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COST ANALYSIS FOR AIRCRAFT SYSTEM TEST AND EVALUATION: EMPIRICAL SURVEY DATA STRUCTURING AND PARAMETRIC MODELING, VOLUME I

by

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Cost Analysis for Aircraft System Test and Evaluation: Empirical Survey, Data Structuring and Parametric Modeling
Volume I

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ABSTRACT

There is an increasing requirement from high levels within the Government that the Navy's aircraft cost estimators and analysts provide explicit estimates for the sub-elements of Aircraft System Test and Evaluation (AST&E) efforts. The data required to produce more accurate and detailed estimates represent lower levels in the Aircraft Work Breakdown Structure (WBS) than previously available. This is a two volume thesis. Volume I examines the WBS and Contractor Cost Data Reporting (CCDR) system with a description of current reporting practices and implementation shortcomings. Recommended courses of action to improve reporting requirements and thereby improve data quality and cost estimates are proposed. Major cost drivers for AST&E, from both the perspective of Defense Contractors and Military Flight Test Centers, are discussed. Beginning in Volume II, a relational data base system is introduced to more easily evaluate AST&E cost elements and physical/performance characteristics. A Contractor Flight Test cost estimating relationship (CER) is developed through step-wise multiple regression analysis of data gathered from Defense Contractors and Naval Air Systems Command (NAVAIR).

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I. INTRODUCTION

A. PURPOSE OF PROJECT

There is an increasing requirement from high levels within the Government that the Navy's aircraft cost estimators and analysts provide explicit estimates for the sub-elements of aircraft system test and evaluation efforts. These requests ask for additional data, which represent lower levels in the Aircraft Work Breakdown Structure (WBS) than previously required, and the methods necessary to produce them are needed in order to estimate Aircraft System Test and Evaluation costs in greater detail and with better accuracy than is currently feasible.

The ultimate objective of the Naval Air Systems Command (NAVAIR) is to develop cost estimating relationships for all of the following System Test and Evaluation elements:

1. Wind Tunnel Article and Test
2. Static Article and Test
3. Fatigue Article and Test
4. Drop Article and Test
5. Contractor Flight Tests
6. Flight Test Instrumentation
7. Miscellaneous Ground Tests
8. Support of Contractor Flight Tests

9. **Navy Technical Evaluation**

10. **Operational Evaluation**

11. **Contractor Support of Navy Test.**

The necessary tasks to attain this objective are to:

1. Identify physical, performance, and programmatic parameters which are the primary drivers of each of the major functional cost categories (engineering labor, manufacturing labor, quality control labor, and tooling labor) for each of the major elements of Aircraft System Test and Evaluation

2. Develop parametric cost estimation relationships for each of the above System Test and Evaluation elements and each appropriate functional cost category by:

   a. Defining a sample of pertinent aircraft programs

   b. Formulating a work breakdown structure/ functional cost element matrix

   c. Acquiring historical cost data

   d. Organizing the data for analysis

   e. Employing statistical methods to develop cost estimation relationships, and

   f. Documenting data, sources, rationale, and methodology.

Given the time constraints, attempting to concentrate on all eleven elements simultaneously would prove to be both unmanageable and inefficient. Therefore, the project sponsor has directed that the initial research focus on the area of Contractor Test Flights. If conditions permit, Wind Tunnel Tests, Static Tests, and Fatigue Tests, could be included.

B. IMPORTANCE OF THIS STUDY

The importance of this study is justified by the following reasons. First, due to the rapidly increasing cost of new aircraft systems in a budgetarily constrained environment, the accuracy of cost analysis performed by NAVAIR becomes imperative. Second, an integral study of the cost problem would provide more insight to NAVAIR to answer the ever increasing informational needs that originate as high as Congressional Budget Committees and Executive Branch Agencies. More important, it is crucial for cost analysts to take into consideration new cost drivers, particularly in the area of avionics. Also, it is felt that better coordination with contractors via an improved implementation of the Contractor Cost Data Reporting (CCDR) system, WBS format, and cost estimation model will result in the standardization of reporting procedures across the industry and will increase the likelihood of contractor delivery of guaranteed performances for allocated funds.

C. ORGANIZATION OF THIS STUDY

This is a two volume research study. Volume I is organized as follows: Chapter II provides an overview of the Contractor Cost Data Reporting (CCDR) system and the Military Standard Work Breakdown Structure (WBS). A critical analysis of the current cost estimation system and its shortcomings is the focus of Chapter III. It proposes a set of feasible courses of action that could be implemented to improve the present system. Chapter IV outlines the various steps taken to accomplish the proposed research. Specifically, a three-step approach is undertaken: exploration, analysis, and refinement. Such a study helps identify research processes and keys upon which this study should concentrate. These issues are analyzed in detail in Chapter V. Results obtained from an extensive survey of experts in the contractors' System Test and Evaluation field are reported. In particular, major cost drivers that are frequently identified include aircraft weight, speed, avionics, software, and management practices and policies.

Volume II focuses on the analysis of data discussed in Volume I. Chapter I describes the available current data and its structure. Current parametric techniques are surveyed in Chapter II. A requirements analysis, design, and development of a data base management system called TIGER is performed in Chapter III. The purpose of the data base is threefold. First, it provides immediate and precise answers to ad hoc queries that cost analysts could pose. Second, it outlines a well-structured basis for standardizing the accounting process handled by various contractors. Third, it can be used to assist statistical analysis for cost estimation. The data collected is analyzed, discussed and cost driver models are developed and presented in Chapter IV. Finally, conclusions derived as a result of this study are discussed in Chapter V.

II. DEPARTMENT OF DEFENSE REQUIREMENTS FOR CONTRACTOR COST DATA REPORTING

A. THE CONTRACTOR COST DATA REPORTING (CCDR) SYSTEM

1. Introduction to CCDR

During the decision process on any major defense acquisition, the primary focus is on the development and attainment of performance objectives. An accurate acquisition cost estimate is an equally significant program parameter that must be considered in detail during this decision process. Standardized, accurate and detailed cost data are indispensible to analysts required to develop reliable cost estimates.

In July 1970, the Defense Blue Ribbon Panel Report stated, "the extent of availability of such (cost) data in usable form is a limiting factor on the potential accuracy of cost predictions." (NAVMAT P-5241, 1973, p. i) The Contractor Cost Data Reporting (CCDR) system was established by the Office of the Secretary of Defense in 1973 to provide for "continual improvement in the ability of the Department of Defense (DOD) to develop and use valid cost estimates". (NAVMAT P-5241, 1973, p. i) This system is intended to provide decision makers with a means by which contract costs and other related data can be collected to aid in acquisition management. The reporting requirements are designed to collect data on defense weapon systems utilizing standard data definitions and reporting structures which facilitate integration with other defense management systems. To provide a common ground from which to view this research, the following excerpts from the Contractor Cost Data Reporting (CCDR) System (NAVMAT P-5241), and the Military Standard Work Breakdown Structures for Defense Materiel Items (MIL-STD-881A) are included in this study.

2. Purposes of the CCDR System

The data collected from the Defense Contractors is intended to be used by DOD components in establishing cost estimating, programming, budgeting and procurement responsibilities. This data collection effort is to provide a common data base and assist the Department of Defense in the following areas:

a. Preparing estimates in support of the Five Year Defense Program

b. Developing independent government cost estimates in support of cost and price analyses and contract negotiations

c. Evaluating contractors' proposals

d. Responding to requirements for summary information to the Secretary of Defense concerning selected acquisitions to reflect a comparison of current estimates, original plans, and current approved program costs and

e. Preparing cost estimates for major system review by the Defense Systems Acquisition Review Council (DSARC) at each program decision milestone. (NAVMAT p-5241, 1973, p.3-1)

3. Reporting Structure

Reporting requirements are differentiated in accordance with the following contract categories:

a. Category I--Major contracts for Prototypes in Advanced Development, Full Scale Development, and Production, within programs which are estimated in the Five Year Defense Program to require a cumlative financing for Research, Development, Test and Evaluation in excess of $200 million or a total procurement investment in excess of $1 billion

b. Category II--Contracts for defense materiel items not satisfying the Category I criteria but selected by the DOD component for cost data reporting because of complexity, criticality, future procurement plans and contract value. (NAVMAT P-5241, 1973, p. 1-2)

The data elements which produce the common data base are generated by four reports:

1.	Cost Data Summary Report	DD Form 1921
2.	Functional Cost-Hour Report	DD Form 1921-1
3.	Progress Curve Report	DD Form 1921-2
4.	Plant-Wide Data Report	DD Form 1921-3

These standardized reports are designed to satisfy a wide range of weapon system acquisitions. The following excerpts from NAVMAT P-5241 provide a basic description of these four CCDR system reports which are submitted at varying frequencies as negotiated in the contract:

a. DD Form 1921--Cost Data Summary Report (Figure 2-1)

Primarily designed for Category I contracts, the Cost Data Summary Report summarizes all activities included in the contract and aggregates cost against the reporting elements selected from the work breakdown structures defined in MIL-STD-881 and specified in the contract. WBS elements below Level 3 of MIL-STD-881 may be designated for CCDR but should be limited to those for which cost data can be realistically utilized. The Cost Data Summary Report is also used to present the contractor's program estimate for RFP's, program reviews, or special studies in accordance with the fiscal years and quantities specified by the DOD component for the total program. (NAVMAT P-5241, 1973, p. 3-3)

b. DD Form 1921-1--Functional Cost-Hour Report (Figure 2-2)

The Functional Cost-Hour Report is the means of identifying and collecting comparable functional costs, e.g., engieering, tooling, manufacturing, for (1) specific contracts and (2) estimates for the fiscal years and quantities specified by the DOD component for the total program. Reports may be required for recurring, non-recurring, and total costs, as determined and specified by the DOD contracting component. (NAVMAT P-5241, 1973, p. 3-9)

c. DD Form 1921-2--Progress Curve Report (Figure 2-3)

The Progress Curve Report provides a unit or an average unit cost of the unit or lot accepted during the report period. All costs reported on this form are recurring. (NAVMAT P-5241, 1973, p. 3-17)

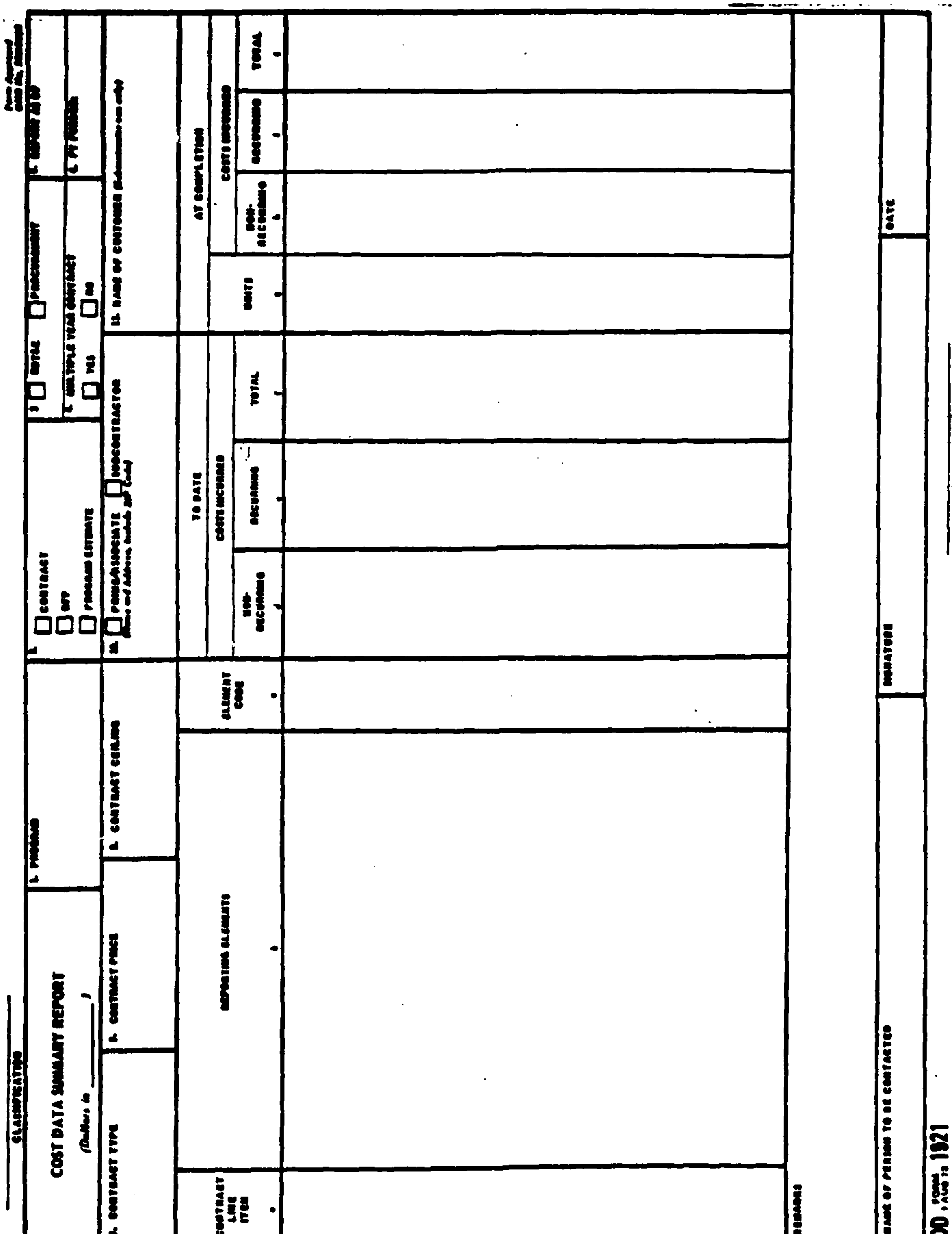


Figure 2-1. DD Form 1921--Cost Data Summary Report

SECURITY CLASSIFICATION

OMB No. 22R0033

FUNCTIONAL COST - HOUR REPORT

1. PROGRAM	2. REPORT AS OF
3. DOLLARS IN	4. HOURS IN
5. ☐ CONTRACT ☐ RFP ☐ PROGRAM ESTIMATE	
6. ☐ NON-RECURRING ☐ RECURRING ☐ TOTAL	7. ☐ RDT&E ☐ PROCUREMENT ☐ OTHER
8. MULTIPLE YEAR CONTRACT ☐ YES ☐ NO	10. ☐ PRIME/ASSOCIATE ☐ SUBCONTRACTOR (Name and address Include ZIP Code)
9. FY FUNDED	11. NAME OF CUSTOMER (Subcontractor use only)
12. REPORTING ELEMENT(S)	

SECTION A

FUNCTIONAL CATEGORIES	ADJUSTMENTS TO PREVIOUS REPORTS a	CONTRACTOR TO DATE b	CONTRACTOR AT COMPL. c	SUBCONTRACT OR OUTSIDE PROD. & SERV. TO DATE d	SUBCONTRACT OR OUTSIDE PROD. & SERV. AT COMPL. e	TOTAL TO DATE f	TOTAL AT COMPL. g
ENGINEERING							
1. DIRECT LABOR HOURS							
2. DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
3. OVERHEAD	$	$	$	$	$	$	$
4. MATERIAL	$	$	$	$	$	$	$
5. OTHER DIRECT CHARGES (Specify)	$	$	$	$	$	$	$
6. TOTAL ENGINEERING DOLLARS	$	$	$	$	$	$	$
TOOLING							
7. DIRECT LABOR HOURS							
8. DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
9. OVERHEAD	$	$	$	$	$	$	$
10. MATERIALS AND PURCHASED TOOLS	$	$	$	$	$	$	$
11. OTHER DIRECT CHARGES (Specify)	$	$	$	$	$	$	$
12. TOTAL TOOLING DOLLARS	$	$	$	$	$	$	$
QUALITY CONTROL							
13. DIRECT LABOR HOURS							
14. DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
15. OVERHEAD	$	$	$	$	$	$	$
16. OTHER DIRECT CHARGES (Specify)	$	$	$	$	$	$	$
17. TOTAL QUALITY CONTROL DOLLARS	$	$	$	$	$	$	$
MANUFACTURING							
18. DIRECT LABOR HOURS							
19. DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
20. OVERHEAD	$	$	$	$	$	$	$
21. MATERIALS AND PURCHASED PARTS	$	$	$	$	$	$	$
22. OTHER DIRECT CHARGES (Specify)	$	$	$	$	$	$	$
23. TOTAL MANUFACTURING DOLLARS	$	$	$	$	$	$	$
24. PURCHASED EQUIPMENT	$	$	$	$	$	$	$
25. MATERIAL OVERHEAD	$	$	$	$	$	$	$
26. OTHER COSTS NOT SHOWN ELSEWHERE (Specify)	$	$	$	$	$	$	$
27. TOTAL COST LESS G&A	$	$	$	$	$	$	$
28. G&A	$			$	$	$	$
29. TOTAL COST PLUS G&A	$			$	$	$	$
30. FEE OR PROFIT	$			$	$	$	$
31. TOTAL OF LINES 29 & 30	$			$	$	$	$

SECTION B

DIRECT LABOR MAN-HOURS INCURRED THIS REPORT PERIOD

	ENGINEERING a	TOOLING b	QUALITY CONTROL c	MANUFACTURING d
1. TOTAL BEGINNING OF REPORT PERIOD				
2.				
3.				
4.				
5.				
6. TOTAL END OF REPORT PERIOD				

SECTION C (CAT II ONLY)

FORM CONTINUED ON REVERSE

DD FORM 1 AUG 73 1921-1

Figure 2-2a. DD Form 1921-1--Functional Cost-Hour Report

PLANT-WIDE LABOR AND OVERHEAD INFORMATION															
	1. DIRECT LABOR			2. PLTWIDE OH		1. DIRECT LABOR			2. PLTWIDE OH		1. DIRECT LABOR			2. PLTWIDE OH	
	WORK a	BASIC RATE b	EFF RATE c	IND WORK d	RATE e	WORK f	BASIC RATE g	EFF RATE h	IND WORK i	RATE j	WORK k	BASIC RATE l	EFF RATE m	IND WORK n	RATE o
1. ENGINEERING															
2. TOOLING															
a. DESIGN															
b. FABRICATION															
3. QUALITY CONTROL															
4. MANUFACTURING															
5. MATERIAL															
6. G & A															
	1. DIRECT LABOR			2. PLTWIDE OH		1. DIRECT LABOR			2. PLTWIDE OH		1. DIRECT LABOR			2. PLTWIDE OH	
	WORK a	BASIC RATE b	EFF RATE c	IND WORK d	RATE e	WORK f	BASIC RATE g	EFF RATE h	IND WORK i	RATE j	WORK k	BASIC RATE l	EFF RATE m	IND WORK n	RATE o
1. ENGINEERING															
2. TOOLING															
a. DESIGN															
b. FABRICATION															
3. QUALITY CONTROL															
4. MANUFACTURING															
5. MATERIAL															
6. G & A															

SECTION II (CAT III ONLY)

REMARKS

NAME OF PERSON TO BE CONTACTED	SIGNATURE	DATE

Figure 2-2b. DD Form 1921-1--Functional Cost-Hour Report, Page 2

PROGRESS CURVE REPORT
(Recurring Cost Only)

1. PROGRAM

Form Approved
OMB No. [illegible]

SECTION A

2. DOLLARS IN
3. HOURS IN
4. TOTAL UNITS ACCEPTED PRIOR TO THIS REPORT
5. CONTRACT
6. REPORT FOR ____ MONTHS

ENDING: ____________

7. MULTIPLE YEAR CONTRACT ☐ YES ☐ NO
8. FY FUNDED:
9. ☐ PRIME/ASSOCIATE ☐ SUBCONTRACTOR *(Name and address include ZIP Code)*
10. NAME OF CUSTOMER *(Subcontractor use only)*
11. REPORTING ELEMENTS

SECTION B

ITEM	UNITS/LOTS ACCEPTED					ESTIMATE OF NEXT UNIT/LOT TO BE ACCEPTED	TO COMPLETE CONTRACT
	a	b	c	d	e	f	g
1. MODEL AND SERIES							
2. FIRST UNIT OF LOT							
3. LAST UNIT OF LOT							
4. CONCURRENT UNITS							
CHARACTERISTICS 5.							
6.							
7.							
CONTRACTOR DATA (PER UNIT/LOT)							
8. DIRECT QUALITY CONTROL MAN-HOURS							
9. DIRECT MANUFACTURING MAN-HOURS							
10. QUALITY CONTROL DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
11. MANUFACTURING DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
12. RAW MATERIAL & PURCHASED PARTS DOLLARS	$	$	$	$	$	$	$
13. PURCHASED EQUIPMENT DOLLARS	$	$	$	$	$	$	$
14. TOTAL DOLLARS	$	$	$	$	$	$	$
SUBCONTRACT/OUTSIDE PROD. & SERV.							
15. DIRECT QUALITY CONTROL MAN-HOURS							
16. DIRECT MANUFACTURING MAN-HOURS							
17. TOTAL MAN-HOURS							
18. QUALITY CONTROL DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
19. MANUFACTURING DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
20. RAW MATERIAL & PURCHASED PARTS DOLLARS	$	$	$	$	$	$	$
21. PURCHASED EQUIPMENT DOLLARS	$	$	$	$	$	$	$
22. TOTAL DOLLARS	$	$	$	$	$	$	$
UNIT TOTAL ☐ AVERAGE ☐							
23. DIRECT QUALITY CONTROL MAN-HOURS							
24. DIRECT MANUFACTURING MAN-HOURS							
25. TOTAL MAN-HOURS							
26. QUALITY CONTROL DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
27. MANUFACTURING DIRECT LABOR DOLLARS	$	$	$	$	$	$	$
28. RAW MATERIAL & PURCHASED PARTS DOLLARS	$	$	$	$	$	$	$
29. PURCHASED EQUIPMENT DOLLARS	$	$	$	$	$	$	$
30. TOTAL DOLLARS	$	$	$	$	$	$	$
31. % SUBCONTRACT OR OUTSIDE PROD. & SERV.							
MFG FLOW TIME							
MOS OR QTRS 32. START							
33. FINISH							
34.							
35.							
36.							
37.							
38.							
39							

DD FORM 1 AUG 73 1921-2

Figure 2-3a. DD Form 1921-2--Progress Curve Report

ITEM	UNITS/LOTS ACCEPTED					ESTIMATE OF NEXT UNIT/LOT TO BE ACCEPTED	TO COMPLETE CONTRACT
	a	b	c	d	e	f	g
PERFORMANCE DATA (PER UNIT/LOT)							
40. STANDARD HOURS							
41. VARIANCE							

SCHEDULE OF RELEASE DATES	ENGINEERING a	MATERIAL b	TOOLING c	MANUFACTURING d
1. PLANNED				
2. ACTUAL				

SECTION C (CAT II ONLY)

REMARKS

NAME OF PERSON TO BE CONTACTED	SIGNATURE	DATE

SECURITY CLASSIFICATION

Figure 2-3b. DD Form 1921-2--Progress Curve Report, Page 2

d. **DD Form 1921-3--Plant Wide Data Report (Figure 2-4)**

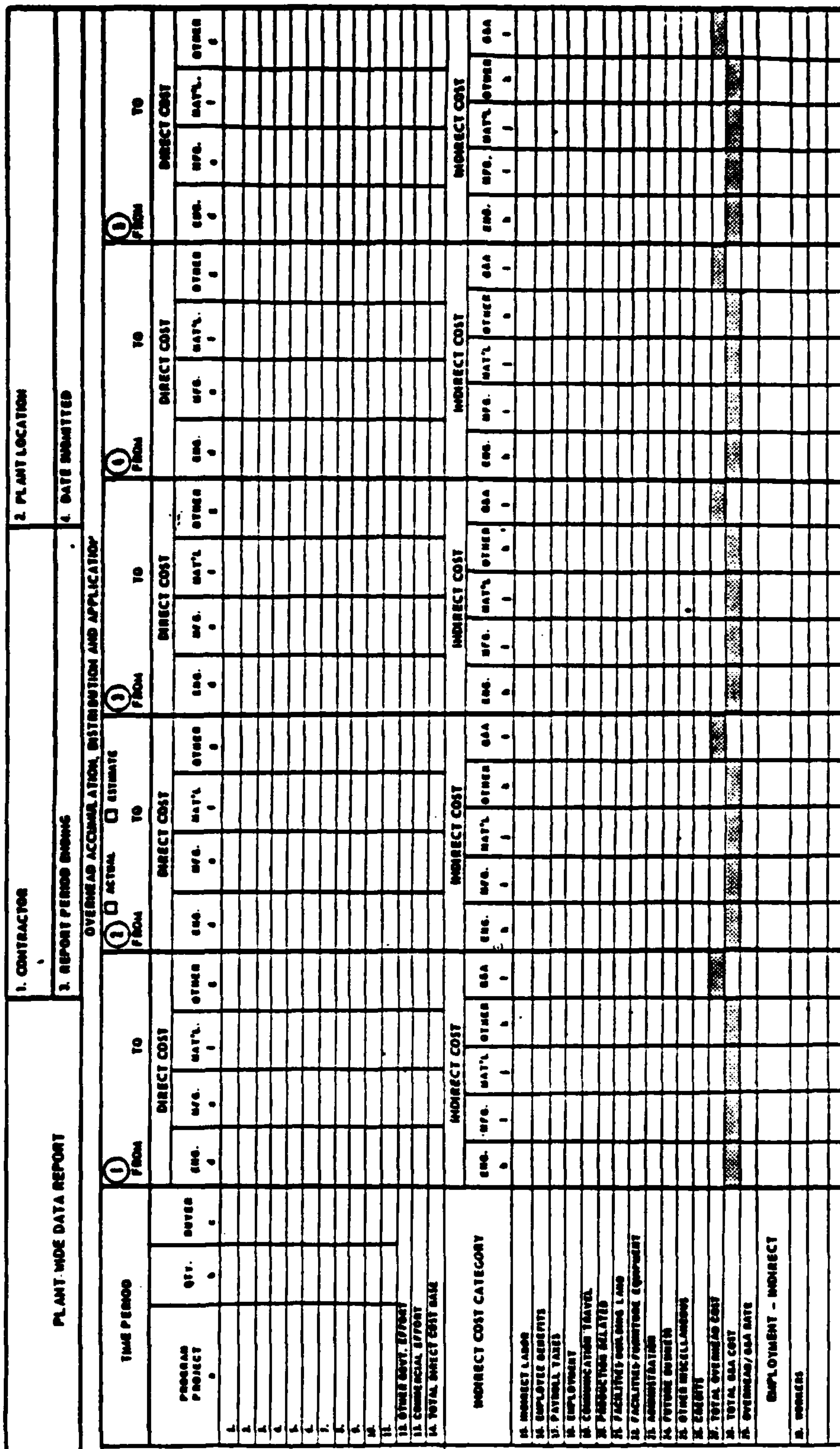
The report shall be prepared based on the contractor's accounting system and the estimating procedure. The reporting dates should be established to coincide with the contractor's fiscal year. It will be submitted for Category I contracts only. This report is a standardized plant-wide overhead report which replaces the various types of overhead analyses now provided to Administrative Contracting Officers (ACOs) for major acquisition. (NAVMAT P-5241, 1973, p. 3-24)

The Contractor Cost Data Reporting system pamphlet, NAVMAT P-5241, explains how to complete these forms and lists definitions of cost data elements to include engineering, tooling, quality control and manufacturing.

4. Reporting Elements

The reporting elements required for data collection are included in the Request for Proposal and/or the initial contract. The level of detail to be included in the contractor cost reports will be limited to that which can be realistically generated by the contractor and utilized by the appropriate DOD contracting component.

Reporting elements for Category I contracts are selected from the Work Breakdown Structure (WBS) as defined in Military Standard--Work Breakdown Structures for Defense Materiel Items (MIL-STD 881). Reporting elements for Category II contracts are to utilize the WBS elements


PLANT-WIDE DATA REPORT
1. CONTRACTOR
2. PLANT LOCATION
3. REPORT PERIOD ENDING
4. DATE SUBMITTED
OVERHEAD ACCUMULATION, DISTRIBUTION AND APPLICATION
☐ ACTUAL ☐ ESTIMATE

TIME PERIOD			(1) FROM TO				(2) FROM TO				(3) FROM TO				(4) FROM TO				(5) FROM TO			
			DIRECT COST				DIRECT COST				DIRECT COST				DIRECT COST				DIRECT COST			
PROGRAM PROJECT a	QTY. b	BUYER c	ENG. d	MFG. e	MAT'L. f	OTHER g	ENG. d	MFG. e	MAT'L. f	OTHER g	ENG. d	MFG. e	MAT'L. f	OTHER g	ENG. d	MFG. e	MAT'L. f	OTHER g	ENG. d	MFG. e	MAT'L. f	OTHER g
1.																						
2.																						
3.																						
4.																						
5.																						
6.																						
7.																						
8.																						
9.																						
10.																						
11.																						
12. OTHER GOVT. EFFORT																						
13. COMMERCIAL EFFORT																						
14. TOTAL DIRECT COST BASE																						

INDIRECT COST CATEGORY	(1) INDIRECT COST					(2) INDIRECT COST					(3) INDIRECT COST					(4) INDIRECT COST					(5) INDIRECT COST				
	ENG. h	MFG. i	MAT'L j	OTHER k	G&A l	ENG. h	MFG. i	MAT'L j	OTHER k	G&A l	ENG. h	MFG. i	MAT'L j	OTHER k	G&A l	ENG. h	MFG. i	MAT'L j	OTHER k	G&A l	ENG. h	MFG. i	MAT'L j	OTHER k	G&A l
15. INDIRECT LABOR																									
16. EMPLOYEE BENEFITS																									
17. PAYROLL TAXES																									
18. EMPLOYMENT																									
19. COMMUNICATION TRAVEL																									
20. PRODUCTION RELATED																									
21. FACILITIES-BUILDING LAND																									
22. FACILITIES-FURNITURE EQUIPMENT																									
23. ADMINISTRATION																									
24. FUTURE BUSINESS																									
25. OTHER MISCELLANEOUS																									
26. CREDITS																									
27. TOTAL OVERHEAD COST																									
28. TOTAL G&A COST																									
29. OVERHEAD/G&A RATE																									
EMPLOYMENT - INDIRECT																									
30. WORKERS																									

SECTION A
SECTION B
DD FORM AUG 73 1921-3
SECURITY CLASSIFICATION

Figure 2-4a. DD Form 1921-3--Plant-Wide Data Report

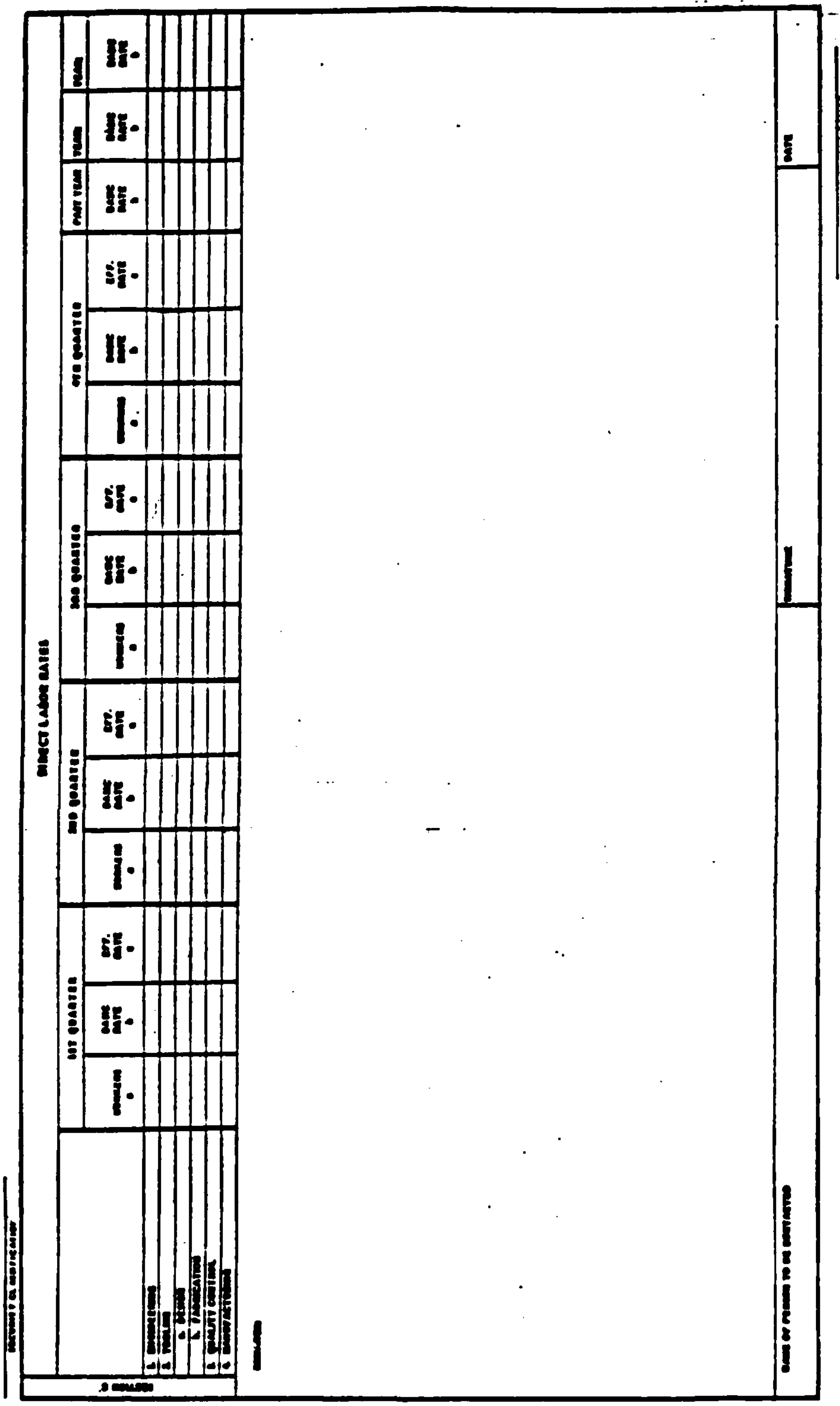


Figure 2-4b. DD Form 1921-3--Plant-Wide Data Report, Page 2

whenever possible or other criteria most readily reported by the contractor using their existing management and accounting systems.

5. <u>Direct Labor Hour Definitions</u>

a. Engineering Direct Labor Hours

The hours expended in the study, analysis, design, development, evaluation, and redesign of the specified reporting element. Includes the preparation of specifications, drawings, parts lists, wiring diagrams, technical coordination between engineering and manufacturing, vendor coordination, test planning and scheduling, analysis of test results, data reduction, and report preparation. This also includes the determination and specification of requirements for reliability, maintainability and quality control. (NAVMAT P-5241, 1973, p. 4-1)

b. Tooling Direct Labor Hours

The hours expended in the planning, design, fabrication, assembly, installation, modification, maintenance and rework of all tools, including assembly tools, dies, jigs, fixtures, master forms, gauges, handling equipment, load bars, work platforms (including installation of utilities thereon), and test equipment (such as checkers and analyzers in support of manufacturing the specified reporting element). This entry includes hours expended in the determination of tool requirements, planning of fabrication and assembly operations, maintaining tool records, establishing make-or-buy plans and manufacturing plans on components and equipment, scheduling and controlling all tool orders, and programming and preparation of templates and patterns, and form block manufacture. (NAVMAT P-5241, 1973, p. 4-2)

c. Quality Control Direct Labor Hours

The hours expended in the design and implementation of the necessary controls to ensure that a manufacturing process produces an item or product meeting prescribed standards. Includes such tasks as receiving inspection, in-process and final inspection of tools, parts, subassemblies and complete assemblies, and reliability testing and failure report reviewing; also included are such tasks as the establishment of acceptable quality level (AQL) and statistical methods for determining performance of manufacturing processes. The preparation of reports relating to these tasks are to be considered quality control effort. (NAVMAT P-5241, 1973, p. 4-2)

d. Manufacturing Direct Labor Hours

The hours expended on or chargeable to such operations as production scheduling and expediting, fabrication, processing, subassembly, final assembly, reworking, modification, experimental production, and installation of parts and equipment, power plants, boosters, electronic equipment, explosives, and other ordnance items (including government furnished equipment) and the proving of such equipment, instruments, etc., for the specified reporting element. This includes the construction of detail parts from raw materials. It includes hours expended in the cutting, forming, stretching and blanking operations performed on material of any kind (metal, wood, plastic, glass, cloth, tubing, etc.) to make individual parts. It includes bench assemblies of all detail parts, all minor and major assemblies, mating or jointing of primary sections, installation of special and general equipment, instruments and accessories performed after the mating and all other preparation and/or processing including all flashing operations, annealing, heat treating, baking, refrigeration, anodizing plating, painting and dope operations and preflight and production service operations, etc. (NAVMAT P-5241, 1973, p. 4-3)

6. Dollar Values

The CCDR system provides for the reporting of various categories of contractor costs, e.g., Direct Labor Dollars, Overhead, Material, and Other Direct Charges. However, because of the fact that all of the data for this research would be historical, coupled with the lack of constant dollar data due to inflation, it would be statistically more significant to use Direct Labor Hours as the only cost data element in this project.

B. WORK BREAKDOWN STRUCTURE

1. Definition

A Work Breakdown Structure (WBS) is a product-oriented family tree composed of hardware, services, and data which result from project engineering efforts during the development and production of a defense materiel item and which completely defines the project/program. A WBS displays and defines the product(s) to be developed or produced and relates the elements to work to be accomplished to each other and to the end product. (MIL-STD-881A, 1975, p. 2)

When a weapons system is viewed as a whole, the importance of standardized reporting elements is reduced. The Level 1 total system hours/cost will remain the same regardless of what specific indentured sub-element they are reported against. However, as individual reporting elements are examined at each level of the Work Breakdown Structure the need for these standardized definitions is imperative. A lack of standardization will result in inconsistent data, and in turn, unreliable cost estimates.

2. Purposes of the Work Breakdown Structure MIL-STD 881A

As stated in the MIL-STD-881A, the purpose of the WBS is to establish criteria governing the preparation and employment of work breakdown structures for use during the acquisition of designated defense materiel items. These work breakdown structures would provide a consistent and visible framework that facilitates:

a. A more effective management and technical base for planning and assigning management and technical responsibilities by operations within the government offices responsible for the acquisition of defense materiel items and those contractors furnishing the items

b. More consistent control over and reporting of the progress and status of engineering and other contractor efforts, resource allocations, cost estimates, expenditures, and procurement actions throughout the acquisition of defense materiel items

c. Consideration of total life cycle effects, including development, production, activation, operational use, and phase-out, when making system development and acquisition decisions.

The uniformity in definition and approach for developing the upper three levels of the WBS established by this standard is expected to assure compatibility of multiple-data requirements. The benefits expected from increased uniformity in the generation of work breakdown structures and their application to management practices will be realized by the improved interpretation and reconciliation of all reports prepared to this uniform framework throughout acquisition of a defense materiel item. (MIL-STD-881A, 1975, p. ii)

3. Additional Work Breakdown Structure Definitions

a. Summary Work Breakdown Structure (Summary WBS)

A Summary Work Breakdown Structure consists of the upper three levels of a WBS prescribed by the standard and having uniform element terminology, definition, and placement in the family-tree structure. The upper three levels of a summary WBS have been organized within the following categories of defense materiel items:

1. Aircraft Systems
2. Electronics Systems
3. Missile Systems
4. Ordnance Systems
5. Ship Systems
6. Space Systems
7. Surface Vehicle Systems. (MIL-STD-881A, 1975, p. 2)

The three levels specified are defined as follows:

1. Level 1 is the entire defense materiel item; for example, the Minuteman ICBM System, the LHA Ship System, or the M 109A1 Self-Propelled Howitzer System. Usually, Level 1 is directly identified in the DOD programming/budget system either as an integral program element or as a project within an aggregated program element

2. Level 2 elements are major elements of the defense materiel item; for example, a ship, an air vehicle, a tracked vehicle, or aggregations of services, (e.g., systems test and evaluation); and data

3. Level 3 elements are those subordinate to Level 2; for example, an electric plant, an airframe, the power package/drive train, or type of service, (e.g.,

development test and evaluation); or item of data (e.g., technical publications).

b. Project Summary Work Breakdown Structure (Project Summary WBS)

Project Summary WBS is a Summary WBS tailored to a specific defense materiel item.

c. Contract Work Breakdown Structure (Contract WBS)

A Contract WBS is defined as the complete WBS for a contract, developed and used by a contractor in accordance with this standard and the contract work statement.

d. Project Work Breakdown Structure (Project WBS)

A Project WBS is defined as the complete WBS for the project, containing all WBS elements, related to the developments and/or production of the defense materiel item.

e. Work Breakdown Structure Element

A work breakdown structure element is a discrete portion of a work breakdown structure. A WBS element may be either an identifiable item of hardware, set of data, or a service. (MIL-STD-881A, 1975, p. 3)

C. SUMMARY WORK BREAKDOWN STRUCTURE AND DEFINITIONS OF AIRCRAFT SYSTEMS

1. Project Scope

As previously discussed, MIL-STD-881A provides seven Summary WBS's for use by all contractors and DOD components in the development of work breakdown structures for the acquisition of defense materiel systems. Since this study addresses only aircraft systems, the WBS in Appendix A of MIL-STD-881A will be the only structure presented and discussed.

2. Summary Work Breakdown Structure

The following is a Summary Work Breakdown Structure for an aircraft system (MIL-STD-881A, 1975, p. 19) with the elements of System Test and Evaluation in bold type:

Level 1	Level 2	Level 3
Aircraft system		
	Air vehicle	
		Airframe
		Propulsion unit
		Other propulsion
		Communications
		Navigation/guidance
		Fire control
		Penetration aids
		Reconnaissance equipment
		Automatic flight control
		Central integrated checkout
		Antisubmarine warfare
		Auxiliary electronics equipment
		Armament
		Weapons delivery equipment
		Auxiliary armament/weapons delivery equipment
	Training	
		Equipment
		Services
		Facilities
	Peculiar support equipment	
		Organizational/intermediate (Including equipment common to depot)
		Depot (Only)

Level 1	Level 2	Level 3
	System test and evaluation	
		Development test and evaluation
		Operational test and evaluation
		Mockups
		Test and evaluation support
		Test facilities
	System/project management	
		System engineering
		Project management
	Data	
		Technical publications
		Engineering data
		Management data
		Support data
		Data depository
	Operational/site activation	
		Contractor technical support
		Site construction
		Site/ship/vehicle conversion
	Common support equipment	
		Organizational/intermediate (Including equipment common to depot)
		Depot (Only)
	Industrial facilities	
		Construction/conversion/ expansion
		Equipment acquisition or modernization
		Maintenance
	Initial spares and initial repair parts	
		(Specify by allowance list, grouping or hardware element)

3. System Test and Evaluation Definitions

a. System Test and Evaluation

The System Test and Evaluation element refers to the use of prototype, production, or specially fabricated hardware to obtain or validate engineering data on the performance of the aircraft system. This element includes the detailed planning, conduct, support, data reduction and reports from such testing, and all hardware items which are consumed or planned to be consumed in the conduct of such testing. It also includes all effort associated with the design and production of models, specimens, fixtures, and instrumentation in support of the test program. Test articles which are complete units (i.e., functionally configured as required by the aircraft equipment) are excluded. Development component acceptance, etc., testing which can be specifically associated with the hardware element, unless these tests are of special contractual or engineering significance (e.g., associate contractor), are also excluded. (MIL-STD-881A, 1975, p. 24)

b. Development Test and Evaluation

The Development Test and Evaluation (DT&E) element refers to that test and evaluation conducted to:

1. Demonstrate that the engineering design and development process is complete
2. Demonstrate that the design risks have been minimized
3. Demonstrate that the system will meet specifications

4. **Estimate the system's military utility when introduced**

5. **Determine whether the engineering design is supportable (practical, maintainable, safe, etc.), for operational use**

6. **Provide test data with which to examine and evaluate tradeoffs against specification requirements, life cycle cost, and schedule.**

DT&E is planned, conducted, and monitored by the developing agency of the DOD component. It includes, for example, such models and tests as wind tunnel, static, drop, and fatigue; integration ground tests, engine military qualification tests (MQT), preliminary flight rating tests (PFRT), test bed aircraft and associated support; development flight test, test instrumentation, test equipment (including its support equipment), chase aircraft and support thereto, etc. (MIL-STD-881A, 1975, p. 24)

c. Operational Test and Evaluation

The Operational Test and Evaluation element refers to that test and evaluation conducted by agencies other than the developing command to assess the prospective systems' military utility, operational effectiveness, operational suitability, logistics supportability (including compatibility, interoperability, reliability, maintainability, logistic requirements, etc.), cost of ownership, and need for any modifications. Initial Operational Test and Evaluation (IOT&E) conducted during the development of a weapon system will be included in this element. This element encompasses such tests as flight tests, sea trials, etc., and support thereto, required to prove the operational capability of the deliverable system. It also includes contractor support (e.g., technical assistance, maintenance, labor, material, etc.) consumed during this phase of testing. (MIL-STD-881A, 1975, p. 24)

d. Mockups

The Mockups element refers to the design engineering and production of system or subsystem mockups which have special contractual or engineering significance, or which are not required solely for the conduct of one of the above elements of testing. (MIL-STD-881A, 1975, p. 24)

e. Test and Evaluation Support

The Test and Evaluation Support element refers to all support elements necessary to operate and maintain systems and subsystems during flight test and evaluation which are not consumed during the flight-testing phase and other support requirements that are not allocable to a specific phase of testing. This element includes, for example, repairable spares, repair of repairables, repair parts, contractor technical support, etc., not allocable to preceding test and evaluation elements. Operational and maintenance personnel, consumables, special fixtures, special instrumentation, etc., which are utilized and/ or consumed in a single element of testing and which should, therefore, be included under that element of testing are excluded. (MIL-STD-881A, 1975, p. 25)

f. Test Facilities

The Test Facilities element refers to those special test facilities required for performance of the various developmental tests necessary to prove the design and reliability of the system or subsystem. This element includes for example, engine test fixtures, white rooms, test chambers, etc. The brick-and-mortar-type facilities allocable to industrial facilities are excluded. (MIL-STD-881A, 1975, p. 25)

III. COST ANALYSIS PROBLEMS IN TEST AND EVALUATION OF AIRCRAFT

A. INTRODUCTION

The Cost Analysis Division of the Naval Air Systems Command (NAVAIR) in the early stage of concept formulation initiates action to estimate costs and programmatics. These concepts begin prior to the issuance of the initial request for proposals when there is a perceived need for a new aircraft system to the end of the demonstration/validation phase of the aircraft system development life cycle.

The current practices in data collection and standardization have been primarily designed for cost analysis and estimation. There are several reasons for this lack of analytical capability. First, definitions of costs elements are sometimes ambiguous. Too frequently, there is a lack of mutual effort to eliminate this ambiguity, which often leads to a lack of standardization within contractors' reports required by the Department of Defense (DOD). In addition to their ambiguity, MIL-STD-881A definitions apply only to Levels 1, 2, and 3 of the Work Breakdown Structure (WBS). Below Level 3, definitions are generally tailored to the specific contract. This lack of specificity, for whatever reason, makes it difficult to normalize data submitted under different contracts, which results in the inability to effectively support trade-off analysis in the cost estimating process. NAVAIR established a CCDR Committee to enforce compliance and provide oversight to ensure consistency across programs, where appropriate. Figure 3.1 reproduces the current draft generic structure of the WBS used by NAVAIR when establishing the Project Summary WBS for use in estimating/negotiating individual aircraft programs. The final decision as to whether or not this WBS is used in the negotiation of a program rests with the Program Manager.

B. THE COST ANALYSIS PROCESS

1. Description of Current Practices

a. Development of the Project Work Breakdown Structure

The cost analysis process is triggered at the beginning of the conceptual phase of the Defense Material Acquisition process. A Project Summary Work Breakdown structure is developed by the DOD component utilizing the category summaries in the appendices of MIL-STD-881A. This Project Summary WBS will be identified to the concerned contractors during RFP or solicitation. This proposed structure will be negotiated with the contractors, who may recommend changes to the proposed Contractor WBS that they believe would improve its effectiveness in achieving the goals of the system acquisition. The negotiated Contract WBS will then be extended as far below Level 3 as required

	Level					
WBS #	1	2	3	4	5	6
2000		Systems Test & Evaluation (ST&E)				
2100			Development Test & Evaluation			
2110				Contractor Flight Tests		
2111					Instrumentation	
2112					Functional Ground Checkout	
2113					Flight Test & Demonstration	
2114					Flight Test Support	
2114.1					Flight Test Spares & Repair Parts	
2114.2					Support Equipment	
2114.3					Contractor Technical/ Maintenance Services	
2120				Wind Tunnel Article & Test		
2121					Wind Tunnel Article	
2122					Wind Tunnel Test	
2130				Static Article & Test		
2131					Static Article	
2132					Static Test	
2140				Fatigue Article & Test		
2141					Fatigue Article	
2142					Fatigue Test	

Figure 3-1A. AIR-524 Standard Aircraft CCDR Work Breakdown Structure Format

WBS #	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
2150				Drop Article & Test		
2151					Drop Article	
2152					Drop Test	
2160				Simulation Testing		
2170				Avionics Integration Testing		
2171					Test Bench/Laboratory	
2172					Flying Test Bed	
2173					Air Vehicle Equipment	
2174					Avionics Test Program	
2175					Software	
2180				Navy Flight Test Prelim DT II		
2190				Navy Flight Test Final DT II		
21AO				Navy Flight Test DT III		
21_0				Other DT&E (Specify at Level 4)		
2200				Operational Test & Evaluation		
2210				Preliminary OT II		
2220				Final OT II		
2230				OT III & IV		
2300			Mockups			
2400			Test & Evaluation Support			
2410				Test & Evaluation Spares & Repair Parts		
2420				Test & Evaluation Support Equipment		
2430				Test & Evaluation Technical/ Maintenance Services		
2500			Test Facilities			
2510				Avionics Integration Facility		
25_0				Other (Specify at Level 4)		
2600			Other ST&E (Specify)			

Figure 3-1B. AIR-524 Standard Aircraft CCDR Work Breakdown Structure Format to clearly define the extent of the contract. The Contract WBS is combined with the Project Summary WBS to form the Project WBS.

b. Purpose of the Project Work Breakdown Structure

The Project Summary WBS, and its derivatives, are established early in the acquisition process to provide a managerial and technical framework for all activities throughout the acquisition life cycle. DOD Project Managers are directed to utilize these work breakdown structures, "as a coordinating medium in planning for further systems engineering, resource allocation, cost estimates, contract actions, and work execution. The reporting of progress, performance, and engineering evaluations, as well as financial data, shall be based on the Project WBS". (MIL-STD-881A, 1975, p. 5)

c. Initial Cost Estimates

An initial part of the acquisition process involves the Cost Analysis Division of NAVAIR. This division is responsible for providing an initial rough order of magnitude cost estimation of the proposed system, which will be continually refined toward absolute accuracy throughout the program life cycle. Once a program is initiated, the Cost Analysis Division, based on system type and acquisition phase, assigns analysts to perform more detailed cost estimating and establish the initial cost reporting requirements. "During preparation of the Request for Proposals (RFP) or solicitation, the procuring activity, should determine the CCDR requirements. This involves assessment of cost estimating needs and the contents of the data elements which can be generated with the four reporting forms". (NAVMAT P-5241, 1973, p. 2-1) The initial task reports are further refined by a selected CCDR steering committee composed of cost experts. The Program Analysis Evaluation (PAE) section of the Office of the Secretary of Defense (OSD) reviews, directs modifications if necessary, and approves the CCDR.

d. Reporting Requirements

With some exceptions, the data from contractors, normally down to Level 3, are submitted to the NAVAIR Cost Division every six months for dissemination and validation for internal use. NAVAIR then systematically distributes all the CCDR reports to pertinent parties within DOD (e.g., OSD, ASN, PAE). This procedure has been continuously used since 1966 and there is no indication that this routine will be altered in the foreseeable future due to two main reasons. First, the current historical data base is seldom implemented below Level 3 of the WBS, OSD probably feels the need to maintain the integrity of this data base. Second, the Office of Management and Budget (OMB) has established guidelines requiring OSD to minimize the reporting requirements placed on the contractors by the CCDR system. This seems to concur with the administration policy to reduce the volume of bureaucratic paperwork.

2. Implementation Shortcomings of the Present System: A Cost Analysis Perspective

The current system requires contractors to report at varied WBS levels, however, from a cost estimating perspective reporting requirements continue to inappropriately fluctuate from one contract to another. Regardless of the depth required in the WBS, contractors claim (despite the fact that the CIR/CCDR system reporting requirements have been known since the mid 60's) that it is too difficult to convert their accounting systems to accommodate the definitions given by the CCDR system; an argument with which NAVAIR strongly disagrees. To further complicate the problem, dual source and sub-contracts are often granted. Due to their competitiveness, contractors often cannot, or even do not want to cooperate with other contractors.

For a long time, by analyzing all of the elements of the work breakdown structure, discrete answers were generated to reply to trade-off questions coming from high-level authorities (e.g., ASN, SYSCOM). However, the required data are often not available. When they are available, their quality is questionable, making it difficult to provide reliable estimates for lower level WBS elements. Usually, answers to questions require data below Level 3 of the WBS.

It is difficult to obtain periodic (six-month period) reporting costs below Level 3 of the WBS without encountering resistance from OSD and contractors. The latter often claim that it would cost too much to maintain such a data base. This argument may be true for some contractors, but it is not true industry-wide. Interviews performed for this study have indicated that most contractors have for a long time maintained data bases with monthly data for internal use that potentially contain information for detailed and frequent estimation needs. Most of the contractors interviewed maintain data at least one level below that required by the Project WBS. In fact, some of these data bases reflect elements down to Levels 8 and 9. It would probably be neither as expensive nor as time-consuming, as contractors claim, to provide periodic cost reports below Level 3, especially considering the fact that CIR/CCDR requirements have existed since 1967, and the capabilities of modern day computers to reformat/reaggregate contractor's cost accounts into CCDR format.

C. RECOMMENDED COURSE OF ACTION

1. Necessity to Break the WBS to Lower Level

Regardless of fiscal, political and technical considerations, it is critical for the cost analyst to have access to accurate data below Level 3 of the WBS for meaningful data analysis. In Level 2, System Test and

Evaluation WBS and distribution of Direct Contract Labor Hours of a typical military fixed-wing aircraft. Of the four Level 3 sub-elements, Development Test and Evaluation accounts for 93.6% of the contract total System Test and Evaluation labor hours.

The Level 3 element Development Test and Evaluation (WBS # 2100) had to be broken down to its Level 4 sub-elements to capture its major cost WBS elements. By referring to WBS # 2119, it can be found that Contractor Flight Tests account for 43.3% of Level 3 Development Test and Evaluation, which corresponds to 40.6% of Level 2 System Test and Evaluation. The three remaining Level 3 sub-elements account for only 6.4% of the total contract labor hours. In particular, TECHEVAL costs which are on Level 3 (WBS # 2200) were minimal, amounting to 0.4% of Level 2 System Test and Evaluation.

In the long run, it would be advisable to restructure the WBS system by revising the hierarchy of the WBS elements. One recommendation for revision would be to remove Development Test and Evaluation (WBS # 2100) from Level 3 and replace it with selected major WBS elements currently located on Level 4. In addition to the obvious choice of selecting the Contractor Flight Test element to be moved to Level 3, other Level 4 sub-elements contain

TABLE 3-1. SYSTEM TEST AND EVALUATION DIRECT CONTRACT LABOR HOUR DISTRIBUTION

WBS #	---Level--- 2	3	4	Percentage of Total Contract Labor Hours		
2000	SYSTEM T&E			100		
2100		DEV TEST			93.6	
2110			SYSTEM REQ			9.4
2111			WIND TUNNEL			4.3
2112			STATIC T&A			5.8
2113			FATIGUE T&A			6.0
2114			A/V SUB TEST			8.6
2116			AVNX INT TEST			6.6
2117			ARM/WPN INT			0.7
2118			FLT SIM PROG			1.5
2119			CTR FLT TEST			40.6
2190			MISC			6.6
2191			DROP & ACL LOADS			3.5
2200		TECHEVAL			0.4	
2220			FLT TEST PRO SPT			0.4
2400		MOCKUPS			4.5	
2500		T&E SUPPORT			1.5	

significant percentages of the total System Test and Evaluation efforts and should also be considered for a move to Level 3 of the WBS.

The prospective of implementing a revised version of the WBS system depends much on the personalities of the constituencies involved in the process, and the organizations created around programs. System Commands should ensure that CCDR oversight committees are formed to review current procedures, and enforce proper implementation. The cooperation of contractors, as well as DOD components, will be a vital part of this effort, which will involve optimizing and sharing by all concerned.

2. <u>Necessity to Provide Time-Phased Data Reporting</u>

Data should be reported in more depth, systematically, and in a time-phased fashion. Time is a big cost driver in some elements. For example, Contractor Test Flight costs seem to relate to the length of the test periods. A side benefit of this would be that cost estimators would have an improved historical base for profiling cost estimates into annual budget increments to predict Research and Development costs for each year. While it is difficult to derive an optimal frequency of time series data reporting, it would make sense to argue that yearly reports are minimally adequate. Monthly data would be preferable since they would capture the detailed trend of labor hours incurred throughout the system development life-cycle, but might not be cost effective. It is a question of the effort required to convert data from contractor to the CCDR system format, and the normalization of data across various contractor inputs. As a compromise, semi-annual data would be acceptable and more cost effective, since all contractors have computerized accounting systems to maintain their costs internally. Due to the long process of aircraft system development, semi-annual data are expected to provide sufficiently detailed information for trend analysis.

3. Implementation of a well-defined CCDR Data base System

As it is defined in Chapter II, the purpose of the CCDR system is to provide the primary data base for use in most cost estimating efforts including procurement management activities. As discussed earlier, the realization of this effort has been dampened by the lack of standardized data format among similar programs below Level 3 of the WBS. It seems thus evident that one of the first steps to be taken is to elaborate a comprehensive, consistent, and precise WBS Elements Dictionary that can be:

1. Agreed upon by all DOD components as well as the Defense Industry
2. Implemented for cost analysis purposes.

Ideally, the new definitions would serve as foundations for building a data base system that compiles all data in an accessible, dynamic, and evolving data base, readily available for retrieval and modification for modelling and analysis. Historically, required reporting elements have been inconsistently determined across contracts for similar weapon systems. The required levels of reporting within the WBS have often been inconsistent among the different DOD components. Individual contracts have also been negotiated to allow some obscuring of information due to subcontractor reporting variances and deficiencies. Labor cost comparisons in terms of dollar expenditures do not provide a basis for consistent comparison due to changing economic price levels. Variances between contractor methods of accounting also generate ambiguity. For instance, some contractors may allocate labor hour expenditures for direct maintenance and operational support of the test vehicle to engineering costs, while others may allocate the same function to manufacturing costs. These factors do not imply inaccuracy of the data, but do induce inconsistency when comparing and correlating individual models of aircraft and Defense Contractors.

The utilization of the Contractor Cost Data Reporting system data base to provide explicit estimates for sub-elements of aircraft system test and evaluation has not been expedient. Lower levels of data than previously found in the Work Breakdown Structure should be analyzed in order to effectively obtain the desired information and accurate results.

IV. RESEARCH METHODOLOGY

A. OBJECTIVES AND SCOPE OF RESEARCH

1. Objectives

This research seeks to: (i) assess current problems in Cost Analysis in Aircraft System Test and Evaluation, (ii) establish guidelines for estimating data, (iii) design and implement a database structure for Aircraft System Test and Evaluation, and (iv) develop parametric cost estimating relationships for selected System Test and Evaluation elements and four functional cost categories. Specifically, this research will focus on:

1. Defining a sample of pertinent aircraft programs
2. Formulating a WBS structure/functional cost element matrix
3. Acquiring historical cost data
4. Organizing the data for analysis
5. Employing statistical methods to develop cost estimating relationships
6. Documenting data, sources, rationale, and methodology.

2. Scope

This research attempts to apply econometric theory and cost analysis in the area of Aircraft Systems Test and Evaluation (ASTE). Multiple linear and logarithmic regression are probably major analytical tools. Since data are not readily available from a single source to the detail required for econometric studies, it is necessary to establish an operational data structure that can be used as a basis for this research and facilitate its data collection.

This research also applies the concepts defined in system analysis and design to implement decision support software for ASTE. Such an implementation would greatly help cost analysts interact with the complex and diverse data base. Consequently, the reliability of their cost estimation would be enhanced, or, at least, limitations of estimating methods clearly understood.

Interviews with defense contractors, Patuxent River Naval Air Test Center, Edwards Air Force Base Flight Test Center, and on-site data collection are envisaged for the first part of the research. Utilization of statistical software packages to identify elasticities of cost drivers will constitute the second part of the research.

B. RESEARCH METHODOLOGY

As stated in the previous section, this research encompasses both analytical and empirical studies. The methodology adopted for this research follows a three-step process shown in Figure 4-1. The activities of each of the three steps are briefly described below.

1. **Exploration Phase:** This phase includes the initial statement of the problem, the assessment of its importance and feasibility, and the establishment of contacts with access to relevant data.

2. **Analysis Phase:** This is an analytical approach to problem solving that requires the clarification of goals, definition of objectives and identification of systematic research activities to achieve these goals.

3. Refinement: This constitutes an iterative process to gradually readjust actions required to better meet stated objectives. Particularly, this process would highlight the sensitivity of decisions, the values of the key cost drivers and assumptions on which estimates are base including economic, technical, operational, schedule and other problematic considerations.

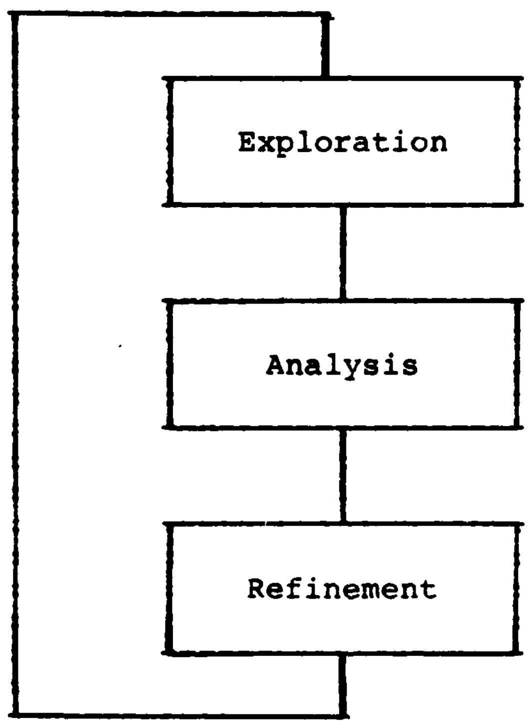


Figure 4-1. Phases of Research Methodology

C. EXPLORATION

The Exploration Phase was generated by an attempt to define the scope and objectives centering on the issues of controlling and estimating test and evaluation costs. However, this research team's focus was not clarified until initial meetings with the Cost Analysis Division of NAVAIR, held on August 7-8, 1986. Although there is a need to develop cost estimators for all of the Systems Test and Evaluation elements, it was confirmed at that time that initial efforts should be confined to the Contractor Flight Test element, and if feasible, expand the research to include the Wind Tunnel Article and Test, Static Article and Test, and Fatigue Article and Test elements. On-site visits at the Naval Air Test Center, as well as interaction with a selected group of representatives, demonstrated some feasibility of data collection and identified potential cost drivers, particularly in the area of aircraft weight and speed, and flight test hours. The initial Problem Definition in Figure 4-2 was developed following these meetings.

D. ANALYSIS

Based on the initial problem definition (Figure 4-2), a study was conducted to investigate the economic, political and technical feasibility of attaining the defined objectives. While no insurmountable problems in the financial and technical aspects were envisaged, the accessibility of contractors' proprietary data was identified as a potentially insurmountable political consideration that could severely constrain the realization of the intended research.

PROBLEM DEFINITION

STATEMENT OF SCOPE AND OBJECTIVES: August 7-8, 1986

BETWEEN: Naval Postgraduate School
AND: Naval Air Systems Command

PROJECT: Cost Analysis for Aircraft System Test and Evaluation - Data Collection.

PROBLEM: There is an increasing requirement from high levels that the Navy's aircraft cost estimators/analysts provide explicit estimates for the sub-elements of aircraft systems test and evaluation efforts. These data are not presently available at the levels required by the Naval Air Systems Command (NAVAIR).

OBJECTIVES: Collection of data to facilitate NAVAIR's development of cost estimating relationships for the following test and evaluation elements: Contractor Flight Test, Wind Tunnel Article & Test, Static Article & Test and Fatigue Article & Test.

SCOPE: Project to be completed within six calendar months at a cost of no more than $45,000. Availability and willingness of contractors to provide data that could be considered proprietary. Inflexibility of NPS Officers' schedules due to curriculum requirements.

PRELIMINARY SOLUTION:
Visits to Defense Contractors' facilities to discuss the problem and to ascertain the accessability and availability of the required data. Establish a database to facilitate the analysis of the data.

FEASIBILITY STUDY:
A feasibility study should be conducted with the results submitted within two calendar weeks. The cost of the feasibility study is included in the project scope and will not exceed $2000.

Figure 4-2. Initial Problem Definition

To minimize the impact of this political constraint, a strategy was formulated to ensure the viability of the data collection process by:

1. Identifying contacts and soliciting their cooperation
2. Conducting on-site interviews.

1. Identifying Contacts and Soliciting Cooperation

NAVAIR provided a list of twenty-one contacts throughout the defense industry. Through phone conversations and correspondence (Appendix A), this list was refined and expanded to those that indicated not only an interest in the results of the research, but a cooperative attitude concerning the request for company data (Appendix B) dealing with System Test and Evaluation.

In general, respondents were highly interested in the nature of the project and indicated their willingness to assist in data collection and critical evaluation of the present cost analysis process. Those who declined to participate cited the following reasons:

1. The lack of available data
2. The current political climate within the industry, and
3. On-going contract negotiations.

The final list consisted of thirteen companies, which made available personnel from a wide range of aircraft-related disciplines as depicted in Figure 4-3.

Job Description	Number of Contacts
Cost Estimation	18
Data Managers	7
Engineers	11

Figure 4-3. Interviewees Job Description Breakdown

2. <u>On-site Interviews</u>

Interviews were conducted at thirteen locations throughout the United States. Interview teams consisted of at least two research members per visit. Surveying time lasted, on the average, approximately three hours for each location, varying from forty-five minutes to ten hours.

To prepare for the interviews, the research team brainstormed to establish the following initial list of issues that appeared to be important for the research methodology.

1. What are the cost drivers in ASTE?
2. How do the characteristics and complexity of the aircraft relate to the average engineering hour?
3. What statistical and econometric models can be appropriately applied to ASTE? Is multiple regression appropriate to this problem?

4. Are the military work-breakdown structures pertinent to ASTE?

5. How can a computer system (hardware and software) be designed and implemented to conduct testing of the models?

6. How have data been defined and collected in different test sites (military and civilian)? Can they be filtered, and standardized? What extrapolation method should be used for missing data?

7. How do these cost drivers affect the average engineering hour per hour of flight?

8. Is there any correlation between the number of instrumentation channels and the number of engineering hours?

9. Is there a linear cost relationship between different types of aircraft with respect to their complexity and characteristics?

10. How sensible and stable are the elasticities of the cost drivers?

11. What are the implications of the findings?

12. Where is it most cost-effective to conduct future military ASTE--at the contractors facilities or at the established flight test centers. Is the answer the same for both flight test centers?

13. Do the findings have an impact on the service's operational test and evaluation?

14. How does inflation affect the predictive power of the findings?

This initial list of questions was sent to interested parties. Additionally, to improve our own understanding of industry practices and procedures, the list of issues were distilled to the following set of questions that could be addressed in on-site interviews.

1. Would you provide general specifications of all your company's aircraft to include: aircraft type and mission, thrust to weight ratio, speed, size, ceiling,

combat radius, commonality/GFE between models, and use of exotics and/or composites?

2. What methodologies do you use for accounting and record keeping of cost items (development and testing)?

3. How are these accounting and record keeping items defined? Are these definitions standardized company wide? Do you have a computerized cost accounting system?

4. What methodologies do you use to extrapolate cost estimators from these data?

5. In the area of avionics, what impact do variations in the following items have on the labor hours and flight test hours of your aircraft systems:

   a. The number of instrumentation channels.

   b. Number of lines of delivered software code.

   c. The number of separate CPU's installed in the aircraft.

   d. New electronic technology (e.g., VSLI).

   e. What hardware integration factors affect the cost (i.e., is a decentralized system more cost-effective than a centralized system?).

   f. Power usage.

6. What do you believe are the most important cost-drivers? Could you prioritize them?

7. If due to cost constraints you had to reduce test and evaluation activities, what would be your primary candidates for elimination? Which activities do you consider indispensible to test and evaluation?

8. What would you do to reduce costs?

This set of questions permitted a cross comparison among companies. More interesting, it was found that, as the interview progressed, the domain knowledge of the research team expanded exponentially which improved the quality of the remaining discussions. The contacts below also raised numerous issues they thought significant enough to included in the research.

12 November 1986	Rockwell International Corporation Los Angeles, California
12 November 1986	Boeing Seattle, Washington
13 November 1986	Air Force Flight Test Center Edwards Air Force Base, California
13 November 1986	McDonnell Douglas Corporation Long Beach, California
14 November 1986	Lockheed California Company Burbank, California
17 November 1986	Rockwell International Columbus, Ohio
17 November 1986	General Dynamics Corporation Fort Worth, Texas
17 November 1986	LTV Aerospace and Defense Dallas, Texas
18 November 1986	Grummann Aerospace Corporation Bethpage, New York
18 November 1896	Fairchild Aircraft Farmingdale, New York
18 November 1986	McDonnell Aircraft Company St. Louis, Missouri
19 November 1986	Lockheed Georgia Company Marietta, Georgia
20 November 1986	Naval Air Test Flight Center Patuxent River, Maryland

As the interview process continued, important issues converged demonstrating a industry-wide commonality of problems (see Chapter V).

E. REFINEMENTS

A post-interview meeting was convened at NAVAIR to assess the results of the contractor visits. The research team reported to the sponsor the nature and amount of data that were, and could be, collected. Also, the sponsor was briefed on the areas considered most important by contractors (see Chapter V), which they had recommended be added to the present cost process to make it more reliable and accurate, in particular:

1. Software
2. Avionics
3. Instrumentation channels
4. Requirements to meet performance guaranties
5. Contract warranties required by the Government
6. Fixed-priced contracts and
7. Combined DOD / Contractor Flight Testing.

It became obvious that these new dimensions could contribute to the rapid growth of the present project scope. If they were all included, it would no longer be feasible to accomplish the totality of the project given the constraints imposed. Therefore, the team requested the sponsor to refocus the problem and set research priorities in light of these new factors. It was then stated that the focus would remain on Contractor Flight Test, with Wind Tunnel Test, Static Test, and Fatigue Test studies as secondary goals.

In order to achieve this restated goal, interpretation, review, and standardization of data became indispensible. Due to his expertise, the sponsor offered his assistance. This operation is time intensive, requiring tedious and systematic efforts. In the meantime, a follow-up letter was sent to contractors seeking time-phased data (Appendix C). In parallel, a data base was designed to accommodate the data received from the contractors (see Volume II, Chapter III).

V. COST DRIVERS IN SYSTEM TEST AND EVALUATION

A. INTRODUCTION

Past studies have primarily considered, weight, speed and the number of aircraft as the most statistically significant cost estimators. In fact, other cost drivers--such as avionics, software, management strategies--have recently emerged as important, if not more important than these three drivers. Unfortunately, due to the current practices of data collection, it is impossible to statically quantify the new cost drivers. The only approach that remains appropriate to evaluate the importance of these drivers is to use the Delphi technique to solicit expert opinions in the aircraft system cost estimation area. Interviews with aerospace engineers, pilots, Test and Evaluation managers from Defense Contractors and DOD, test flight centers, and defense contractors have been conducted to brainstorm issues regarding Aircraft Systems Test and Evaluation costs.

B. IDENTIFICATION OF THE MOST IMPORTANT COST DRIVERS

1. Mission as the Determinant of Cost Drivers

Mission is the cornerstone upon which any major program is built. Until the mission of the proposed aircraft system is defined, it is not possible to determine specifications; even at a broad level. However, once the mission is known, then the many factors that form the complex world of Defense Systems Development and Acquisition begin to come together. Many of these factors are clearly defined and are measurable cost drivers that will be discussed later in this chapter. It is important to note, however, that there exists an environment within which DOD and Defense Contractors operate that effects all programs as surely as the more obvious cost drivers.

One of the major managerial concerns is whether a bid can be submitted in such a way that it will not only allow the company to develop and produce the system within the defined financial constraints, but insure that there is a means available to recoup the cost of DOD's "inevitable" modifications to the specifications and/or performance guarantees. It is no longer a matter of "if" there will be changes, but rather a question of "when and how many". The Cost Plus Contract provided the contractor with an insurance clause, which often proved to be very expensive from the government's perspective. The Fixed Price Contract now mandated by DOD has removed this insurance clause, provided DOD with protection from cost overruns, and has moved the "risk factor" to the contractor. Since it should not be considered unreasonable for either DOD or the contractor to expect some changes over the long developmental life cycle of a major weapon system, the present relationship is one punctuated with compromise and conciliation. If it were otherwise, the development and attainment of a program's performance objectives would be impossible.

The requirement to provide warranties on an aircraft system that has yet to be built, and whose operational life is unknown, is another major management concern in the early stages of a program. How does an analyst quantify costs, for inclusion in a bid, that are so unpredictable? And how does management calibrate the experience and expertise of its engineers in cost estimators? Are the cost estimates as accurate as the specifications and performance guarantees?

Sub-contractors and secondary vendors are often trapped into making guarantees too early in the process. Their desire to be a part of the program leaves them with no other alternative, and as a result the integrated overall mission is typically not met.

When a ceiling dollar value is included in a Request for Proposals there are few contractors who will refrain from bidding the indicated ceiling, even if their own cost estimators believe that it will be impossible to stay below that figure. "If we get our foot in the door, we'll renegotiate later."

2. Aircraft Weight

All companies interviewed indicated that weight still constitutes a major cost driver in system development. Because of the availability of the data on weights, it has been relatively easy to use weight as a cost estimator. Dollars and hours per pound have often been used as estimators. Everything else being equal, the larger the aircraft the greater the cost, i.e., a bomber, which is approximately five times heavier than a fighter, has overall costs (Level 2 of the WBS) that are roughly five times more than that of the fighter. This interpretation corresponds to earlier studies performed by PRC (1967), RAND (1972, 1975, 1976), and Noah (1973). These studies all ranked weight as the primary cost driver. As weight increases, cost increases too. However, as weight increases, at some point, cost per pound decreases. Additionally, aircraft density effects the cost per pound of aircraft. As an aircraft is loaded with more sub-systems (e.g., Avionics), cost per pound of the aircraft increases.

Recent use of composites has altered the statistical quality of weight as a cost estimator since historical data are associated with metal. It has been hypothesized that as more experience is gained with composites, weight will again become a more stable and predictable factor because of the nature of building with composites. Although testing an aircraft component built entirely with composites should be easier, one of the major uncertainties when dealing with composites in the Contractor Flight Test phase occurs when an test-site modification or repair to an aircraft is required. With the increased use of composites in the future, weight is expected to move from labor-intensive to a automation(capital)-intensive factor. While it is still difficult to predict at the present time how the use of composites will drive the cost associated with weight, it is plausible that developmental testing will progressively become less expensive. It is also hard to relate weight of composites to cost since there are more parts in non-composite aircraft than in composite aircraft.

3. Aircraft Speed

After weight, speed is also recognized as an important cost drivers. However, it was identified only by 70% of the opinions solicited. Thrust being constant, weight is related to speed. One of the reasons that speed represents an important cost driver is the fact that due to the requirement to meet performance guaranties, development costs increase at a spiraling rate as engineers work with the aircraft at critical speeds. The reduced total weight of an aircraft due to the use of composites will decrease the thrust required to attain the same speed of a non-composite aircraft, and as a consequence, developmental cost in this area should be diminished.

4. Avionics Complexity

With one exception, avionics complexity was another cost driver that emerged from the interviews. Advanced electronic technology has resulted in improved reliability of avionics and substantial amelioration in troubleshooting and maintenance procedures. Test effectiveness, test vehicle flight frequency, and data validity have greatly improved. Many contractors claimed that achievement in avionics have been responsible for their recent gain in program planning effectiveness and sortie rates of their flight test programs.

While software-intensive avionics substantially innovates the capabilities of aircraft systems, it also presents enormous testing requirements. For example, a high percentage of test work accomplished by the Air Force for the F-15, F-16, and B-1 is related to software. When the volume allocated to avionics within the airframe is constant, advanced technology decreases the weight and increases the avionics capabilities. This implies that while more complex aircraft can be built without affecting the costs related to increased weight and speed, the complexity of avionics will drive the total system costs up. Avionics is a difficult cost to estimate due to the difficulty in estimating software.

5. Software

Indeed, an important factor that has emerged from the increased avionics complexity is software. Unlike weight, there is a predominant concern on developing the ability to accurately estimate software costs. This element is regarded as the most difficult cost driver to estimate. First, there is little consistency among companies in the way aircraft system software is developed. Some develop by total system concepts, others modularize by functional areas (e.g., navigation, fire controls, weapons), and still others concentrate on implementing interfaces between blackboxes developed by various sub-contractors. Second, estimation methods range from dollars-per-word to parametric models based on total lines of codes. These models include COCOMO, SLIM, RCA/PRICE/S, IBM Walston-Felix, and Boeing Computer Service. (Wolverton, 1980) However, the complete lack of historical data and experience with Aircraft System Test and Evaluation software makes it virtually impossible to apply these parametric models. (For a survey of parametric models, see Volume II, Chapter II.) The estimation problem is further complicated by the fact that software costs depend on the number of modules, the size of the modules, the degree of integration complexity, and the number of processors in distributed systems available to run the integrated software system.

It is felt that the mission determines the software costs. For example, a training mission does not require a complex software structure as compared to an all-weather attack mission. Consequently, software costs for the trainer are much less expensive than for those of the all-weather attack aircraft. In addition to the primary mission, the specific number of mission tasks the aircraft is capable of performing does play an important factor. For example, in general, the ECM mission would derive a higher software cost than the ASW mission. However, the software cost of the AWACS is higher than the E-2C. These two aircraft perform similar missions but on different scale. Another comparison would be between the F/A-18 and the A-6. If both aircraft were built from the ground up using today's technology, the software cost of the multi-mission F/A-18 would probably be substantially higher than the A-6.

A strategy to deal the increasing cost of testing software intensive system is to use simulation. Research conducted at the Air Force Flight Test Center, Edwards Air Force Base argues that:

1. Three-fourths of all software problems are resolvable on the ground at a fraction of a cost of a flight

2. A reduction in test flying hours translates into a reduction of test costs and an acceleration of the test schedule

3. The costly and inefficient fly-fix-fly approach is minimized

4. **Ground testing is more efficient than flight testing because the experiment is controlled, repetition of test conditions is rapid and simple**

5. **Flight test time is used more effectively by isolating/keying on risks areas and smarter profile planning. (Adolf and Montgomery, 1985, p.3)**

Tables 5-1 and 5-2 show expected cost savings for a typical fighter test program utilizing simulation of software-intensive systems.

A second approach to resolving the problem of software cost estimation would be for the entire Defense Industry to officially endorse the utilization of structured analysis and design methodology through functional decomposition. (Yourdon, 1986) Such decomposition by functions would make it easier for software developers to capture the complexity of each function and systematically integrate them as a total system for cost estimation. Similar software engineering techniques and experience will result in more standardized data collection needed for future estimation.

Another potential area of improvement is the implementation of distributed systems using parallel processors. While no statistical evidence was gathered to assess the impact of separate CPUs on aircraft testing, the majority of interviewees believe that the conduct of tests and the probability of completion during a specific flight were enhanced when several CPUs were installed, permitting the successful testing of some aircraft systems when others

TABLE 5-1

AIRCRAFT	TEST FLIGHT FREQUENCY (FLIGHTS/MONTH)	TEST AIRCRAFT OPERATIONS COST ($1000/HOUR)	FLIGHT TEST FIXED SUPPORT COST ($1000/MONTH)	PROGRAMMABLE CAPACITY (1000 WORDS)
CURRENT GENERATION FIGHTER	10	20	$1,000	300 - 700
CURRENT GENERATION BOMBER	5	100	$2,000	600 - 800
NEXT GENERATION FIGHTER	10	40	$1,500	1,000

TABLE 5-2

COST OF FLIGHTS:	
(250 FLIGHTS) (1.25 HRS/FLT) ($20,000/HR) =	$ 6,250,000
LESS COST OF SIMULATION:	
(250 FLIGHTS) (1 HR/FLT) ($4,000/HR) =	$ 1,000,000
NET SAVINGS FROM REDUCED FLIGHTS:	$ 5,250,000
(20 AIRCRAFT MONTHS) ($1,000,000/MONTH) =	$20,000,000
TOTAL SAVINGS: $5,250,000 + $20,000,000 =	$25,250,000

have failed. In the past, a central CPU failure precluded continuation of the testing process.

6. Power Supplies

Power supplies play a vital role in the operation of all aircraft. These power sources provide a range of outputs depending on the requirements and number of the devices they support. This accounts for the varied capabilities, sizes and quantities of power supplies that can be found in any aircraft system.

The majority of the volume and weight of a typical power unit is taken up by the filters required to ensure that delivered current is within specified operating ranges. When compared to the technological advances made in other avionics areas, it is obvious that there has been very little progress in the area of reducing or eliminating these unit filters, thereby improving the overall efficiency, presently necessary to meet the requirement specifications. If more efficient power units were developed, the number of these sources could be reduced, thereby reducing the total weight and volume of avionics in the aircraft. Also, if power sources were more stable and cleaner, testing costs would be reduced.

7. Data Reduction

Data reduction, which is the process of reviewing and analyzing the data gathered during testing, presents another area of concern. Compounding this problem is the increased number of instrumentation channels. With the advent of a central bus within the airframe, engineers have recognized the potential for monitoring additional data points that were not previously feasible. Convinced that these data could now be gathered relatively easily, they requested that procedures for monitoring additional data points be included in the test plan. Most contractors felt that this process would be cost effective since it would provide a wide cross section of data on each and every flight which would allow maximum concurrent testing regardless of the primary purpose of that flight.

However, the current technology that assists in analyzing data has not progressed as fast as technology's ability to produce raw data. Collected data have become so voluminous and overwhelming to the extent that it has become impossible for the engineers to properly analyze all of the data unless the time constraints of the test program were extended.

8. The Number of Test Aircraft

The number of test aircraft also constitutes an important cost element. Historically, it was observed that this cost driver was considered one of the most significant in flight test cost estimation, along with weight and speed. (PRC, 1967; RAND, 1972; RAND 1975) As the number of aircraft increases, the number of separate test flight augments and drives the total cost higher. Aircraft are instrumented to perform specific portions of the test plan and therefore cross utilization is infeasible unless aircraft are modified for other specific tests. The determination of an optimal number of aircraft is extremely difficult since the cost relationship is not linear. If the number of aircraft is below the testing capacity then testing resources are wasted. Conversely, when the number of aircraft exceeds the testing capacity, there is a loss of the maximum utilization of test aircraft assets and experienced personnel. As an attempt to reduce costs, contractors argue that the number of aircraft used in flight testing should be held to the minimum required to meet the test plan schedule. They felt that DOD as a whole should not have as much input in determining the number of test aircraft as it is presently exercised.

9. Delivery Schedule

It is expected that this cost element is gaining in importance due to the:

1. Increasing complexity of aircraft
2. Requirements to meet all performance guaranties imposed by the Government prior to the first delivery of production aircraft.

As a proposition to reduce this problem, it was proposed by several contractors that aircraft be delivered in a block (phase) program. A block program would consist of quickly delivering a small number of operational aircraft capable of meeting at least 80% of mission requirements. As the aircraft are used by operational units, additional feedback would be inputted to improve the performance of subsequent production blocks of aircraft. Operational input to the test program would insure that the aircraft, as designed, are in fact meeting real needs. This would allow contractors to continue utilizing test aircraft to solve any problems which inhibited the attainment of all performance guaranties, without delaying the delivery of operational aircraft to DOD. Although this would most certainly result in a requirement to retrofit/modify the initial block of aircraft, it is felt that this procedure would ultimately provide a more capable aircraft to operational units in a more timely manner. However, this strategy would create a potential problem in the upgrading of the early delivered aircraft. Usually, the cost of modification is significantly greater than the cost of initial production.

10. <u>Joint Contractor/Military Testing</u>

Various degrees of joint testing have been practiced by DOD. It consists of combining the efforts of the contractors and the military in the parallel testing. These combined efforts include the development, test, and evaluation phases. Advantages of this approach include:

1. Early involvement of operational aircrew and sharing of test data from the genesis of the test program
2. Reduced duplication of efforts
3. A new critical perspective of the progress of the program that could help identify shortcomings or

problem areas in the early stages of the test program that otherwise might not have been identified until the Operational Test and Evaluation phase; this would lead to substantial savings in time and costs.

Contractors feel that they no longer have primary control over their own flight test programs. The requirement to use government test sites and facilities, which are inadequately equipped to support simultaneous test programs of major aircraft systems, is viewed as counterproductive. These inadequacies require that program priorities be established which results in test delays and some, if not all, of the following ramifications to the contractors:

1. They have to relocate their personnel and test equipment to governmental facilities

2. They have to train military test pilots in highly instrumented test aircraft

3. Flight schedules must be submitted to the military for approval before actual real time planning can begin

4. They are subject to DOD rules and regulations, which many find too restrictive

5. Their schedules are often reviewed by military personnel who may not be familiar with the intricacies of the contractor's flight test program. The explanations and briefings required to clear up these misunderstandings cause unnecessary interruptions in the test program

6. The turnover of key military personnel during the Test and Evaluation programs often precipitates revisions of previously reviewed and approved cockpit/aircraft configurations.

From the contractors' viewpoint, the requirements specifications initially established at the beginning of the program are constantly modified during the System Test and Evaluation life cycle. Contractors contend that, given accurate, detailed, and complete DOD specifications, they could complete the required Developmental Test and Evaluation more effectively and efficiently without interference from external agencies. As such, the contractors would ultimately be responsible for development testing, test management, and more important, test success.

It is important to note that opinions in this issue have been extremely bimodal. Historical data could be found to support both sides of the issue as both management strategies have been successful in producing high quality aircraft for the Department of Defense. Since these arguments cover only a partial view of the entire problem, further studies are necessary to determine which strategy is capable of producing the highest quality and most cost-efficient aircraft. Specifically, a more integral approach appears to be the only way to assess the total impact of the two strategies.

11. Political

Last but not least, Congressional funding delays are cited as having a non-trivial impact on the total system cost. These delays caused an unnecessary time lag between the development and production phases. This lack of immediate follow-up results in loss of experience and expertise gained in the prototyping phase and serious economical and personnel problems in maintaining qualified manpower.

C. SUMMARY

The interviews conducted with Defense Contractors and the military test centers resulted in numerous recommendations for improvement of the present process of System Test and Evaluation. While the following summarized list of recommendations addressed in this chapter represents neither an exhaustive nor final list of possible actions, they do highlight several areas of major concern:

1. The use of simulation in software testing
2. The utilization of a structured analysis and design methodology to develop software
3. The implementation of distributed systems using parallel processors
4. The development of more efficient power units, thereby reducing the total weight and volume of avionics in the aircraft
5. The reduction of the required number of test aircraft
6. The delivery of aircraft in a block (phase) program.

Also, further studies are necessary to determine if joint testing is producing the highest quality and most cost-efficient aircraft.

APPENDIX A: CONTRACTOR FORM LETTER #1

Naval Postgraduate School
Monterey, Ca. 93943
October 24, 1986

Dear

I have extracted some information from our thesis proposal to give you a better idea of what this project entails and will try to accomplish. I have also enclosed a tentative format depicting a Work Breakdown Structure/Functional Cost Element Matrix which, with some flexibility, will attempt to use in our data collection effort. I will call you on the rd to answer any questions you may have concerning the project and provide you an update of our latest discussions with NAVAIR.

The week of November 16th, we will be making a cross-country collection trip to all of the defense contractor facilities involved in this project. We would like to meet with you in Columbus, Monday morning, November 17th, to collect the initial data you have extracted, and discuss the project in more detail. We realize that doesn't give you very much time, but we are trying to have most of the initial data, from all sources, collected and reviewed for discussion at a NAVAIR meeting in Washington D. C. November 20th. This meeting will be used to finalize the focus of the data needed to complete this research project. We will contact you immediately upon our return from the NAVAIR meeting to advise you of the results of the meeting and to eliminate any ambiguities concerning the data we received and finalize our further data collection requirements. We anticipate two follow-on trips. The first for final collection of data, the second to present the results of our research and copies of our cost estimating tools.

The basic data we will need will be the direct labor hours and flight hours related to all DOD aircraft systems your facility helped produce.

The information we require necessitates a breakdown of Contractor Flight Test, Wind Tunnel Test, Static Test, and Fatigue Test into the lowest available indentured sub-elements that your company used during system test and evaluation. It is important to our efforts that we obtain the Contractor Flight Test labor hours, in particular, in a time-phased fashion along with time-phased flight hours, so as to be able to relate the two. We would also like to obtain time-phased cost data for the other test elements if possible.

We would like to meet with the individuals who develop the initial Work Breakdown Structure (WBS) estimates to discuss their ideas on what factors became the cost-drivers. If available, inputs from flight test engineers would contribute significantly to the balance of the data we are collecting.

I realize that we are asking for what you may consider to be part of your company's proprietary information. I assure you, in the strongest possible terms, that all data will be held in the strictest confidence, used only for the generation of a cost estimating algorithm, and not divulged outside of the government.

We appreciate your cooperation and look forward to working together in the coming months.

Semper Fi,

William J. Foster   David F. Lee

A. PROJECT TEAM

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B. DISCUSSION

Current budget constraints have resulted in an increasing emphasis on the cost effective procurement of aircraft systems within the Department of Defense. Of late, the Cost Analysis Division of the Naval Air Systems Command (NAVAIR) has received numerous requests to provide explicit estimates for the sub-elements of aircraft system test and evaluation efforts. These data represent lower levels in the Work Breakdown Structure than previously required. This additional data and the methods necessary to produce them are needed in order to estimate aircraft system test and evaluation costs with better accuracy and in greater detail than is currently feasible.

NAVAIR has funded this project to collect the data and develop an accurate and reliable way to estimate these cost relationships. The key problems related to this research will involve the data collection from the defense contractors and the standardization of their data. Representatives at NAS Patuxent River, Md., and Edwards Air Force Base Flight Test Center have already stated that they will assist in the collection of data at their installations.

C. AREA OF RESEARCH

Estimation of cost drivers in Aircraft System Test and Evaluation (ASTE): conceptual modeling and some empirical evidence. (Air Force, Navy, and civilian contractors--subject to data availability)

D. RESEARCH QUESTIONS

1. What are the cost drivers in ASTE?

2. How do the characteristics and complexity of the aircraft relate to the average engineering hour?

3. **What statistical and econometric models can be appropriately applied to ASTE? Is multiple regression appropriate to this problem?**

4. **Are the military work-breakdown structures pertinent to ASTE?**

5. **How can a computer system (hardware and software) be designed and implemented to conduct testing of the models?**

6. How have data been defined and collected in different test sites (military and civilian)? Can they be filtered, and standardized? What extrapolation method should be used for missing data?

7. How do these cost drivers affect the average engineering hour per hour of flight?

8. Is there any correlation between the number of instrumentation channels and the number of engineering hours?

9. Is there a linear cost relationship between different types of aircraft with respect to their complexity and characteristics?

10. How sensible and stable are the elasticities of the cost drivers?

11. What are the implications of the findings?

12. Where is it most cost-effective to conduct future military ASTE--at the contractors facilities or at the established flight test centers? Is the answer the same for both flight test centers?

13. Do the findings have an impact on the service's operational test and evaluation?

14. How does inflation affect the predictive power of the findings?

E. SCOPE OF THE RESEARCH

Develop essentially parametric cost estimating relationships for selected system test and evaluation elements and each appropriate functional cost category by:

1. Defining a sample of pertinent aircraft problems.

2. **Formulating a work break-down structure/functional cost elements matrix.**

3. **Acquiring historical cost data.**

4. **Organizing the data for analysis.**

5. **Employing statistical methods to develop cost estimating relationships.**

6. **Documenting data, sources, rationale, and methodology.**

F. METHODOLOGY

This research seeks to apply microeconomic theory and cost analysis in the area of Aircraft Systems Test and Evaluation (ASTE). Multiple linear and logarithmic regression are considered as analytical tools. This research also applies the concepts defined in system analysis and design to implement a decision support software for ASTE.

Interviews with defense contractors, Patuxent River Naval Test Flight Center, Edwards Air Force Base Flight Test Center, and on-site data collection are envisaged for the first part of the research. Utilization of statistical software packages to identify elasticities of cost drivers will constitute the second part of the research.

I. BENEFITS OF STUDY

There is an increasing requirement from high levels that the DOD's aircraft cost estimators/analysts provide explicit estimates for the sub-elements of aircraft systems test and evaluation efforts. This research project will attempt to develop cost estimating relationships for test and evaluation elements used for aircraft systems. The results of this project will benefit DOD, Patuxent River Naval Test Flight Center, Edwards Air Force Base Flight Test Center, and civilian contractors.

DATA REQUESTED

This form contains the information requested. Any further breakdown if available, is desirable.

	ENGINEERING HOURS	MAINUFACTURING HOURS	TOOLING HOURS	ILS/PS HOURS	MATERIAL DOLLARS	TOTAL DOLLARS
CONTRACTOR FLIGHT TEST						
instrumentation						
functional ground checkout						
flight test and demonstration						
flight test support						
flight test spares & repair parts						
support equipment						
contractor technical/maintenance services						
WIND TUNNEL ARTICLE & TEST						
wind tunnel article						
wind tunnel test						
STATIC ARTICLE & TEST						
static article						
static test						
FATIGUE ARTICLE & TEST						
fatigue article						
fatigue test						

OTHER INFORMATION REQUIRED:

1. Number of flight test A/C and first flight of each.
2. Flight hours (time phased).
3. Wind tunnel occupancy hours (time phased).
4. Type of wind tunnel test.
5. Number of instrumentation channels for instrument flight test A/C.

APPENDIX B: NAVAIR PROJECT POINTS OF CONTACT

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APPENDIX 3: CONTRACTOR FORM LETTER #2

December 5, 1986

Navair Research Team
Code 54Bd
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Monterey, Ca. 93943

We would like to thank you again for the opportunity we had to meet with you and visit your facilities to discuss our research project last month. Your inputs were extremely valuable in giving us an overview of _______'s methods used for the cost estimation of aircraft systems and your test and evaluation cprograms. At that time, we promised to clarify our data collection requirements following a meeting with our Naval Air Systems Command (NAVAIR) project sponsor on 20-21 November. The information you provided was discussed and helped focus the scope of our project and the specific areas of data required for our research.

The scope of this project will initially include only the following areas of aircraft system test and evaluation:

Contractor Flight Test
Wind Tunnel and Article Test
Static Article and Test
Fatigue Article and Test.

In our initial letter, we provided a matrix of Work Breakdown Structure (WBS) sub-elements in these areas and a listing of the following direct labor hour/dollar cost categories pertaining to these sub-elements:

Engineering Hours
Manufacturing Hours
Tooling Hours
Quality Control Hours
Logistic/Product Support Hours
Material Dollars
Total Dollars.

The basic System Test and Evaluation data required for our project are direct labor hours and dollar values for the ______ aircraft system(s) your facility produced, broken down into the sub-element matrix, and also listed in a time-phased fashion.

In order to normalize this information between contractors, it is important that we know your specific definition of the WBS sub-elements used by your company for direct labor hour tracking. For the direct labor hours, we request that you provide a brief description of how the engineering, manufacturing, tooling, quality control and support hour categories were derived if your records differ from the Contractor Cost Data Reporting methods.

For the aircraft flight test portion of our research, we request the number of aircraft used in your flight test program with associated flight hours.

We request the data for direct labor hour/dollar categories and the flight test hours be expressed in a time-phased fashion. If this data is not available from your records time-phased, please estimate the start and completion dates and indicate the peak activity levels within the test period.

A cost driver indicated for the flight test program was the total number of separate tests to be conducted during the flight phase. If you have information available to indicate the total number of separate tests and a brief description of these test categories, it will help in the quality of our final product.

We feel that this research can be valuable to our military project sponsor and also useful to ______________ as a cost estimating tool. The accuracy of our final product will depend primarily on the data we receive from your company and our ability to correlate it with the data from the other contractors we have visited.

We realize the constraints of your busy schedule, but would appreciate to be able to receive as much of this data as possible by January 10, 1987 to be used in a meeting which will be held with the NAVAIR project sponsor January 15, 16 and 17.

We again express our thanks for the assistance that you have provided and your continued interest in our program. We will call you next week and attempt to answer questions that you may have concerning this data format or limitations that may be peculiar to a specific aircraft system.

Sincerely,

The following are to be broken down by:

1. **Engineering hours**
2. **Manufacturing hours**
3. **Tooling hours**
4. **QC/ILS/Product support**
5. **Material $**
6. **Total $**

CONTRACTOR FLIGHT TEST
- INSTRUMENTATION
- FLIGHT AND DEMONSTRATION
- FUNCTIONAL GROUND CHECKOUT
- FLIGHT TEST AND DEMONSTRATION
- FLIGHT TEST SUPPORT
  - FLIGHT TEST SPARES & REPAIR PARTS
  - SUPPORT EQUIPMENT
  - CONTRACTOR TECHNICAL/MAINTENANCE SERVICES

WIND TUNNEL ARTICLE & TEST
- WIND TUNNEL ARTICLE
- WIND TUNNEL TEST

STATIC ARTICLE & TEST
- STATIC ARTICLE
- STATIC TEST

FATIGUE ARTICLE & TEST
- FATIGUE ARTICLE
- FATIGUE TEST

Other breakdowns:

1. # of flight test a/c and first flight of each.
2. Flight hours (time phased)
3. Wind tunnel occupancy hours (time phased)
4. Type of wind tunnel test
5. # of instrumentation channels for instrument flight test A/C.

LIST OF REFERENCES

Adolph, C. E., and Montgomery, P. Cost-effective Testing of Software Intensive Systems. Paper presented at Society of Flight Test Engineers, Sixteenth Annual Symposium, Seattle, WA, August 1985.

Department of Defense. Contractor Cost Data Reporting System, NAVMAT P-5241. Washington D.C., 1973.

Department of Defense. Military Standard Work Breakdown Structures For Defense Materiel Items, MIL-STD-881A. Washington D.C., 1975.

Boren, H. E., Jr. A Computer Model for Estimating Development and Procurement Costs of Aircraft (DAPCA-III). The Rand Corporation Report R-1854-PR, March 1976.

Large, Joseph P., Campbell, Harry G., and Cates, David. Parametric Equations for Estimating Aircraft Airframe Costs. The Rand Corporation Report R-1693-PA&E, May 1975.

Levenson, G. S., Boren, H. E., Tihansky, D. P., and Timson, F. Cost-Estimating Relationships for Aircraft Airframes. The Rand Corporation Report R-761-PR, February 1972.

Noah, J. W., Daniels, J. M., Day, C. F., and Eskew, H. L. Estimating Aircraft Costs By Parametric Methods. J. Watson Noah Associates, Inc. Report FR-103-USN, September 1973.

Sanchez, Luis R., and DeiRossi, James A. Methods of Estimating Fixed-Wing Airframe Costs. Planning Research Corporation Report PRC R-547A, April 1967.

Wolverton, R. W. Airborne Systems Software Acquisition Engineering Guidebook for Software Cost Analysis and Estimating. TRW Defense and Space Systems Group Report ASD-TR-80-5025, September 1980.

Yourdon, Edward. Managing the Structured Techniques. New York, NY: Yourdon Inc., 1986.

BIBLIOGRAPHY

Anderson, Lee G., and Settle, Russell F. Benefit - Cost Analysis; A Practical Guide. Lexington Book, 1974.

Bard, Yonathan. Nonlinear Parameter Estimation. New York, NY: Academic Press, 1974.

Beck, C. L., and Pfeil, D. L. Airframe RTD&E Cost Estimating: A Justification For and Development of Unique Cost Estimating Relationships According to Aircraft Type. M.S. Thesis, Air Force Institute of Technology, Wright-Patterson Air Force Base, OH, September 1982.

Bennett, Bruce R. The Use of Parametric Cost Estimating Relationships as They Pertain to Aircraft Airframes; A New Perspective. M.S. Thesis, Naval Postgraduate School, Monterey CA, March 1980.

Blecke, Curtis J. Financial Analysis For Decision Making. Englewood Cliffs, NJ: Prentice-Hall, 1966.

Boehm, Barry W. Software Engineering Economics. Englewood Cliffs, NJ: Prentice-Hall, 1981.

Clark, Forrest D. Applied Cost Engineering. New York: M. Dekker, 1978.

Committee For Economic Development, Improving Federal Program Performance: A Statement of National Policy. Washington D.C. 1971.

Cummins, J. M. Cost Overruns In Defense Procurement, A Problem Of Entrepreneurial Choice Under Uncertainty. Northwestern University, 1973.

Day, C. F., and Findley, D. P. Aircraft Cost Handbook. J. Watson Noah Inc. Report FR-1834-USAF, December 1982.

Dryden, J., Britt, T., and Binnings-DePriester, S. An Analysis of Combat Aircraft Avionics Production Costs. The Rand Corporation Note N-1685-AF, March 1981.

Greenberg, Joel S. "Risk Analysis: Challenge to the Aerospace Decision-Maker." Astronautics & Aeronautics, 12 (1974), 48-57.

Johnston, J. Econometric Methods. New York: McGraw-Hill, 1963.

Kroenke, David M. Database Processing: Fundamentals, Design, Implementation. Chicago, IL: Science Research Associates, Inc., 1983.

Livingston, John J. Management Planning And Control, Math Models. New York: McGraw-Hill, 1970.

Noah, J. W., et al., Aircraft Cost Handbook. J. Watson Noah Associates, Inc. Report TR-103-USN, July 1973.

US Task Force on Reducing Cost of Defense System Acquisition. Design to Cost, Commercial Practices vs. DOD Practice. Washington D.C., 1973.

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