.)

$$C'_{\ell 2} = 12{,}400F^{.336}$$

Propellant = LOX JP4

(Sample data are estimated costs of 3 points: F = 150,000 lbs., 300,000 lbs., and 1,000,000 lbs.)

$$C'_{\ell 2} = 9{,}240F^{.336}$$

Propellant = LOX JP4

Solid Fuel Rocket Engines Cost per Firing for 100 Development Firings

(Sample data based on estimated costs)

$$C_{s2} = 1.74(I_t^{-0.211} + 850\ I_t^{-0.943})$$

This is maximum cost for high performance rockets.

Based on 92% learning curve for larger number of firings.

Development and Qualification Test Cost of Solid Propellant Rockets

$$D_{s2} = 5.5 + 0.41\ W_{s2}$$

Engineering	4.8%
Fabricated components (material & labor)	8.6
Processed propellant (materials, labor, tests)	59.7
Tooling	2.4
Facilities	24.5
	100.0%

Propellant performance: specific impulse 235-240 seconds

Reference 44 (Continued)

Direct Labor Man-Hours per Pound of Airframe Weight for Liquid Rocket Airframe Production at Unit 100

$$h_{\ell 1} = 160 \, W_{\ell 1}^{-0.283} \, \gamma$$

Average Material Cost - Production of Liquid Vehicle Airframe

$$C_{\ell 1M} = 78.5 \, W_{\ell 1} \lambda N_{\ell 1}^{-0.152}$$

Other Airframe Cost Categories

$$C'_{\ell 1} = 29.1 \, W_{\ell 1} \lambda N_{\ell 1}^{-0.152} + 371 \, W_{\ell 1}^{0.718} \, \gamma N_{\ell 1}^{-0.322}$$

G&A = 6.5% of labor, overhead and materials
ECP = 11% of labor, overhead, materials, engineering, tooling and G&A
Fee = 6% of labor, overhead, materials, engineering, tooling, and G&A
Engineering and tooling = 10% of materials cost

Total Liquid Airframe Cost

$$\bar{C}_{\ell 1t} = 107.6 \, W_{\ell 1} \lambda N_{\ell 1}^{-0.152} + 1836 \, W_{\ell 1}^{0.718} \, \gamma N_{\ell 1}^{-0.322}$$

Reference 44 (Continued)

Terminology

$C'_{\ell 1}$ = Other airframe costs

$C_{\ell 1M}$ = Average material cost ($/airframe)

$\bar{C}_{\ell 1t}$ = Average total cost for $N_{\ell 1}$ airframes ($)

$C'_{\ell 2}$ = Cost of first production unit ($)

c'_{s2} = Cost per pound second of impulse ($/lb.second)

D_{s2} = Cost of development and qualification test of solid propellant rockets ($millions)

F = Thrust (lbs.)

$h_{\ell 1}$ = Direct labor at unit 100 (man-hours)

I_t = Total impulse (lb.seconds/rocket)

$N_{\ell 1}$ = Number of airframes

$W_{\ell 1}$ = Weight of airframe, liquid missile (lbs.)

W_{s2} = Engine weight, solid propellant (thousands of lbs.)

γ = Complexity factor: 1.0 for Thor; 2.0 for Titan

λ = Complexity factor. 1.0 for Thor; 1.7 for Titan

Reference 44 (Continued)

Comments

Generalized expressions are developed for use as a first cut at subsequent rocket system costing. Some of the data used to derive the relationships are fairly firm costs for equipment now in the hardware stage; others are brochure-type estimates. Heavy reliance is placed upon the "Boeing Weapon System Cost Manual" as a data source.

The expression derived for missile (liquid vehicle) airframes was based on 20 "sheet and stringer" aircraft (AMPR data) calibrated on data for the Thor and Titan missiles. Most solid propulsion cost data is referenced to Phillips Petroleum and Aerojet-General estimates.

The author notes that the quantity and quality of the data presented does not justify rigorous statistical treatment, and that the results of the simple correlations indicated cannot be applied on an absolute basis with a high degree of confidence. He cautions that all factors considered in the report should be reviewed critically as the availability of applicable data increases.

Reference 47

LIQUID PROPELLANT BALLISTIC MISSILES

Airframe Development Cost

$$D_{\ell 1} = 4.4 f_2 c_E \left(\frac{U}{U'}\right)^{.5} N_{2\ell}^{.1} \left[.9 + .1\alpha\right] + C'_{\ell t} N_{\ell 1e}$$

$$N_{\ell 1e} = 31\,\alpha^{-.5} \left(\frac{U}{U'}\right)^{.5}$$

$$= \frac{\text{Total cost of all development hardware}}{\text{First production article unit cost}}$$

Propulsion Development Cost

$$D_{\ell 2} = (.58F^{.4} f_3 c'_E)(.90 + .01N_{\ell 2e}) + C'_{\ell 2} N_{\ell 2e}$$

GSE Development Cost

$$D_{\ell 3} = 1.5 V_{\ell D}^{.15} f_1 c_E$$

Preliminary Design (Solid and Liquid)

$$PD = .06 \sum_j D_{\ell j}$$

Development Instrumentation Cost

$$I_{\ell 2} = 33,000 - X_1 + 40N_{\ell 2e}$$

Flight Test Operations

$$T_{\ell} = 950 V_{\ell}^{.2} N_1^{.25} N_4^{.82} f_{5\ell}(.9 + .03N_5) + P_1$$

Reference 47 (Continued)

LIQUID PROPELLANT BALLISTIC MISSILES (Continued)

Captive Test Operations

$$T_{CA\ell} = 2850V_{\ell i}^{.2}N_3 f_{5\ell}(.9 + .03N_{2\ell}) + P_2$$

Data Processing Station Cost

$$DP = 90,000N_6$$

Launch Site Equipment

$$E_{\ell 3} = 10.3N_7N_8 + 1.1N_9\left[3.5(w_3^{.93} + w_4^{.93}) + .8w_5 + f_6w_6 + f_7w_7\right]$$

System Flight Test Instrumentation

$$I_{\ell 3} = (207,000N_4)* + 78N_4N_5^{.39}$$

* from Atlas and Titan data for airframe instrumentation

Data Reduction and Analysis

$$C_{DR} = .7(207,000N_4)* + .1(I_{\ell 2} + 78N_4N_5^{.39})$$

* from Atlas and Titan data for airframe instrumentation

System Engineering and Management

$$M = .10\left[\sum_{ij} D_{ij} + T_\ell + T_{\ell CA}\right]$$

Reference 47 (Continued)

SOLID PROPELLANT BALLISTIC MISSILES

Motor Development Cost

$$D_{s2} = c_E 5.2(I_t d)^{.233} \left[\frac{\mu}{\mu'}\right] \left[.5 + .008N_{13}\right] + C'_{st}N_{13}$$

where μ = Standard $(1 - \frac{W_p}{W_t})$; see Figure 54 page SP-12

μ' = Proposed $(1 - \frac{W_p}{W_t})$

Interstage and Skirt Structure

$$D_{s1} = c'_E N_{10}^{.86} W_{s1}^{.2}$$

GSE Development Cost

$$D_{s3} = .44W_t^{.15} c'_E$$

Development Instrumentation Cost

$$I_{s2} = .10 C'_{st} N_{s2e}$$

Solid Propellant Manufacturing Facilities for R&D Operations

$$C_{mf} = .51p^{.87} f_8$$

See Figure 2, page 19 of Reference 47 for supporting data.

Reference 47 (Continued)

TERMINOLOGY

c_E = Cost/engineering man-hour (direct + burden + materials) ($/man-hour)

c'_E = Cost/engineering man-hour (direct + burden) ($/man-hour)

C_{DR} = Cost of data reduction and analysis ($thousands)

$C'_{\ell t}$ = Estimated total cost of first liquid missile production article ($millions)

$C'_{\ell 2}$ = Cost of first liquid rocket engine production unit ($millions)

C'_{st} = Total cost of 1st solid propellant unit ($millions)

C_{mf} = Cost of manufacturing facilities for solid propellants to support R&D and operational programs ($millions)

d = Solid propellant motor diameter (inches)

$D_{\ell 1}$ = Development engineering and hardware fabrication cost/stage estimate for liquid missile airframe ($millions)

$D_{\ell 2}$ = Development engineering and harware fabrication cost estimate for liquid rocket engine ($millions)

$D_{\ell 3}$ = Development engineering and hardware fabrication cost estimate for liquid vehicle GSE ($millions)

DP = Data processing station cost ($millions)

Reference 47 (Continued)

TERMINOLOGY (Continued)

D_{ij}	=	Development engineering & hardware fabrication cost for subsystem j of stage i
D_{s1}	=	Development engineering and hardware fabrication cost estimate for solid missile interstage and skirt structure ($millions)
D_{s2}	=	Development engineering and hardware fabrication cost estimate for solid propellant motor ($millions)
D_{s3}	=	Development engineering and hardware fabrication cost for GSE, solid vehicle ($millions)
$E_{\ell 3}$	=	Cost estimate for launcher electronics, electrical, mechanical and structural equipment/complex ($thousands)
F	=	Thrust (thousands of lbs.)
f_1	=	Propellant factor for ground equipment: $LO_2/RP = 1.00$; $LO_2/LH_2 = 1.20$
f_2	=	Propellant factor for airframe: $LO_2/RP = 1.00$; $LO_2/LH = 1.25$; $LE_2/LH_2 = 1.30$
f_3	=	Liquid rocket engine factor:

	Nozzle Configuration	
	Bell	Plug
Pump-fed	1.00	1.10
Pressure-fed	.82	.90

$f_{5\ell}$	=	Propellant factor, test operations: $LO_2/RP = 1.00$; $LO_2/LH_2 = 1.10$
f_6	=	Launcher assembly cost factor: Solids = 3.00; liquids = 3.40

Reference 47 (Continued)

TERMINOLOGY (Continued)

f_7	=	Flame deflector cost factor: steel and water = 1.55; Gunite over steel = 1.00
f_8	=	Proportion of total solid propellant manufacturing facility allocable to R&D program
i	=	Stage
$I_{\ell 2}$		Development instrumentation cost, liquid engines ($thousands)
$I_{\ell 3}$	=	Cost of system flight test instrumentation, liquid engine ($thousands)
I_{s2}	=	Development instrumentation cost, solid motor ($millions)
I_t	=	Total impulse (pound seconds)
j	=	Subsystem
M	=	Cost of system engineering and technical management
N_1	=	Number of liquid stages/vehicle
N_3	=	Number of captive test vehicles (stages)
N_4	=	Number of flight test vehicles (stages)
N_5	=	Number of engines (thrust chambers)/ vehicle (all stages)
N_6	=	Number of equivalent continuous data channels

Reference 47 (Continued)

TERMINOLOGY (Continued)

N_7 = Number of consoles/blockhouse

N_8 = Number of blockhouses/complex

N_9 = Number of launchers/complex

N_{10} = Number of dissimilar interfaces, i.e., joints between motors and skirt at aft end

N_{13} = Number of full diameter solid motors fabricated for test

$N_{2\ell}$ = Number of liquid propellant missile engines/stage

$N_{\ell 1e}$ = Number of liquid propellant missile airframe equivalents

$N_{\ell 2e}$ = Number of liquid propellant engine equivalents

N_{s2e} = Number of solid propulsion engine equivalents

p = 10-year solid propellant production capacity (millions of pounds)

P_1 = Cost of liquid propellants for flight test ($thousands)

P_2 = Liquid propellant cost for captive test operations ($millions)

PD = Preliminary research and design studies cost

Reference 47 (Continued)

TERMINOLOGY (Continued)

$T_{CA\ell}$ = Total captive test operations costs, liquid vehicle ($millions)

T_{ℓ} = Cost of flight test operations, liquid vehicle ($thousands)

U = $\frac{W_{\ell 1}}{W_p}$ Standard; see Fig. 2, RM-3067-PR

U' = $\frac{W_{\ell 1}}{W_p}$ Proposed

V_{ℓ} = Tot. liq. propellant vol. in vehicle (thous.cu.ft)

$V_{\ell D}$ = Liquid propellant volume, design stage (thousands of cubic feet)

$V_{\ell i}$ = Propellant volume/stage, liquid vehicle (thousands of cubic feet)

W_{s1} = Weight of interstage and skirt structure for solid propellant missile (thousands of lbs.)

W_t = Total stage weight (millions of lbs.)

w_3 = Weight of service tower (thousands of lbs.)

w_4 = Weight of umbilical tower (thousands of lbs.)

w_5 = Weight of transfer table (thousands of lbs.)

w_6 = Weight of launcher assembly (thousands of lbs.)

w_7 = Weight of flame deflector (thousands of lbs.)

X_1 = Amount by which inherited instrumentation equipment may reduce total requirement ($thousands)

Reference 47 (Continued)

TERMINOLOGY (Continued)

α = Ratio of propellant weights, design vehicle to Thor

μ = Standard solid propellant motor weight ratio; see Fig. S-4, RM-3067-PR, Supp.

μ' = Proposed solid propellant motor weight ratio; see Fig. 2, RM-3067-PR

COMMENTS

Liquid & Solid Propellant Missile Development

In combination, the various equations for liquid and solid missiles provide a fairly complete coverage of RDT&E cost, excluding the fabrication of test vehicles (which is treated in References 29 and 60).

The data used in developing relationships for liquid missiles are limited to Thor, Atlas and Titan; and, for solid missiles, Minuteman plus contractor estimates for various proposed systems.

While these relationships are presented as course material for the Air Force Institute of Technology, they do represent working material. These cost estimating relationships, together with those in Reference 60, represent some of the most useful material collected in the survey.

Reference 55

LIFE CYCLE COST ESTIMATING RELATIONSHIPS

Engineering Manpower

$$H_E' = 2H_{ET} a\, t\, e^{-at^2}$$

$$t_1 = \sqrt{\frac{1}{2a}}$$

$$t_2 = \sqrt{\frac{3}{2a}}$$

$$H_{ET} = 1.65 (H_E')_{MAX} t_1$$

$$H_{EC} = H_{ET}\left[1 - e^{at^2}\right]$$

$$T \approx 3t_1$$

Average Relationships (Ratios) Between Cycles:

Cycle	H_{ET}	T
Planning: Design	4.0	1.4*
Design: Prototype	1.0	1.0
Prototype: Release	1.0	1.0
Release: Product Support	0.4	0.7

* This factor seems to vary quite widely. Use of the average is only recommended if the planning cycle peaks in the third month or later; otherwise use best available estimates.

Reference 55 (Continued)

TERMINOLOGY

a = A coefficient which determines the month of peak manpower

H_E' = Number of engineering man-months utilized in any given month

H_{EC} = Cumulative engineering man-months to date for one cycle

H_{ET} = Total engineering man-months required to accomplish the work in one cycle.

T = Total cycle time

t = Time, in months, from start of cycle

t_1 = Month within cycle of maximum engineering manpower utilization

t_2 = Month within cycle of curve inflection in decrease of monthly utilized manpower

Reference 55 (Continued)

COMMENTS

To make a Life Cycle estimate before the start of a project, one needs three types of information:

1. For any one cycle, the months required to reach peak manpower in this cycle.

2. For the same cycle, the amount of manpower to be utilized at peak of cycle.

3. Factors which give relationships between successive cycles.

While it is possible to use any cycle (i.e., Planning, Design, Prototype, or Release and Product Support) as a base for projection, the parameters of the first cycle, Planning, can usually be more readily essimated because they are in the immediate future. Using the relationships for H_{ET} and $a = \frac{1}{2t_1^2}$, the coefficients for the base cycle are readily computed. The total cycle time, T, is approximately $3t_1$. Using the factors relating successive cycles, each cycle can be completely described.

By employing different inputs or base cycles, one can obtain several checks on the estimate. The approach can also be used for revising total estimates and obtaining expenditures by fiscal year once the project has started.

This technique has been sucessfully pilot tested on a number of IBM R&D programs for computer systems. In these programs, engineering costs accounted for 60% to 70% of total costs. The listed ratios between cycles may be unique to the types of IBM programs represented.

Reference 64

PROCUREMENT COST OF MILITARY RADIO COMMUNICATIONS EQUIPMENT

$$C_C = 10^2 W_C^{.7}$$

$$W_C = \begin{cases} 19\ P_C & \text{portable sets} \\ 60\ P_C^{.36} & \text{fixed, transportable sets} \\ 15\ P_C^{.75} & \text{shipborne sets} \\ 55\ P_C^{.32} & \text{vehicular sets} \\ 19\ P_C^{.43} & \text{airborne sets} \end{cases}$$

TERMINOLOGY

C_C = Procurement cost of radio communications equipment ($)

P_C = Power Output, radio communications equipment (watts)

W_C = Weight of radio communications equipment (pounds)

Reference 64 (Continued)

COMMENTS

The relationships presented in this report are based on the characteristics of about 150 existing and developmental radio communications equipments. An attempt is made to relate procurement cost to one design parameter, output power. Cost correlates well with weight for all of the units considered, but the application of the equipment (i.e., airborne, vehicular, etc.) must be considered to develop reasonably good dependencies on power. By specifying the type of installation (or, alternatively, frequency range or type of modulation) cost estimates based on the relationships given should be accurate to within about 50%.

Reference 70

Debiasing Formula for Hardware Manufacturing Cost Estimates

$$R' = \{12\} \left\{ \exp. \left[0.097(Ti_4) - 0.032(Ti_4)(AD) - 0.311(AD) + 0.015(AD)^2 + 0.008(Pd) - 0.075(Y-1940) \right] \right\} \cdot X$$

TERMINOLOGY

AD = Degree of technological advance required in the program (numerical scale from 5 to 16)

Pd = Length of development period (months)

R' = Ratio of actual cost to adjusted estimate of hardware article manufacturing cost

Ti_4 = Fraction of development program time elapsed

X = A residual

Y = Program starting calendar year

COMMENTS

This debiasing relationship was developed from a sample of 68 estimates encompassing 22 flight vehicles. The samples included jet fighters, bombers, and the following missiles:

Bomarc	Atlas	Rascal	Thor
Falcon	Titan	Snark	

Reference 71

AIRCRAFT AIRFRAME COSTS

Materials Fabrication Cost/Pound AMPR Weight

$$c_{alM} = 17.5 N_a^{-.154}$$

$1 \leq N_a \leq 200$ (1962 $ value; learning slope 90%)

Production Labor Cost

$$\bar{H}_{alL} = 70 W_{al}^{.69} \alpha N^{-.242}$$

$1 \leq N_a \leq 10$ (learning slope 85%)

Model	Factor (α)
F-100A	1.07
F-107A	1.07
FJ-2	1.075
F-86D	1.10
T-28A	.60
T-39	.74

Engineering Hours

$$H_{alE} = 17.4 f_p^{2.46} \quad \left\{ \begin{array}{l} \text{Scale of } f_p \text{ arbitrarily} \\ \text{defined:} \\ f_p = 5 \text{ for } H_{alE} = 900 \end{array} \right.$$

Approximately 55% learning curve on engineering hours per aircraft from the first aircraft on.

Reference 71 (Continued)

TERMINOLOGY

c_{a1M} = Aircraft airframe material cost per pound AMPR ($/lb.)

f_p = Aircraft performance factor, not defined in reference

H_{a1E} = Engineering hours through production of first prototype aircraft airframe (thousands of man-hours)

$\overline{H}_{a1L}$ = Cumulative average direct labor hours for aircraft airframe production (thousands of man-hours)

N_a = Number of aircraft

W_{a1} = Aircraft airframe AMPR weight (thousands of lbs.)

α = Aircraft airframe complexity factor

COMMENTS

This report contains a number of learning curves which apply to engineering and production costs of aircraft airframes. One parametric cost estimating relationship is given (NAA) which correlates engineering hours with an "air vehicle factor derived from the application of several parameters". The following aircraft are among those considered:

A3J-1	T-28
F-107A	YF-100A
F-100A	F-86A
FJ-4	YF-86A
T2J-1	

Neither the parameters nor the air vehicle factor are contained in the report.

Reference 72

RECURRING COSTS FOR AIRCRAFT MANUFACTURE

$$C_{a1M} = 10W_{a1}$$

$$H_{aL} = 6.05W_{a1}^{.825}$$

$$c_{a2} = \frac{15}{F/W_{a2}}$$

TERMINOLOGY

C_{a1M} = Total recurring materials cost, aircraft airframe ($thousands)

c_{a2} = Turbojet engine cost per pound of specific weight, 1960 dollars ($/pound)

$\frac{F}{W_{a2}}$ = Turbojet engine thrust to weight ratio

H_{aL} = Total recurring on/off site direct labor man-hours (thousands of man-hours)

W_{a1} = Aircraft airframe weight (thousands of pounds)

COMMENTS

The authors do not describe in any detail the quantitative basis of their relationships. It appears that most of the data was obtained from "AMPR/MMPR, Quarterly Tabulation - Basic Productivity and Utilization Data from Producers of Aircraft, Missiles and Major Supporting Subsystems."

Reference 73

AIRCRAFT PROCUREMENT COST

Airframe Labor and Overhead

$$\bar{C}_{a1L} = 45.2(W_{a1})^{0.88}(v_{amA})^{0.32}N_a^{-0.36}$$

$$10 \le N_a \le 1000$$

Airframe Materials

$$\bar{C}_{a1M} = 0.0093(W_{a1})(v_{amA})^{1.24}N_a^{-0.12}$$

$$10 \le N_a \le 1000$$

Engineering and Tooling

$$\bar{C}_{aET} = 1.21W_{a1}\left(\frac{220}{N_a} + 7.5N_a^{-0.15}\right)$$

$$10 \le N_a \le 1000$$

PROPULSION

Production Cost for Turbojet Engine Where Available at Production Price

$$\bar{C}_j = N_{a2}\left[0.135(-467 + .088F + 43.7\frac{F}{W'_{a2}} + 207M_m)\right]$$

Production Cost for Turboprop/Shaft Engine where Available at Production Price

$$\bar{C}_s = N_{a2}\left[.135(71.9 + .152HP - 21.0\frac{HP}{W''_{a2}})\right]$$

Reference 73 (Continued)

PROPULSION (Continued)

Production Cost of Turbojet Engine Where Development is Required

$$\bar{C}_j' = N_{a2} \left[\left(N_{a2}(1.33N_a) \right)^{-.22} \left(-467 + .088F + 43.7\frac{F}{W'_{a2}} + 207\ M_m \right) \right]$$

Production Cost of Turboprop/Shaft Engine Where Development is Required

$$\bar{C}_s' = N_{a2} \left[\left(N_{a2}(1.33N_a) \right)^{-.22} \left(71.9 + .152HP - 21.0\frac{HP}{W''_{a2}} \right) \right]$$

OTHER GFAE (ELECTRONICS)

Fighters: $\overline{GFAE} = -329 + 0.4v_{amA} + 17.3W_{a1}$

Bombers: $\overline{GFAE} = -1280 + 2.37v_{amA} + 11.8W_{a1}$

Transport or Tanker: $\overline{GFAE} = -3.76 - 1.05v_{amA} + 4.79W_{a1}$

Trainer: $\overline{GFAE} = -37.7 + .033v_{amA} + 15.2W_{a1}$

TERMINOLOGY

$\bar{C}_{a1L}$ = Cumulative average cost, aircraft airframe labor ($thousands)

$\bar{C}_{a1M}$ = Cumulative average aircraft airframe materials cost ($thousands)

$\bar{C}_{aET}$ = Airframe cumulative average engineering and tooling cost ($thousands)

Reference 73 (Continued)

TERMINOLOGY (Continued)

$\overline{C}_j$ = Cumulative average production cost where engine is available at production price, turbojet engine ($thousands)

$\overline{C}'_j$ = Cumulative average production cost where new engine is required, turbojet engine ($thousands)

$\overline{C}_s$ = Cumulative average production cost where engine is available at production price, turboprop/shaft engine ($thousands)

$\overline{C}'_s$ = Cumulative average production cost where new engine is required, turboprop/shaft engine ($thousands)

F = Thrust (thousands of lbs.)

$\overline{GFAE}$ = Cumulative average cost, other government furnished aircraft equipment ($thousands)

HP = Horsepower by military rating

M_m = Maximum Mach number

N_a = Number of aircraft

N_{a2} = Number of engines/aircraft

V_{amA} = Aircraft maximum speed at operational altitude (knots)

W_{a1} = Aircraft airframe weight (AMPR) (thousands of lbs.)

W'_{a2} = Aircraft turbojet engine weight, less afterburner (thousands of lbs.)

Reference 73 (Continued)

TERMINOLOGY (Continued)

W''_{a2} = Aircraft engine weight, less propeller (lbs.)

COMMENTS

This report contains a detailed treatment of the problem of estimating total aircraft procurement cost with a number of cost estimating relationships. Data are based on production experience with 24 airframes, 34 turbojet and turboprop/shaft engines, and 47 aircraft "other GFAE" (electronics). These relationships are presented in the form of cumulative average production costs at the 1000th unit. Various learning curves are given for extrapolation of the estimates to smaller or larger production numbers. Of the 8 aircraft sampled, from the regression data, for cost testing and evaluation, the average estimating errors ranged from 33% (- 2% to + 65%) at unit 100 to 12% at unit 1000. The aircraft sampled were:

B-47	F-104
B-52	F-105
F-100	C-133
F-101	KC-135

Use of the relationships to predict the costs of a few prototype aircraft for test is not recommended.

Reference 74

ACQUISITION COST OF ELECTRONIC DATA PROCESSING EQUIPMENT

Acquisition Cost of Core Storage

$$C_{e1} = 1734S_1^{.873}$$

Purchase Cost of Magnetic Tape Handling Unit

$$C_{e2} = 9664t_2^{.321}$$

Rental Cost of Magnetic Tape Handling Unit

$$C'_{e2} = 276t_2^{.252}$$

TERMINOLOGY

C_{e1} = Acquisition cost of computer core storage ($)

C_{e2} = Acquisition cost of magnetic tape handling unit ($)

C'_{e2} = Monthly rental cost of magnetic tape handling unit ($/month)

S_1 = Storage capacity of memory unit (binary digits/1,000)

t_2 = Transfer rate in characters per second divided by 1,000 for magnetic tape handling unit

Reference 74 (Continued)

COMMENTS

Core Storage Procurement

Acquisition cost was correlated with core storage capacity for 34 storage units produced by eight major manufacturers. The coefficient of correlation was found to be greater than 0.97. It appears that this single performance parameter is quite useful for estimating procurement costs of core storage without regard to access time.

Magnetic Tape Handling Unit Procurement

Acquisition cost and monthly rental cost were correlated with transfer rate for 22 tape handling units produced by nine major manufacturers. The coefficient of correlation was found to be greater than 0.87. It appears that this single performance parameter is quite useful for estimating procurement costs of these units.

<u>Reference 80</u> (RAND visit notes, not included in bibliography)

ENGINEERING COST THROUGH 100th AIRCRAFT AIRFRAME

$$C_{E100} = .41 W_{at}^{.89} M_{m}^{1.60} \gamma^{.54}$$

TERMINOLOGY

C_{E100} = Total engineering cost through the 100th aircraft airframe exclusive of tests, tooling fabrication ($thousands)

M_m = Maximum Mach number

W_{at} = Total empty weight of airframe (thousands of pounds)

γ = Technological difficulty factor

COMMENTS

This relationship was developed at RAND (but not documented) from cost data on the following programs:

F-84	F-100	F-106
F-84f	F-101	B-47
F-86a	F-102	B-52
F-86d	F-104	B-57
F-89	F-105	B-58

Technical difficulty ratings were obtained from three RAND personnel and summed for each aircraft on the basis of

1 = Minimum
2 = Small
3 = Medium
4 = Large

This model is still under development, and its evaluation is not complete. The data used is extensive, however.

Appendix 5

INSTRUCTIONS AND FORMATS FOR
PROPOSED SAMPLE COLLECTION OF
SERVICE COST DATA ON SELECTED WEAPON SYSTEMS

General Explanation and Instructions

The purpose of this request is to determine the availability of historical development cost and program information within the Military Departments. It is preliminary to the establishment within OSD of a development cost data bank which can be used on a DOD-wide basis as a reference for cost estimates on new developments.

Two kinds of information are requested:

- Specific development program characteristics, cost data and performance/design characteristics for three sample weapon systems from each Military Department;

- Information on the availability of cost information to varying degrees of depth on a larger number of weapon systems or major developments (approximately 20) within each Military Department. At this time the cost information itself is not being requested but merely the depth in which it is available.

The following points apply:

- Information submitted should be from Military Department records only. Special information should not be requested from contractors. Cost data not available within the Department should be omitted;

- In those cases (for information on performance/design characteristics) where information is already available within ODDR&E, it is so indicated on the forms. Please advise of any changes that should be made in this information.

- The development cost data bank is to be used ultimately as a cost reference and to establish cost correlations with performance/design and program characteristics in evaluating estimates of development cost for future weapon systems. Since some of the previous developments have been partially financed with non-development funds, and accounting categories have changed substantially in the past several years, it is essential that the cost information submitted reflect true development cost regardless of the source or type of funds. Therefore, include as development costs all costs that would today be funded by RDT&E appropriations. However, do not include costs for supporting technological developments which are not directly attributable to the specific weapon system in question.

- Formats for program and performance/design information are intended to be typical and may be varied where other information is more appropriate. The intent is to provide the information that is most pertinent for the particular system involved and will permit correlation with other similar systems. Note that different formats are provided for each broad category of weapon system (missiles, aircraft, and electronics).

DEFINITIONS OF TERMS RELATING TO PROGRAM CHARACTERISTICS

Terms used in Section 1 on the following pages are defined below. Numbers refer to paragraphs in which the terms appear.

1.1.4 Contracting Structure refers to the relationships between system and major subsystem contractors and the procuring service. For example, Air Force contracts to a single prime who does system engineering and integration but lets subcontracts for major subsystems.

1.1.5 Degree of Program Time Compression refers to the degree of shortening applied to total development/production cycle by concurrency and by expediting individual development activities through intensive effort.

1.1.6 Degree of Technological Advance required at Program go-ahead is a measure of the increment in technology spanned by the program over that existing at its start.

DEVELOPMENT PROGRAM, COST AND PERFORMANCE/ DESIGN CHARACTERISTICS SUMMARY

Program Title: ______________________ **Date:** __________

1. PROGRAM CHARACTERISTICS

1.1 System Program Characteristics

1.1.1 General Comments ______________________

1.1.2 Schedule Milestones[3] ______________________

Program Approval ______________________
First Contract Award ______________________
Deliver First Complete Test Article ______________
Completion of First System Test ______________
Deliver Last Test Article ______________
Completion of System Tests ______________

1.1.3 Type of Contract (e.g., CPFF, CPIF, FP, etc.) ______

1.1.4 Describe Contracting Structure for Total System and Major Subsystems[1] ______________________

1.1.5 Degree of Program Time Compression[2] ______________

1.1.6 Degree of Technological Advance Required at Program Go-Ahead[2] ______________________

1.1.7 Number of Complete System Test Articles Produced ______________________

---

1. Attach additional material where necessary.
2. Indicate minimum, small, medium or large.
3. Attach milestone charts if available.

1.1.8 Describe on a separate sheet Major Changes during the Program in:

Performance & Design Characteristics (incl. model variations)
Test Program (e.g., number, units, tests)
Schedule Milestones
Funding
Other

1.2 Major Subsystem Program Characteristics

1.2.1 Subsystem ______________________

1.2.2 General Comments[1] ______________________

1.2.3 Schedule Milestones[3] ______________________

Program Approval ______________________
First Contract Award ______________________
Begin Test on 1st Complete Subsystem ____________
Deliver 1st Subsystem for System Test ____________
Deliver 1st Production Subsystem ____________

1.2.4 Number of Subsystem Test Articles Produced (for other than system test)[4] ______________________

1.2.5 Extent of tests (e.g., for aircraft engines, number of test hours) ______________________

1.2.6 Degree of Technological Advance Required at Program Go-Ahead[2] ______________________

Important: Duplicate 1.2 above for each major subsystem

---

[1] Attach additional material where necessary

[2] Indicate minimum, small, medium, or large

[3] Attach milestone charts if available

[4] For example, number of solid rocket motors required for static tests through qualification

DEFINITIONS OF TERMS RELATING TO COST SUMMARY

Terms used in Section 2 on the following pages are defined below. Numbers refer to paragraphs in which the terms are used.

Item 2.1, Subsystem Design, Development and Test, is the sum of items 2.1.1, 2.1.2, 2.1.3, etc.

Item 2.1.1 Airframe (Subsystem Design, Development & Test), is the sum of 2.1.1.1, 2.1.1.2, 2.1.1.3, etc.

Item 2.1.1.1 Design, Engineering & Test, includes costs of all subsystem engineering activities and all in plant testing of prototype and full scale models.

Item 2.1.1.2 Hardware Fabrication, includes the fabrication or purchase of breadboard models, mockups, and special test articles and special tooling required primarily for development. Fabrication of subsystems for complete system tests is not to be included.

Item 2.1.1.3 Test Facilities, Equipment and Instrumentation, include the additional plant or plant modifications required for development of the subsystem, and instrumentation plus equipment required for conduct of the in plant development and test work.

Item 2.2 System Test, is the sum of the costs of items 2.2.1, 2.2.2, 2.2.3.

Item 2.2.1 Test Vehicle Fabrication Cost is the sum of fabrication costs of all complete vehicles for system test. Tooling costs to be included here should pertain only to fabrication and assembly of complete test articles and not subsystem development as earlier defined or tooling for production of operational vehicles. The number of vehicles included in RDT&E costs may require an attached explanation where the delineation is not clear. Include also the cost of spares for the system test program.

Explanations for Cost Formats (continued)

Item 2.2.2	Test Operations include all the costs associated with tests of the complete system. Include data reduction and analysis, maintenance and supply, fuels and propellants, etc., where applicable.
Item 2.2.3	Test Facilities, Equipment and Instrumentation, etc., are the sum of such cost items as launching equipment, blockhouses, vehicle assembly building, propellant and storage facilities, test site instrumentation, and other equipment (maintenance and otherwise) required for the test program.
Item 2.3	System Integration & Management should include the costs of those management and technical activities not associated with one particular subsystem or system test operations as defined above, i.e., systems engineering and integration program planning and management, service in-house systems design, etc.
Item 2.4	is the sum of costs of items 2.1, 2.2 and 2.3

ALTERNATE A: FOR AIRCRAFT SYSTEMS

2. **DEVELOPMENT COST SUMMARY**

2.1 Subsystem Design, Development & Test[1] ________

2.1.1 Airframe[1] ________

2.1.1.1 Design, Engineering & Test ________

2.1.1.2 Hardware Fabrication ________

2.1.1.3 Test facilities, Equipment & Instrumentation ________

2.1.2 Propulsion[1] ________

2.1.2.1 Design, Engineering and Test ________

2.1.2.2 Hardware Fabrication ________

2.1.2.3 Test Facilities, Equipment & Instrumentation ________

2.1.3 Electronics[1] ________

2.1.3.1 Design, Engineering and Test ________

2.1.3.2 Hardware Fabrication ________

2.1.3.3 Test Facilities, Equipment & Instrumentation ________

2.1.4 Ground Support Equipment[1] ________

2.1.5 Other[1] (identify) ________

---

1. Indicate on attached sheet the major components included in each subsystem.

2. **DEVELOPMENT COST SUMMARY** (Continued)

2.2 System Test ______

2.2.1 Test Vehicle Fabrication Cost ______

2.2.1.1 Number of Units ______

2.2.1.2 Average cost for each lot fabricated:
First lot ______
Second lot, etc. ______

2.2.2 Test Operations ______

2.2.3 Test Facilities, Equipment and Instrumentation, etc. ______

2.3 System Integration & Management ______

2.4 Total Development Cost ______

2.5 Total Development Costs & Engineering Man-Hours by FY for System and Major Subsystem[2]:

	Total Development Costs ($)	Eng. Man-Hours[3]
1st FY		
2nd FY		
3rd FY		
4th FY		
5th FY		
6th FY		
7th FY		

Average Cost per Engineering Man-Hour (including burden)

1st FY ______________ Last FY ______________

2.6 Sources for above data:

[2] Attach additional tables for major subsystems

[3] Furnish by quarter where available

ALTERNATE B: FOR MISSILE SYSTEMS

2. DEVELOPMENT COST SUMMARY

2.1 Subsystem Design, Development & Test[1] ______

2.1.1 Airframe, 1st Stage[1] ______

2.1.1.1 Design, Engineering & Test ______

2.1.1.2 Hardware Fabrication ______

2.1.1.3 Test facilities, equipment and instrumentation ______

2.1.2 Airframe, 2nd Stage[1] ______

2.1.2.1 Design, Engineering & Test ______

2.1.2.2 Hardware Fabrication ______

2.1.2.3 Test facilities, equipment and instrumentation ______

2.1.3 Airframe, 3rd Stage[1] ______

2.1.3.1 Design, Engineering & Test ______

2.1.3.2 Hardware Fabrication ______

2.1.3.3 Test facilities, equipment and instrumentation ______

2.1.4 Propulsion, 1st Stage[1] ______

2.1.4.1 Design, Engineering & Test ______

2.1.4.2 Hardware Fabrication ______

2.1.4.3 Test facilities, equipment and instrumentation ______

2.1.5 Propulsion, 2nd Stage[1] ______

2.1.5.1 Design, Engineering & Test ______

2.1.5.2 Hardware Fabrication ______

2.1.5.3 Test facilities, equipment and instrumentation ______

---

[1] Indicate on attached sheet the major components included in each subsystem

ALTERNATE B: FOR MISSILE SYSTEMS (Continued)

2.1.6 Propulsion, 3rd Stage[1] ______

2.1.6.1 Design, Engineering & Test ______

2.1.6.2 Hardware Fabrication ______

2.1.6.3 Test facilities, equipment and instrumentation ______

2.1.7 Guidance & Control[1] ______

2.1.7.1 Design, Engineering & Test ______

2.1.7.2 Hardware Fabrication ______

2.1.7.3 Test facilities, equipment and instrumentation ______

2.1.8 Warhead or Re-entry Vehicle[1] ______

2.1.9 Ground Support Equipment[1] ______

2.1.10 Other (identify) ______

2.2 System Test ______

2.2.1 Test Vehicle Fabrication Cost ______

2.2.1.1 Number of Units ______

2.2.1.2 Average cost for each lot fabricated:
First lot ______
Second lot, etc. ______

2.2.2 Test Operations ______

2.2.3 Test facilities, equipment and instrumentation ______

2.3 System Integration & Management

2.4 Total Development Cost

ALTERNATE B: FOR MISSILE SYSTEMS (Continued)

2.5 Total Development Cost & Engineering Man-Hours by FY for System and Major Subsystem[2]:

	Total Development Cost ($)	Engineering Man-Hours[3]
1st FY		
2nd FY		
3rd FY		
4th FY		
5th FY		
6th FY		
7th FY		

Average cost per Engineering Man-Hour (including burden)

1st FY ________________ Last FY ________________

2.6 Sources for above data:

[2] Attach additional tables for major subsystems

[3] Furnish by quarter where available

ALTERNATE C: FOR ELECTRONIC SYSTEMS

2. DEVELOPMENT COST SUMMARY

2.1 Subsystem Design, Development & Test[1] ______

2.1.1 Data Acquisition/Surveillance[1] ______

2.1.1.1 Design, Engineering & Test ______

2.1.1.2 Hardware Fabrication ______

2.1.1.3 Test Facilities, equipment and instrumentation ______

2.1.2 Data Processing[1] ______

2.1.2.1 Design, Engineering & Test ______

2.1.2.2 Hardware Fabrication ______

2.1.2.3 Test Facilities, equipment and instrumentation ______

2.1.3 Communications[1] ______

2.1.3.1 Design, Engineering & Test ______

2.1.3.2 Hardware Fabrication ______

2.1.3.3 Test Facilities, equipment and instrumentation ______

2.1.4 Presentation/Display[1] ______

2.1.4.1 Design, Engineering & Test ______

2.1.4.2 Hardware Fabrication ______

2.1.4.3 Test Facilities, equipment and instrumentation ______

2.1.5 Other[1] (identify) ______

2.2 System Test ______

2.2.1 System Fabrication ______

2.2.1.1 Number of Units ______

2.2.1.2 Average cost for each lot fabricated:
First lot ______
Second lot, etc. ______

[1] Identify number and type of major equipment items in each subsystem on attached sheet

2.2.2 Test Operations ______

2.2.3 Test Facilities, equipment and instrumentation ______

2.3 System Design Integration & Management ______

2.4 Total Development Cost ______

2.5 Total Development Costs & Engineering Man-Hours by FY for System and major Subsystems[2]:

	Total Development Costs ($)	Engineering Man-Hours[3]
1st FY		
2nd FY		
3rd FY		
4th FY		
5th FY		
6th FY		
7th FY		

Average cost per engineering man-hour (including burden)

1st FY ____________________ Last FY __________________

2.6 Sources for above data: ______

[2] Attach additional tables for major subsystems

[3] Furnish by quarter where available

Alternate A: Typical for Aircraft Systems 1/

3. PERFORMANCE AND DESIGN CHARACTERISTICS

3.1 Over-all System:

3.1.1 Missions (list and define each major mission separately, if possible in order of importance, such as low level ground support, high altitude intercept of mach 2 bombers, etc.)

3.1.2 Basic mission radius ______________________

3.1.3 Take-off and landing distance (for basic mission) ____________

3.1.4 Maximum speed ___________ 1.5 Cruising speed ____________

3.1.6 Weights:

Basic mission take-off ________ Payload ____________
Landing ____________________ Fuel ____________

3.1.7 Maintenance man-hours/flight hour ____________________

3.1.8 Mission reliability (basic mission) ____________________

3.1.9 Bombing accuracy ____________________________

3.1.10 TAR 2/ ________________________________

3.2 Subsystems:

3.2.1 Airframe:

3.2.1.1 Airframe weight ________________________

3.2.1.2 Material and type of construction ______________

3.2.1.3 TAR 2/ ____________________________

3.2.1.4 Configuration (fixed wing, swept wing, variable sweep, etc.) ____________________

3.2.1.5 Catapult and arresting operations ______________

3.2.1.6 Number in crew ________________________

1/ Those performance and design characteristics should be included which are most pertinent to the kind of system for which data is being supplied. The format is not rigid and may be varied to fit the system provided that characteristics are supplied both for the over-all system and the major subsystems.

2/ Technological advance required: indicate "minimum", "small", "medium" or "large".

3.2.1.7 Dual control ______________________

3.2.1.8 STOL/VTOL ______________________

3.2.1.9 Major Development Problems ______________________

3.2.2 <u>Propulsion</u>:

3.2.2.1 Number of engines and type: ______________________

3.2.2.2 Thrust rating per engine ______________________

3.2.2.3 Weight per engine ______________________

3.2.2.4 Specific fuel consumption ______________________

3.2.2.5 Thrust augmentation ______________________

3.2.2.6 TAR 2/ ______________________

3.2.2.7 Major Development Problems ______________________

3.2.3 <u>Avionics Subsystems</u>:

3.2.3.1 Fire Control 1/ consisting of ______________________
____
____
____

3.2.3.1.1 Weight ____________ Volume ______________________

3.2.3.1.2 Reliability ______________________

3.2.3.1.3 Accuracy ______________________

3.2.3.1.4 Kind of construction (microelectronics, solid state elements on printed circuit cards, etc.) ______________________

3.2.3.1.5 TAR 2/ ______________________

1/ Those performance and design characteristics should be included which are most pertinent to the kind of system for which data is being supplied. The format is not rigid and may be varied to fit the system provided that characteristics are supplied both for the over-all system and the major subsystems.

2/ Technological advance required: indicate "minimum", "small", "medium" or "large".

3.2.3.1.6 Major Development Problems ______________

3.2.3.2 Communications 1/ consisting of ______________
____
____
____
____

3.2.3.2.2 etc. Similar to 3.2.3.1.2 etc.

3.2.3.3 Navigation (similar to 3.2.3.1)

3.2.3.4 ECM (similar to 3.2.3.1)

3.2.3.5 Automatic Flight Control (similar to 3.2.3.1)

Continue for other subsystems as appropriate such as:
Environmental control subsystem
Secondary power
Ground support equipment
Trainers

1/ Those performance and design characteristics should be included which are most pertinent to the kind of system for which data is being supplied. The format is not rigid and may be varied to fit the system provided that characteristics are supplied both for the over-all system and the major subsystems.

ALTERNATE B: TYPICAL FOR BALLISTIC MISSILES [1]

3. PERFORMANCE & DESIGN CHARACTERISTICS

3.1 Overall System:

3.1.1 General Mission ______________________________

____

3.1.2 Range ______________ 3.1.3 Payload Weight ______________

3.1.4 Reliability Specifications ______________________________

____

3.1.5 No. of Stages ______________ 3.1.6 Length & Diameter ______________

3.1.7 Launch Weight ______________ 3.1.8 Tot.Propellant Wgt. ______________

3.1.9 Reaction Time ______________ 3.1.10 Time to Target ______________

3.1.11 Hardness ______________

3.1.12 TAR[2] ______________

3.2 Subsystem:

	First Stage	Second Stage	Third Stage
3.2.1 Airframe:			
3.2.1.1 Dry Weight	______	______	______
3.2.1.2 Length & Diam.	______	______	______
3.2.1.3 Material	______	______	______
3.2.1.4 TAR[2]	______	______	______
3.2.1.5 Major Develop. Problems	______	______	______
3.2.2 Propulsion:			
3.2.2.1 Type Propellant	______	______	______
3.2.2.2 Propellant Wgt.	______	______	______
3.2.2.3 Engine Weight	______	______	______
3.2.2.4 No. Nozzles	______	______	______
3.2.2.5 No. Pumps	______	______	______

[1] Those performance and design characteristics should be included which are most pertinent to the kind of system for which data is being supplied. The format is not rigid and may be varied to fit the system provided that characteristics are supplied both for the over-all system and the major subsystem.

[2] Technological advance required; indicate "Minimum", "Small", "Medium" or "Large".

3.2.2.6 Rated Thrust ________ ________ ________

3.2.2.7 Burning Time ________ ________ ________

3.2.2.8 TAR [1] ________ ________ ________

3.2.2.9 Major Develop. Problems ________ ________ ________

3.2.3 Guidance & Control:

3.2.3.1 Guidance Type ________________

3.2.3.2 Circular Error Probability (or equivalent) ________

3.2.3.3 Weight ________________

3.2.3.4 Key Dimensions ________________

3.2.3.5 Type of Flight Control ________________

3.2.3.6 TAR[1] Minimum ____ Small ____ Medium ____ Large ____

3.2.3.7 Major Develop. Problems ________________

3.2.3.8 Other ________________

3.2.4 Ground Support Equipment and Facilities:

3.2.4.1 General Description ________________

3.2.4.2 No. Blockhouses/Comples ________________

3.2.4.3 No. Consoles/Blockhouse ________________

3.2.4.4 No. of Major Equipment Items ________________

3.2.4.5 TAR[1] Minimum ____ Small ____ Medium ____ Large ____

3.2.4.6 Major Develop. Problems ________________

3.2.4.7 Other ________________

3.2.5 Payload:

3.2.5.1 General Description ________________

3.2.5.2 Weight ________ 3.2.5.3 Key Dimensions ________

3.2.5.4 TAR[1] Minimum ____ Small ____ Medium ____ Large ____

3.2.5.5 Major Develop. Problems ________________

3.2.5.6 Other ________________

[1] Technological advance required; indicate "Minimum", "Small", "Medium" or "Large".

Alternate C: Typical for Electronic Systems

3. PERFORMANCE AND DESIGN CHARACTERISTICS

There are such large variations in composition of electronic systems that we have not outlined a typical system. In this section, those performance and design characteristics should be included which are most pertinent. Characteristics should be included for the over-all system and major subsystems and the major equipment items for major subsystems should be indicated. Reliability and Technical Advance Required should be included in the characteristics for the system and subsystems. See Alternates A and B for aircraft and missile systems as a guide.

DEFINITION OF TERMS

Terms used on the following pages are defined below.
Numbers refer to column numbers.

DETAIL LEVEL OF DEVELOPMENT COSTS	DESCRIPTION
1. TOTAL SYSTEM	
1a. TOTAL	The sum of costs (actual ≠ estimated to complete) incurred under those RDT&E contracts applying to the system specified. Contributing R&D from other programs and contracts is not to be included. Service in-house development costs should be included if significant and if directly applied to this program.
1b. Design and Development	A breakdown of total system cost into a. Sum of design engineering, hardware fabrication, in plant testing of all subsystems, systems engineering/integration, and program management, and
System Fabrication and Test	b. TOTAL COST OF FABRICATING complete system test articles (w/spares) and their subsequent test operations. Included are specialized tooling costs, test facilities and instrumentation, fuels, data reduction and analysis, etc.
2. MAJOR SUBSYSTEMS	
2a. Total each Subsystem	The total development costs for each specific subsystem such as airframe, propulsion, guidance, ground support facilities, etc. Costs attributable jointly to several subsystems or only to the system as a whole are not included here.
2b. Design and Development; Hardware Fabrication; and Facilities for each subsystem	A breakdown of each subsystem development cost into a. design engineering and in plant test operations; b. fabrication of prototype subsystems for in plant tests, including specialized tooling; and c. industrial facilities and test instrumentation required during subsystem development and test.

Explanation of Terms (Continued)

DETAIL LEVEL OF DEVELOPMENT COSTS		DESCRIPTION
3. ACCOUNTING CATEGORIES		
3a	By system	A total program cost breakdown into such accounting categories as engineering labor, production labor, materials, G&D, etc. or categories similar to these.
3b	By Subsystem	Same as above but individually for major subsystems.

LEVEL OF DETAIL TO WHICH HISTORICAL DEVELOPMENT COSTS CAN BE DEFINED

ARMY	TOTAL SYSTEM DEVELOPMENT COST (1)		MAJOR SUBSYSTEM DEVELOPMENT COST (2)		DEVELOPMENT COST BY ACCOUNTING CATEGORIES i.e., LABOR, MATERIALS, G&A, etc. (3)	
WEAPON SYSTEM	TOTAL (1a)	Des. & Dev. vs. Sys. Fab. & Test (1b)	TOTAL Each SUBSYSTEM (2a)	Des. & Dev., Hdwr. Fab., & Facil. for Ea. Subsystem (2b)	BY SYSTEM (3a)	BY SUBSYSTEM (3b)
PERSHING						
NIKE-AJAX						
NIKE-HERCULES						
SERGEANT						
LACROSSE						
HAWK						
CORPORAL						
HONEST JOHN						
REDEYE						
MAULER						
LITTLE JOHN						
MOHAWK						
CHINOOK						
JUPITER						
MISSILE MASTER						
REDSTONE						
AN/USD-2						
NIKE-ZEUS						

NOTES: a. In each column above, indicate "T" where only a total $ figure is available and "FY" if available by fiscal year.

b. Explanations of terms are on attached page.

LEVEL OF DETAIL TO WHICH HISTORICAL DEVELOPMENT COSTS CAN BE DEFINED

NAVY	TOTAL SYSTEM DEVELOPMENT COST (1)		MAJOR SUBSYSTEM DEVELOPMENT COST (2)		DEVELOPMENT COST ACCOUNTING CATEGORIES i.e., LABOR, MATERIALS, G&A, etc. (3)	
WEAPON SYSTEM	TOTAL (1a)	Des. & Dev. vs. Sus. Fab. & Test (1b)	TOTAL Each SUBSYSTEM (2a)	Des. & Dev., Hdwr. Fab. & Facil. for Ea. Subsystem (2b)	BY SYSTEM (3a)	BY SUBSYSTEM (3b)
POLARIS						
BULLPUP						
TERRIER						
TARTAR						
TALOS						
SIDEWINDER						
SPARROW III						
SUBROC						
REGULUS						
ASROC						
A4D						
A3J						
A2F						
F4H						
NTDS						
CAESAR						
AN/SPS-48						

NOTES: a. In each column above, indicate "T" where only a total $ figure is available and "FY" if available by fiscal year.

b. Explanations of terms are on attached page.

LEVEL OF DETAIL TO WHICH HISTORICAL DEVELOPMENT COSTS CAN BE DEFINED

AIR FORCE	TOTAL SYSTEM DEVELOPMENT COST (1)		MAJOR SUBSYSTEM DEVELOPMENT COST (2)		DEVELOPMENT COST ACCOUNTING CATEGORIES i.e., LABOR, MATERIALS, G&A, etc. (3)	
WEAPON SYSTEM	TOTAL (1a)	Des. & Dev. vs. Sys. Fab. & Test (1b)	TOTAL Each SUBSYSTEM(2a)	Des. & Dev., Hdwr. Fab., & Facil. for Ea. Subsystem (2b)	BY SYSTEM (3a)	BY SUBSYSTEM (3b)
ATLAS						
TITAN I						
TITAN II						
MINUTEMAN						
BOMARC						
BULLPUP						
FALCON						
HOUND DOG						
QUAIL						
THOR						
C-141						
B-47						
B-52						
B-58						
RS-70						
F-101						
F-102						
F-104						
F-105						
F-106						

(cont'd)

LEVEL OF DETAIL TO WHICH HISTORICAL DEVELOPMENT COSTS CAN BE DEFINED

Air Force (cont'd)

C-135						
465-L						
412-L						
416-L						
466-L						
433-L						

NOTES: 1. In each column above, indicate "T" where only a total $ figure is available and "FY" if available by fiscal year.

2. Explanations of terms are on attached page.

Appendix 6

TASK STATEMENT

OSD/ODDR&E CONTRACT NO. SD-142

Task #3, Development Cost Estimating

This task is directed primarily toward providing data and techniques which will permit ODDR&E, using the type and degree of information which is normally available to it, to check the validity of development cost estimates. A later, supplementary task might consist of the development and reporting of improved techniques for estimating development costs using information of the sort available to Service project offices or, additionally, of the sort available to contractors.

Part One is a survey and evaluation of:

a. Cost estimating techniques (with emphasis on parametric cost estimating) already developed or being developed within the Department of Defense and its contractor organizations.

b. Correlations between cost and cost sensitive parameters.

c. Types and sources of pertinent historical data (i.e., cost, design/performance and program characteristics) for selected weapon systems, subsystems and major components.

This survey will result in the following, which will be included in a report:

1. An identification of the more significant estimating techniques and cost correlations in use or under development.

2. An identification of the significant sources of data and the usefulness of the data.

3. A recommendation of the specific historical data on selected weapon systems, subsystems and major components which should be gathered from its present points of storage for use in later phases of this task.

4. Recommended use of the data to be collected, including any statistical analyses and tests to be performed by MSC.

<u>Additional Parts</u>

"This work statement is incomplete. Additional work will be agreed to by the contractor and ODDR&E following completion of Part One. The following is tentative and for planning purposes only:

<u>Part Two</u> will consist of the actual gathering of existing historical data by DOD and its tabulation and analysis by MSC. Any additional parametric techniques which this analysis indicates to be useful for ODDR&E evaluations will be recommended.

<u>Part Three</u> will contain a procedural plan for enhancing future ODDR&E capability in parametric estimates of R&D costs through the collection and storage of data and periodic review of parametric functions.